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.

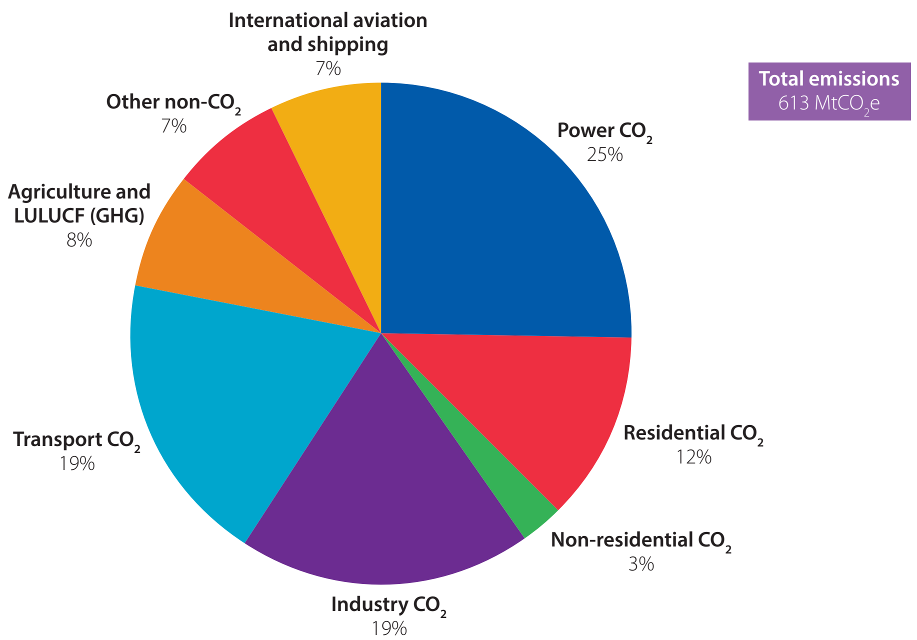
1. Current emissions across the UK economy

Economy-wide emissions of greenhouse gases (GHGs) that are covered by carbon budgets were 570 $MtCO_2e$ in 2012 (Figure 1.1).

- CO_2 emissions were 479 $MtCO_2$, with the largest contributions from the power sector (156 $MtCO_2$, see Chapter 2), buildings (91 $MtCO_2$, see Chapter 3), industry (116 $MtCO_2$, see Chapter 4) and transport (116 $MtCO_2$, see Chapter 5).
- Non-CO_2 emissions were 91 $MtCO_2e$. The largest contributor was agriculture (47 $MtCO_2e$, 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 $MtCO_2e$ of emissions from international aviation (33 $MtCO_2e$ in 2011) and international shipping (10 $MtCO_2e$ in 2011), although these are not currently covered by carbon budgets.

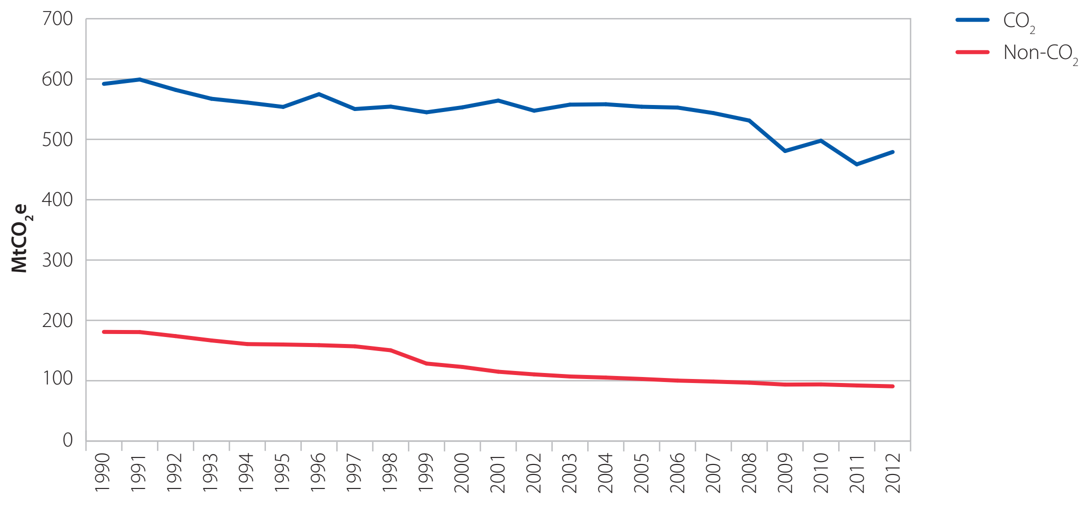
Since 1990, economy-wide greenhouse gas emissions have fallen 26%, within which CO_2 emissions have fallen 19%, and non-CO_2 emissions have fallen 50%. Since 2009 (the latest year of data available when we advised on the fourth carbon budget), total CO_2 emissions have been broadly flat, whereas non-CO_2 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)



Source: DECC (2013) 2012 Provisional UK greenhouse gas emissions.

The legislated fourth carbon budget requires that emissions are reduced to 390 $MtCO_2e$ 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-CO_2), our scenarios are based on baseline forecasts of GHG emissions and our assessment of the cost-effective abatement measures to reduce GHG emissions below this level. We use DECC's Updated Emissions Projections for baseline GHG emissions for the industry, buildings, agriculture, and other non-CO_2 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.

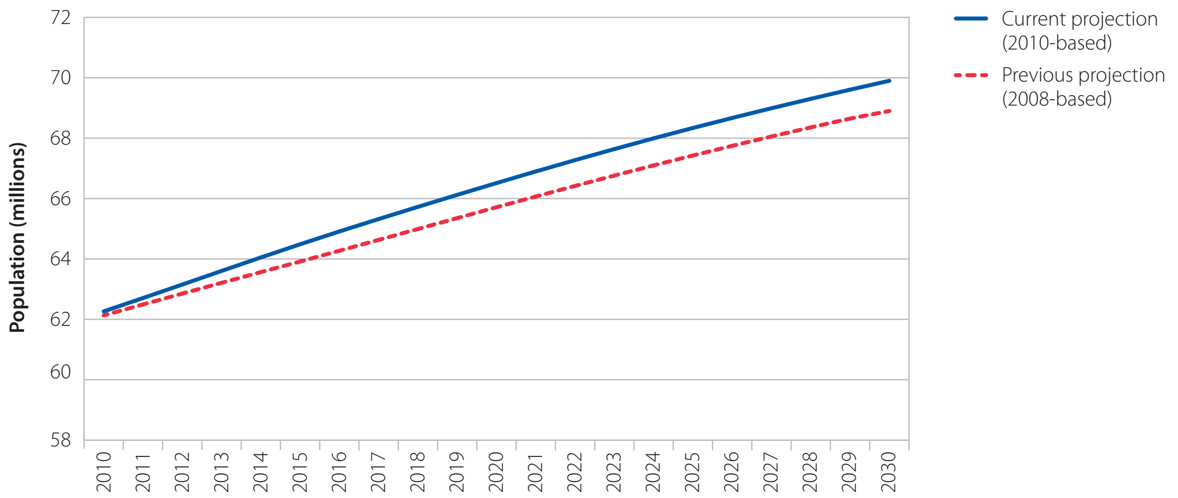
Since 2010, when we originally advised on the fourth carbon budget, there have also been updates to the assumptions of some key drivers of emissions:

- **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-intense gas, although there may be an offsetting effect if the lower gas price discourages efficiency improvements or switches to low-carbon technologies.

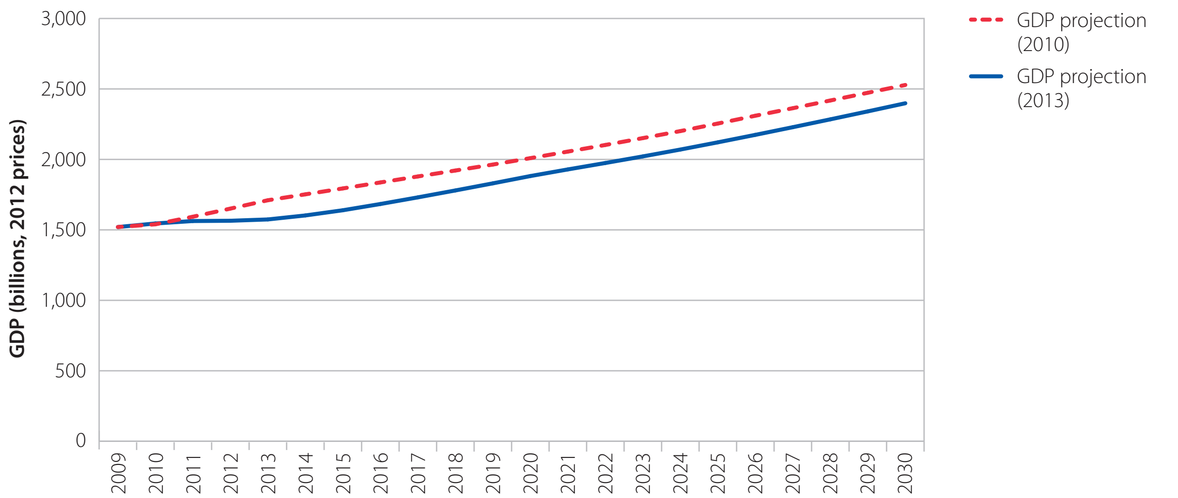
As a result of the new modelling and the new expectations for the drivers of emissions, the projections of energy demand and emissions *in the absence of abatement effort* have been revised (Figure 1.6):

Figure 1.3: UK population projections (2010-2030)



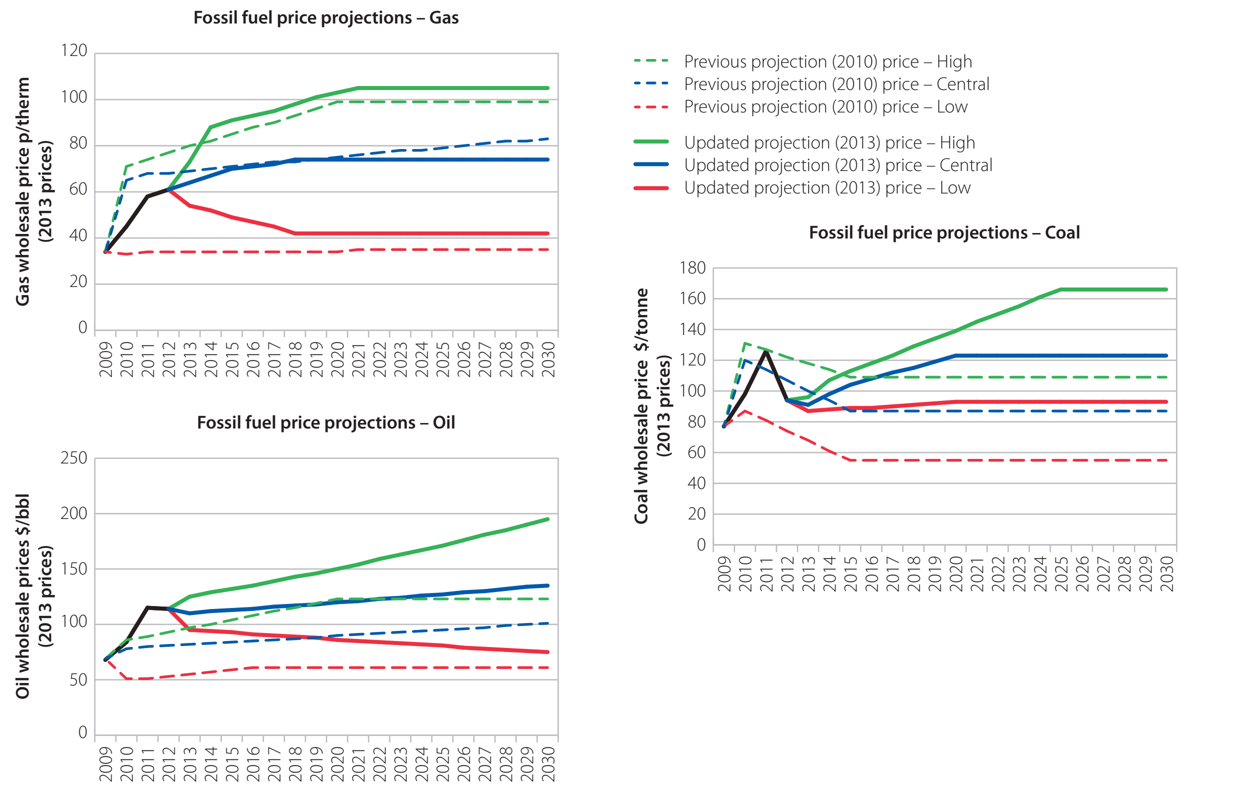
Source: ONS (2010) 2008-based population projections (low-migration variant); ONS (2011) 2010-based population projection (low-migration variant).

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)



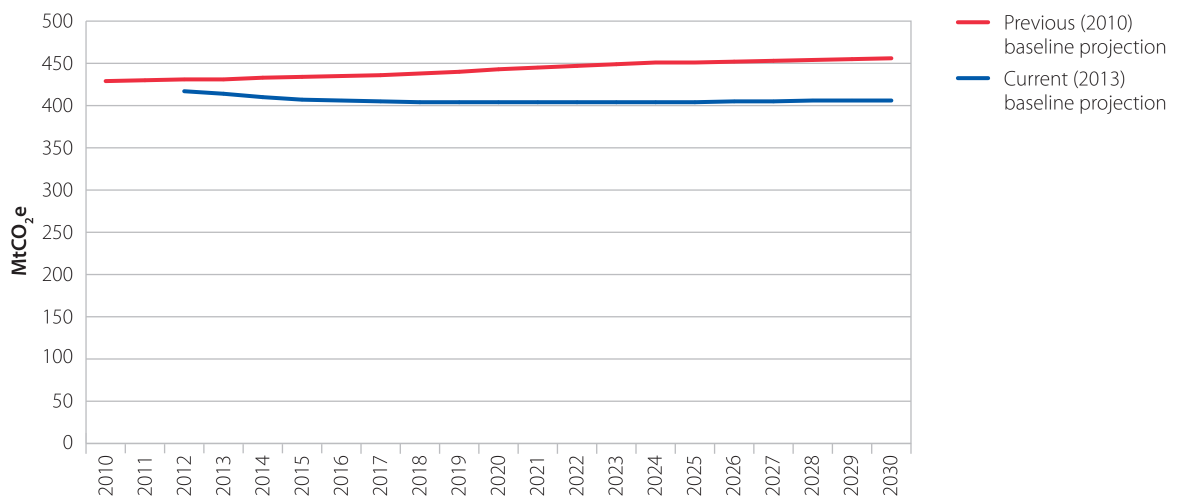
Source: DECC (2010) Energy and emissions projections; DECC (2013) Energy and emissions projections.

- Greenhouse gas emissions outside the power sector are now projected to fall by 6.3% from 2010 to reach 408 MtCO_2e in 2030. Relative to our previous assessment, this is a substantial reduction in projected emissions before abatement action (220 MtCO_2e less across the five-year fourth budget period). It reflects lower projections of both CO_2 and non-CO_2 emissions.
  - CO_2 emissions (excluding power emissions) are projected to fall by 1.8% from 2010 to reach 335 MtCO_2 in 2030 in our baseline projection. Across the fourth budget period CO_2 emissions are now projected to be 183 MtCO_2 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 MtCO_2 lower than previously assumed across the carbon budget period.
  - Non-CO_2 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 MtCO_2e in 2030 in our baseline scenario. Projected emissions across the fourth budget period are now 37 MtCO_2e 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

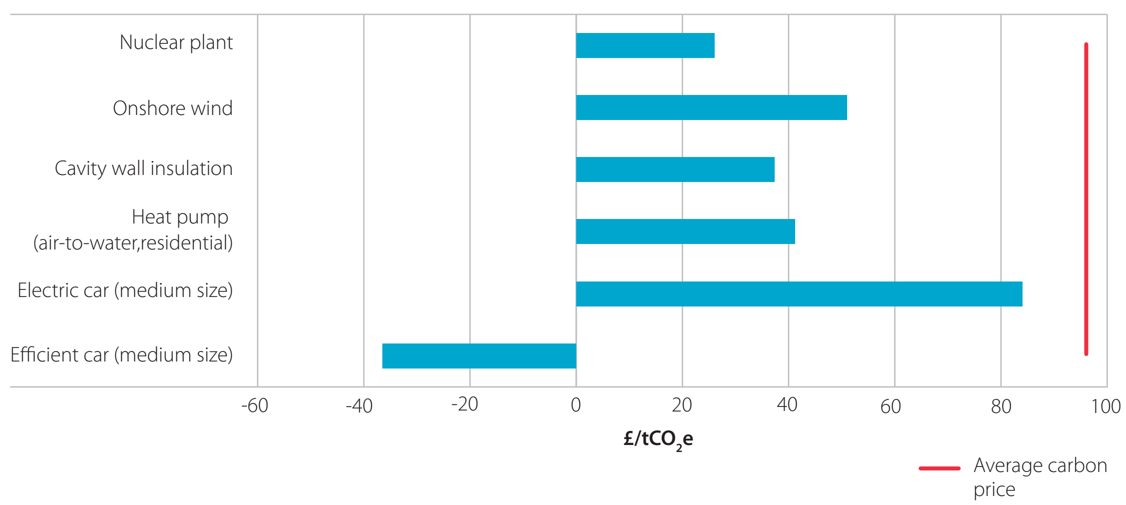
and 2040s. In the short term, this may cost more than investment in conventional fossil fuel alternatives, even when a projected carbon price is included. However, this additional cost can be justified in terms of option development and long-term reductions in cost and risk. Our previous analysis has 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/tCO_2 in 2020 to £76/tCO_2 in 2030 and to £216/tCO_2 in 2050.

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

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



Source: CCC modelling.
Notes: Carbon price shown is average carbon price over an indicative 15-year technology lifetime.

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 Pöyry[1] 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).

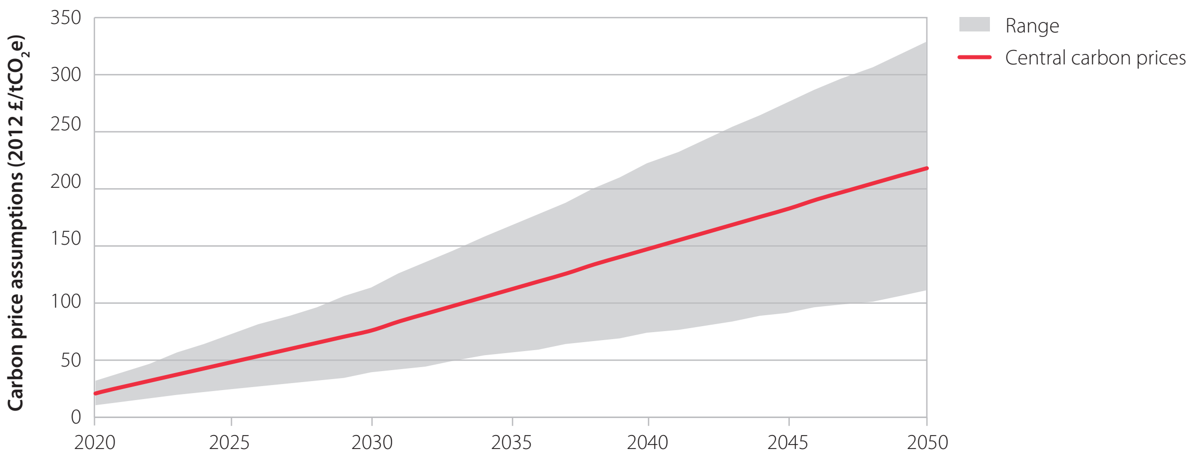
As set out in more detail in the first part of our review[2], our updated assessment of the cost-effective abatement path uses carbon values based mainly on the Government's projected values (Figure B1.4):

- 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 $MtCO_2$ 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 $MtCO_2$ lower than we assumed in our 2010 advice. Average grid intensity is assumed to reduce 49% to 211 gCO_2/kWh in 2020, compared to 323 gCO_2/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 CO_2 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 $MtCO_2$ in 2020. This would be a 17% reduction on 2010 and is 9 $MtCO_2$ 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 $MtCO_2$ in 2020. We add to this projected emissions from rail and domestic aviation and shipping, bringing total domestic transport emissions to 93 $MtCO_2$. 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 $MtCO_2$ 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 $MtCO_2$ in 2020. This is a 21% reduction on 2010 and is 21 $MtCO_2$ 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 $MtCO_2e$ 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 $MtCO_2e$ 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

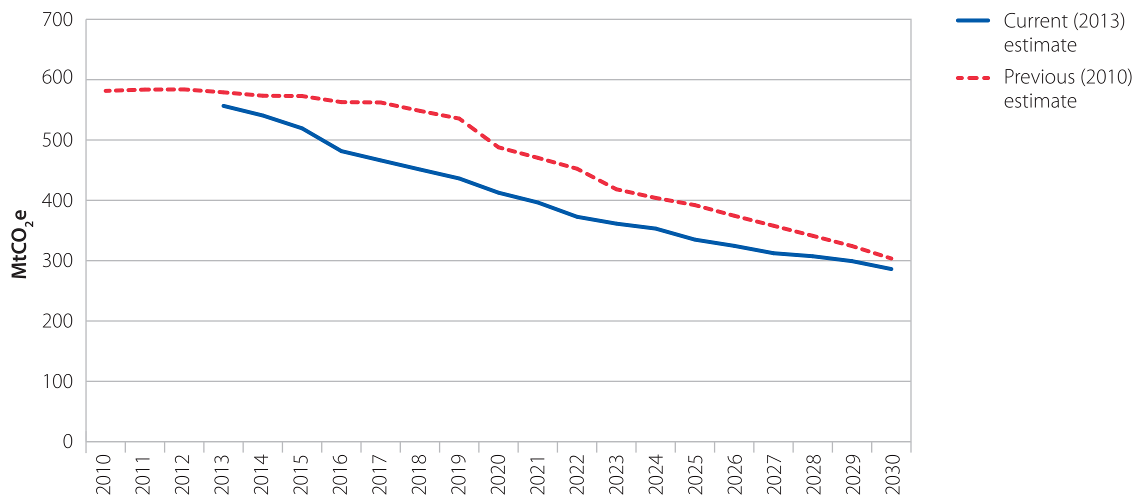
We have updated our assessment of the cost-effective path in light of new evidence on emissions projections and the costs and feasibility of abatement options. This results in an updated abatement scenario with emissions cuts of 56% in 2025 and 63% in 2030 on 1990 levels, compared to the scenario underpinning 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 gCO_2/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.

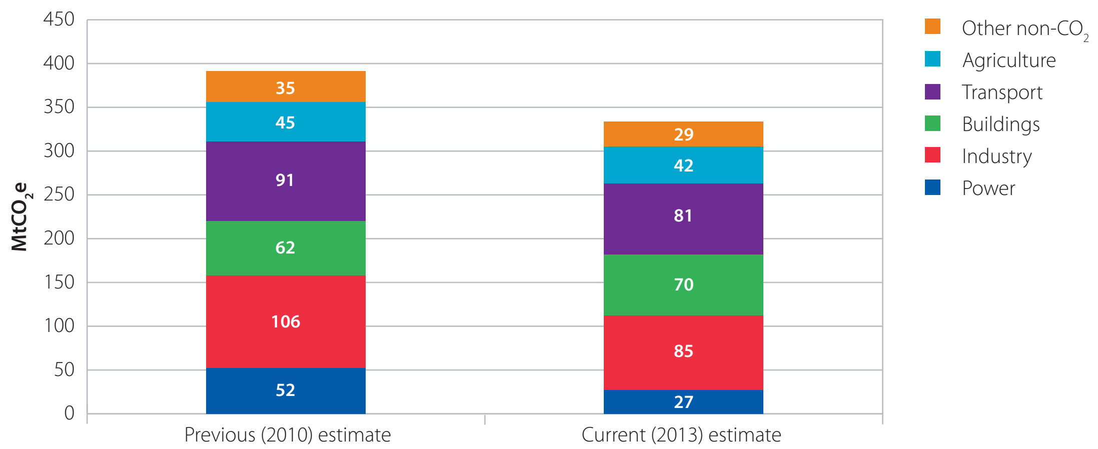
- We have revised our uptake down from 7 million heat pumps in homes to 4 million by 2030 (i.e. 13% of homes have heat pumps in 2030, rather than 21%), along with lower deployment in non-residential and industrial buildings.
- This is offset to a degree by higher uptake of district heating – increased 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 N_2O emissions from soils and CH_4 emissions from livestock and manures. This results in GHG emissions of 39 Mt in 2030, a 18% reduction on 2012 levels.
- **Non-CO_2 greenhouse gases.** We assume that non-CO_2 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 $MtCO_2e$ across the fourth budget period, compared to the currently legislated limit of 1,950 $MtCO_2e$. 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 $MtCO_2e$ (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 $MtCO_2e$ across the budget period. This would be around 50 $MtCO_2e$ (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 $MtCO_2e$ across the budget period. This would be around 210 $MtCO_2e$ (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-CO_2 scenarios

Non-CO_2 GHG emissions comprise methane (CH_4), nitrous oxide (N_2O) and fluorinated gases (F-gases). The main sources of these emissions outside the agriculture sector are emissions of CH_4 and N_2O 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 CH_4 leakage from gas pipes and coal mines, some industrial processes and catalytic converters in vehicles.

Non-CO_2 emissions excluding agriculture were 44 $MtCO_2e$ in 2012. Non-CO_2 baseline projections have been revised down, primarily due to an improved methodology for measuring and projecting waste emissions. The latest projections are for non-CO_2 emissions excluding agriculture to fall to 25 $MtCO_2e$ 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-CO_2 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-CO_2 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 $MtCO_2e$ in 2012 to 11 Mt in 2030.
- **F-gases.** Emissions of F-gases (HFCs, PFCs and SF_6) decrease 64%, from 14 $MtCO_2e$ in 2012 to 5 Mt in 2030.
- **Other non-CO_2.** Non-CO_2 emissions from transport, industry and other sources decrease 35%, from 13 $MtCO_2e$ 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 $MtCO_2e$ in 2012 to 287 $MtCO_2e$ 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 $MtCO_2e$ in 2050, a 4.3% annual reduction between 2030 and 2050. This implies an acceleration of effort beyond 2030 (Figure 1.10).

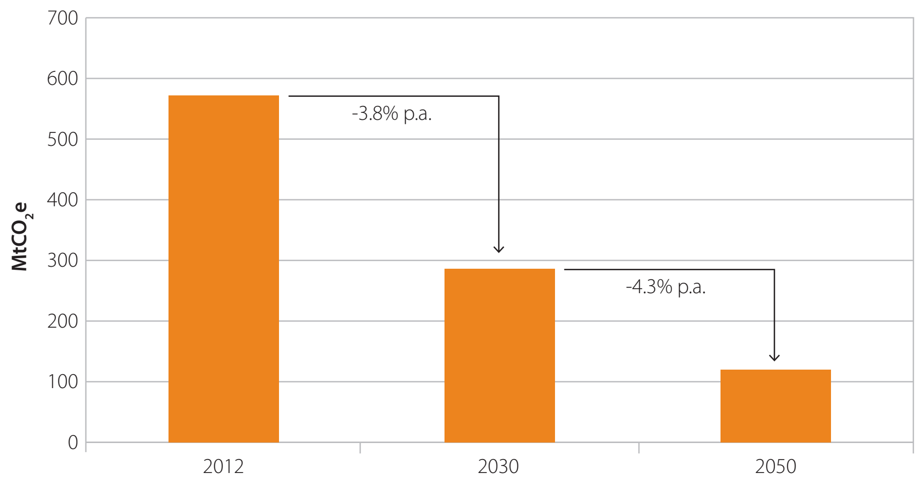
Our analysis indicates that this acceleration of effort is feasible, provided the options to deploy key technologies are developed in the 2020s:

- **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 can 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 $MtCO_2$ 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 CO_2 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 gCO_2/kWh in 2030 rather than 50 gCO_2/kWh, increasing emissions by around 65 $MtCO_2$ (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 $MtCO_2$ (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 $MtCO_2$ (<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 $MtCO_2e$ (<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]

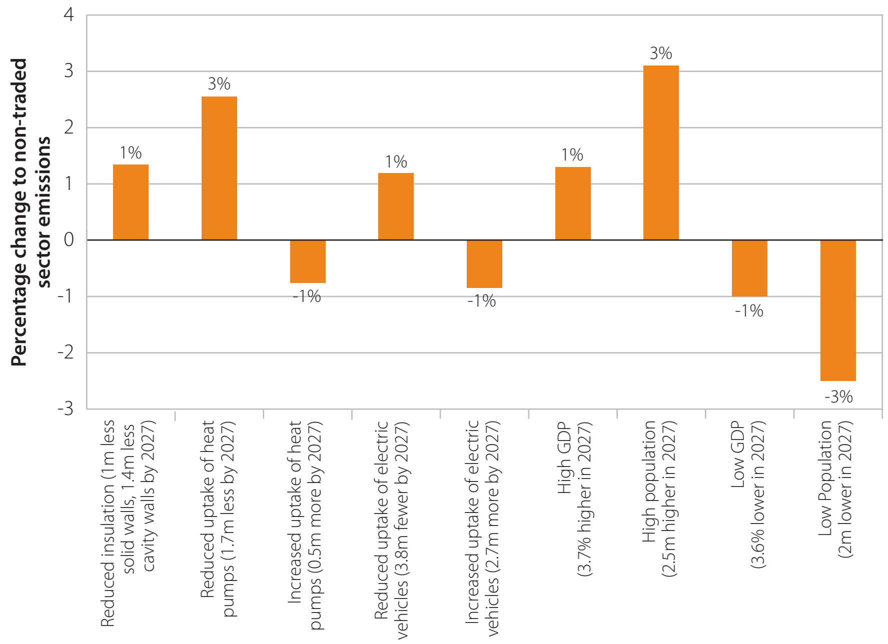
Alternatively, it may be desirable to go further than assumed in our scenario if measures prove cheaper than we have assumed, or if fossil fuel and/or carbon prices turn out to be high. This could lead to more rapid reductions in emissions than we have assumed or compensate for some of the other sensitivities 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-CO_2 emissions than we have assumed. We demonstrated in our original advice that together these options could deliver a further 64 $MtCO_2e$ (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 Sciencewise[3]) 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 constraint[6]. 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-CO_2 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' macroeconometric 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*).

- 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/tCO_2 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 CO_2 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, CO_2 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/tCO_2e), 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/tCO_2, 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/tCO_2.
- **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/tCO_2, 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.