Chapter 3: The cost-effective path to the 2050 target

Introduction and key messages

This chapter sets out our updated assessment of the cost-effective path to meeting the 2050 target.

The updated assessment allows for new evidence on: emissions projections; the feasible pace at which measures can be implemented; and whether these measures are cost effective, depending on technology costs, fossil fuel prices and carbon prices.

We compare our updated assessment with the path reflected in the legislated fourth carbon budget.

Our key conclusion is that there is no rationale to change the budget based on our updated assessment of the cost-effective path to meeting the 2050 target.

- **Feasibility of the budget**. The budget can be met based on more prudent assumptions on implementation of measures than in our original advice (e.g. lower assumed uptake of heat pumps and more limited contribution from solid wall insulation). This is because official projections of energy demand have been revised down to reflect updated evidence on key demand drivers and improved approaches to projecting emissions in line with previous Committee advice.

- **Cost savings of early action.** The budget provides insurance against risks of dangerous climate change and rising energy bills. It offers significant cost savings relative to a path where action to meet the 2050 target is delayed until the 2030s. We estimate that the saving could be over £100 billion in present value terms under central assumptions about fossil fuel and carbon prices, allowing for expected impacts of shale gas; in a world of high fossil fuel prices, the benefit could be as high as £200 billion. Even with low fossil fuel or carbon prices, the budget would offer a cost saving compared to an alternative path where action to reduce emissions is delayed.

- **Keeping the budget at its current level.** Our updated best estimate of the cost-effective path to the 2050 target implies a larger reduction in emissions in the 2020s than required by the budget. This could imply that a tighter budget (i.e. requiring a larger emissions reduction) is appropriate. However, it would be premature to tighten the budget now, given 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.

- **Non-traded sector** (i.e. emissions outside the EU Emissions Trading System – transport, buildings, agriculture and non-CO_2 greenhouse gases). If all cost-effective measures were to be implemented, our best estimate is that this would result in outperformance of this part of the budget by around 4%. However, this is within the likely margin of error and could provide flexibility to deal with 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.
- **Traded sector** (i.e. emissions from those sectors of the economy covered by the EU ETS – power generation and energy-intensive industry). The current accounting rules of the Climate Change Act require that this part of the budget should be aligned with the EU ETS path through the 2020s, once this is agreed. While current discussions in the EU suggest a tightening of the budget may be required, the negotiations are ongoing and further decisions are required before the budget can be aligned. From a domestic perspective, a judgement on any budget revision should be taken together with setting a target for power sector decarbonisation; the Government and Parliament have decided that any power sector decarbonisation target should be set in 2016 alongside the fifth carbon budget (covering 2028-32).
- **Investor confidence.** We have received the clear message from a wide range of business stakeholders that there is a benefit in sticking with the currently legislated budget, and that any change to this could undermine the certainty that the budget provides.
- Our updated analysis shows that there should be no lowering of ambition in the budget. This would imply a further departure from the cost-effective path to meeting the 2050 target, which could not be justified in terms of any change in the impacts associated with meeting the budget (e.g. affordability or competitiveness, see Chapter 4). Furthermore, any proposal to loosen the budget would undermine credibility of the UK in EU and international negotiations and further undermine already fragile investment conditions, particularly as such a proposal would be counter to the available evidence.

Taken together with our assessment of the impacts from meeting the budget, which remain unchanged (see Chapter 4), and our assessment of climate science, international and EU circumstances (see Chapter 2), there is therefore no legal or economic basis to change the budget at the current time.

Given the short lead-time to the 2020s, the focus now should be on putting in place policies to support implementation of cost-effective measures, including early decarbonisation of the power sector.

- **Power.** Implement the Electricity Market Reform such that this supports portfolio investment in low-carbon technologies and supply-chain investment, thereby ensuring early decarbonisation of the power sector with significant consumer benefit. Key challenges include setting strike prices at the right level, and providing confidence to investors that there will be sufficient and ongoing volume to 2020 and beyond.

- **Buildings energy efficiency.** Put in place incentives for uptake of the full range of cost-effective measures in residential and non-residential buildings. Monitor the effectiveness of these policies, responding as necessary if uptake is low, while ensuring that there are safeguards in place to prevent cost escalation.
- **Low-carbon heat.** Put in place approaches to address financial and non-financial barriers to support very significantly increased levels of investment in heat pumps; and to carry out detailed feasibility studies and move forward with investments in district heating infrastructure.
- **Transport.** Continue to press for stretching efficiency standards for new vehicles at the EU level, out to 2030. Continue to support market development for electric vehicles through purchase subsidy and investment in charging infrastructure.
- **Industry.** Develop approaches to demonstration and then deployment of carbon capture and storage (CCS) in industry. Continue to develop the evidence base on potential for improved energy efficiency. Ensure that policies to address potential competitiveness effects of low-carbon are clear and extend sufficiently into the future to cover investment cycles (see Chapter 4).

We will set out a detailed assessment of these challenges in our sixth report to Parliament on progress reducing emissions, to be published in July 2014.

We will continue to monitor closely all the relevant factors in budget design. We will report on the fifth carbon budget and the power sector decarbonisation target together with any possible adjustment to the fourth carbon budget in 2015, by which time we expect better information to be available about the EU and international contexts for emissions reduction.

1. Recap of approach in the fourth carbon budget: the cost-effective path to the 2050 target

Principles upon which the fourth carbon budget was designed

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), subject to the wider economic and social impacts being manageable (see Chapter 4).

We define the cost-effective path as comprising measures that cost less than the projected carbon price across their lifetimes (Box 3.1), together with measures that may cost more than the projected carbon price, but are necessary in order to manage costs and risks of meeting the 2050 target.

- **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 CCS can be justified on this basis.

Recent decisions and analysis reinforce the need to prepare for deep emissions cuts by 2050:

- The Government confirmed in December 2012 that emissions from international aviation and shipping are included in the 80% emissions reduction target for 2050. Given the difficulty in delivering deep reductions in emissions from international aviation and shipping (e.g. due to limited opportunities for low-carbon fuels and projected aviation demand growth), this reinforces the need to develop options that could reduce emissions in other sectors to very low levels.
- The Committee's 2012 report on *The 2050 target* reinforced the finding from our first report[1], when we argued that the UK should put itself in a position to meet the 2050 target through domestic (i.e. UK) action, with a potential role for credits to reduce costs at the margin. This is because reducing global emissions to an average of 2 tCO_2e per capita by 2050 is sufficiently stretching that extensive volumes of credits are unlikely to be available in the long term at reasonable cost.
- The Committee's April 2013 report on the UK's carbon footprint[2] concluded that the UK is likely to continue being a net importer of emissions embodied in industrial products out to 2050 and beyond. This will make emissions targets in other countries relatively harder to meet, and emphasises the need for the UK to prepare to meet the 2050 target through domestic action, rather than through purchasing emissions credits.

1 CCC (2008). *Building a low-carbon economy.* Available at http://www.theccc.org.uk/publication/building-a-low-carbon-economy-the-uks-contribution-to-tackling-climate-change-2/
2 CCC (April 2013). *Reducing the UK's carbon footprint and managing competitiveness risks.* Available at http://www.theccc.org.uk/publication/carbon-footprint-and-competitiveness/

Box 3.1: 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).

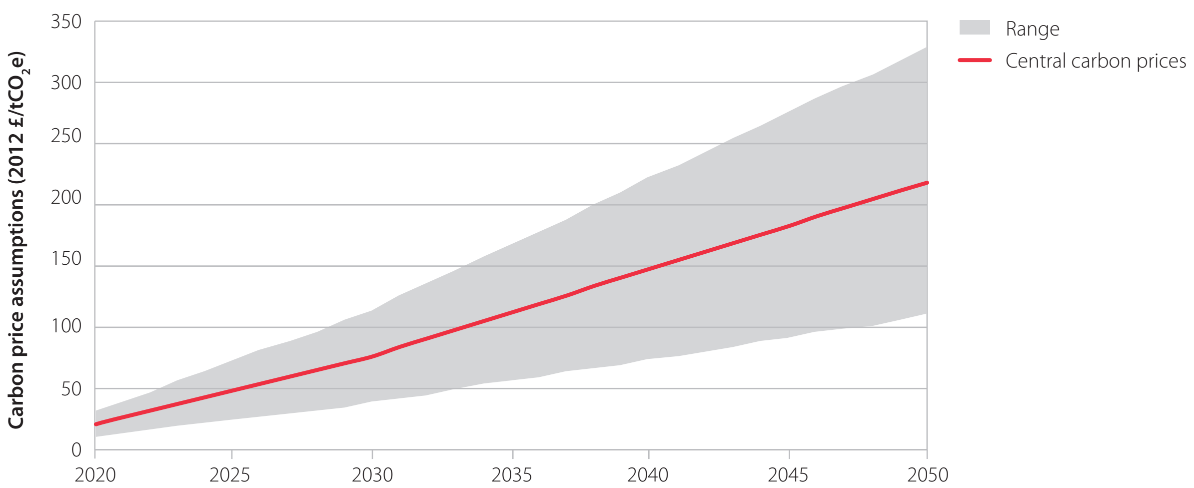
As set out in more detail in the first part of our review[3], our updated assessment of the cost-effective abatement path uses carbon values based mainly on the Government's projected values (Figure B3.1):

- 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 B3.1: 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.

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

The level of the fourth carbon budget – and how to meet it

Our previous analysis led us to recommend a fourth carbon budget involving a 50% cut in emissions in 2025 relative to 1990 levels (32% on 2012 levels).

Meeting the budget requires investment in each of energy efficiency improvement, fuel efficiency improvement, power sector decarbonisation, some electrification of surface transport and heat, and use of sustainable bioenergy (Figure 3.1). Our original fourth budget advice included an illustrative scenario which would achieve the budget, including the following measures:

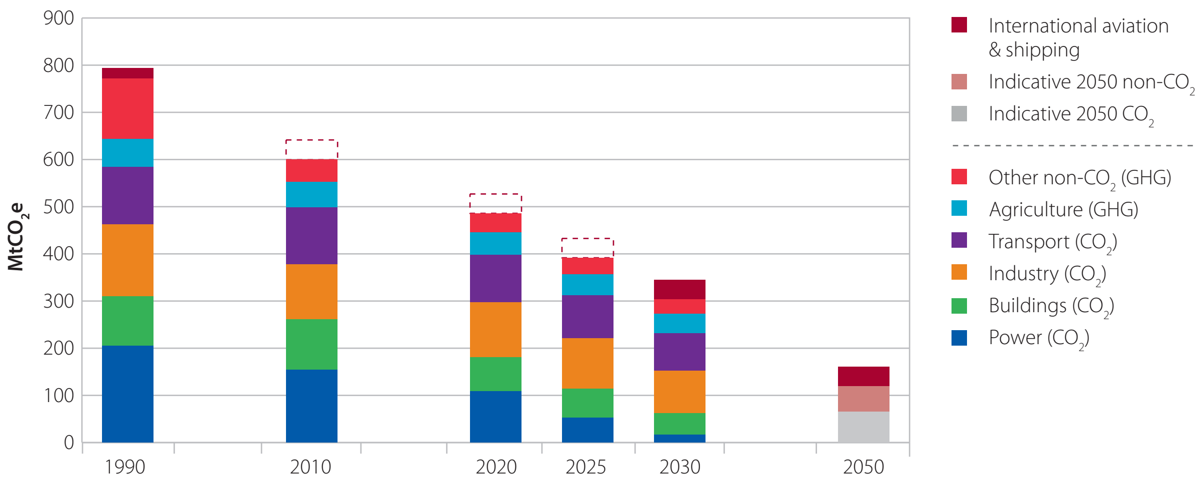
- **Power sector decarbonisation.** Investment focused on low-carbon capacity through the 2020s, resulting in a reduction in carbon intensity from around 300 gCO_2/kWh in 2020 to around 50 gCO_2/kWh in 2030. The aim should be to achieve these kinds of emissions reduction through investment in a technology portfolio including renewables, nuclear and carbon capture and storage (CCS) applied to coal and gas. The scenario included a 30% demand increase from 2020 to 2030, reflecting increased uptake of electric vehicles and heat pumps.
- **Energy efficiency improvement.** Continued improvements in energy efficiency, following on from substantial roll-out during the first three carbon budget periods.
  - **Buildings.** Ongoing energy efficiency improvement through the 2020s, including cumulative insulation of 3.5 million solid walls by 2030 in the residential sector.
  - **Transport.** Further improvement of new conventional vehicle efficiency, to 80 gCO_2/km for conventional cars and 120 gCO_2/km for conventional vans in 2030.
  - **Industry.** We did not assume any further improvements in industrial energy efficiency during the 2020s, reflecting the weakness of the evidence base on the potential for such measures.
- **Electrification of surface transport.** A 60% penetration of electric vehicles in new car sales by 2030, the majority of which were assumed to be plug-in hybrids rather than pure electric, reflecting ongoing concerns around range constraints. We assumed some role for hydrogen vehicles in niche sectors (e.g. 50% of new buses in 2030), with the possibility of broader penetration.
- **Electrification of heat.** The key option for supply-side decarbonisation in our scenario was deployment of heat pumps. These reached a penetration rate of 25% of heat demand in the residential sector, and around 60% in the non-residential sector by 2030. We assumed a limited role for district heating, reflecting uncertainties around technical and economic aspects of this option, with the possibility of deeper penetration as uncertainties are resolved.
- **Use of sustainable bioenergy.**
  - **Biofuels in transport.** We took a cautious approach to sustainable biofuels, assuming no growth in the 2020s from the level recommended for 2020 in the Gallagher Review.

– **Bioenergy in heat.** Bioenergy provides a particularly useful option in the industrial sector, given the lack of low-carbon alternatives for industry decarbonisation. A limited deployment of biomass and biogas for buildings heat was assumed.

– **Biomass in power.** We assumed limited use of biomass in the power sector, given available alternatives for sector decarbonisation and the scarce resource of sustainable bioenergy.

- **Agriculture non-CO_2.** Continuation of progress during the 2010s implementing soils and livestock measures. The scenario recognised the possibility of, but does not require, consumer behaviour change, both as regards reducing waste and rebalancing diet to less carbon-intensive foods. It included emissions reduction potential from increasing afforestation in the 2020s.

Figure 3.1: UK Greenhouse gas emissions scenarios (1990-2050) from the CCC's 2010 advice on the Fourth Carbon Budget



Source: NAEI (2010); CCC modelling.
Notes: Emissions from international aviation and shipping are not currently included in carbon budget accounting, but Government have confirmed that they are included in the 80% emissions reduction target for 2050.

These measures led to emissions of 690 $MtCO_2e$ in the traded sector of the economy (i.e. for those sectors covered by the EU ETS – power generation and energy-intensive industry) and 1,260 $MtCO_2e$ in the rest of the economy – the non-traded sector. Together they formed the basis for the legislated budget of 1,950 $MtCO_2e$ (i.e. 690 plus 1,260). This implies a reduction of 50% in emissions by 2025 relative to 1990, which we suggested should be regarded as a minimum level of effort given the need to prepare for the 2050 target and to contribute to global emissions reduction.

2. Update of cost-effective abatement options and scenarios

This section summarises the updated evidence on baseline emissions and abatement potential, and the implications for the cost-effective path to meeting the 2050 target. We also set out this evidence in full in a technical report published on our website alongside this report.

a) New evidence that we consider in this report

Our updated assessment looks at new evidence on the cost-effective path to the 2050 target, including: emissions projections; the feasible pace at which measures can be implemented; and whether these measures are cost effective, depending on technology costs, fossil fuel prices and carbon prices.

- **Baseline emissions projections.** The emissions scenarios underpinning the fourth carbon budget were developed from DECC's official baseline projections assuming no further low-carbon investment beyond 2020, which were then adjusted to reflect uptake of abatement options. Updated baseline projections of emissions reflect the latest economic data and expectations for fossil fuel prices, as well as improved approaches to forecasting. They have been reduced significantly since the fourth budget was set, particularly for industry and electricity sectors. Other things equal, this could suggest that a tightening of the budget is appropriate.
- **Feasibility of abatement options.** The analysis for the fourth carbon budget made assumptions about the pace at which abatement options could be implemented. In turn, these reflected assumptions on capital stock turnover, consumer acceptability, and supply chain development. In this report, we consider new evidence on the pace of feasible investment in low-carbon technologies. A faster or slower pace of feasible investment could suggest the need to adjust the budget.
- **Cost-effectiveness of abatement options.** The cost of reducing emissions depends on the relative costs of the low-carbon solutions compared to the cost of continuing to consume fossil fuels as currently. Whether these are cost-effective depends on the carbon price that the UK faces.
  - **Low-carbon technology costs.** Future costs of abatement options are inherently uncertain, reflecting uncertainty over current costs and scope for cost reduction. In this report we review cost assumptions underpinning the fourth carbon budget, and update these based on latest evidence. Significantly higher or lower costs than previously assumed could suggest that a different level of uptake is appropriate on the cost-effective path.

– **Fossil fuel price projections.** These are important in estimating the cost of conventional fossil fuel investments, against which cost effectiveness of investments in energy efficiency and low-carbon technologies can be assessed. We consider latest fossil fuel price projections, including potential impacts of shale gas on gas prices (Box 3.2). Higher or lower fossil fuel prices could suggest a different set of cost-effective investments in low-carbon technologies.

– **Carbon price projections.** These are a key driver of whether low-carbon investments are cost effective compared to conventional fossil fuel alternatives. For example, a higher carbon price would suggest more investment in low-carbon technologies is appropriate, while a lower price would point to less. We consider a set of carbon price projections consistent with our updated assessment of climate science, international and EU contexts, and which reflect the range of uncertainty for each (see Box 3.1 above).

Subject to other impacts remaining manageable (see Chapter 4), and other relevant circumstances remaining unchanged (see Chapter 2), only if there were a substantive change in the assessment of the cost-effective path to meeting the 2050 target would a change in the fourth carbon budget be justified, and allowed under the Climate Change Act.

We now summarise the latest evidence on emissions projections and our updated assessment of feasibility and costs of abatement measures.

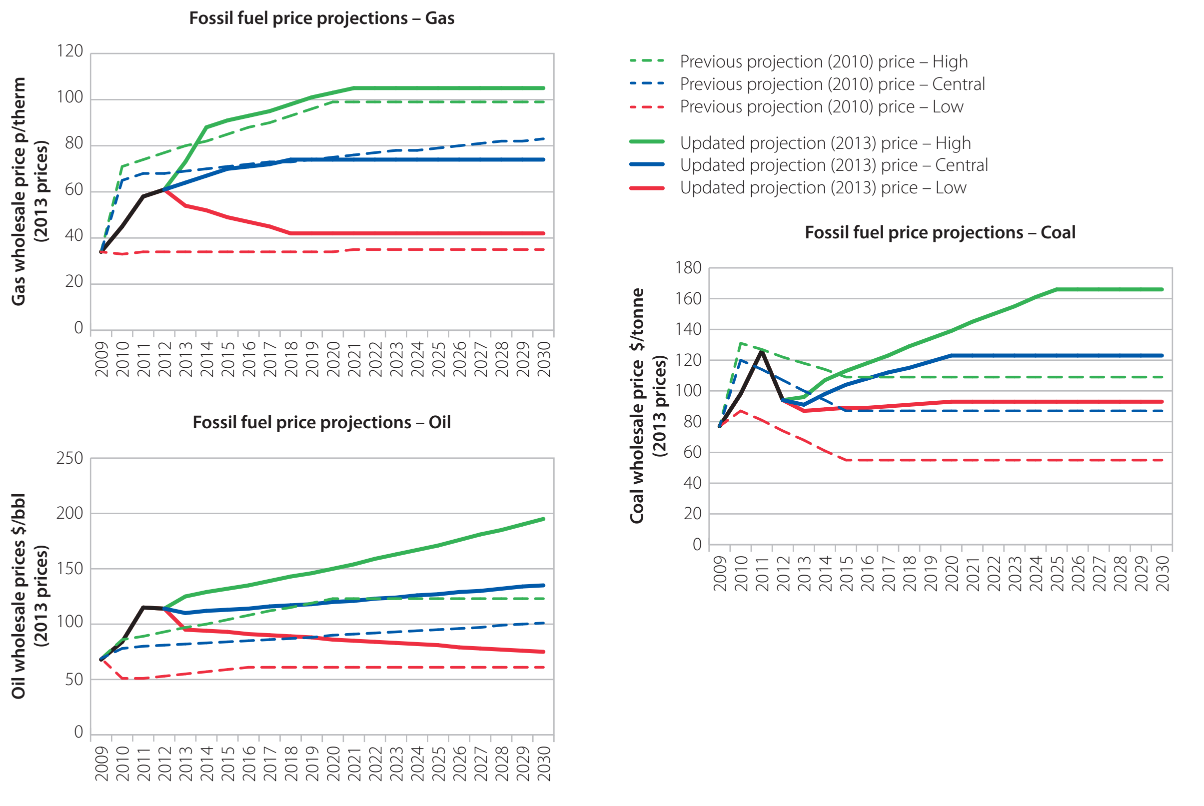
Box 3.2: Changes to DECC's fossil fuel price scenarios since 2010

In our 2010 advice on the level of the fourth carbon budget we used DECC fossil fuel price scenarios from June 2010. These scenarios have since been updated. In this report, we use the latest fossil fuel price projections from DECC's 2013 Updated Energy Projections (UEP). The changes to the fossil fuel price projections (Figure B3.2) are as follows (all data in 2013 prices):

- **Gas.** In 2010, DECC's central gas price scenario anticipated an increase from 75p/therm in 2020, to 79p/therm in 2025 and 83p/therm in 2030. The latest central price assumption has now decreased slightly to 74p/therm in 2020 and then remains constant at that level to 2030. In 2010 DECC's range for gas prices in 2030 was 39-108p/therm, whereas in 2013 the assumed range for 2030 is 42-105p/therm.
- **Oil.** In 2010 central oil prices were projected to increase from 90$/bbl in 2020, to 95$/bbl in 2025 and 101$/bbl in 2030. The central price has now increased to 120$/bbl in 2020, 127$/bbl in 2025 and 135$/bbl in 2030. In 2010 DECC's range for oil prices was 67-134$/bbl in 2030, whereas in 2013 the assumed range for 2030 is 75-195$/bbl.
- **Coal.** In 2010 central coal prices were projected to reach 87$/tonne in 2020 and remain there until 2030. In the latest projections, the central price reaches 123$/tonne in 2020 and remains there until 2030. In 2010 DECC's range for coal prices was 55-109$/tonne in 2030, whereas in 2013 the assumed range for 2030 is 93-166$/tonne.

DECC's latest scenarios take account of the potential for shale gas production in the UK and elsewhere. This has only a minor impact on gas prices in the central scenario, given the interconnectedness of the European gas network, constraints on shale gas production in Europe (e.g. due to high population density and environmental regulation) and the context of declining conventional natural gas production.

Figure B3.2: UK fossil fuel price projections (2010-2030)



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

b) New projections for baseline emissions

Since our original advice, assumptions for the drivers of energy demand have changed, with lower expected GDP in the 2020s, higher population numbers and changes in fossil fuel prices (see Box 3.2 above). DECC have also improved their modelling approach for projecting emissions.

- **GDP.** In the 2013 updated projections, GDP is projected to grow by 35% to 2025, at which time it will be 6% lower than was projected in 2010.
- **Population.** Under updated 2011 Office of National Statistics projections, the UK population is projected to grow by 10% from 2010 to 2025. This gives a population around 1.3% higher in 2025 than the projection published in 2009.
- **Modelling approach.** In 2011 the Committee commissioned a review of the DECC energy demand model, which made a number of recommendations for how this could be improved. Subsequently, the DECC model has been updated to include a new model of electricity supply, and energy demand equations have been improved, especially for the industrial sector, where the equations now better reflect historic trends and current structure.

There have also been changes in how the UK emissions inventory is defined and calculated. This has specifically affected shipping emissions, where an improved estimate has reduced the share allocated to domestic shipping and increased that for international shipping (which is not currently covered by carbon budgets), and waste emissions, where an improved methodology has been adopted for calculating methane emissions from landfill.

As a result, DECC's projections for emissions within the scope of carbon budgets have been reduced for the 2020s. In a baseline scenario that includes measures which we have previously recommended should be implemented to 2020 (and which the Government has largely already implemented or committed to, e.g. deployment of renewables, efficiency standards for new vehicles, insulation in buildings), but no further measures beyond 2020:

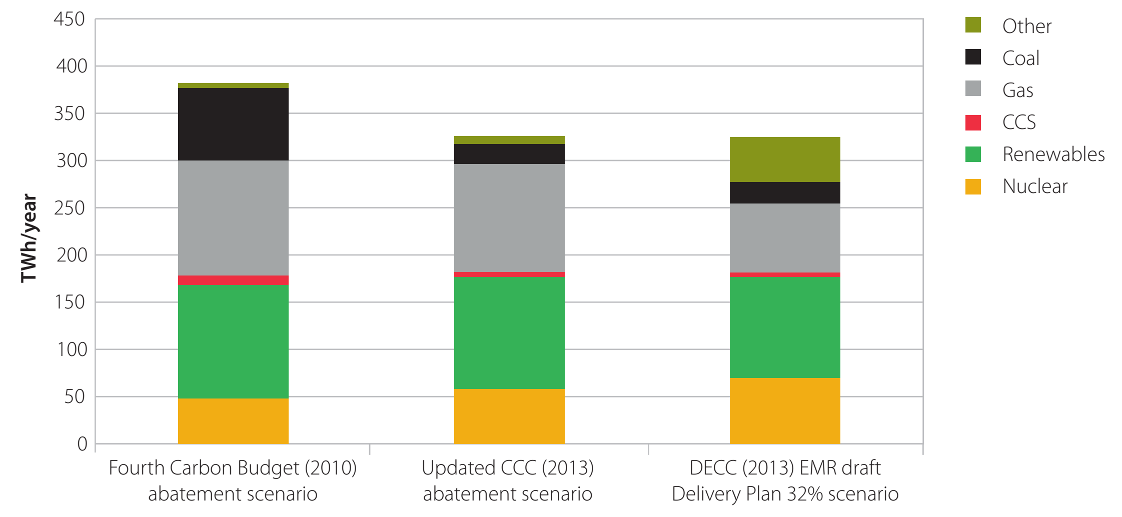
- Greenhouse gas emissions outside the power sector are now projected to fall by 6.3% from 2010 to reach 408 $MtCO_2e$ in 2030. Relative to our previous assessment, this is a substantial reduction in projected emissions before abatement action (220 $MtCO_2e$ less across the five-year fourth budget period). 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.

- In the power sector, we use DECC's baseline projection of demand for electricity and undertake our own modelling of supply
  - 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.
  - Projected power sector emissions have decreased significantly since our advice in 2010, mainly due to a more rapid assumed fall in coal-fired generation. The amount of unabated coal-fired generation assumed for 2020 has reduced by 72% to 21 TWh (Figure 3.2). This is due to a combination of: reduced overall demand reducing the need for coal generation; greater assumed generation from existing nuclear plants due to announced life extensions; plans to convert existing coal units to biomass; an assumption that any coal CCS demonstrations would have CO_2 capture applied to all units; and latest assumptions relating to the impact of the Industrial Emissions Directive on coal-fired capacity. These new assumptions are also reflected in DECC's latest analysis for the EMR Delivery Plan.

Taken together these updated projections suggest that the legislated budget could be met with less abatement effort than we previously expected in both the traded and non-traded sectors of the economy (Figure 3.3).

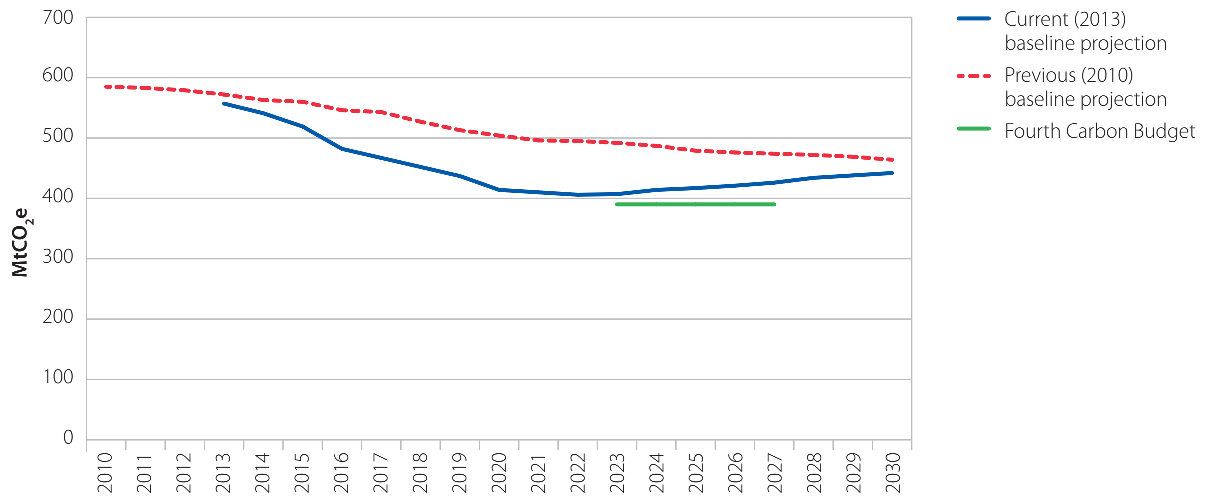
However, the new projections still imply that meeting the fourth carbon budget will need a significant reduction in emissions against the baseline scenario. We now turn to the latest evidence on the potential to make these reductions.

Figure 3.2: UK power generation in 2020



Source: CCC (December 2010) The Fourth Carbon Budget – Reducing emissions through the 2020s; DECC (July 2013) Draft EMR Delivery Plan; CCC calculations based on Redpoint (2012) and (2013) modelling.
Notes: Generation from major power producers only; renewable generation from all generators. DECC scenario reflects generation mix in 32% scenario in draft EMR Delivery Plan (July 2013). Other category includes pumped storage, gas CHP, oil, and imports. CCC updated abatement scenario assumes no imports in 2020 (instead generation is supplied by gas CCGT) while DECC EMR scenario includes imports. Renewables includes onshore and offshore wind, solar PV, marine. biomass and hydro as well as other renewables identified in DECC's 2013 draft EMR Delivery Plan. Nuclear generation in updated CCC (2013) abatement scenario is lower than DECC (2013) EMR draft Delivery Plan to reflect recently announced (October 2013) delay in Hinkley Point C timeline.

Figure 3.3: Projections for UK greenhouse gas emissions covered by carbon budgets with committed ambition to 2020 and no further measures in the 2020s



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

c) Updated evidence on cost-effective abatement potential

Options for reducing emissions in the power sector

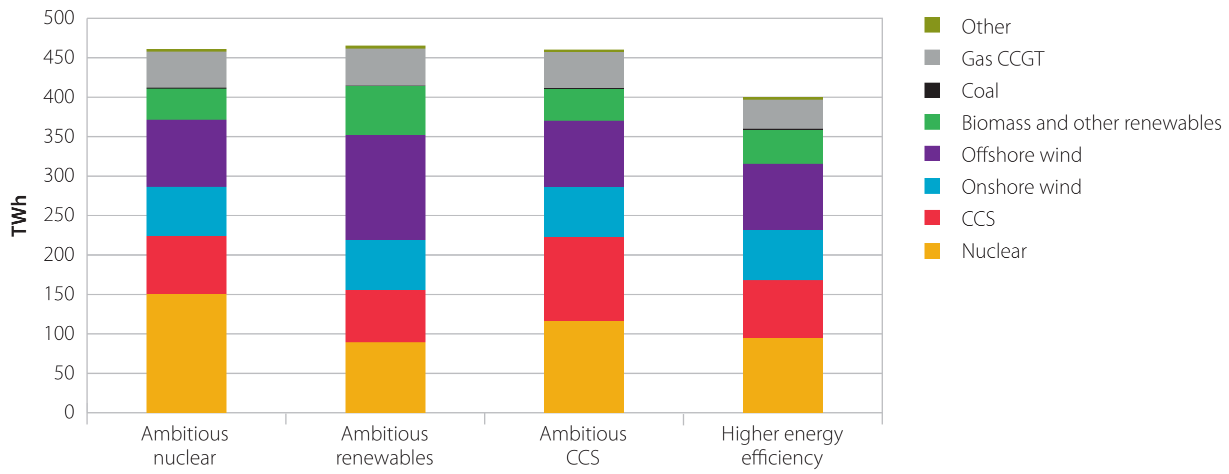
We reviewed the latest evidence on low-carbon power technologies (nuclear, renewables and carbon capture and storage – CCS) in our report *Next steps on Electricity Market Reform*, published in May 2013. In that report, we concluded that the pace of investment in low-carbon technologies assumed when designing the fourth carbon budget remains feasible, and that there is potential for each of the key technologies to become cost-effective through investment in the period to 2030.

- There are various investment pathways that remain feasible to achieve carbon-intensity of around 50 gCO_2/kWh in 2030, as reflected in the fourth carbon budget. These pathways embody a different balance of investment between renewables, nuclear and CCS or more success in reducing electricity demand (Figures 3.4 and 3.5).

- Our updated assessment of low-carbon technology costs reinforced our previous conclusions, which are also consistent with recent announcements on strike prices (Figures 3.6 and 3.7).
  - 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.
  - Projected costs of offshore wind and CCS in the 2020s are currently relatively high. This reflects the fact that these technologies are less mature. There is scope for significant cost reduction such that offshore wind and CCS become cost-effective compared to gas generation under central carbon prices during the 2020s or soon after. These technologies are potentially important in the long run, suggesting that deployment to drive down costs is desirable.
  - Recent announcements on strike prices are in line with these conclusions, noting that these are not directly comparable to costs. At £92.50/MWh the price for the first nuclear plant is in line with our assumptions of £85-100/MWh, and the contract terms explicitly recognise the scope for costs to fall for future projects. The strike prices proposed in the Government's draft delivery plan for onshore and offshore wind (£100/MWh and £150/MWh for contracts signed this year) are broadly comparable to the prices that we suggested would be required in our May 2013 report.

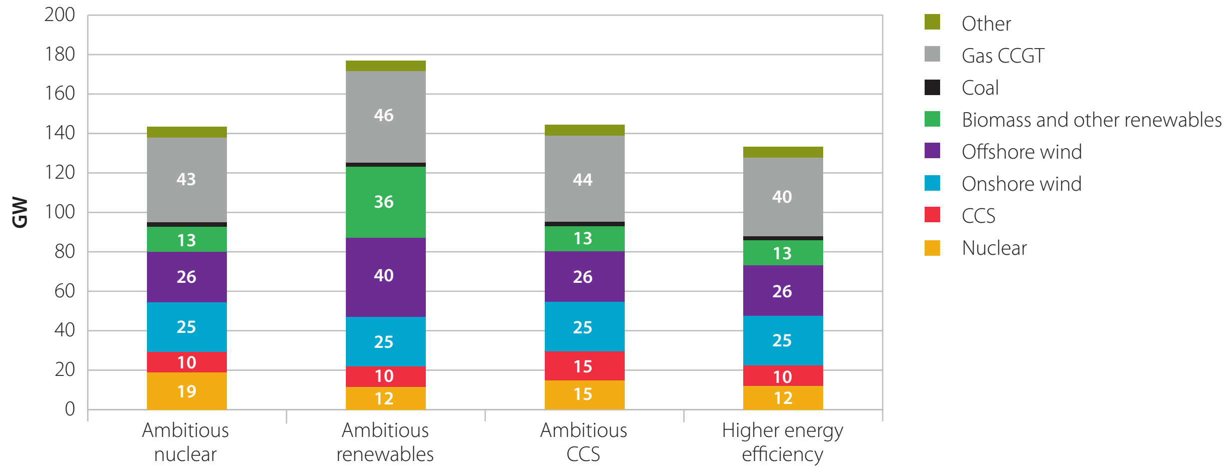
This updated assessment of the feasible pace of investment and costs informs our updated core emissions scenario. We also consider a sensitivity where deployment is slightly slower.

Figure 3.4: Power sector scenarios reaching 50gCO_2/kWh by 2030 – generation (TWh)



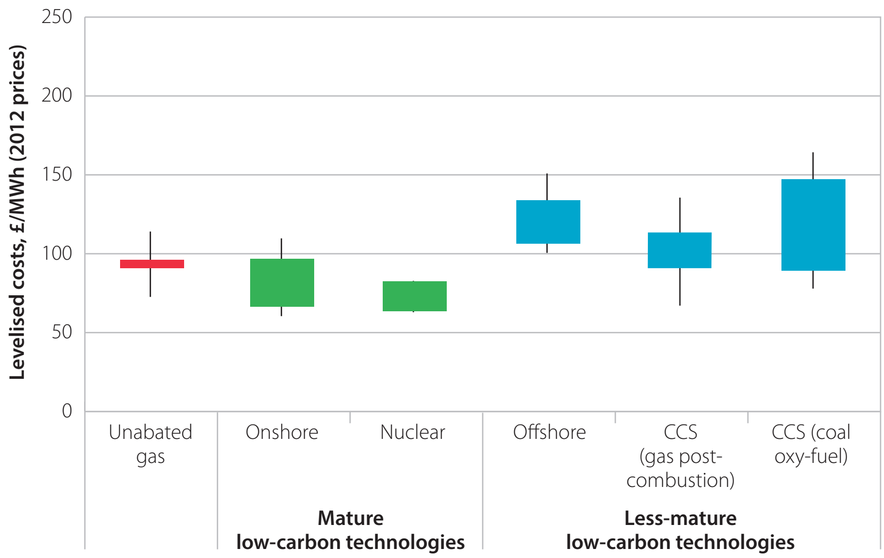
Source: Redpoint, CCC calculations.
Notes: Other includes Pumped Storage and Gas CHP. Other renewables include solar PV, marine and hydro. Excludes autogeneration consumed onsite. CCGT: Combined Cycle Gas Turbine. All the scenario data are presented at UK level, including a small adjustment to add Northern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

Figure 3.5: Power sector scenarios reaching 50gCO_2/kWh by 2030 – installed capacity (GW)



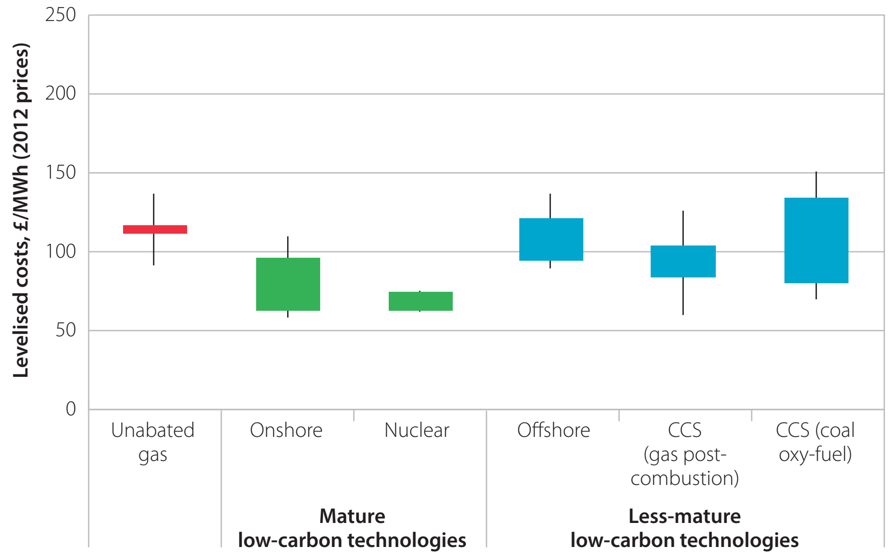
Source: Redpoint, CCC calculations.
Notes: Other includes Pumped Storage and Gas CHP. Other renewables include solar PV, marine and hydro. Excludes autogeneration consumed onsite. CCGT: Combined Cycle Gas Turbine. Nameplate capacity (not derated for availability).

Figure 3.6: Projected costs of low-carbon technologies (2020) relative to unabated gas



Source: CCC calculations based on Poyry, Parsons Brinckerhoff.
Notes: Costs for projects starting construction in 2020. Excludes conversion of existing coal plants to biomass, which comes on in 2010s. Fuel price assumption consistent with 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 3.7: Projected costs of low-carbon technologies (2030) relative to unabated gas



Source: CCC calculations based on Poyry, Parsons Brinckerhoff.
Notes: Costs for projects starting construction in 2020. Excludes conversion of existing coal plants to biomass, which comes on in 2010s. Fuel price assumption consistent with 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% 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).

Opportunities for improving energy efficiency in buildings

The evidence base on energy efficiency potential in buildings has developed significantly since our 2010 advice. We therefore commissioned Element Energy to inform us in updating our assumptions in this area in light of the new evidence.

Our updated assessment suggests that for certain measures there has been a change in the remaining technical potential and/or reduced energy/carbon savings. Reduced energy/carbon savings will mean that some measures are now less cost-effective than we previously assumed in reducing emissions:

- **Thermal insulation**. New evidence based on actual experiences of installed measures on the level of energy savings from solid wall, loft and cavity wall insulation suggests these may be roughly half as effective at cutting energy use as previously assumed. As a result, our assessment of feasible potential from these measures has roughly halved based on the same level of uptake. Reduced effectiveness also implies that much solid wall insulation is no longer cost-effective, potentially costing several hundred pounds per tonne of CO_2 abated, raising questions over its desirability.
- **Lights and appliances**. We now have better disaggregation of the types of efficient lighting, which suggests that switching from halogens to LEDs (a process that has begun) offers the greatest abatement potential from lighting. We now expect the efficiency of cold and wet appliances (e.g. fridges and dishwashers) to continue improving from 2020 to 2030, suggesting greater feasible abatement than we previously assumed.

The implications of this analysis are that cost-effective abatement potential from improving energy efficiency in buildings is lower than we previously assumed. We reflect this in our updated abatement scenario and consider sensitivities with reduced uptake of measures that are now judged to be less cost-effective (i.e. insulation of solid walls and hard-to-treat cavity walls).

Electrifying heat and transport

In our original advice on the fourth carbon budget we included scenarios with significant penetration of electric vehicles and heat pumps, as a route to increasing the share of low-carbon fuels for the transport and buildings sectors.

However, progress deploying these important long-term technologies has been slow since 2010. We therefore commissioned Element Energy and Frontier Economics to reassess the feasible levels of uptake of these technologies to 2030, focusing on the barriers to consumer uptake and policy options to overcome these. We also commissioned Element Energy and Imperial College London to assess the network infrastructure requirements of large-scale electrification alongside deep decarbonisation of the power sector.

These projects reinforce the view that a major roll-out of electric vehicles is possible and desirable, but raise a question over how far heat pump deployment can and should go by 2030:

- Achieving a 60% market share of electric vehicles (EVs) by 2030 is possible provided manufacturers continue to bring new models to market and that industry and Government extend the package of measures to address current financial and non-financial barriers. These measures 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 3.3).
- Although heat pumps remain a cost-effective abatement option for some types of dwelling for the 2020s, our new evidence on capital costs, performance and durability suggest lower deployment is desirable than in our previous scenario. This is offset to a degree by higher assumed uptake of district heating, given greater long-term potential identified (Box 3.4).
- The additional electricity distribution infrastructure required in a scenario with extensive deployment of heat pumps and electric vehicles represents a small (2%) part of the cost of decarbonising the power sector and is not expected to present serious technical challenges (Box 3.5).

We reflect these findings in our updated core scenario, in which we assume a lower level of uptake of heat pumps than previously. We also consider a sensitivity in which heat pump uptake is reduced further for the 2020s.

Box 3.3: New evidence on electric vehicle 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 in the period to 2030. The lower running costs of electric vehicles (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.
- 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 EV purchase, and best delivered overnight at home/depot. Around 70% of vehicle buyers have access to off-street parking where this could take place.
- Public charging infrastructure. Despite overnight charging being likely to dominate, a public rapid-charging network would offer a number of benefits: it would increase the proportion of fleet vehicles for which pure battery electric vehicles are range-compatible (i.e. rather than only plug-in hybrid EVs), address the perceived need for public charging among private buyers and reduce 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. the Plug-In Car Grant) and/or non-financial (e.g. preferential access to parking etc). We will return to policy options for EVs in the 2014 progress report.

While we maintain our previous assumption for EVs to comprise 60% of new car sales in 2030, we scale back our assumption for 2020 to reflect the likely share of projected overall EU production that the UK would access.

Source: Element Energy et al (2013). *Pathways to high penetration of electric vehicles*. This report will be published at www.theccc.org.uk.

Box 3.4: New evidence on low-carbon heat

Heat pumps

We commissioned Frontier Economics and Element Energy to review our uptake scenarios for heat pumps. The key findings were:

- Financial barriers and cost-effectiveness.
  - Additional costs. The study reviewed the evidence on cost data and provided revised assumptions. These include additional costs for upgrading radiators and underfloor heating to account for the lower flow temperatures of heat pumps. There is also evidence that the potential for capital costs to decrease over time is limited, with cost savings to be found mainly in the installation costs.
  - Lower performance. Performance measurements from field trials suggest that the potential for improvements over time may be limited, in part by the low efficiency of the UK housing stock. This particularly affects the uptake of air source heat pumps (ASHPs), which are less efficient than ground source heat pumps (GSHPs).
  - Durability of air-source heat pumps (ASHPs). The evidence on the life expectancy of heat pumps is weak, with a range of 15-20 years commonly given for ASHPs. As heat pumps have similar costs to gas boilers in the 2020s, estimates of the cost-effective level of uptake are strongly affected by this assumption.
- Non-financial barriers. The most significant barriers relate to consumer confidence and awareness, the suitability of the housing stock and a lack of installer capacity.

The study suggests that the barriers can largely be addressed by a set of cost-effective policy options, and that a significant level of uptake is still likely to be desirable in the long run. We will return to the policy options in our 2014 progress report to Parliament.

District heating

Since 2010, the evidence base on the potential for district heating to contribute to low-carbon heat supply has been strengthened.

- In 2012 we commissioned AEA and Element Energy to look at scenarios for low-carbon heat to 2050 for our report on the 2050 Target, published alongside our advice on inclusion of international aviation and shipping in carbon budgets. This project 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 a very high level of heat pump uptake.
- DECC's Heat Strategy has also identified a greater role for district heating than we had previously allowed for, drawing on heat from a range of low-carbon sources including a potentially important contribution from larger-scale heat pumps.

Keeping in play this potential long-term deployment is likely to require a greater level of roll-out to 2030 than we had previously envisaged, which we reflect in our scenarios in section (d).

Source: Frontier Economics et al (2013). *Pathways to high penetration of heat pumps*. This report will be published at www.theccc.org.uk.

Box 3.5: New evidence on the infrastructure required to support our scenario

We commissioned Element Energy, with Imperial College London and Grid Scientific, to characterise and cost the infrastructure required to support our abatement scenarios to 2030 and to identify barriers to its delivery. The project identified the type, scale, and cost of three types of required infrastructure:

- Electricity transmission and distribution infrastructure (including interconnection with other countries).
- Carbon capture and storage (CCS) infrastructure.
- "Smart grid" infrastructure required to achieve demand-side response (e.g. electric vehicles charging off-peak, and/or in response to real-time price signals).

The project confirms that expected costs of the required electricity transmission and distribution and CCS infrastructure are broadly similar to high-level estimates we used in our original advice on the fourth carbon budget.

Relative to a baseline with no climate action (i.e. with limited take-up of electric vehicles and heat pumps, lower energy efficiency improvement and continued reliance on unabated gas and coal for power generation):

- Additional costs of electricity transmission and interconnection infrastructure are estimated to be around £0.8 billion in 2030 (around 5% of the cost of decarbonising the power sector);
- Costs of electricity distribution infrastructure are estimated to be around £350 million in 2030 (for a scenario with several million heat pumps and electric vehicles);
- Costs of CCS infrastructure in power and industry are estimated to be around £350 million in 2030.

The costs of implementing a smart grid are worth paying in order to secure wider benefits in grid management, with additional costs to meet low-carbon requirements expected to be negligible.

While there remains some uncertainty over the technical feasibility of CCS, the political, regulatory and commercial challenges are manageable, given appropriate actions from government and industry. Similarly, we find that barriers to deployment of the other required infrastructure can be overcome with an appropriate response. We will set out more detail on the challenges and policy responses required in our 2014 progress report to Parliament.

Source: Element Energy et al (2013). *Infrastructure in a low-carbon energy system to 2030.* This report will be published at www.theccc.org.uk.

Other abatement options

Other evidence on costs and feasibility of low-carbon measures has generally reinforced our previous assumptions, or suggested only small changes:

- **Transport.** We commissioned AEA to review our assumptions for vehicle technologies and costs[4] for our report on *The 2050 target*, published alongside our advice on whether emissions from international aviation and shipping should be included in budgets. We use the results of that work here, and have also updated our modelling to better reflect real-world driving conditions and the higher annual mileages of large cars.
- **Industry.** For this report, we commissioned Ricardo-AEA to review abatement potential and associated costs[5]. The review identified a few small abatement options (e.g. impulse drying) that have not achieved, in demonstration, the energy efficiency improvement previously assumed. Updated modelling also suggests slightly less low-carbon heat uptake is likely to be cost-effective.

4 AEA (2012). *A Review of the Efficiency and Cost Assumptions for Road Transport Vehicles to 2050.* Available at http://www.theccc.org.uk/publication/international-aviation-shipping-review/
5 Ricardo-AEA (2013). *Updating and extending carbon budget trajectories: A review of the evidence.* This report will be published at www.theccc.org.uk

- **Agriculture.** There have been minimal developments in the evidence base on low-carbon measures on farms since our 2010 advice. Defra is currently developing a 'Farmscoper' tool which could potentially improve estimates of abatement from new and existing mitigation methods. We will consider the outputs of this tool in our 2014 progress report, by which time they should be available.
- **Bioenergy.** In December 2011 we published our *Bioenergy Review*. We identified a valuable role for bioenergy in meeting carbon budgets and the 2050 target, but also concluded that the amount of global bioenergy resource available sustainably is uncertain and likely to be limited. We therefore recommended that bioenergy should be used only where it can contribute most effectively to reducing emissions and should be strictly limited to available sustainable supply. Bioenergy use in the abatement scenarios in our fourth budget advice were within the constraint estimated in the Bioenergy Review; we use a similar bioenergy penetration in this report (260 TWh in 2030).

We reflect these findings in our updated abatement scenario, in which we assume a slightly lower level of abatement than previously in industry.

d) Update of our abatement scenario to 2030

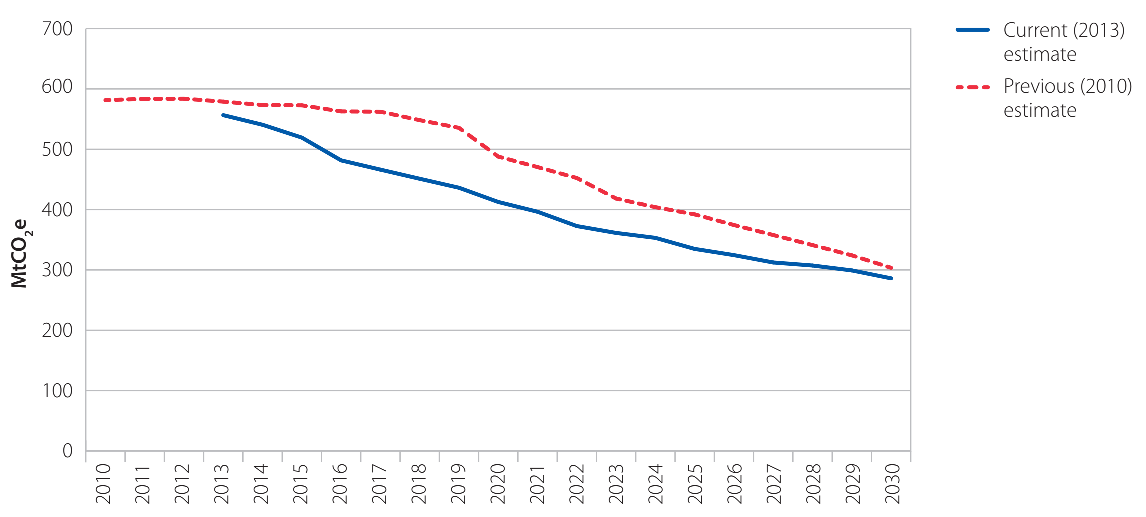
Our economy-wide scenarios reflect the updated evidence in Sections 2(b) and 2(c) above. Our updated abatement scenario results in emissions cuts of 56% in 2025 and 63% in 2030 on 1990 levels, compared to the scenario underpinning the budget which resulted in a 50% cut in 2025 and a 60% cut in 2030 on 1990 levels (Figures 3.8 and 3.9).

- **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. Estimated emissions in the 2020s are lower than we previously assumed due to the lower starting point in 2020 and lower demand projection.
- **Buildings.** The updated abatement scenario involves changes in the assumed abatement across a range of measures.
  - 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.

- **Transport**. The updated core scenario reflects lower baseline emissions and changes to the assumed mix of pure battery and plug-in hybrid electric vehicles with lower assumed range, informed by our new consumer choice modelling (see Box 3.3).
- **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, which is only slightly offset by the reduction in assumed abatement potential. The updated core scenario includes slightly less abatement from energy efficiency improvements to reflect the conclusions of our review of potential and costs.
- **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. Together with the latest projections this implies a 19% fall in emissions from 2012 to 2025, to an emissions level 2% lower than we previously assumed.

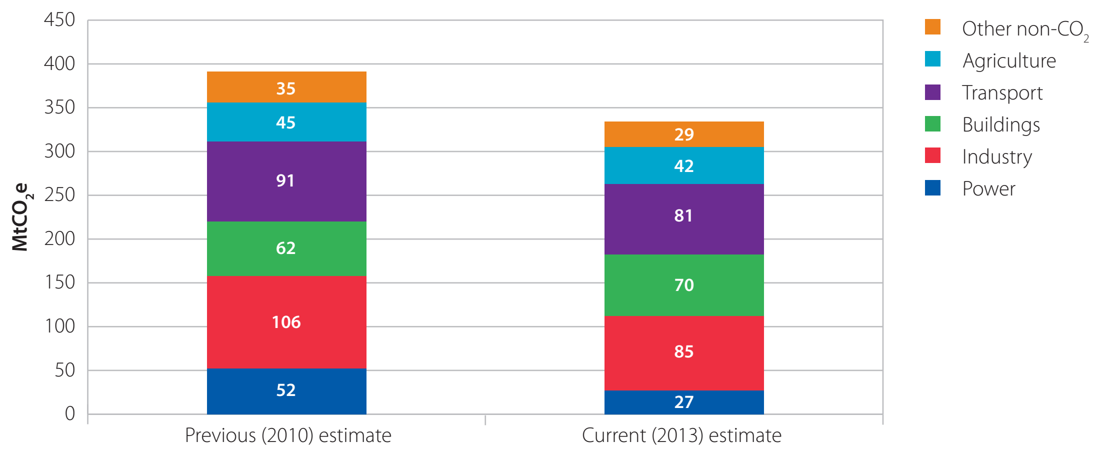
We consider departures from this scenario under different assumptions about the feasible pace of investment, technology costs, fossil fuel and carbon prices in the following sub-section.

Figure 3.8: Estimates of the cost-effective path to 2030 (total GHG)



Source: CCC modelling.

Figure 3.9: Estimates of the cost-effective level of emissions in 2025 (GHG by sector)



Source: CCC modelling.

e) Sensitivities for abatement measures to 2030 and resulting emissions

Notwithstanding potential benefits from the core scenario, departures from it could be justified if the feasible pace of investment were shown to be limited, if cost reductions were to occur more slowly than assumed, or if low fossil fuel and/or carbon prices were to make the higher carbon alternative relatively more attractive.

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 (see Chapter 4).

- **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.[6]

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.

We use these alternative scenarios in assessing approaches to meeting the fourth carbon budget, and in particular, the extent to which the budget offers appropriate flexibility given the current set of uncertainties.

3. Implications for the fourth carbon budget

The budget should not be tightened at the current time

Our updated abatement scenario 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.

6 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.

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, or whether to maintain the budget at the present level (with the possibility to outperform by full implementation of measures). In answering this question, it is important to recognise the inherent uncertainties and the flexibility that exists in the budget:

- **Evidence base**. In a number of areas, the evidence base is limited. For example, there is considerable uncertainty over the current level of emissions in agriculture and over future opportunities to reduce emissions in industry. It is important that work continues to improve this evidence base; in so doing, the expectation is that these improvements will change estimates of the suitable path for emissions across the budget period.
- **Uncertainty in projections**. It is inevitable that in making projections there will be uncertainty across a range of factors and that a later updated assessment would result in some changes to projected emissions across the budget period.
- **Possible further changes in circumstances**. Budget recommendations are made in the context of an expectation of future circumstances. Our new assessment is based on the latest expectations, which have changed since our original advice. However, it is likely that they will change again in the future.
- **Flexibilities**. The Climate Change Act allows for flexibilities in both directions. It is perfectly possible to outperform a budget by reducing emissions to below the legislated level (e.g. the Government is aiming and expecting to do this in each of the first three budgets, following the large emissions reduction during the recession). It is also possible to accommodate higher emissions than the legislated budget with purchase of carbon credits, by banking outperformance from previous budget periods or, to a limited extent, by borrowing from future periods.
- An important question for any review is whether the legislated budget sufficiently requires effort to reduce emissions, while managing the many uncertainties, given available flexibilities and interaction with EU and international objectives.

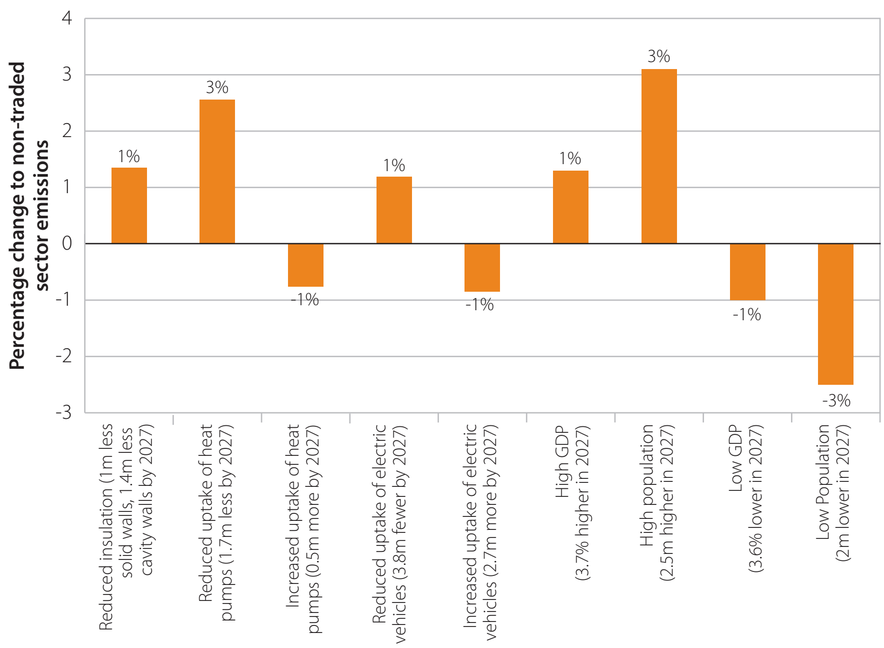
We have concluded that the evidence is not sufficient to justify a tightening at the current time. In the non-traded sector, the potential outperformance is within the likely margin of error and could provide useful flexibility. In the traded sector, while the implied contingency is larger than required, 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.

- **Non-traded sector.** The 50 $MtCO_2e$ (4%) potential outperformance in the non-traded sector if all cost-effective measures were to be implemented is small compared to the uncertainties relating to the feasibility and cost of the various measures, and over the future growth of energy demand and emissions (Figure 3.10). It could provide some increased flexibility in how the budget is met and some useful contingency against the key risks that we have identified, for example, faster than expected population growth, or reduced implementation of some measures where these are more expensive or more constrained than we have assumed.
- **Traded sector.** The current accounting rules of the Climate Change Act require that this part of the budget should be aligned with the EU ETS path through the 2020s, once this is agreed. While current discussions in the EU suggest a tightening of the budget may be required, the negotiations are ongoing and further decisions are required before the budget can be aligned. From a domestic perspective, a judgement on any budget revision should be taken together with setting a target for power sector decarbonisation; the Government and Parliament have decided that any power sector decarbonisation target should be set in 2016 alongside the fifth carbon budget (covering 2028-32).
  - **EU ambition**. Under the current accounting rules of the Climate Change Act, performance against the budget in the traded sector will be determined by the UK's share of the EU ETS cap. As we set out in Chapter 2, this could end up broadly in line with assumptions underpinning the legislated budget (i.e. at 690 $MtCO_2e$) if the EU adopts ambition at the low end of current discussions. In this case the UK would be a net seller of allowances under the cost-effective path, but the budget would not necessarily need to be changed. Although a tightening of the budget may be required if the EU adopts a higher level of ambition, this would be premature at this time, since it remains unclear exactly what the outcome of the EU process will be (see Chapter 2).
  - **The decarbonisation target**. From a domestic perspective, the Government has included a provision to set a power sector decarbonisation target for 2030 in the Energy Bill, with a decision to be taken on this in 2016. The direction for the UK power sector, and specifically for investments contracted under the Electricity Market Reform, will largely be determined by a combination of the carbon budgets and the decarbonisation target. To the extent that the carbon budgets and EU ETS do not reflect the cost-effective path, it will be even more important to signal the Government's intention to follow this by setting a suitable carbon-intensity target for 2030 (e.g. at 50 gCO_2/kWh, with some flexibility to adjust this in the light of new information).

– **Medium-term objective**. In the meantime it remains appropriate to plan for early decarbonisation of the power sector. This is the cost-effective path in a carbon-constrained world and should be reflected in any revised fourth carbon budget, together with the fifth carbon budget and the power sector decarbonisation target to be set in 2016.

- **Investor confidence.** When there is a change to projected emissions across a budget period, there is a tension over whether to maintain the level of required policy effort (implying a change to the budget level) or to maintain the level of the budget. However, we have received the very clear message from a wide range of business stakeholders that there is a benefit in sticking with the currently legislated budget, even though this could imply a different level of required policy effort, and that changing this to reflect changes in emissions projections or other assumptions, which remain inherently uncertain, would undermine the certainty that the budget is intended to provide[7].

Figure 3.10: Uncertainties in non-traded sector emissions



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

Given these considerations, on the basis of our reassessment of the cost-effective path, we conclude that the budget should be kept at the current level rather than tightened, and that the aim should still be to achieve early decarbonisation of the power sector. This is economically sensible and offers significant cost savings relative to an alternative approach which delays investment in low-carbon power generation technologies from the 2020s to the 2030s. A decision on the traded sector part of the fourth carbon budget and on the power sector decarbonisation target should be taken together, alongside the fifth carbon budget decision in 2016.

7 As part of the evidence gathering for this report, we issued a Call for Evidence and held workshops with key stakeholders. The outputs will be published alongside this report, at www.theccc.org.uk.

There is no rationale to loosen the budget

While there could be a case to tighten the budget, there is no case to loosen it, and we strongly recommend against doing so. This would be neither economically sensible, nor allowed under the Climate Change Act, given that other impacts remain manageable (see Chapter 4), and other relevant circumstances remain unchanged (see Chapter 2). It would further undermine investor confidence and the UK's role in international negotiations.

- Loosening the budget would allow it to be met with a significant departure from implementation of cost-effective abatement measures. Proceeding in this way would raise the costs and risks of meeting the 2050 target. In particular, it would prolong use of conventional fossil fuel technologies that will become increasing expensive as carbon costs increase. These would then have to be replaced with immature and expensive low-carbon technologies deployed at very high build rates.
- A loosening of the budget might be allowed under the Climate Change Act if the cost-effective pathway to meeting the 2050 target were to imply emissions above the currently legislated level; the evidence in this report suggests that the opposite is the case. Alternatively, the budget could be changed if wider costs and impacts had become prohibitive; this is also not the case (Chapter 4).
- Only if there were a significant departure from the climate objective *and* fossil fuel prices are much lower than current levels would the budget entail significant costs over a delayed action path (see section 4). 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.
- Furthermore, any proposal to loosen the budget would undermine credibility of the UK in EU and international negotiations and further undermine already fragile investment conditions, particularly as such a proposal would be counter to the available evidence.

We will continue to monitor technology costs, fossil fuel prices and carbon prices and draw out any implications for approaches to meeting carbon budgets.

Uncertainties relating to EU ambition through the 2020s

Another justification for loosening the budget could be a view that the budget is not sufficiently aligned to the EU ETS, given the accounting rules in the Climate Change Act.

Our assessment is that if the UK is successful in achieving its goals in the European negotiations (i.e. at least a 40% reduction in EU 2030 emissions relative to 1990, rising to a 50% reduction under an ambitious global agreement), then the fourth budget would need to be tightened to align to the EU ETS.

In the event that there is total failure to agree an EU 2030 emissions reduction target, the analysis in this chapter suggests that there may be enough flexibility in the budget to allow for this.

- In Part One of the review, we estimated that the default trajectory would imply a UK share of the EU ETS cap that is 50 $MtCO_2e$ above that assumed when setting the budget for the period 2023-27. If the budget is not changed then the allowable emissions in the non-traded sector would be 50 $MtCO_2e$ lower as a result. This would align to our updated best estimate of the cost-effective path for emissions in the non-traded sector.
- The other flexibilities for carbon budgets built into the Climate Change Act could be used to meet the legislated budget under the EU default trajectory:
  - **Banking and borrowing.** Subject to the advice of the Committee on Climate Change and consultation with other national authorities, outperformance of a carbon budget may be carried forward to the subsequent budget period, while a small amount may be borrowed from a later period in order to address underperformance, limited to 1% of the size of the later budget.
  - **Credit purchase.** Performance against carbon budgets is judged on the net carbon account, after allowing for purchase of carbon credits. The budget could therefore still be met under the default EU ETS trajectory without increased effort in the non-traded sector with the purchase of 50 $MtCO_2e$ across the fourth budget period. At our central carbon values, this would cost around £0.5 billion per year.

We will continue to monitor the EU process and identify any implications for carbon budgets as this is resolved, for example in 2015 when we provide advice on the fifth carbon budget, if not before.

Policies to cut emissions through the 2020s

There is a short lead-time to the 2020s in terms of policy development, supply-chain investment, project development and consumer behaviour change. Given that this is the case, it is important to focus now on putting in place policies which provide incentives for cost-effective measures to be delivered.

Major challenges remain in each of the key policy areas to deliver cost-effective abatement measures:

- **Power.** Implement the Electricity Market Reform such that this supports portfolio investment in low-carbon technologies and supply-chain investment, thereby ensuring early decarbonisation of the power sector with significant consumer benefit. Key challenges include setting strike prices at the right level, and providing confidence to investors that there will be sufficient and ongoing volume to 2020 and beyond.
- **Buildings energy efficiency.** Put in place incentives for uptake of the full range of cost-effective measures in residential and non-residential buildings. Monitor the effectiveness of these policies, responding as necessary if uptake is low, while ensuring that there are safeguards in place to prevent cost escalation.

- **Low-carbon heat.** Put in place approaches to address financial and non-financial barriers to support very significantly increased levels of investment in heat pumps; and to carry out detailed feasibility studies and move forward with investments in district heating infrastructure.
- **Transport.** Continue to press for stretching efficiency standards for new vehicles at the EU level, out to 2030. Continue to support market development for electric vehicles through purchase subsidy and investment in charging infrastructure.
- **Industry.** Develop approaches to demonstration and then deployment of carbon capture and storage (CCS) in industry. Continue to develop the evidence base on potential for improved energy efficiency. Ensure that policies to address potential competitiveness effects of low-carbon are clear and extend sufficiently into the future to cover investment cycles (see Chapter 4).

We will provide a full assessment of these challenges in our sixth report to Parliament on progress reducing emissions, to be published in July 2014.

4. Costs and benefits of meeting the budget

Economic benefits of the core emissions scenario

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[8]. We argued that this cost is worth paying given the much higher costs and risks associated with dangerous climate change. We estimated that the cost of the additional measures required in the 2020s would be around 0.5% of GDP in 2030, with limited implication for GDP before 2020. Our updated assessment of the cost-effectiveness of low-carbon measures gives a broadly unchanged estimate.

Given that the budget is based on the cost-effective pathway to the 2050 emissions reduction target in the Climate Change Act, the implication is that a departure from this pathway would increase costs and risks. However, 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.

8 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*).

- 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.
- 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.

- **Power sector.** The cost-effective path involves ongoing portfolio investment in low-carbon technologies through the 2020s, such that the carbon intensity of power generation is reduced to 50 gCO_2/kWh in 2030. We compare this with a situation where the focus in the 2020s is on investment in unabated gas-fired generation, followed by rapid roll-out of low-carbon technologies in the 2030s, without the benefits of cost reduction from earlier deployment. Our assessment here reflects analysis in our May 2013 report Next steps on Electricity Market Reform.
- **Heat.** We consider the impact of delaying deployment of heat pumps and district heating by ten years, with no uptake in the 2020s. This amounts to a scenario of 0.7 million heat pumps in homes in 2030, compared to 4 million in our abatement scenario. District heating capacity remains constant at 6 TWh/year throughout the 2020s. After 2030, we assume that uptake of low-carbon heat grows at a rate constrained by the pace at which the supply chain can be expanded.

- **Transport.** We consider the impact of delayed uptake of electric vehicles, assuming no further policy intervention beyond 2020 (but assuming costs continue to fall with global deployment). This results in a 26% market share for car sales (22% for vans) by 2030, against 60% in our core scenario. We also assume no improvement in conventional vehicle efficiency between 2020 and 2030, and that biofuels penetration falls to 5%. However after 2030, we assume that uptake of electric vehicles and improvement to new conventional vehicle efficiency can be accelerated to 'catch' up with our core scenario by 2050, in terms of vehicles sales; however, emissions in 2050 are higher under the delayed scenario, as the stock still contains high-carbon vehicles purchased in the 2030s and early 2040s.
- **CCS with bioenergy and on industrial installations.** We consider timely development of carbon capture and storage (CCS) in the power sector, which could have spillover benefits for application to industrial and bioenergy installations. CCS deployment at scale in the power sector during the 2020s would drive the development of CO_2 infrastructure clusters, creating opportunities for industrial/bioenergy CCS projects to connect with low risks and at relatively low cost. Such CCS applications would not otherwise be feasible, due to the high risks and costs of infrastructure development specifically for individual projects producing relatively small volumes of CO_2. The greater deployability of CCS in these sectors during the 2030s enables greater cumulative deployment by 2050, given slow refurbishment cycles in relevant industries (e.g. 20 years) and the potential for bioenergy resources to be locked in to use in facilities without CCS.

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 3.1).
  - 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 (Box 3.6).
- 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 3.7).

Box 3.6: Benefits of 2020s deployment of electric vehicles and low-carbon heat for the path to 2050

The 2020s is likely to be an important decade for developing options that are important for meeting long-term emissions targets. This is true both on the supply side, where low-carbon generation technologies need to be proven and improved, and on the demand side, where markets for end-use technologies such as electric vehicles and heat pumps need to be developed.

Therefore the value of deploying low-carbon heat and electric vehicles in the 2020s derives not only from the emissions avoided in that decade, but also from the increase in the possible deployment rates in subsequent decades resulting from market development. Given that these technologies are projected to become cost-effective during the 2020s, there is an economic benefit in the opportunity to deploy them at greater scale in subsequent decades, when they will save money against high-carbon technologies:

- Low-carbon heat. Deployment of heat pumps in the 2020s is cost-effective in some building types, and has a benefit in market development, enabling heat pumps to be deployed at a greater rate in the 2030s, when they have a significant saving versus gas boilers at our assumed carbon prices. Over the period to 2050, the benefit relative to the delayed scenario has a net present value of £16 billion under central assumptions. Delaying roll-out of district heating would add a further £13 billion.
- Electric vehicles. Electric vehicles are projected to become cost-effective during the 2020s, and deployment during this decade also has a market development benefit, enabling greater uptake in the 2030s and early 2040s. Over the period to 2050, the benefit relative to the delayed scenario has a net present value of £27 billion under central assumptions.

Box 3.7: 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 3 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 3.8).
- 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)[9]. Furthermore, were this shortfall to be replicated internationally, this would jeopardise meeting of the climate objective.

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.

9 See Chapter 4 of CCC (November 2013) *Fourth Carbon Budget Review – part 1: Assessment of climate risk and the international response.* Available at www.theccc.org.uk/publications

Box 3.8: 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.

Broader economic benefits of the core emissions scenario – opportunities for UK industries

The analysis above is focused on the resource cost of the fourth carbon budget, based on summing the direct additional costs of implementing measures to reduce emissions. Decarbonising the energy system will also have broader economic impacts, relating to redeployment of resources towards building a low-carbon economy.

Production and supply of low-carbon goods and services already makes up a significant part of the UK economy, and are set to increase:

- The CBI estimate that the UK 'low-carbon economy' was worth £122 billion in 2010/11 (7% of GDP) and involved close to a million jobs. They also estimate that these sectors grew by 2.3% in 2012, contributing over a third of the total GDP growth in the economy[10].
- New markets associated with the measures in our abatement scenario (i.e. investment in low-carbon power generation, installation of energy efficiency measures and heat pumps, roll-out of electric vehicles, etc) provide scope for this part of the economy to grow considerably. For example, BIS project that the low-carbon economy could grow by over 5% per year.
- Globally, the market for low-carbon technologies is already worth over £3 trillion/year and is expected to grow by 2015/16 to around £4 trillion/year[11]. This suggests that firms in low-carbon supply chains could also have markets for their products and services beyond the UK.

UK companies are well-placed to take advantage of these opportunities:

- Some of the low-carbon measures, such as installation of insulation in buildings inherently require local supply chains and jobs. For example, over 110,000 people in the UK are currently employed in the low-carbon building technologies industry (insulation and heat-retention materials, double-glazing, etc).
- UK firms have skills and expertise and are well-placed to compete and prosper in low-carbon markets (e.g. heavy and offshore engineering, vehicle and engine manufacture).

In the long run there is no reason to think employment will be any higher or lower in a low-carbon versus a high-carbon world. There may be structural costs associated with the transition however, if it is not well managed. In the near to medium term there may also be a net addition of jobs to the extent that the economy is currently operating below capacity.

An appropriate goal for policy is to ensure that the transition to a low-carbon economy involves as little disruption as possible. Keeping the fourth carbon budget could send a useful signal to businesses that the UK is planning for a low-carbon world and is a suitable location for low-carbon investments. By contrast, a weakening of ambition in the budget could put off investors and require greater and more rapid structural change in later years, with associated economic cost.

10 CBI (2012), *The colour of growth*.
11 Low Carbon Environmental Goods and Services (LCEGS) Report for 2011/12.