Fourth Carbon Budget Review – part 1

Assessment of climate risk and the international response

Committee on Climate Change | November 2013

Preface

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

Setting carbon budgets

In December 2008 we published our first report, 'Building a low-carbon economy – the UK's contribution to tackling climate change', containing our advice on the level of the first three carbon budgets and the 2050 target. This advice was accepted by the Government and legislated by Parliament in May 2009. In December 2010, we set out our advice on the fourth carbon budget, covering the period 2023-27, as required under Section 4 of the Climate Change Act. The fourth carbon budget was legislated in June 2011 at the level that we recommended. In April 2013 we published advice on reducing the UK's carbon footprint and managing competitiveness risks.

Progress meeting carbon budgets

The Climate Change Act requires that we report annually to Parliament on progress meeting carbon budgets. We have published five progress reports in October 2009, June 2010, June 2011, June 2012 and June 2013.

Advice requested by Government

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

Acknowledgements

The Committee would like to thank:

The team that prepared the analysis for the report: This was led by David Kennedy, Adrian Gault and Mike Thompson and included Owen Bellamy, Ute Collier, David Joffe, Ewa Kmietowicz, Sarah Leck and Stephen Smith.

Other members of the Secretariat that contributed to the report: Andrew Beacom, Swati Khare-Zodgekar, Eric Ling, Jo McMenamin, Nisha Pawar and Joanna Ptak.

A number of organisations and individuals for their significant support: the Department of Energy and Climate Change, the Environment Agency, the European Commission, the Foreign and Commonwealth Office, the Met Office Hadley Centre, the Potsdam Institute; Aproop Bhave, Matthew Carson, Andy Challinor, Vivienne Geard and Duncan Gray.

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

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Foreword

When the Government – in 2011 – accepted this Committee's advice on the level of the fourth carbon budget, it also accepted its advice to keep this under review in the light of developing international circumstances. It scheduled a Review, as provided for in the Climate Change Act, which the Committee agreed that it would carry out in 2013.

Carbon budgets are an important part of a long-term framework in the UK designed to provide greater certainty of our intent. Nevertheless, the Act explicitly provides for a Review and lays down the terms upon which that Review should be conducted. Those terms are that the level of a budget can only be revised where there has been a significant change in the circumstances upon which the budget was set. This procedure ensures that a legislated budget can be changed only with evidence of such significant change. It is the duty of the Climate Change Committee to determine whether such change has taken place and report upon its conclusions.

We are publishing the Review in two stages.

In the first stage, we review the evidence on climate science and in international and EU circumstances.

The second stage will be in December, when we will publish our final assessment, which will review the cost-effectiveness of the budget, taking account of latest emissions projections and evidence on abatement options, and will update our assessment of implications for other criteria in the Act (such as affordability, and competitiveness).

The conclusion from this first stage is clear. Based on a thorough assessment of the latest evidence, we have found no significant change in relation to climate science or international and EU circumstances since we provided our original advice in December 2010. There is therefore, based on these legislated criteria, no legal or economic basis for a change in the budget at this time.

There is a specific issue of alignment to the EU's Emissions Trading System, which was the Government's focus when announcing the review. When there is an agreed EU emissions trajectory through the 2020s then the UK should look at the case for aligning the fourth carbon budget with that trajectory. This is the subject of current discussions that could be resolved in the next few years; our analysis demonstrates that it is more likely to require a tightening of the budget than a loosening.

More generally, our assessment and the latest report from the IPCC, reiterates the seriousness of the climate threat and the urgency demanded of the international response. It also demonstrates that this response has begun around the world with ambitious commitments being made and delivered upon – the UK is not acting alone.

The Government has made it clear that in the EU, in line with the demands of current scientific evidence, it is looking to achieve a more stretching Europe-wide target for emission reduction in 2030. The Fourth Carbon Budget is fully complementary to the UK's intention to secure an ambitious global and EU response to tackling climate change.

We will continue to monitor developments, and provide further advice, should circumstances change.

Preparation of this report has required a substantial effort from across the Committee's secretariat. I thank them for their work, and also, of course, the members of the Committee for their considerable contribution and guidance.

Lord Deben

Chairman, Committee on Climate Change

The Committee

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

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

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

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Executive summary

The fourth carbon budget, covering 2023-2027, was set in June 2011 following advice from the Committee in December 2010. It was designed to reflect the cost-effective path to the 2050 target in the Climate Change Act (i.e. to reduce emissions by at least 80% relative to 1990), taking into account the range of criteria in the Act including affordability, competitiveness and security of supply.

As part of the agreement to set the budget, the Government announced that it would be reviewed in 2014. If there is to be a review, then the Climate Change Act states that it must be based on advice from the Committee, and must consider whether there has been a significant change in the circumstances upon which the budget was set.

Only if there is a significant change, demonstrable on the basis of evidence and analysis, can the budget be changed.

We are publishing the results of our review in two stages:

- This report focuses on developments in three categories of circumstance on which the budget was set: climate science, international circumstances and EU pathways.
- We will set out our final advice in December of this year. That report will reassess the cost-effectiveness of the budget given the findings in this report together with updated projections of emissions and fossil fuel prices and the latest evidence on the costs and feasibility of options to reduce emissions. It will also assess again the impact of the budget on the various criteria in the Climate Change Act (i.e. affordability, competitiveness, fiscal circumstances, security of supply).

We conclude in this report that, in respect of science, international and EU criteria, there has been no significant change in the circumstances upon which the budget was set. In this regard, there is therefore no basis to support a change in the fourth carbon budget.

- **Climate science.** The latest evidence on climate science confirms that without action to reduce emissions the world will be exposed to significant risks of very dangerous climate change. In particular, there is a significant risk of warming of 4°C or more by the end of the century, which would result in very high economic, social and environmental costs and consequences. The best way to limit these risks is to cut global emissions very significantly, such that these peak around 2020 and halve by 2050, with further reductions in the second half of the century. This implies the need for cuts in the UK at least to the level of the legislated fourth carbon budget, which was designed as a minimum UK contribution to required global emissions reduction.

- **International circumstances.** The UK is not acting alone. Rather, many countries have made progress towards delivering the commitments made under the Copenhagen Accord, often beyond what was envisaged when the fourth carbon budget was set. The UN process working towards global agreement continues slowly but broadly as expected; the aim is that there is a new agreement by the end of 2015 to deliver deep emissions cuts compatible with limiting warming to 2°C. Given these developments, the global emissions pathways assumed when designing the fourth carbon budget remain feasible if challenging. They continue to be an appropriate basis for policy given the high costs and risks associated with lower ambition. An ambitious fourth carbon budget is important in the context of the UN process given the key role of the UK in international negotiations.
- **EU pathways.** EU developments have been consistent with the assumptions underpinning the fourth carbon budget. While there is not yet an agreed path for EU emissions in the 2020s, the budget is broadly consistent with the EC analysis of cost-effective emissions pathways, and is at the low end of ambition currently being discussed in the EU for 2030 emissions targets. Consistency of the budget with EU ambition will have to be revisited when EU agreement is reached, with a possible adjustment to ensure that the budget aligns with the agreed EU approach. For example, if the Government successfully secures its stated objectives for a 2030 EU package then the budget would need to be tightened.

Climate science

- The latest evidence generally gives more confidence in the reality of climate change, in its cause and in projections for the future. For example, the IPCC's Fifth Assessment concludes that warming of the climate system since the mid-20th Century is unequivocal, and it is extremely likely that human activity is the dominant cause.
- The recent slowdown in surface temperature rise can be explained in terms of short-term fluctuations and cooling from other natural factors. Similar periods occurred in the 20th Century, and they are consistent with longer-term warming.
- Recent assessments of the likely temperature change in response to greenhouse gas concentrations confirm previous ones. In particular, the IPCC provides the same likely range for climate sensitivity as in its first three assessments in 1990, 1995 and 2001, with a slight revision from the fourth assessment in 2007.
- In a scenario where global greenhouse gas emissions continue to increase, it is likely that global temperature will increase by 4°C or more above pre-industrial levels by the end of the century.
- The latest evidence on risks and damages reinforces our climate objective: to limit central estimates of warming to as close to 2°C as possible, and keep the probability of an extremely dangerous rise of around 4°C to very low levels. To achieve this, global emissions should peak around 2020 followed by rapid cuts, such that emissions are halved by 2050 and fall further thereafter. Delaying peaking to 2030 would raise the costs and risks of achieving the objective, and probably make it unattainable.

International circumstances

- Progress towards a global deal has been slow but broadly as expected when the fourth carbon budget was set. The UN has formally adopted an objective to limit warming to 2°C and is working towards an agreement aimed at peaking and reducing emissions consistent with this goal. The aim is to resolve that process in Paris at the end of 2015.
- The UK is not acting alone. Many countries have made ambitious commitments to reduce emissions, and are delivering against these commitments. There is now widespread coverage by low-carbon policies of major emitting sectors around the world. This provides a good basis for agreeing and implementing an ambitious global deal.
  - Amongst the major emitters, China (29% of global CO_2 emissions) has made significant progress on low-carbon investment. It has made commitments to reduce carbon-intensity by 40-45% from 2005 to 2020, and introduced policies to deliver this as part of the 12th five-year plan. With ongoing action, China's emissions could peak in the early 2020s.
  - The United States (16% of global CO_2 emissions) has a good chance of delivering its Copenhagen Accord commitment to reduce 2020 emissions by 17% on 2005 levels. Going beyond this, there is a major challenge to develop and implement approaches to drive further cuts required through the 2020s.
  - Commitments comparable to the UK's have been made by a range of developed and developing countries: Germany in terms of medium-term emissions reduction; China and the US against a 2005 baseline on the basis of carbon-intensity; the US, Japan, the EU and Mexico in terms of 2050 commitments.
  - Coverage of low-carbon laws and policies has increased internationally: legally-binding legislation requiring emissions reduction has been passed in South Korea and Mexico; global coverage of carbon pricing is now 20% of non-transport emissions and rising (e.g. this has been introduced in parts of China and the US and is being considered by Brazil, Chile, the Ukraine, Turkey, Mexico and others); vehicle standards now cover around 80% of global emissions from road transport.
- Our climate objective and the global emissions reduction required to achieve it remain feasible, but very challenging. These remain an appropriate basis for policy, both because of the very significant risks associated with dangerous climate change and the costs of delayed-action pathways. An ambitious fourth carbon budget is important to the global process because of the key role of the UK in securing an effective global agreement.

EU circumstances

- EU ambition for both 2020 and 2030 are relevant for the path through the 2020s and therefore to the fourth carbon budget.
- In relation to 2020, the fourth carbon budget is consistent with the current EU target for a 20% reduction relative to 1990. If a 30% target were to be agreed, which is the UK Government's objective, tightening of the budget might be justified.
- In relation to 2030, negotiations are ongoing, with various options being considered; the legislated budget is towards the low end of ambition being discussed.
  - The EC's Low-Carbon Roadmap, published in 2011, identifies cost-effective decarbonisation pathways, and suggests at least a 40% reduction in 2030 emissions relative to 1990. These pathways broadly match the ambition in the fourth carbon budget.
  - The range currently being discussed for EU ambition in 2030 goes beyond this. For example, the Government has stated a negotiating position to secure an EU emissions reduction of 30% in 2020 and 50% in 2030 relative to 1990 in the context of an effective global deal; this would require a tightening of the budget.
- There is a default trajectory for the EU Emissions Trading System (EU ETS) to continue the slow rate of decline from the pre-2020 phase should the negotiations fail to agree a new package. A strategy of aligning to this now and then realigning later once an EU package is agreed would not be legal, practical or sensible:
  - It would amount to a change in the budget without a corresponding change in circumstances and would represent a significant departure from the cost-effective path to the 2050 target. As such, it would not meet the criteria under the Climate Change Act.
  - The precise level of carbon budget implied by the default trajectory is unclear, given that the detailed rules for calculating the UK share of the EU ETS cap in the 2020s are not yet known.
  - Such a strategy and the frequent changes in the budget that it entails would undermine investor confidence. Moreover, it would undermine credibility of the UK in EU negotiations.
  - It would not offer any benefits for competitiveness or a more favourable share for the UK when negotiating how EU-wide targets are split across countries.
- The Government has rightly considered it essential that the UK continues to push for an ambitious EU 2030 package. The UK has an important role in these discussions and an ambitious package is required as part of an effective global response to climate change.

Next steps

We will continue to monitor climate science, international circumstances and EU pathways as part of our ongoing statutory work and draw out any implications for carbon budgets as appropriate. In the particular case of the EU, this report should be regarded as our advice on current circumstances. If and when there are developments, we will provide further advice, consistent with the Climate Change Act, on whether this constitutes a significant change in the circumstances upon which the budget was set and if a change in the budget to tighten or loosen it would be appropriate.

We will publish our full assessment of costs and benefits associated with the fourth carbon budget, building on the analysis in this report, in December of this year.

Our assessment of the cost-effectiveness of the carbon budgets depends on assumptions over the international carbon price, which in turn depends on international action to reduce emissions. When updating this assessment in December, we will use a range of scenarios for global and EU emissions, including stress testing the budget against scenarios that are insufficiently carbon-constrained to meet the climate objective.

We set out the analysis that underpins the conclusions above and the implications for our December report in four chapters:

1. Update on climate science
2. Latest evidence on international action to reduce emissions
3. EU emissions pathways and targets
4. Global emissions pathways and carbon price projections.

Chapter 1: Update on climate science

Introduction and key messages

The scientific understanding of climate change is a critical element guiding the Committee's advice on carbon budgets. We have used the science to assess the risks from continued greenhouse gas emissions and the global pathways for emissions necessary to reduce those risks. From these we have drawn implications for the UK's 2050 target and the carbon budgets to get there.

- Our advice reflects a climate objective: to limit central estimates of 21st Century global temperature rise to as close to 2°C above pre-industrial levels as possible, and to keep the probability of an extremely dangerous 4°C rise at very low levels (e.g. less than 1%).
- Global pathways which meet this objective embody peaking of emissions around 2020, followed by rapid reductions, such that they are halved by 2050 and further reduced thereafter.
- The UK's 2050 target reflects average per capita emissions consistent with these pathways, and an assumption that it is unlikely a future global deal would be agreed in which the UK and other developed countries have per capita emissions above this level. This requires an 80% reduction in UK emissions relative to 1990.
- The carbon budgets are designed to reflect the cost-effective path to the 2050 target.

In this chapter we consider evidence from climate science that has emerged in the three years since we advised on the fourth carbon budget. Our aim is to assess whether the climate objective remains appropriate, and whether global emissions cuts previously modelled remain consistent with achieving this objective.

Part of the new evidence we consider is the Fifth Assessment (AR5) by the Intergovernmental Panel on Climate Change (IPCC). This is the most comprehensive assessment of the latest research on climate change. The IPCC Working Group 1 report (WG1) on the physical science of climate was released in September, written by 259 scientists from around the world reviewing over 9,000 studies since the fourth assessment (AR4) in 2007[1].

Our key conclusions are:

- The latest evidence generally gives more confidence in the reality of climate change, in its cause and in projections for the future. For example, the IPCC's Fifth Assessment concludes that warming of the climate system since the mid-20th Century is unequivocal, and it is extremely likely that human activity is the dominant cause.
- The recent slowdown in surface temperature rise can be explained in terms of short-term fluctuations and cooling from other natural factors. Similar periods occurred in the 20th Century, and they are consistent with longer-term warming.

1 IPCC AR5 will also include a Working Group 2 report on impacts, adaptation and vulnerability, and a Working Group 3 report on mitigation. Both will be published in 2014.

- Recent assessments of the likely temperature change in response to greenhouse gas concentrations confirm previous ones. In particular, the IPCC provides the same likely range for climate sensitivity as in its first three assessments in 1990, 1995 and 2001, with a slight revision from the fourth assessment in 2007.
- In a scenario where global greenhouse gas emissions continue to increase, it is likely that global temperature will increase by 4°C or more above pre-industrial levels by the end of the century.
- The latest evidence on risks and damages reinforces our climate objective: to limit central estimates of warming to as close as 2°C as possible, and keep the probability of an extremely dangerous rise of around 4°C to very low levels. To achieve this, global emissions should peak around 2020 followed by rapid cuts, such that emissions are halved by 2050 and fall further thereafter. Delaying peaking to 2030 would raise the costs and risks of achieving the objective, and probably make it unattainable.

The chapter is set out in four sections:

1. Recap of climate science underpinning the fourth carbon budget
2. Update on current and future warming
3. Update on potential impacts of warming
4. Global emissions pathways for the fourth carbon budget review

1. Recap of climate science underpinning the fourth carbon budget

Our advice on the fourth carbon budget[2] included a detailed summary of climate science. This showed that the case for human-induced climate change is underpinned by a vast body of theory and observation. Overall, this forms a coherent picture and points to significant risks:

- Climate has varied regionally and globally throughout Earth's history, in response to a variety of factors. As part of this, increases and decreases in carbon dioxide (CO_2) and other atmospheric greenhouse gases have given rise to natural warming and cooling.
- Concentrations of greenhouse gases increased significantly during the 20th Century and continue to rise as a direct result of fossil fuel burning and other human activities.
- During this time the climate system has warmed, with rising surface and air temperatures, ocean heat content and sea level, and melting glaciers, snow and ice cover.
- The pattern of warming matches that expected from greenhouse gases. It is inconsistent with other drivers being the main cause. For instance, if the surface were being warmed by a natural 'internal' climate fluctuation, we would expect other parts of the climate system, such as the oceans or ice caps, to cool; this is not happening. If the Sun were the main cause we would expect upper air temperatures to rise, when in fact observations show they are falling as lower air temperatures rise.

2 CCC (2010) *'The Fourth Carbon Budget – Reducing emissions through the 2020s'*.

- A continued rise in emissions is likely to cause sustained global warming of a magnitude and rate unprecedented in the course of civilisation, with major risks to human welfare and ecological systems.

It is clear there will be further warming over the coming decades, with social, economic and environmental impacts. Nevertheless, uncertainties remain in some areas. These arise partly from incomplete knowledge of the climate system, but also from limits inherent in any future projections:

- Although there are uncertainties about some key processes, ongoing research will continue to improve understanding over time. Examples include the heating and cooling effects of short-lived particles, the feedback response from clouds, the nature of climate fluctuations in past centuries, and future climate change at a local level.
- The forecasting of individual weather events is inherently uncertain, due to the nature of the climate system.
- The precise impacts of future climate will also depend on social factors: where people are living, what they are doing and the resources they have to cope and adapt; these are increasingly uncertain further out in time.

Our overall assessment in 2010 was that we face significant risks of dangerous climate change. This reinforced the approach we took in advising on the first three carbon budgets, which set a climate objective, identified global emissions pathways to achieve this objective, and suggested an appropriate UK contribution. Specifically, we concluded that:

- Central estimates of global temperature increase by 2100 should be limited to as little above 2°C relative to pre-industrial levels as possible. The likelihood of a 4°C increase should also be kept to very low levels (e.g. less than 1%).
- To meet this objective the aim should be that global emissions peak by 2020 and be halved or more by 2050, with further reductions thereafter.
- Such a global path implies emissions of around 2 tCO_2e per person in 2050, compared to UK emissions of just under 14 tCO_2e per person in 1990. It is hard to imagine a global deal which would allow the UK and other developed countries to emit more than the global average per capita in 2050. The target to reduce UK emissions by at least 80% below 1990 levels reflects this[3].

We also noted that significant research efforts were underway to resolve current uncertainties, suggesting the need to continue monitoring scientific developments and periodically review implications for targets and budgets. The rest of this chapter considers these developments.

3 While 2 tCO_2e emissions per capita is a reduction of more than 80% in per capita emissions relative to 1990, the 80% target also accounts for expected growth in UK population to 2050.

2. Update on current and future warming

In this section we consider updates to the scientific understanding of current climate change and projections of future global temperature. We start by considering developments in understanding warming since the mid-twentieth century, and the extent to which this is attributable to human activity.

We next consider the latest trends in global greenhouse gas emissions, atmospheric concentrations, and in key climate indicators such as surface and air temperatures, sea level, snow and ice cover. As part of this, we address the recent slowdown in observed surface temperature increase, and consider whether this has implications for long-term temperature projections.

We follow this with an assessment of the sensitivity of global temperature to changes in greenhouse gas concentrations. Climate sensitivity has been much debated recently, with suggestions that this is lower than previously thought. If true, this might imply that our climate targets could be met by less ambitious reductions in emissions.

Finally in this section we consider new evidence on other processes that determine future temperature change. In previous reports we have noted that climate projections exclude potentially important feedbacks that are poorly understood, such as release of methane and CO_2 from melting permafrost. Recent studies provide tentative estimates for the magnitude of some of these effects.

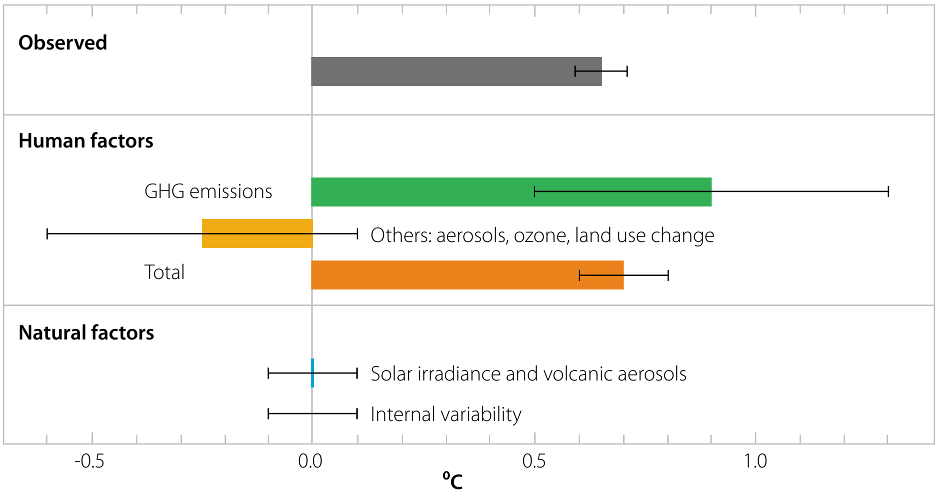
(a) Understanding current warming: human versus other factors

Identifying the causes of observed warming is vital for considering likely future climate change and impacts. Climate is known to vary in response to both 'external' drivers which alter the amount of energy in the Earth system, and 'internal' fluctuations:

- **Natural external drivers.** Several natural factors can alter the amount of energy arriving at or leaving the Earth, causing climate change. Changes in the amount and distribution of solar energy are known to have influenced the cycle in and out of ice ages. Also, volcanic eruptions can load the air with small particles (aerosols) which reflect sunlight and lead to cooling for a few years.
- **Natural internal fluctuations.** Even in the absence of a change in total energy, surface temperatures can oscillate over years to decades due to interactions between the oceans and atmosphere. An example of this variability is El Niño, where warmer water periodically spreads across the surface of the Pacific Ocean and raises global average temperature.
- **Human external drivers.** Greenhouse gas emissions from human activity trap additional heat in the atmosphere. Fuel burning also leads to aerosol emissions which can either warm or cool the climate. Changing land use can influence the reflectivity of the Earth, altering the amount of sunlight absorbed.

When we gave our advice on the fourth carbon budget, we noted the IPCC's previous conclusion (in its Fourth Assessment, AR4) that "warming of the climate system is unequivocal"

Figure 1.1: Contributions of human and natural factors to observed global temperature change during 1950-2010



Source: Adapted from IPCC AR5.
Notes: Whiskers on grey bar denote 90% uncertainty range in observations. Whiskers on other bars denote likely (i.e. at least 66%) uncertainty ranges in contributing factors. The sum of the contributions from total human factors, solar irradiance and volcanic aerosols and internal variability matches the observed temperature change to within uncertainties.

and "most of the observed increase in global average temperatures since the mid-20th century is very [i.e. at least 90%] likely due to the observed increase in anthropogenic [i.e. human-caused] greenhouse gas concentrations".

More recent scientific research has underlined and strengthened this evidence. IPCC AR5 concludes that "it is extremely [i.e. at least 95%] likely that human influence has been the dominant cause of the observed warming since the mid-20th century" (Figure 1.1).

- There has been an increase in the number of studies and the range of methods used to assess the different natural and human contributions to warming[4]. All point to human activity causing at least half of the temperature rise since 1950.
- The simple passage of time has lengthened the record of observations available, and this permits a greater separation of the different signals from human activity and other factors. New studies have also taken greater account of the uncertainties in observations, providing more robust conclusions.
- Human influence has also been detected in other aspects of climate change, such as warming of the oceans, declining Arctic sea ice, changing rainfall and humidity, and higher temperature extremes[5].

This reinforces the already well-established conclusion that continued emissions of greenhouse gases will result in further warming. Scientists have used this information as a method to

4 For example Ribes and Terray (2013) *Application of regularised optimal fingerprinting to attribution. Part II: application to global near-surface temperature*; Drost and Karoly (2012) *Evaluating global climate responses to different forcings using simple indices*; Huber and Knutti (2011) *Anthropogenic and natural warming inferred from changes in Earth's energy balance.*

5 For example Gleckler (2012) *Human-induced global ocean warming on multidecadal timescales*; Min et al. (2008) *Human influence on Arctic sea ice detectable from early 1990s onwards*; Stott et al. (2010) *Detection and attribution of climate change: a regional perspective*; Christidis et al. (2011) *The role of human activity in the recent warming of extremely warm daytime temperature.*

predict how much temperature increase can be expected in future, and it is one line of evidence used to estimate climate sensitivity (see below).

Summary: Scientific evidence now shows even more clearly that human activity is heating the Earth. A wider range of studies, using improved models and different methods, all show that the warming since 1950 is mainly due to human-induced greenhouse gas emissions. The signal of human influence is also emerging in the retreat of snow and ice, and the shifting extremes of temperature and rainfall.

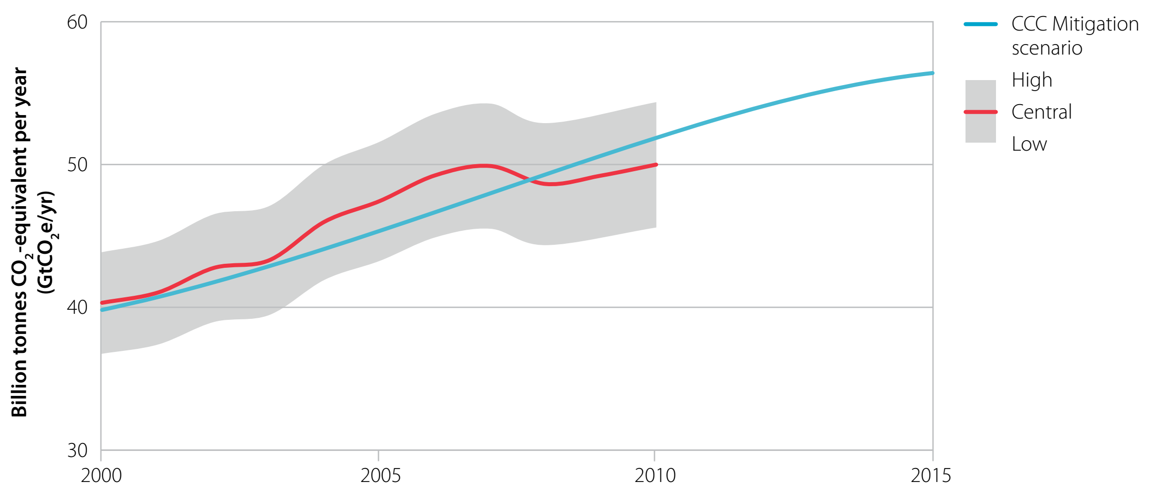
(b) Emissions, concentrations and warming

(i) Greenhouse gas emissions and atmospheric concentrations

The latest data show that global emissions of greenhouse gases continue to grow, and that atmospheric concentrations continue to rise as a result.

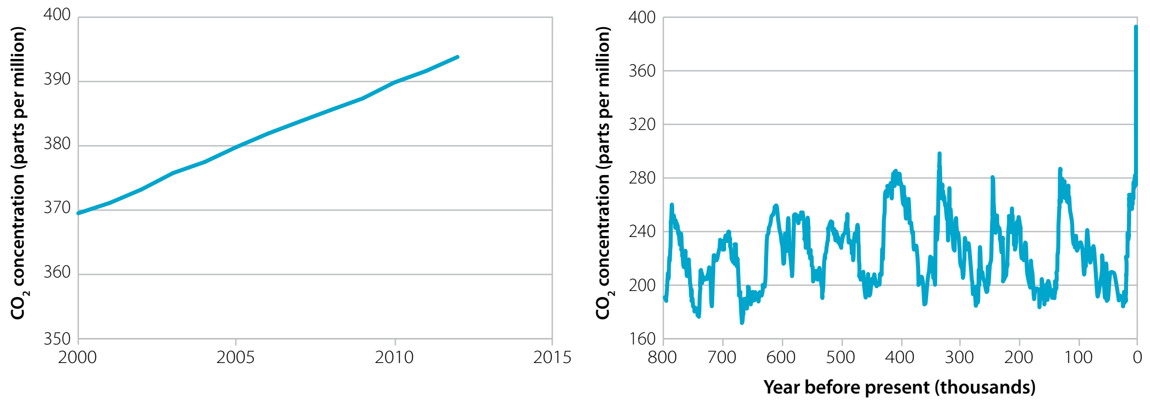
- **Global emissions.** Global emissions data for greenhouse gases are available up to 2010. The additional two years of data since our original fourth carbon budget advice mark a return to increasing emissions, following the global financial crisis. CO_2 emissions increased 3.6% over the period 2008-10, while total greenhouse gas emissions increased 2.8%. The longer-term trend since 2000 follows closely our previously-assumed global pathway (Figure 1.2).
- **Atmospheric concentrations.** The concentration of CO_2 temporarily reached 400 parts per million (ppm) this year, and continues to rise at 2-2.5 ppm per year. Concentrations of other greenhouse gases, including methane and nitrous oxide, have also increased. All are at levels far above those seen for at least 800,000 years (Figure 1.3).

Figure 1.2: Recent trends in global greenhouse gas emissions



Source: EDGAR v4.2, edgar.jrc.ec.europa.eu; CCC.
Notes: Red = observed global emissions of Kyoto-basket greenhouse gases with shaded region showing 95% confidence interval. Blue = Scenario previously used by CCC consistent with UK 2050 target (peaking in 2016 and falling to 20 $GtCO_2e$ by 2050).

Figure 1.3: Recent increases in annual average atmospheric CO_2 concentration (left) and in the context of changes over the last 800,000 years (right).



Source: NOAA NCDC, www.ncdc.noaa.gov/paleo/icecore/antarctica/domec/domec_epica_data.html; NOAA ESRL, www.esrl.noaa.gov/gmd/ccgg/trends/; and CDIAC, http://cdiac.ornl.gov/trends/co2/lawdome-data.html

Given the historically high atmospheric concentrations and our understanding of the greenhouse effect, we would expect the Earth's climate system to have warmed, unless there have been offsetting factors.

(ii) Evidence of warming

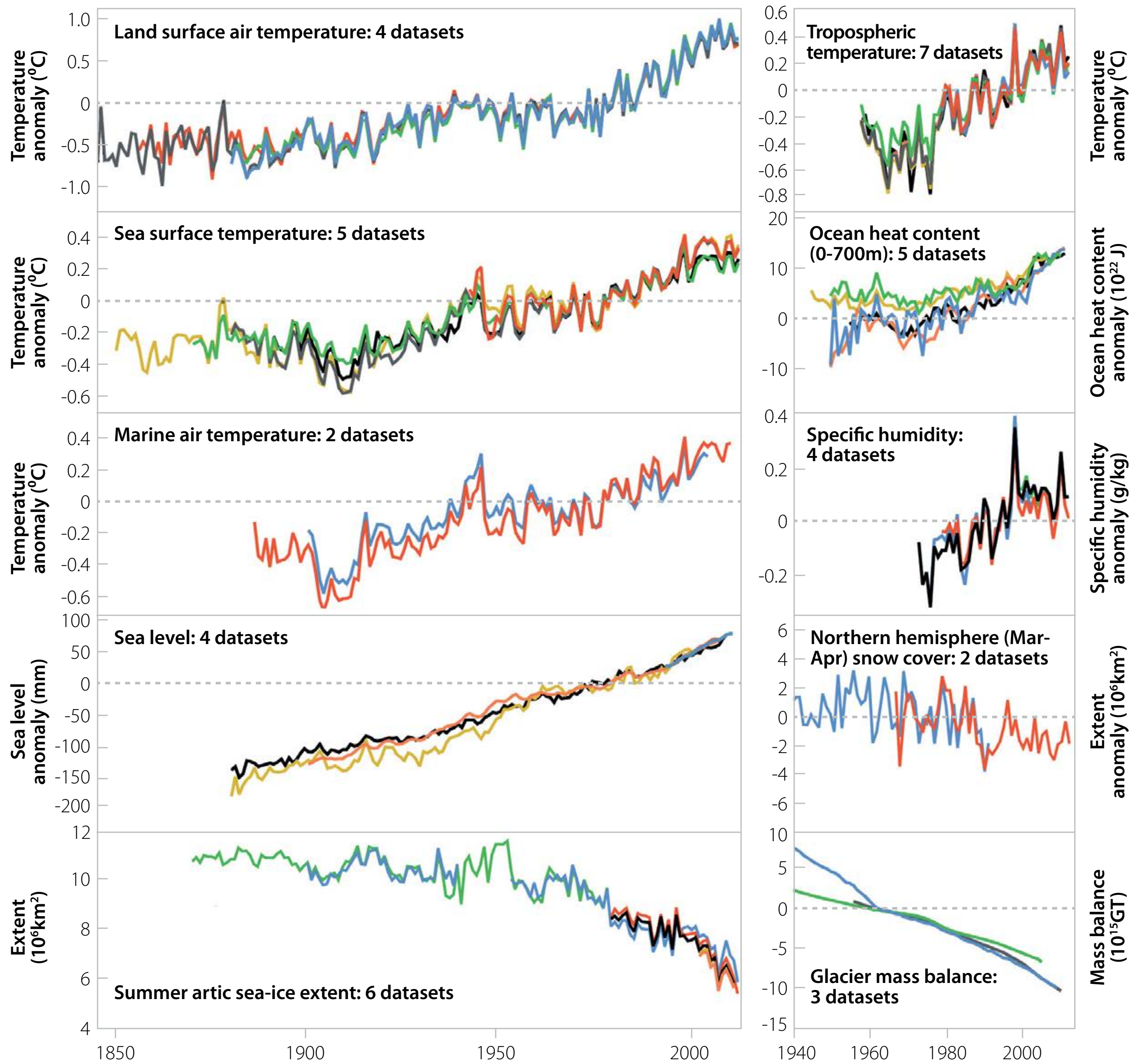
The latest evidence is consistent with a pattern of continued overall warming of the climate system. There are small extensions to the data available since 2010 for key climate indicators (such as surface and atmospheric temperatures, sea level, ocean heat, snow and ice cover – see Figure 1.4) which show:

- The oceans, which are the largest reservoir of heat in the climate system, have continued to warm.
- Global sea level continues to rise. Given water expands as it warms, this is consistent with ocean warming.
- Total global ice (from glaciers, the sea, and the major ice sheets over Greenland and Antarctica) has continued to decrease, also contributing to sea level rise.
- Temperatures over the land, sea, and in the lower atmosphere have all risen over the past few decades.

Global surface temperatures are currently among the hottest on record, albeit they have increased more slowly over the last 15 years (Figure 1.5). Similar fluctuations are seen in the earlier parts of the temperature record. They are to be expected and are consistent with longer-term warming.

- Each of the last three decades has been the warmest since 1850, the start of the thermometer-based global record.

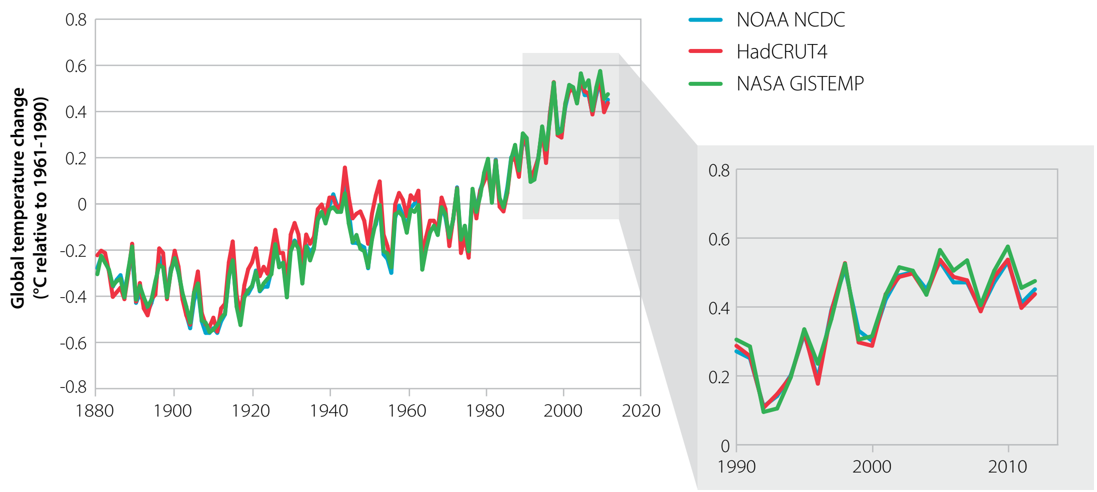
Figure 1.4: Global climate indicators



Source: IPCC AR5.
Notes: Datasets start at different dates depending on when reliable measurements can first be made.

- The trend in global surface temperature since 1998 has been around 0.04°C/decade increase compared to an average trend since 1950 of about 0.11°C/decade.
- There have been other periods in the past where global temperatures have shown flat or negative trends, even while greenhouse gas emissions were rising (e.g. the 1950s-1970s).
- Such periods are to be expected, given natural internal fluctuations and the role of natural external drivers which can exert a cooling influence, partially offsetting greenhouse gas warming (Box 1.1).

Figure 1.5: Global average surface temperature 1880-2012



Source: NOAA, http://www.ncdc.noaa.gov/cmb-faq/anomalies.php; Met Office Hadley Centre, www.metoffice.gov.uk/hadobs/hadcrut4/; NASA, data.giss.nasa.gov/gistemp/

Box 1.1: Mechanisms causing the recent "slowdown" in surface temperature rise

Global surface temperatures are influenced by natural internal fluctuations within the climate system, as well as external drivers from human and natural sources. Scientists think the recent slower rate of temperature rise has been due to a combination of natural fluctuations and external drivers.

Natural internal fluctuations mean that periods with little or no change are to be expected in the context of a warming climate system in which surface temperatures will ultimately rise.

- Variations of a few tenths of a degree can be seen in both observations and climate models. They can temporarily offset, or enhance, any underlying temperature trend. For instance, a very strong El Niño caused global average temperature to be markedly high in 1998.
- These fluctuations are driven by interactions between the atmosphere and ocean which cannot at present be predicted beyond a few years.
- Projections from climate models are therefore not expected to correctly forecast the exact size and timing of these short-term trends. But they do show decades of temperature 'pause' under scenarios of longer-term warming.

Natural external drivers have contributed to the size and duration of the recent slowdown by exerting a cooling influence. This has probably offset about a third of the warming influence from greenhouse gases. Nevertheless, the climate system as a whole continues to gain heat.

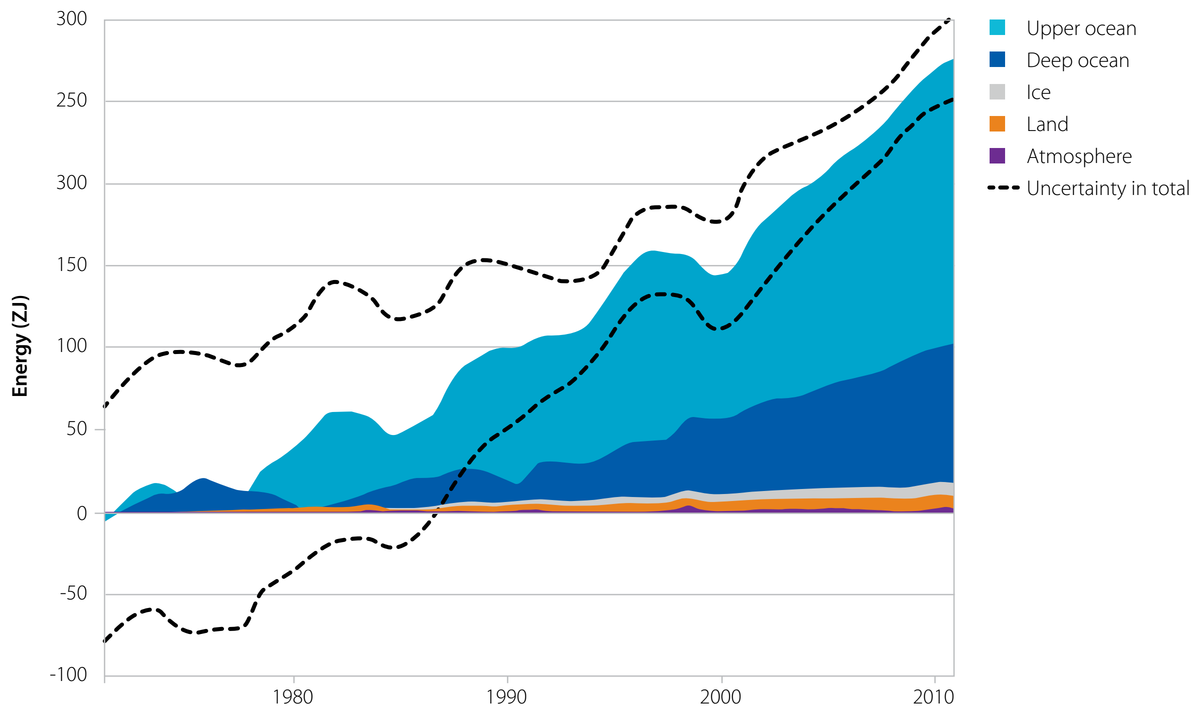
- The Sun undergoes a regular cycle of output, which most recently peaked in 2000 and troughed in 2009. Over the period 1998-2011 this had a cooling influence, reducing the energy imbalance in the atmosphere by about 0.1 Watts per square metre (Wm^{-2}).
- Aerosol emissions from a series of small volcanoes also acted to cool, further reducing the energy imbalance by about 0.05 Wm^{-2}.
- Combining these cooling influences with the growing warming influence from human activity, the net increase in energy imbalance during 1998-2011 was about 0.23 Wm^{-2}. During the preceding 15-year period of 1984-1998, when surface temperatures rose faster, the equivalent net increase was about 0.34 Wm^{-2}.
- This continuing energy imbalance means that the climate system is gaining heat. When looking at the oceans, atmosphere, land and ice combined, it is clear that the slowdown is restricted to surface temperature (Figure B1.1).

Box 1.1: Mechanisms causing the recent "slowdown" in surface temperature rise

Given the likely causes of the slowdown, there are several reasons to expect global temperature to resume its more rapid rise in the near future.

- The solar cycle will continue and the recent downward trend will average out over longer time periods. Even if the Sun undergoes another 'Grand Minimum' in activity over the next few decades, as suggested by some, it would not be large and lasting enough to offset the projected temperature rise from greenhouse gases.
- Aerosols from individual volcanic eruptions lower temperature for 2-3 years at most. In the absence of a series of major eruptions these will not offset the long-term warming from greenhouse gases.
- Natural internal fluctuations are unlikely to offset the underlying temperature increase for longer than several decades.
- Cooling from air pollution (e.g. sulphate aerosols) emitted as a by-product of fossil fuel burning has partially offset warming over past decades. This pollution is expected to decrease as clean air policies are enacted around the world.

Figure B1.1: Total global energy gain since 1970



Source: IPCC AR5.
Notes: Plotted from 1970 when reliable measurements begin. Energy is plotted in zettajoules (ZJ) = 10^{21} Joules. For comparison, global energy use is currently about 0.5 ZJ per year..

Source: IPCC AR5; Easterling and Wehner (2009) *Is the climate warming or cooling*? Meehl et al. (2009) *Model-based evidence of deep-ocean heat uptake during surface-temperature hiatus periods*; Met Office (2013) *Briefing paper: Recent pause in global warming*; Meehl et al. (2013) *Could a future "Grand Solar Minimum" like the Maunder Minimum stop global warming?*; Feulner and Rahmstorf (2010) *On the effect of a new grand minimum of solar activity on the future climate on Earth.*

Scientists have studied the extent to which the slowdown has implications for future temperature change. While it helps rule out some of the highest projections for the next few decades, it makes little difference to the longer-term warming ultimately expected from raised greenhouse gas concentrations.

- When climate models are scaled to match observations up to 2010, the upper-end of their projections for near-term temperature change (i.e. to the 2020s) is reduced by 20%[6].
- Longer-term projections are largely unchanged by the recent temperature trend, as natural fluctuations and the solar cycle are expected to average out over time.
- A measure of longer-term warming is "climate sensitivity" (see next section). Estimates based on observations from the 2000s are similar, albeit with a narrower range, to those from using the whole 1970-2009 period[7].

These studies are incorporated into the IPCC's judgments about climate sensitivity, to which we now turn.

Summary: The climate system as a whole continues to heat up. Globally, ocean heat content is increasing, ice and snow are retreating, sea level and surface temperatures are rising. The current slowdown in temperature rise remains short on climate timescales, and does not fundamentally change longer-term projections of warming.

(c) Climate sensitivity

Climate sensitivity is defined in terms of the change in temperature due to a doubling of greenhouse gas concentrations in the atmosphere. Two metrics of climate sensitivity are used widely.

- **Equilibrium Climate Sensitivity (ECS).** ECS measures the increase in global temperature after CO_2 concentration in the air is doubled and held fixed. This takes decades or centuries to be fully realised, given that it takes time for the oceans to absorb heat and reach a new equilibrium with the atmosphere[8].
- **Transient Climate Response (TCR).** TCR is measured under a scenario of CO_2 concentration rising at 1% per year, and is the temperature change at the point when concentration is doubled (i.e. in year 70). TCR is arguably more relevant to decision-making as it focuses on warming over the next 70-100 years rather than stabilisation in the more distant future under fixed concentrations.

Climate sensitivity captures the direct warming from greenhouse gases, together with feedback processes which amplify or dampen the warming. Nearly all studies show these feedbacks are a net amplifier of warming, so that ECS and TCR are larger than expected from the influence of greenhouse gases alone:

6 Stott et al. (2013) *The upper end of climate model temperature projections is inconsistent with past warming.*
7 Otto et al. (2013) *Energy budget constraints on climate response.*
8 Note that the usual definition of ECS excludes very long-term processes which are likely to increase temperature further, such as changes in vegetation and ice sheets.

- **Direct heating by greenhouse gases.** On its own, a doubling of CO_2 concentration would eventually increase global surface temperature by around 1°C.
- **Water vapour/lapse rate feedback.** As the surface and air warms, it is able to hold more water vapour, which is itself a potent greenhouse gas. In response to warming the atmosphere will also adjust its temperature structure (also known as its lapse rate). Theory, observations and models all show that this combined water vapour/lapse rate effect amplifies the direct effect from CO_2.
- **Albedo feedback.** Surface warming will melt snow and ice which reflect sunlight (i.e. have a high albedo). As they recede they expose darker land or ocean, which absorb more sunlight (low albedo) increasing the amount of heat trapped by the Earth. Again, this is a well understood amplifier of warming.
- **Cloud feedbacks.** As the atmosphere changes it will affect when and where clouds form. Clouds play a role in both reflecting sunlight and trapping surface heat, meaning they could in theory provide an overall amplifying or dampening effect. Evidence from a range of studies shows they are likely to be a net amplifier[9].

The magnitude of ECS and TCR can be estimated using several different methods:

- **Climate models.** Research centres around the world have developed supercomputer-based models which aim to represent all relevant processes in the atmosphere, land and ocean. In these models ECS and TCR are emergent outputs, not pre-determined inputs. As with any model, they only approximate the real world. Scientists are working continually to improve their representation of key climate processes.
- **Modern-day energy balance.** Much simpler models have been used to derive ECS and TCR from recent observations of temperature, heat uptake, and the energy imbalance from human and natural drivers. This is an attractive approach because it emphasises real-world measurements. Sensitivity estimates using these models are, however, affected by large uncertainties in observed ocean heat uptake and aerosol cooling. The simplest studies also ignore changes in feedbacks over time, which has been argued leads to an underestimate of sensitivity[10].
- **Studies of ancient climates.** Earth's climate has been very different at times in the deep past (such as the peak of the ice age 20 thousand years ago, or the warmer Pliocene 3 million years ago). These past climate states can help constrain ECS. But the data are more patchy, and careful assumptions are required over whether the same feedbacks apply in the same way for the present day.
- **A combination of the above.** Various approaches have been used to blend the information from different methods. For example, some studies weight complex climate model outputs by their degree of fit with current observations, while others use the models to simulate ancient climates.

9 See IPCC WG1 AR5 Chapter 7 for details.
10 Armour et al. (2012) *Time-varying climate sensitivity from regional feedbacks*.

There is no agreed best way to estimate climate sensitivity. No method is entirely independent from the others, each requires a model, and each contains uncertainties about input variables. It is therefore appropriate to consider the full range of evidence from the above methods.

In our previous analysis of global emissions pathways, we used a distribution of ECS values included in the IPCC's fourth assessment report (AR4). Based on the latest evidence, IPCC AR5 provides a similar range to AR4 with a slight reduction in the low end of likely values.

- IPCC AR5 gives a likely (i.e. at least 66%) probability of ECS lying in the range 1.5-4.5°C, a probability of no more than 5% that it is less than 1°C and a probability of no more than 10% that it is greater than 6°C.
- The low end of the likely range (1.5°C) is the same as that assessed in the first three IPCC assessments (in 1990, 1995 and 2001) but is lower than in AR4 (2°C). This adjustment reflects several recent studies, based on energy balance methods, which give low results.
- The upper end of the likely range (4.5°C) remains the same as in all previous IPCC assessments. It reflects evidence from the latest generation of climate models (which show similar sensitivities to earlier models) and from past climates, as well as some energy balance studies.

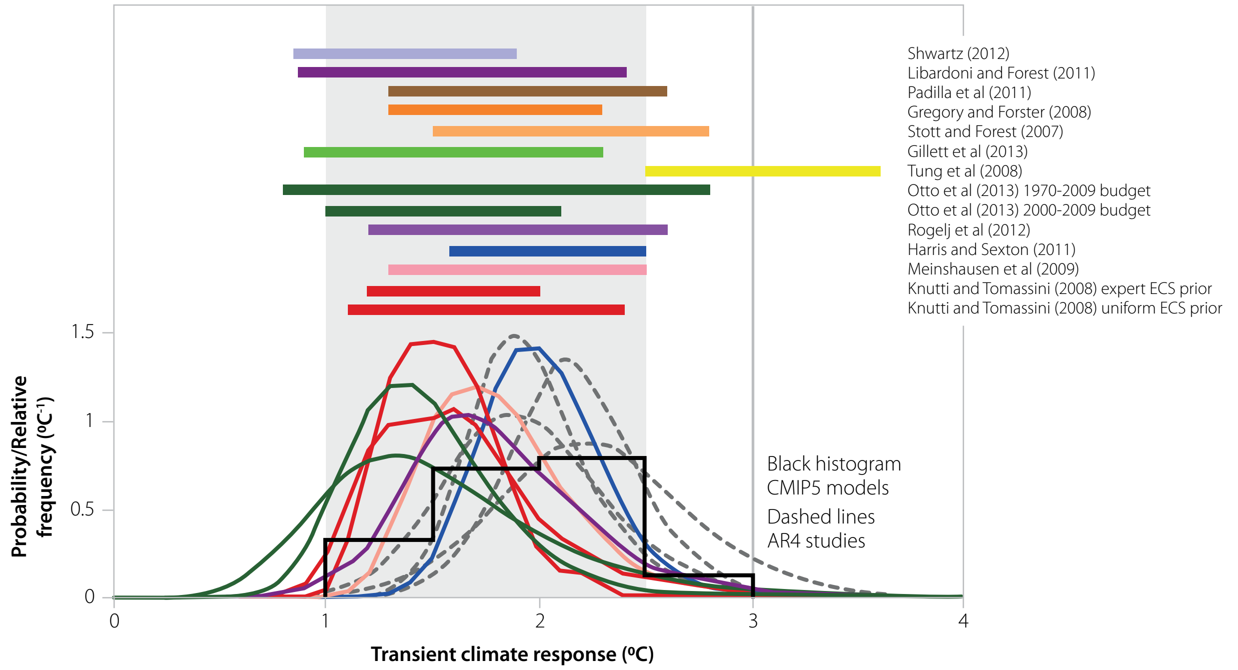
Estimates of TCR generally differ less between methods and show a narrower range than those of ECS. IPCC AR5 gives a similar TCR range to AR4, but with a reduction in the high end (Figure 1.6).

- There is a greater overlap across estimates from the range of studies using climate models and energy balance approaches compared to those for ECS.
- IPCC AR5 concludes that TCR has a likely (i.e. at least 66%) probability of lying in the range 1-2.5°C, and gives a probability of no more than 5% that it is greater than 3°C.
- TCR was first used as a concept by the IPCC in its third assessment, which reported a range from models of 1.1-3.1°C. IPCC AR4 gave a probability of at least 90% that TCR is greater than 1°C and a probability of no more than 10% that it is greater than 3°C.
- While these conclusions over time are not directly comparable, it seems clear that TCR values above 3°C are now considered less likely.

In Section 4 we set out the implications of these estimates for future temperature change under different pathways of global emissions.

Summary: Recent estimates of the eventual warming for a doubling of CO_2 concentration (known as equilibrium climate sensitivity) confirm previous estimates, although some simple approaches allow for slightly lower values than were considered likely in the IPCC 4th assessment. Studies of the warming over the rest of the century (the transient climate response) generally confirm previous assessments, but the highest values are now less likely.

Figure 1.6: Recent estimates of Transient Climate Response (TCR)



Source: IPCC AR5.
Notes: Coloured bars give the 5-95% ranges for TCR estimates from different studies (see IPCC WG1 AR5 Box 12.2 for details). Distributions from a subset of these studies are shown at bottom along with a histogram of results from the 20 or so leading climate models (CMIP5). Shaded grey area shows the IPCC-judged likely TCR range of 1-2.5°C, while grey line marks the extremely unlikely value of 3°C.

(d) Feedbacks between climate and natural chemical cycles

As temperatures, rainfall patterns and atmospheric composition change, the Earth's natural chemical cycles will respond. These will affect the amount of CO_2 and other gases and particles in the atmosphere, creating feedbacks which further enhance or diminish the amount of future climate change. These feedbacks are in addition to the response of water vapour, albedo and clouds set out above.

Some of these chemical feedbacks are already included in climate model projections. Others are not yet included because they are currently less well understood.

- The land and ocean have together absorbed around half of total CO_2 emissions to date. Rising concentrations stimulate some plants to absorb more, but warming reduces the rate of ocean uptake and increases soil emissions. These processes have been added to models, including the Committee's analysis of global emissions pathways, and in total provide additional warming.
- Other potential feedbacks are likely to exist, and we have noted in previous reports that climate projections therefore remain incomplete. For instance, frozen soil (permafrost) will thaw in Arctic regions as temperatures rise, allowing trapped organic matter to decompose into CO_2 and methane. Ocean methane hydrates may destabilise as they warm (but could become more stable as sea levels rise). Warming may also amplify nitrous oxide emissions from soils.

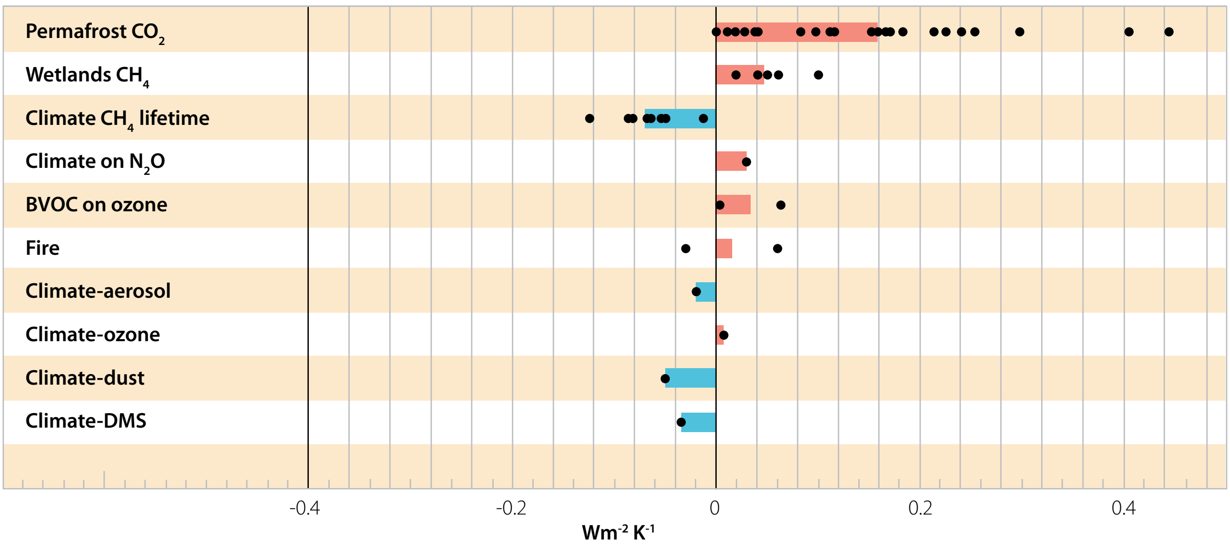
Several recent studies have presented tentative estimates for missing feedbacks (Figure 1.7).

- Most have focussed on thawing permafrost. Estimates show that this would lead to additional warming, although there is a wide range for the potential size of the effect. At most, under the highest warming scenario considered by the IPCC, up to a few hundred billion tonnes of additional CO_2-equivalent may be emitted over the century (around 20 times current global annual CO_2 emissions).
- Several studies have looked at future methane emissions from wetlands as climate changes, and suggest a smaller amplification of warming. Several others address changes to the atmospheric lifetime of methane, which leads to a reduction in warming. The sum of these feedbacks is however thought to be small.
- Small additional warming and cooling influences have been quantified by a very small number of studies looking at other feedbacks (such as hotter and drier conditions driving more dust into the atmosphere, or reducing forest stocks through more fire).

We include estimates for some of these newly-quantified feedbacks in our updated modelling of global emissions pathways in Section 4.

Summary: Tentative estimates are now available for feedbacks in the climate system which were previously known but not quantified. One such feedback with potentially significant warming is carbon release from melting permafrost. The net effect of these newly-quantified feedbacks is likely to be further warming above that projected by current models.

Figure 1.7: Newly-quantified chemical cycle feedbacks in IPCC AR5



Source: IPCC AR5.
Notes: Strength of each feedback given in $Wm^{-2}K^{-1}$, a measure of the additional energy imbalance per degree global warming. Dots give results from individual studies, and bars show the average. Red bars indicate positive feedback (further warming as temperature rises), blue bars indicate negative feedback. The level of scientific confidence in these results is judged to be low. See IPCC WG1 AR5 Figure 6.20 for details.

3. Update on potential impacts of warming

In this section we summarise the potential risks from climate change, and consider new knowledge since our original fourth carbon budget advice. We focus on global impacts to human welfare and ecological systems over the 21st Century to assess whether there has been a clear change in understanding of dangerous levels that should be avoided.

Impacts will depend on how global warming translates into changed patterns of local rainfall, sea level, snow melt and weather extremes such as storms, heat waves, cold snaps, droughts and floods. The size of the risks will also be crucially dependent on other factors: where people live, what they do, the ways they interact with ecosystems and the resources they have to cope and adapt.

In 2010 when we first advised on the fourth carbon budget, we drew on the conclusions of IPCC AR4 and a review we commissioned into research developments since AR4[11]. As with any long-term predictions there are large uncertainties in precisely quantifying these impacts. But the overall picture suggested a risk of increasingly harmful effects, unevenly distributed around the world and quickly becoming severe in some regions (Box 1.2):

- Risks from a relatively small global temperature increase (e.g. 1°C) are likely to be manageable in many regions with adaptation efforts. There may be some benefits in temperate areas.
- Benefits are likely to disappear and scope for adapting likely to decline for more significant warming.
- The impact of temperature change on human welfare is highly likely to be non-linear (e.g. a 4°C rise is highly likely to be more than twice as harmful as a 2°C rise).
- Damage will be pronounced in certain regions (such as polar, mountain, Mediterranean regions, sub-Saharan Africa and coral reefs) even for small further increases, and will disproportionately impact the world's poor.

Since 2010 more scientific studies have been published, using a newer generation of climate models, improved impact models and better data. A comprehensive assessment of the most up-to-date evidence on impacts will be available in spring 2014 from the IPCC's Working Group 2. But new studies appear to extend and build on the broad picture of risks already known.

- There is increasing understanding of how impacts are determined by multiple aspects of climate change (e.g. crops are affected by temperature, rainfall and CO_2 concentration) and factors apart from climate. This complexity can act to increase or decrease risk.
- High heat reduces the productivity of labourers, especially those working outdoors. Recent studies show that reductions in productivity have already occurred as temperatures have risen, and future increases in extremes may be enough to put livelihoods at risk[12]. This effect is not captured in most economic assessments of climate change impacts.

11 AVOID (2010) *An updated review of developments in climate science research since IPCC AR4*. Available on CCC website as supporting research to CCC (2010) *The fourth carbon budget – reducing emissions through the 2020s*.

12 E.g. Dunne et al. (2013) *Reductions in labour capacity from heat stress under climate warming*; Kjellstrom et al. (2013) *Mapping occupational heat exposure and effects in South-East Asia: Ongoing time trends 1980-2009 and future estimates to 2050*.

- IPCC AR4 flagged that projected increases in heat waves, as well as changes to average climate, might cause greater variability in future crop yields and higher risk of crop failures. New studies confirm this effect even in temperate regions[13].
- Studies are shedding further light on risks from ocean acidification, which was only emerging as a research topic at the time of IPCC AR4. As oceans take up more CO_2 from the air they become more acidic. This will benefit marine plants such as algae, but will likely impair the formation of shells for many species and the building of coral reefs.
- Detailed impacts studies continue to predict risks from unmitigated global warming, as well as starting to quantify the benefits of reducing global emissions[14] and adapting to climate changes[15]. They confirm that many impacts can be decreased or delayed, but even under radical mitigation scenarios not all impacts are avoided.

Taken together these developments suggest that the overall risk picture is similar to when the fourth carbon budget was legislated. If anything, new evidence on labour productivity and agriculture suggests lower benefits and higher damages around 2°C.

Given these risks on the one hand, and the continued rise in global emissions on the other, we conclude that our climate objective remains appropriate (i.e. to keep central estimates of global temperature rise by 2100 close to 2°C above pre-industrial levels, and to keep the risk of 4°C to very low levels). Even if the objective is achieved, there is a need for adaptation efforts to reduce some negative impacts that will not be avoided.

Deep uncertainties remain around precise estimates of damage. Their potential size and scope, however, together with likely limits to adaptation, suggest that the appropriate response to uncertainty is to seek to minimise the largest risks by reducing greenhouse gas emissions.

Summary: Current evidence continues to point towards major risks to human welfare and ecological systems over the 21st Century as a result of human-induced climate change. These risks can be limited by taking global action to reduce greenhouse gas emissions.

13 E.g. Teixeira et al. (2013) *Global hot-spots of heat stress on agricultural crops due to climate change.*
14 E.g. Arnell et al. (2013) *A global assessment of the effects of climate policy on the impacts of climate change.*
15 E.g. Challinor et al. (2010) *Increased crop failure due to climate change: assessing adaptation options using models and socio-economic data for wheat in China.*

Box 1.2: Risks from warming – key impacts at 2°C and 4°C

Scientific evidence points to a range of increasingly harmful effects and potential irreversible shifts as the climate warms. Global average temperature is only a rough scale on which to place these, and there is no definitive and obvious threshold beyond which climate change becomes dangerous. It is possible however to identify major risks as a broad function of global temperature above pre-industrial levels:

Around 2°C

- Land areas would warm on average by 3°C, and northern continents such as parts of Canada, Russia and the Arctic would warm by around 6°C in winter.
- Tropical regions, where temperature only varies by a degree or so throughout the year, would start to experience climates out of the range experienced in modern times. Many plants and animals in these areas already live near their thermal limit.
- Crop productivity would be damaged even for warming less than 2°C in Sub-Saharan Africa, and other areas where agriculture is already marginal. Without adaptation, agriculture would also start to decline on average in temperate regions around 2°C.
- There is high confidence that coral reefs will suffer widespread losses due to a combination of ocean warming and acidification (another result of raised CO_2 concentration). Reefs are a habitat for a quarter of the world's fish species and provide a critical source of protein, shore protection and income in the developing world.
- At the global level, ecosystem health will continue to be largely determined by other, non-climate pressures from humans (e.g. deforestation). There is evidence however that up to perhaps a third of all species would be 'stranded' as climate change shifts suitable habitats.
- Global average sea level would be expected to rise 0.4-0.7m by 2100, with further increases for centuries beyond due to the very slow and effectively irreversible process of ocean warming. During the last interglacial period, around 120,000 years ago, global temperature was not more than 2°C above pre-industrial levels and sea level was ultimately 5-10m above present.

Around 4°C

- Land areas would warm on average by 6°C and northern continents in winter by roughly 12°C.
- Extreme heat waves (such as those in Europe, 2003, and Russia, 2010) would become the norm by mid-century, and would be considered cool summers by the end of the century.
- Sea level would be expected to rise 0.6-1m by 2100, and continue rising toward an eventual 20m as the Greenland and West Antarctic Ice Sheets almost completely melt and the East Antarctic Ice Sheet partially melts.
- The Earth system may cross other nonlinear and irreversible 'tipping points', such as dieback of the Amazon forest.
- Crop models suggest that beyond 4°C declines in global food production would become very severe.
- In order to find an analogous event in Earth's history, in which global temperature rose by a similar amount in a few thousand years or less, geologists have to go back 53 million years.

4. Global emissions pathways for the fourth carbon budget review

Without action to reduce global emissions there is a high risk of dangerous warming, reaching 4°C or more and exceeding our climate objective.

- In our previous analysis (Box 1.3) we found that, for a scenario without global mitigation, there is a 50% probability of reaching 4°C above pre-industrial levels by 2100, with a 5-95% probability range of 2.9-5.8°C.
- IPCC AR5 uses four new global scenarios, called Representative Concentration Pathways (RCPs), to estimate future climate change. Each is based on different levels of concentration increases due to different emissions over time.
- One of these scenarios (RCP8.5) assumes emissions increase throughout the 21st Century. For this scenario the IPCC predicts likely warming of 3.2-5.4°C above pre-industrial level towards the end of the century, with a mean estimate of 4.3°C.
- For a scenario consistent with emissions growing more slowly before peaking around 2080 (RCP6.0), the IPCC predicts likely warming by 2100 of 2.0-3.7°C with a mean estimate of 2.8°C.
- Continued warming after 2100 is predicted in all scenarios without CO_2 emissions close to zero by the end of the century.

Our previous assessment was that, in order to achieve our climate objective, there would have to be early peaking of global emissions, with a reduction to 20-24 $GtCO_2e$ in 2050 (i.e. a 50% cut on recent levels) and further cuts thereafter.

Box 1.3: Modelling future temperature rise from global emissions pathways

Previously we developed a set of future global emissions pathways and tested them against our climate objective in collaboration with the Met Office Hadley Centre.

The pathways were defined by a given year in which CO_2 emissions peak, a fixed annual percentage rate at which they then fell, and a specified minimum emissions "floor" that they ultimately reached. Other long-lived greenhouse gases and short-lived air pollutants are also accounted for.

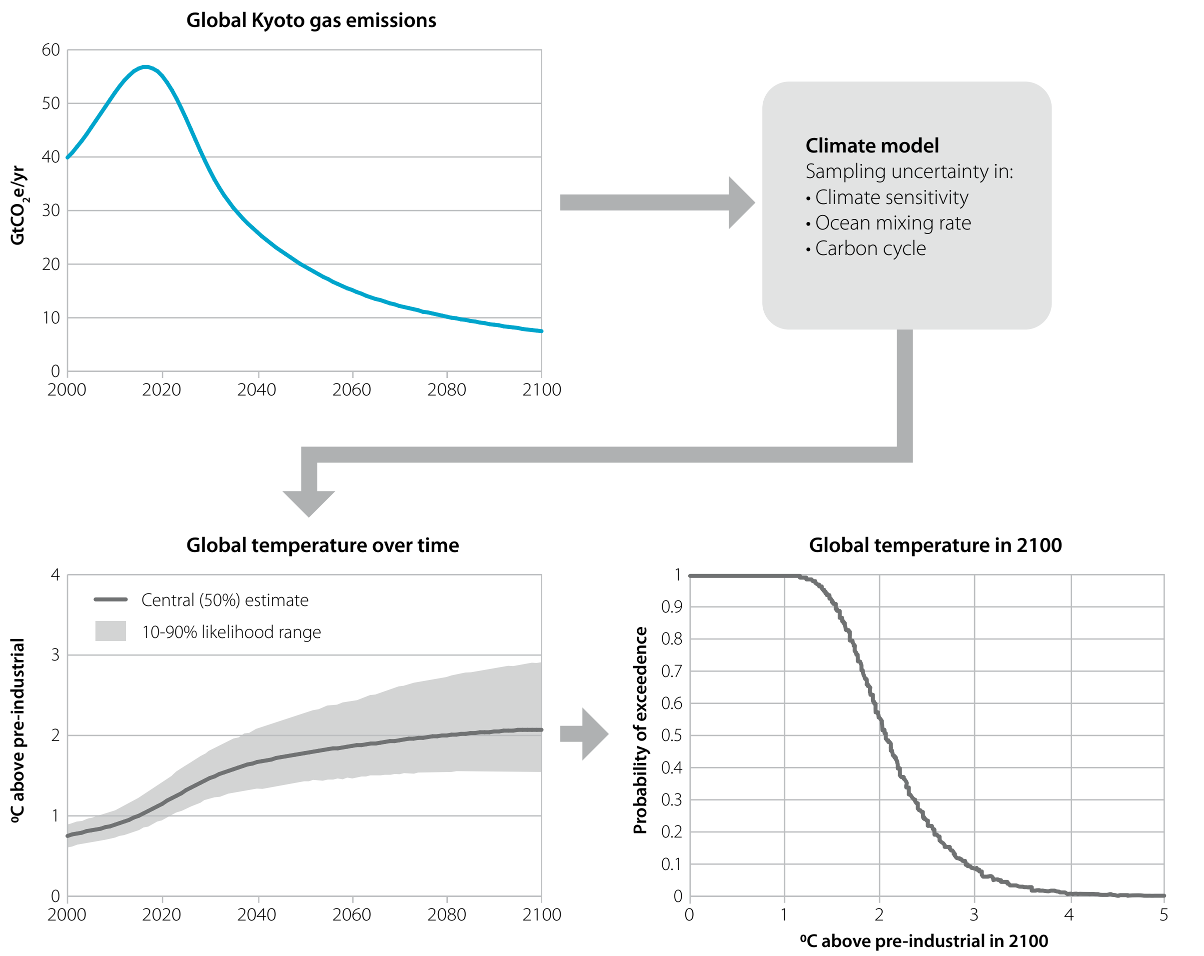
A simple climate model known as MAGICC was used to predict future global temperature rise under these pathways. It has been used extensively in scientific studies and IPCC assessments because it is able to emulate the large-scale features of the most complex models. A key benefit of simpler models such as MAGICC is that they are faster to run, and by varying a small number of parameters they allow exploration of the full range of uncertainty across the complex models.

For each emissions pathway the model was run several hundred times, each with a different combination of values for key climate parameters (Figure B1.3). In this way we accounted for a broad range of climate system uncertainties. By weighting these runs according to the likelihood of each parameter combination, an overall likelihood distribution of global temperature increase was built for each pathway.

We have used this model framework again for the new analysis in this report, building in the updates set out in the main text.

Box 1.3: Modelling future temperature rise from global emissions pathways

Figure B1.3: Schematic of the modelling process for relating emissions pathways to climate objectives



Source: CCC, Met Office Hadley Centre (2008).
Notes: Temperatures shown represent the global average temperature consistent with Earth's energy balance at that time. They do not include the natural year-on-year fluctuations present in the real world.

Note: see *Projecting global emissions, concentrations and temperature*; available on CCC website as technical appendix to CCC (2008) *Building a low-carbon economy.*

We now present new modelling work with the Met Office Hadley Centre, reflecting several updates[16]:

- Global emissions are assumed to peak in 2020 or later, reflecting the date at which a comprehensive global deal is due to come into force (see Chapter 2).
- Transient Climate Response (TCR) is used as an alternative method to determine the range of temperature change in 2100 under these emissions pathways, rather than using a combination of distributions for Equilibrium Climate Sensitivity (ECS) and ocean mixing rate.
- Instead of using a single distribution for TCR values we use all available distributions considered in IPCC AR5.

16 See the Technical Appendix accompanying this report for detailed methods

- Tentative estimates of feedbacks from chemical cycles, such as emissions from melting permafrost, are considered.

We conclude that the global emissions pathways to achieve the climate objective remain broadly unchanged in light of the latest evidence, although more ambitious pathways may be needed if new feedbacks are in line with emerging evidence (Table 1.1).

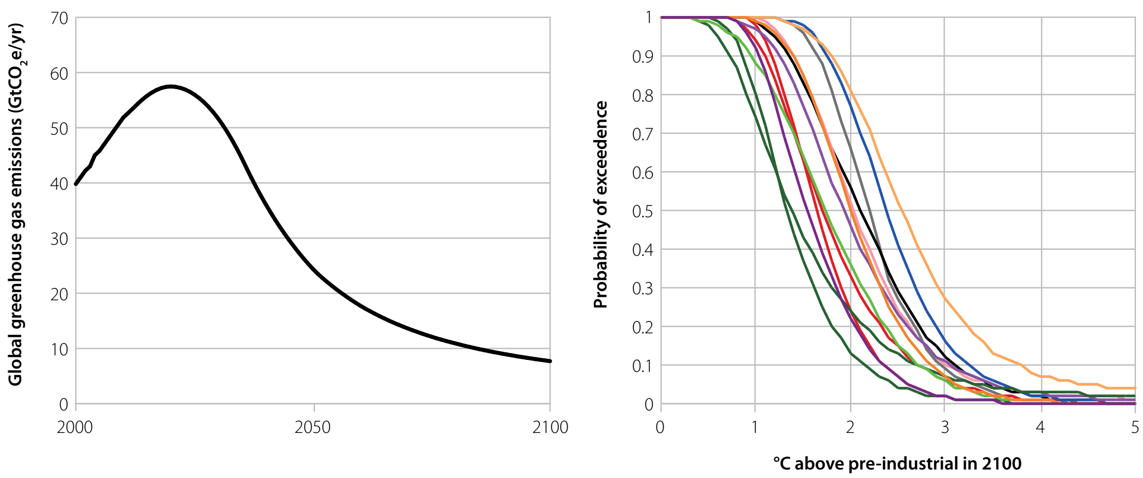
- For pathways peaking in 2020 and then falling to zero CO_2 emissions at such a rate that they pass through 20-24 $GtCO_2e$ in 2050, the range of TCR assumptions provide median (central) estimates of 1.4-2.5 °C for temperature rise in 2100. The likelihood range for a 3°C rise is 2-27%, and for a 4°C rise is 0-7%. Results from using our previous modelling fall within this range (Figure 1.8).
- If estimates of the newly-quantified feedbacks are included, further warming is expected under these scenarios. A few tenths of a degree is added to central estimates of temperature rise by 2100, and the likelihood of reaching 4°C is doubled.
  - We consider three additional effects for which several studies are reported in IPCC AR5: emission of CO_2 and methane from melting permafrost, methane emission from changing wetland coverage, and reduced methane lifetime due to warming.
  - Figure 1.9 illustrates the impact of these effects on temperature rise by 2100. Taking the average feedback strength across the available studies as a best estimate, the net effect is additional warming. The uncertainty range does however allow for slightly reduced warming or very strong additional warming.
  - Across the range of TCR assumptions, including the best estimate for these feedbacks pushes up central estimates of warming by 2100 to 1.5-2.9 °C. The likelihood of a 3°C rise increases to 3-44%, and the likelihood of 4°C to 1-15%.
- Delaying action to reduce emissions raises the risks to meeting the objective, making it unattainable under many plausible assumptions.
  - We have considered a pathway in which global emissions continue to grow until 2030, fall very rapidly such they are still limited to 20-24 $GtCO_2e$ in 2050, and fall to very low levels thereafter.
  - Even if this were feasible, which is unlikely, this pathway raises central estimates of global temperature in 2100 to 1.4-2.7 °C. The likelihood range for a 3°C rise is 2-35%, and for a 4°C rise is 0-10% (Figure 1.10).
  - If the newly-quantified feedbacks were accounted for, this would increase expected warming, and the risks of very high warming, further.

Table 1.1: Summary of estimated warming in 2100 for global emissions pathways

Emissions pathway	Median (°C)	Likelihood of 3°C	Likelihood of 4°C
Peaking in 2020, falling through 24 $GtCO_2e$ in 2050 towards zero CO_2 emissions	1.4-2.5	2-27%	0-7%
As above, including average estimate of permafrost, wetlands and methane feedbacks	1.5-2.9	3-44%	1-15%
Peaking in 2030, falling through 23 $GtCO_2e$ in 2050 towards zero CO_2 emissions	1.4-2.7	2-35%	0-10%

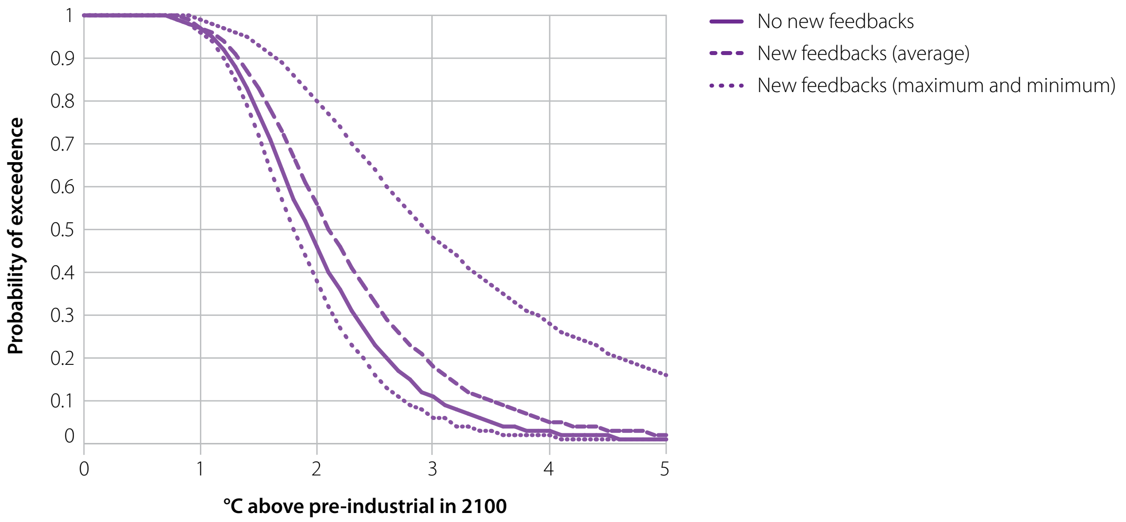
Source: CCC/Met Office Hadley Centre. All temperatures relative to pre-industrial levels.

Figure 1.8: Global pathway involving peak emissions in 2020 (left) with resulting likelihoods of global temperature rise in 2100 (right)



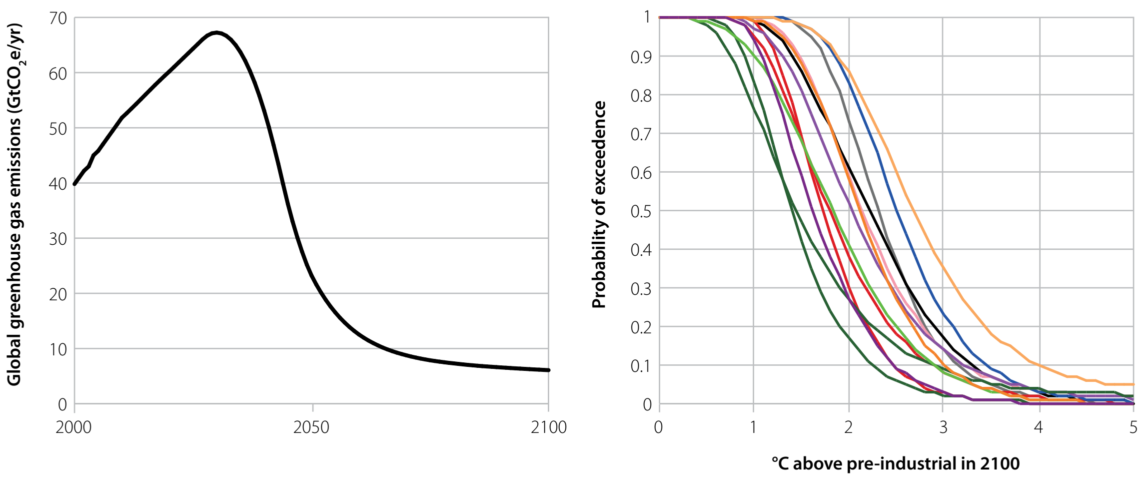
Source: CCC/Met Office Hadley Centre.
Notes: Pathway assumes CO_2 emissions fall at a fixed annual percentage rate towards zero after a peaking phase centred on 2020. Total GHG emissions in 2050 are 24 $GtCO_2e$. Each temperature likelihood curve was generated using a TCR distribution from Figure 1.7, and is colour-coded to match (including CMIP5 models in black). Data from Schwartz (2012), Padilla et al. (2011) and Tung et al. (2008) were not available to us at the time of analysis and so are not shown. The additional grey curve shows results using the previous CCC/Met Office Hadley Centre modelling method.

Figure 1.9: Impact of including newly-quantified feedbacks on estimates of global temperature in 2100



Source: CCC/Met Office Hadley Centre.
Notes: Solid line reproduces the result in the previous figure using the TCR distribution from Rogelj et al (purple in Figure 1.8). Additional lines show the change in warming projected using this TCR distribution and including the feedback effects of warming on permafrost, wetlands and methane lifetime. Dashed line shows inclusion of the average feedback estimate from the studies in IPCC AR5; dotted lines show the sum of maximum and minimum estimates.

Figure 1.10: Global pathway involving peak emissions in 2030 (left) with resulting likelihoods of global temperature rise in 2100 (right)



Source: CCC/Met Office Hadley Centre.
Notes: Pathway assumes CO_2 emissions fall at a fixed annual percentage rate towards zero after a peaking phase centred on 2030. Total GHG emissions in 2050 are 23 $GtCO_2e$. See Figure 1.8 for further details.

Our pathways have larger cumulative CO_2 emissions than the cap suggested by IPCC AR5 for a 50% probability of remaining below 2°C. This underlines that our pathways should be viewed as a minimum level of effort.

- Total CO_2 emissions during 2012-2100 are 1500-1670 $GtCO_2$ for our pathways which peak in 2020, fall through 20-24 $GtCO_2e$ in 2050 and approach zero CO_2 emissions.
- IPCC AR5 suggests a cap on total future CO_2 emissions in order to maintain a 50% probability of keeping within 2°C of pre-industrial levels. Accounting for future emissions of other gases and particles, this cap is set at 220-390 GtC (820-1440 $GtCO_2$).
- The precise level of the required cumulative CO_2 cap is dependent on factors including climate sensitivity, the strength of carbon-cycle feedbacks and future non-CO_2 emissions. The fact that our pathways have higher cumulative emissions than IPCC AR5 means further reductions may be needed to achieve the objective.

In updating our advice on the fourth carbon budget, we use global emissions pathways which reflect peaking around 2020 with deep cuts thereafter to 2100, resulting in emissions of 20-24 $GtCO_2e$ in 2050.

The UK's 2050 target of an 80% emissions reduction relative to 1990 levels is consistent with this. The fourth carbon budget, which is designed to put the UK on a cost-effective path to that target, is therefore also appropriate in this context. There is the possibility that the UK may need to contribute more effort as part of an effective global deal (see also Chapter 2).

We will continue to monitor closely developments in climate science, especially the IPCC AR5 conclusions in 2014 regarding climate impacts and mitigation. We will provide a detailed update of the evidence in our advice on the fifth carbon budget at the end of 2015.

Summary: Accounting for the latest evidence, our climate objective implies global emissions pathways similar to those we used previously to guide the UK's 2050 target and fourth carbon budget. Global emissions should peak around 2020 then fall significantly for the remainder of the century.

Chapter 2: International circumstances

Introduction and key messages

The Climate Change Act requires that we consider international circumstances when designing carbon budgets.

We have interpreted this duty as requiring us to assess the feasibility of global emissions pathways required to meet our climate objective (as set out in Chapter 1).

We gave our advice on the fourth carbon budget one year after the Copenhagen discussions on a new global deal, at which the Copenhagen Accord was agreed.

In this chapter we update our assessment of international circumstances:

- We consider progress towards a new global deal to reduce emissions.
- We assess progress in individual countries and sectors.
- We consider what would be required to deliver global emissions reductions compatible with achieving our climate objective.

Our conclusion is that the international circumstances have progressed broadly as expected in 2010, and that there is therefore no rationale to change the fourth carbon budget on this basis.

- Progress towards a global deal has been slow but broadly as expected when the fourth carbon budget was set. The UN has formally adopted an objective to limit warming to 2°C and is working towards an agreement aimed at peaking and reducing emissions consistent with this goal. The aim is to resolve that process in Paris at the end of 2015.
- The UK is not acting alone. Many countries have made ambitious commitments to reduce emissions, and are delivering against these commitments. There is now widespread coverage by low-carbon policies of major emitting sectors around the world. This provides a good basis for agreeing and implementing an ambitious global deal.
  - Amongst the major emitters, China (29% of global CO_2 emissions) has made significant progress on low-carbon investment. It has made commitments to reduce carbon-intensity by 40-45% from 2005 to 2020, and introduced policies to deliver this as part of the 12th five-year plan. With on-going action, China's emissions could peak in the early -mid 2020s.
  - The United States (16% of global CO_2 emissions) has a good chance to deliver its Copenhagen Accord commitment to reduce 2020 emissions by 17% on 2005 levels. Going beyond this, there is a major challenge to develop and implement approaches to drive further cuts, which are required through the 2020s.
  - Commitments comparable to the UK's have been made by a range of developed and developing countries: Germany in terms of medium-term emissions reduction; China and

the US on the basis of carbon-intensity against a 2005 baseline; the US, Japan, the EU and Mexico in terms of 2050 commitments.

  – Coverage of low-carbon laws and policies has increased internationally: legally-binding legislation requiring emissions reduction has been passed in South Korea and Mexico; global coverage of carbon pricing is now 20% of non-transport emissions and rising (e.g. this has been introduced in parts of China and the US and is being considered by Brazil, Chile, the Ukraine, Turkey, Mexico and others); vehicle standards now cover around 80% of emissions from road transport.

- Our climate objective and the global emissions reduction required to achieve it remain feasible, but very challenging. These remain an appropriate basis for policy, both because of the very significant risks associated with dangerous climate change and the costs of delayed-action pathways. An ambitious fourth carbon budget is important to the global process because of the role of the UK in securing an effective global agreement.

We set out our analysis in five sections:

1. Recap of international assessment in the fourth carbon budget report
2. Update on UN process
3. Action in individual countries and across sectors
4. Consistency of international actions with global emissions pathways
5. Overview of international action and implications for the fourth carbon budget review

1. Recap of international assessment in the fourth carbon budget report

In our original 2010 advice on the fourth carbon budget[1] we considered key global developments in reducing emissions. We focused on the UN process and the Copenhagen Accord and the required reductions in global emissions to 2020 and beyond. This section recaps that assessment.

In 1992 the United Nations Framework Convention on Climate Change (UNFCCC) set out the goal of "preventing dangerous anthropogenic interference with the climate system". At the time of our fourth carbon budget advice in 2010, the Copenhagen Conference of Parties (COP 15) had agreed the Copenhagen Accord which set out that the climate objective should be to limit global temperature increase to 2°C and to review by 2015 whether this limit should be brought down to 1.5°C.

The climate objective is supported by analysis suggesting that it could be achieved at a cost of 1-2% of GDP, compared with much higher costs and consequences associated with dangerous climate change. For example, these have been valued at 5% of GDP based on market impacts, but significantly higher when non-market effects are included.[2]

1 CCC (2010) '*The Fourth Carbon Budget – Reducing emissions through the 2020s*'.
2 E.g. Stern (2006) '*The economics of climate change*'.

The Copenhagen Accord also required that countries come forward with pledges to limit or reduce emissions to 2020. Eighty-seven countries subsequently made pledges, including all major emitters and covering the bulk of global emissions.

In our original advice we examined the Copenhagen pledges and concluded:

- Global emissions pathways that peak by 2020 and halve emissions by 2050 are consistent with achieving the climate objective, with delayed action to reduce emissions increasing risks of dangerous climate change.
- Peaking by 2020 could ensue if high-end ambition Copenhagen Accord commitments were delivered in practice, with deep global emissions cuts through the 2020s and beyond.
- The costs of achieving the climate objective are increased significantly if peaking of global emissions is delayed (Box 2.1).

Box 2.1: Costs and risks of delayed action

Our fourth carbon budget report took account of various analyses suggesting that early action is cost-effective.

- The IEA estimated in their 2010 World Energy Outlook that delayed action, as a result of slow progress agreeing a global deal at Copenhagen, has already added US $1 trillion to the cost of decarbonisation to 2030.
- DECC's GLOCAF modelling and recommended carbon values suggest that the present value of future marginal costs rises over time, implying that the costs of delivering a cumulative budget could be reduced by accelerating action.
- Modelling using the MARKAL model shows that the least-cost path in the UK would be based on approximately equal annual percentage cuts (i.e. with early rather than back-loaded action).

This analysis has been reinforced by more recent studies. For example, work by the Potsdam Institute[3] suggests that a delay in implementing a comprehensive set of climate policies leads to higher costs for reaching a given climate target. For climate targets around 2°C, the additional costs of mitigation are three times higher if global action starts in 2030 compared with 2015.

Delayed action would also lead to higher climate risk:

- Since cumulative emissions are the main driver in determining climate outcome, delayed action requires faster reductions in later years to achieve a given target, at a pace which may not be achievable.
- Delayed action limits options for tightening long-term targets if the science were to suggest that this is appropriate.

We argued in our advice that it would be important to get early agreement on emissions cuts through the 2020s, given the long lead-time for policy development and implementation, supply chain development, investment and capital stock turnover, and consumer behaviour change. This would provide confidence to policy makers, business and others that a cost-effective and credible emissions pathway to meet the climate objective could be delivered.

The process of reaching agreement on the Copenhagen Accord highlighted the important role the UK plays in international negotiations. More generally, the UK continues to have a high degree of influence in EU approaches to emissions reduction (see Chapter 3), and there continues to be much interest from countries around the world in the Climate Change Act and the framework that this established. This is an additional consideration in the decision on the

3 Luderer et al (2013) *'Economic mitigation challenges: how further delay closes the door for achieving climate targets'*. Environmental Research Letters Vol. 8 No. 3 http://iopscience.iop.org/1748-9326/8/3/034033/article

fourth carbon budget, which could affect the international discussions towards a new global deal.

The remainder of this chapter considers whether it remains feasible to achieve the climate objective in the way assumed when designing the fourth carbon budget, given progress moving the UN process forward and action in individual countries to reduce emissions.

Summary: Our original advice on the fourth carbon budget concluded that global emissions pathways consistent with the climate objective remained feasible and were a suitable basis for UK policy. Further developments were needed, particularly towards agreeing emissions targets beyond 2020. The UK has an important role in ensuring that international discussions result in an ambitious global deal.

2. Update on UN process

Since our advice on the fourth carbon budget there have been further international meetings in Cancun (2010), Durban (2011) and Doha (2012). The key results of these negotiations were: to formally incorporate the 2°C objective into the UN process, to agree a process for reaching a new global agreement on emissions reductions for 2020 and beyond, to initiate a new phase of the Kyoto Protocol, and to set up a fund to support mitigation and adaptation in developing countries.

- In December 2010 at Cancun, agreement was reached to formally include the 2°C objective into the UN process for the first time, measured as an increase above pre-industrial levels. Parties agreed to set up a future legally binding commitment applicable to all countries.
- In 2011 there was agreement under the 'Durban Platform' to adopt a new global deal in 2015, applicable to all countries and coming into effect in 2020 (i.e. to cover the period after the 2020 pledges made in the 2009 Copenhagen Accord). This process is ongoing, with interim negotiations at Warsaw (2013) and Lima (2014). In addition, in 2014 the UN Secretary-General will host a leaders conference aimed at developing ambition ahead of negotiations in Paris in 2015.
- In 2012 agreement was reached in Doha to extend the Kyoto Protocol for a second commitment period from 2013 to 2020, providing a transition period and continuing legal framework for the EU and other countries as they head towards a new future agreement.
- The Green Climate Fund was established as the key operating body of the financial mechanism of the UNFCCC. It is responsible for leveraging new and additional finance of up to $100bn per year by 2020 to help developing countries reduce their emissions and adapt to the impacts of climate change. Whilst some countries have agreed to contribute to start-up costs of the fund, there is as yet no clear timetable for agreeing funding from developed countries.

The key point for assessing the fourth carbon budget is that the UN process has moved forward, and is now focused on getting agreement on emissions cuts to 2030 consistent with limiting warming to 2°C. In order to achieve the climate objective, this agreement should embody peaking of global emissions around 2020 with deep emissions cuts through the 2020s; this would require further emissions cuts to 2050 and in the second half of the century, as shown in Chapter 1.

Summary: Progress towards a global deal has been slow but broadly as expected. The key challenge is to get agreement on global emissions pathways to 2030 compatible with achieving the climate objective. The Durban Platform provides the opportunity to address this challenge, with the aim that agreement is reached in Paris by the end of 2015.

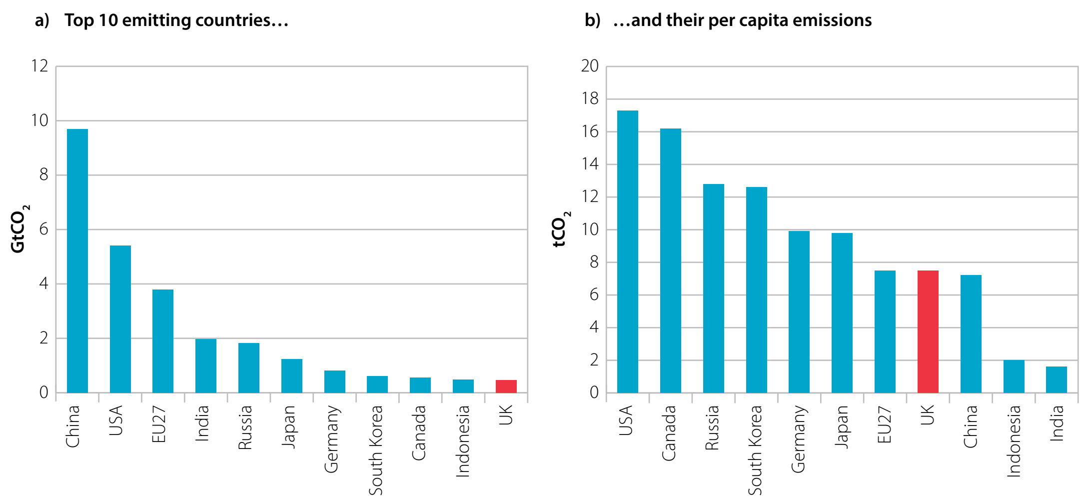
3. Action in individual countries and across sectors

It is important that in parallel to the UN process there is action at the country level so that when targets are agreed they can be delivered. Without such action, it would be questionable whether stretching targets to meet the climate objective could be achieved, given the long lead-time for emissions reduction.

Globally, a small number of countries account for the majority of CO_2 emissions although there are wide differences in emissions per capita:

- China, the United States, and the EU account for 57% of global CO_2 emissions, with the top 10 emitting countries accounting for over three-quarters of global emissions (Figure 2.1a)
- Within the top emitters, the US is the highest emitter on a per-capita basis (17 $MtCO_2$), followed by Canada, Russia and South Korea. Per capita emissions in China are now comparable with the UK and EU average (7.5 $MtCO_2$) (Figure 2.1b).

Figure 2.1: Top CO_2 emitting countries (2011)



Source: EDGAR database.
Notes: Figures are CO_2 only. Includes top ten countries plus the EU.

In this section we focus on actions in the largest emitters: China and the US globally, and Germany in the EU. We also briefly consider other countries and the extent of global coverage of low-carbon policies by sector. Finally we compare commitments made by the UK with other countries. This allows us to assess whether other countries are preparing for a carbon-constrained world or whether the UK is acting alone on emissions reduction.

We conclude that the UK is not acting alone, and various countries have set stretching targets to reduce emissions as the UK has in carbon budgets.

(i) China

China is the world's largest emitter and second largest economy. It was responsible for 29% (9.7 $GtCO_2$) of global CO_2 emissions in 2011, 10% of global GDP, and 20% of global population in 2010. Since 1990 Chinese emissions have grown by 290% and GDP by 699%. As a result Chinese emissions per capita are now comparable to UK and EU levels.

Since 2002 Chinese GDP and emissions have more than doubled, and most additional energy demand was met by coal. More recently, carbon intensity fell 15% between 2005 and 2011, reflecting significant investment in low-carbon capacity, energy efficiency measures and upgrading of old inefficient coal plants. Without these investments, the IEA estimates Chinese emissions would have been higher by 1.5 $GtCO_2$ (19%) in 2011.

In the Copenhagen Accord China pledged to reduce its carbon intensity by 40-45% by 2020 compared to 2005 levels.

In 2011 China adopted its 12th five-year plan, covering the period 2011-15. This set out the policies planned to put China on track to meet its 2020 carbon intensity target. In addition to this, China is pursuing policies aimed at improving local environmental quality which may also reduce greenhouse gas emissions.

The key actions being undertaken in China include:

- **Emission trading.** Seven mandatory pilot schemes for emission trading are being launched, in anticipation of a national-level system. Together the pilot systems cover around 500 $MtCO_2$, equivalent to the UK's annual emissions. The first pilot scheme launched in Shenzhen in June 2013, where permits have traded at 43 yuan (i.e. €5.2, similar to the current EU ETS price).
- **Renewables.** China has targets for 700 GW of renewable capacity by 2020 (an increase of 170% on current levels and representing around 40% of total projected capacity); for comparison, total installed generation capacity – coal, gas, nuclear, renewables – in the UK is currently around 90 GW.
- **Coal power.** Growth in coal consumption is envisaged at a slower rate in the 12th five-year plan compared to the 11th: new coal power plants have been banned in three key industrial regions and six regions have agreed to cap coal consumption. However, risks around coal use remain and there is limited room for growth in unabated coal going forward (see Section 4, Box 2.2).

- **Transport.** A target for fuel efficiency of new vehicles equivalent to 117 gCO_2/km by 2020 (requiring a 4.2% annual reduction), and for five million electric vehicles on the road by 2020 (implying around 2.5% of the car fleet would be electric).
- **F-gases.** In 2013 China agreed a deal through the Montreal Protocol to retire all HCFC production capacity by 2030, saving a cumulative 8 $GtCO_2e$. Separately China has agreed with the US and G20 to phase down production and consumption of HFCs.
- **Energy consumption.** China has introduced targets for reducing energy intensity of the economy by 16% by 2016, and has detailed energy efficiency plans for industry and consumers (e.g. to phase out incandescent lightbulbs by 2016).

Evidence suggests that measures already in place, together with those set out in the 12th five-year plan, mean the high ambition of China's Copenhagen Pledge for 2020 (i.e. to reduce carbon intensity by 45%) is achievable:

- China's 2nd national communication to the UNFCCC, published in 2012[4], projects Chinese emissions to be 9.9 $GtCO_2$ in 2020, in line with a 45% reduction in intensity and reflecting a reduction in emissions of 31% in 2020 compared to a baseline without climate policies.
- Analysis by Ecofys[5] suggests the 45% target for 2020 could be exceeded based on current policies.

There is growing consensus that Chinese emissions could peak in the 2020s with potential for deep cuts thereafter:

- Recent analyses[6] suggest emissions could peak around 2020, through a combination of a move towards a service/consumption-based economy and implementation of policies which reduce demand for energy and increase the proportion of low-carbon electricity generation.
- IEA and other modelling suggests deep cuts in emissions are feasible by 2050 (Figure 2.2), such that emissions would be on a path consistent with achieving our climate objective. Official projections of 2020 emissions are in line with this path.

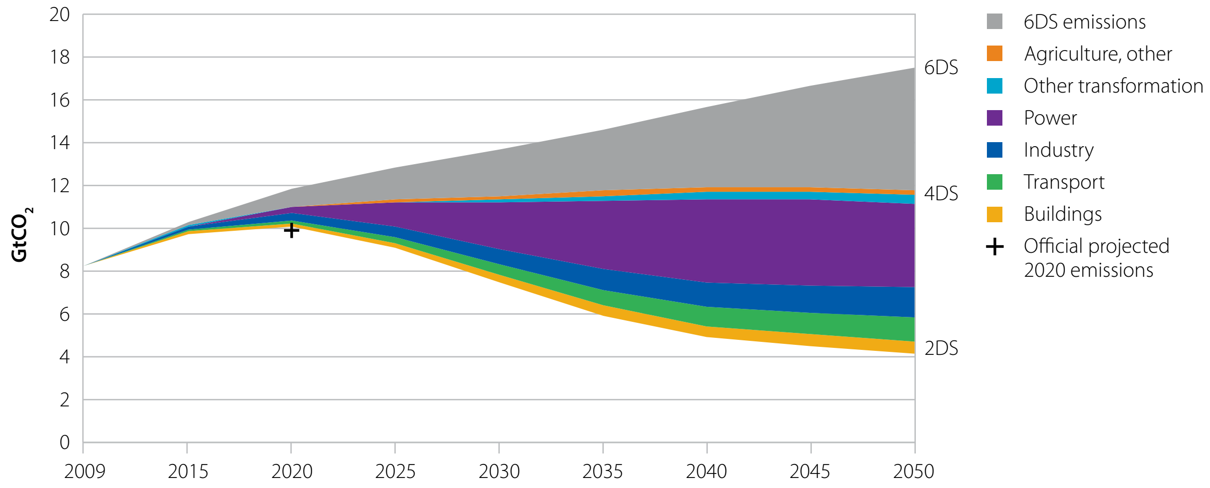
Reducing emissions in the longer-term will be very challenging, and new policies beyond 2020 will be needed. However, recent policy announcements, if agreed and delivered, could put Chinese emissions on a trajectory consistent with the global emissions pathways required to meet our climate objective.

4 National Reform and Development Commission (2012) "Second National Communication on Climate Change of The People's Republic of China" http://unfccc.int/essential_background/library/items/3599.php?rec=j&priref=7666

5 Ecofys (2012) "Greenhouse gas emission reduction proposals and national climate policies of major economies".

6 For example, see Kejun et al (2013) "China's role in attaining the global 2°C target" Climate Policy, 13(S01:55-69). For the power sector see Bloomberg New Energy Finance (2013) "The future of China's power sector". For coal specifically, see Citi (2013) "The Unimaginable: Peak Coal in China".

Figure 2.2: IEA emission pathways: China (2009-2050)



Source: IEA Energy Technology Perspectives (2012).
Notes: Figures are CO_2 only. 6DS = 6 degree scenario; this is a scenario with no policy action. The wedges below show abatement from different options.

(ii) United States

The US is the world's second largest emitter and the largest economy. It was responsible for 16% (5.4 $GtCO_2$) of global CO_2 emissions in 2011, 22% of global GDP, and 5% of global population in 2010. Since 1990 US emissions have grown by 9% and GDP by 88%. US per capita emissions are still significantly higher than EU and Chinese levels.

In recent years US emissions have fallen, and are now 12% below their 2007 peak. This reflects a range of factors, including: switching from coal-to-gas in the power sector; increases in renewable energy generation; improving vehicle fuel efficiency, as well as the economic slowdown.

In the Copenhagen Accord the US pledged to reduce to reduce its emissions by 17% by 2020 and by 83% by 2050, compared to 2005 levels.

In 2013 President Obama launched the Climate Action Plan. This set out how the US Copenhagen Pledge for 2020 would be achieved without further federal legislation:

- **Power sector.** In September 2013 the Environment Protection Agency proposed regulations for new plants which would effectively rule out new unabated coal power generation. Regulations for existing plants are expected in 2014.
- **Transport.** New fuel efficiency standards have been set for light and heavy duty vehicles, including passenger cars. The standard for new cars is equivalent to 93 gCO_2/km for 2025 (requiring a 6.8% annual improvement). Overall the standards are expected to save 6 $GtCO_2$ over the lifetime of new vehicles purchased to 2025.
- **F-gases.** Agreements have been struck with the G20 and China to phase down production and consumption of HFCs.

- **Energy consumption.** New energy efficiency standards have been set for household and industry products which, for example, phase out incandescent lightbulbs and are expected to cumulatively save at least 3 $GtCO_2$ by 2030.
- **Investment.** The R&D grant for clean energy technologies has been increased by 30% (to nearly $8 billion) in 2014. This covers a range of new technologies including advanced biofuels, emerging nuclear and clean coal.

Beyond the federal level there is significant action by individual states:

- **Targets.** 12 US states have legislated emissions targets (primarily for 2020), covering around 20% of US emissions, and five have 2050 targets. 31 states have renewable energy targets, which together would require investment in around 100 GW of generation capacity by 2035.
- **Regional Greenhouse Gas Initiative (RGGI).** In 2009, nine East coast states set up the first mandatory trading scheme for carbon emissions in the US, capping their power sector emissions. To ensure continued effectiveness in light of surplus allowances, RGGI states have recently proposed to tighten the cap by 45%.
- **California.** California's emissions trading system (ETS) began operating in 2012. First auctions were held in 2013, with allowances trading at $13/$tCO_2$ (i.e. €10, around twice the current EU ETS price). The system will be linked to the Quebec ETS from 2014, and in 2015 will be extended to cover around 85% of Californian emissions.
- **Zero emission vehicles.** Eight US states, including California and New York, have recently agreed a joint target for at least 3.3 million zero emission vehicles on the road by 2025, and have agreed to work together to deliver this target (e.g. by developing uniform charging standards).

Given successful implementation of federal and state level actions, US commitments in the Copenhagen Accord for 2020 could be delivered:

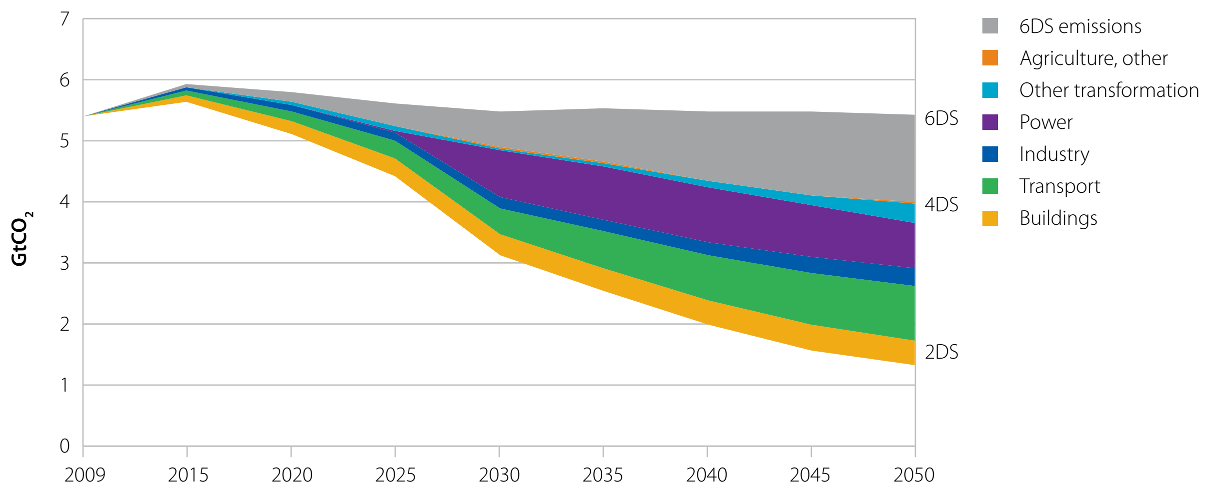
- Recent analysis by the US State Department[7] suggests the combination of current and planned policies could lead to a reduction in emissions of up to 21% below 2005 levels, exceeding the Copenhagen Pledge of a 17% reduction.
- Analysis by the World Resources Institute[8] also suggests the Copenhagen Pledge could be met without further federal legislation.

Going beyond 2020, much deeper emissions cuts will be needed in the US as recognised in the Copenhagen pledge for 2050. This will require going beyond coal-gas switching in power generation, building on progress that has been achieved in renewable generation, and focusing investment on these and other low-carbon generation technologies. Further energy efficiency improvement, increased electrification of heat and surface transport, together with use of sustainable bioenergy (e.g. from waste sources) will also be required if goals are to be achieved.

7 US State Department (2013) *"2014 Climate Change Report – U.S. Biennial Report"*, draft for public review.
8 World Resources Institute (2013) *"Can the U.S. Get There From Here?"*.

While analysis by the International Energy Agency (IEA) and the US Energy Information Administration (EIA) suggests that this transformation is feasible (Figure 2.3), much remains to be done in terms of agreeing emissions targets and putting in place new policies to deliver these longer-term objectives.

Figure 2.3: IEA emission pathways: USA (2009-2050)



Source: IEA Energy Technology Perspectives (2012).
Notes: Figures are CO_2 only. 6DS = 6 degree scenario; this is a scenario with no policy action. The wedges below show abatement from different options.

(iii) Germany

Germany is Europe's largest emitter and largest economy. It was responsible for 2% (0.8 $GtCO_2$) of global CO_2 emissions in 2011, 5% of global GDP, and 1% of global population in 2010. Since 1990 German emissions have fallen by 21% and GDP has grown by 37%. Per capita emissions are above the EU and UK average but below US levels.

German emissions fell substantially in the early 1990s following reunification. Over the last decade emissions have continued to fall, albeit at a slower pace than previously. This reflects substantial increases in renewable generation (with combined solar and wind capacity of 63 GW in 2012), fuel efficiency improvements in transport, energy efficiency improvements in buildings and reductions in methane emissions (e.g. as a result of increased recycling).

In 2010 Germany set out its long-term vision for energy and climate change policy (the "Energiewende"). This committed Germany to ambitious energy and emission reduction targets across a range of sectors:

- An overall reduction in GHG emissions relative to 1990 levels of 40% by 2020, 55% by 2030 and 80-95% by 2050.
- Increasing the share of renewable electricity from 24% currently to 35% by 2020 and 80% by 2050, alongside investing in grid infrastructure and storage capacity to integrate the higher share of renewables on the system.

- Improving energy efficiency across industry, households and the public sector with the aim to cut energy consumption by 20% by 2020 and 50% by 2050.
- Supporting the take-up of electric vehicles, with the aim of having 1 million electric vehicles on the road by 2020 and 6 million by 2030. Together with tightening emission limits for conventional vehicles, to cut transport energy use by 2050 by 40% on 2008 levels.
- In 2011 Germany also committed to phasing out of nuclear generation by 2022. This, together with the expected reduction in coal generation capacity (see Section 4, Box 2.2), implies the need for further investment in renewable generation if targets are to be met.

Modelling by the German Environment Agency suggests that the emissions targets for 2030 and 2050 are achievable, with potential to reduce CO_2 emissions to almost zero by 2060[9].

Moreover, Germany already has well-developed policies in place across the key emitting sectors, and a track record of success investing in renewable energy and energy efficiency. It therefore has very strong foundations on which to build in delivering ambitious medium-term emissions targets.

(iv) Other countries

There has been positive action in many countries to deliver Copenhagen pledges, in terms of both legislation and implementing mechanisms. In some countries (e.g. Canada and Australia) there have been some reversals, albeit with some on-going progress behind the headline developments.

- **Climate legislation.** Since 2010 several countries have passed new climate legislation, formalising their 2020 Copenhagen pledges and committing to longer-term reductions. For example, Mexico's General Law on Climate Change includes a legally binding target to reduce emissions by 50% below 2000 levels by 2050. A number of other countries are also currently debating proposed climate/energy legislation (e.g. Costa Rica).
- **Implementing mechanisms.** Since 2010 many countries have introduced carbon pricing mechanisms or have announced firm plans to do so. For example, South Korea has passed legislation introducing a carbon trading system from 2015 with a cap set out to 2026. South Africa and France are planning to introduce carbon taxes in the next two years. Other countries have set out long-term targets for renewables, such as Mexico (35% electricity from low-carbon sources by 2024), India (20 GW of solar by 2020) and Saudi Arabia (54 GW of renewables by 2032, representing more than a third of projected electricity generating capacity). The International Maritime Organisation has introduced a global energy efficiency standard for new ships, and the International Civil Aviation Organisation has agreed to develop a global market based measure for aviation implementable from 2020 (i.e. aligned to the UNFCCC process for a new global deal).

9 Umweltbundesamt (2013) *"Politikszenarien fuer den Klimaschutz VI – Treibhausgas-Emissionsszenarien bis zum Jahr 2030"*; DLR, IWES & IFNE (2013) *"Langfristszenarien und Strategien fuer den Ausbau der erneuerbaren Energien in Deutschland bei Beruecksichtigung der Entwicklung in Europa und global"*.

- **Reversed action.** Not all developments have been positive since 2010. Canada has withdrawn from the Kyoto Protocol and repealed the associated legislation. However, Canada is taking some action on climate change, including adoption of stretching vehicle fuel efficiency standards and carbon trading systems/taxes in Quebec and British Columbia. The new Australian Government has committed to repeal climate change legislation and carbon pricing, but is aiming to deliver emission reductions through other policies (e.g. a Direct Action Plan) and continues to support renewables deployment.

This experience shows that Governments are acting to make good their commitments in the Copenhagen Accord. It highlights political and other challenges in delivering emissions reduction, particularly in the cases of Australia and Canada.

(v) Low-carbon policy coverage: a sectoral perspective

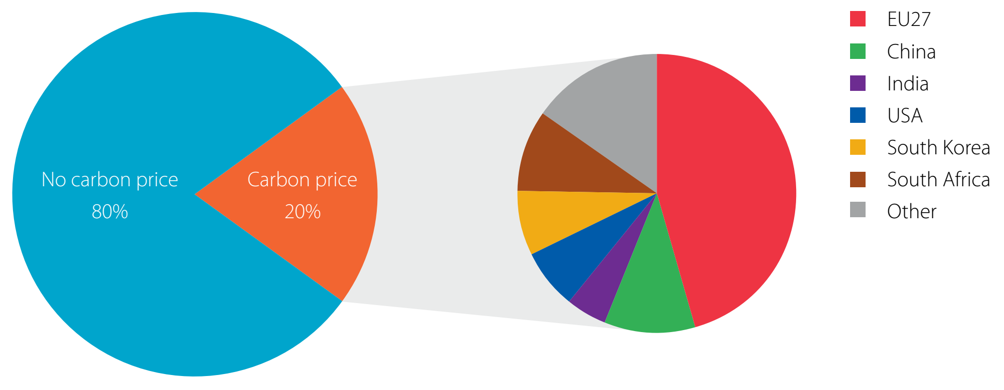
Global action has led to increased coverage of low-carbon measures such as carbon pricing, new vehicle emissions standards and renewables deployment at the global level:

- **Carbon pricing (trading or taxes).** Carbon prices now cover 20% of global (non-transport) emissions, across both developed and developing countries (Figure 2.4). Some national and regional trading systems are starting to link up (e.g. California-Quebec, EU-Swiss), leading to co-ordinated monitoring, reporting and pricing. Emerging trading systems are being considered in Brazil, Chile, Ukraine and Turkey, and other countries are planning carbon taxes (e.g. South Africa, France and Mexico).
- **Vehicle emission/fuel efficiency standards.** In 2010 nearly 80% of global surface transport emissions were covered by legislated vehicle standards, covering the major vehicle markets including the United States, the EU, Japan, China, Australia, Canada and South Korea (Figure 2.5). The stringency of these schemes has increased over time (Figure 2.6) such that the committed annual reductions required are higher in the US (6.8%) and China (4.2%) than the EU (3.8%).
- **Renewables deployment.** Around 120 countries[10] currently have renewable energy targets, covering both developed (e.g. the EU, Japan, Australia) and developing countries (e.g. Egypt, Chile, India, Morocco, Pakistan). This has contributed to more than an 11-fold increase in installed global solar and wind capacity over the past decade, with capacity projected to more than double again to 2020 (Figure 2.7). The rapid increase in the deployment of solar PV, two-thirds of which has been installed since 2011, has led to a rapid fall in module costs (Figure 2.8) with grid parity expected to be reached in many regions by 2020[11].

Existing and planned coverage of policies therefore provides a strong basis for deep future cuts in emissions. The challenge will be for other countries and sectors to adopt measures and strengthen ambition in future.

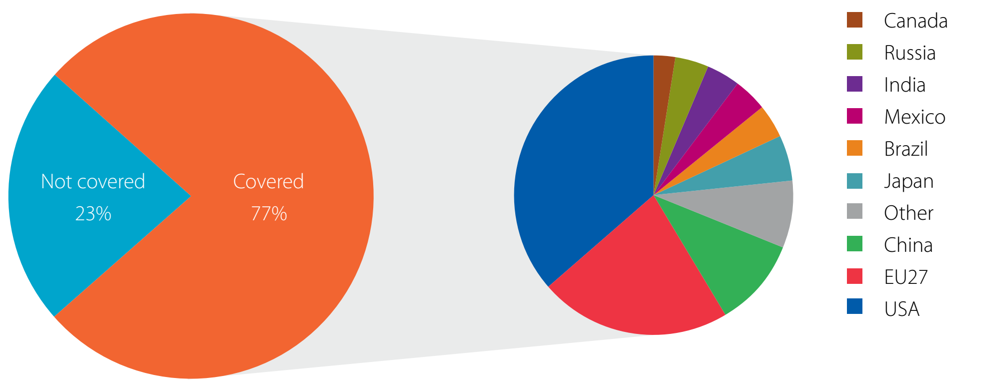
10 REN 21 (2013) 'Renewables Global Futures Report' http://www.ren21.net/Portals/0/REN21_GFR_2013_print.pdf
11 Navigant Research (2013) 'Solar PV market forecasts' http://www.navigantresearch.com/research/solar-pv-market-forecasts

Figure 2.4: Proportion of global emissions covered by a carbon price



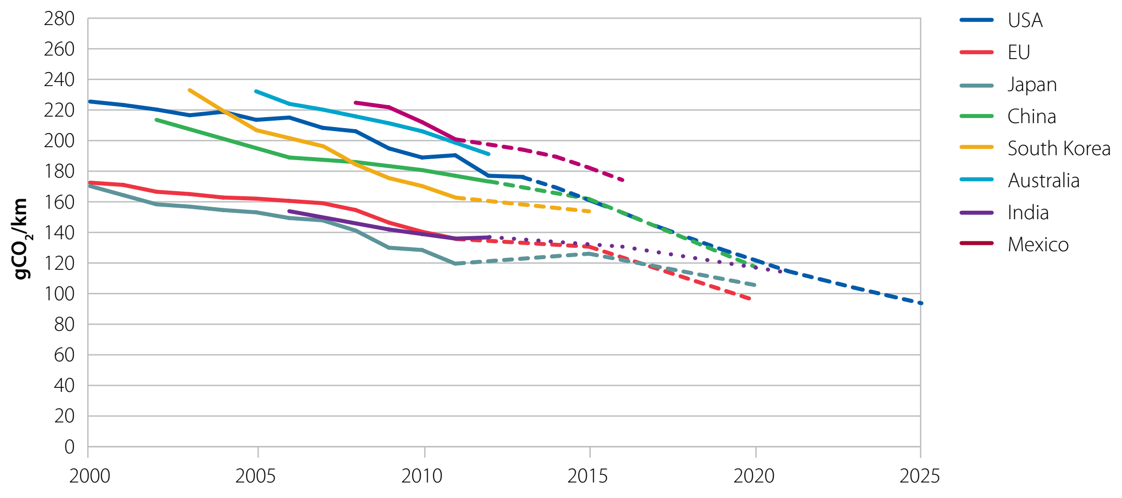
Source: CCC calculations based on World Bank (2013) and various national sources.
Notes: Includes current and firm proposals. Proportion of global emissions excludes surface transport emissions. Based on an original chart by Adam Whitmore (onclimatechangepolicy.org).

Figure 2.5: Proportion of global surface transport emissions covered by emission/fuel efficiency standards



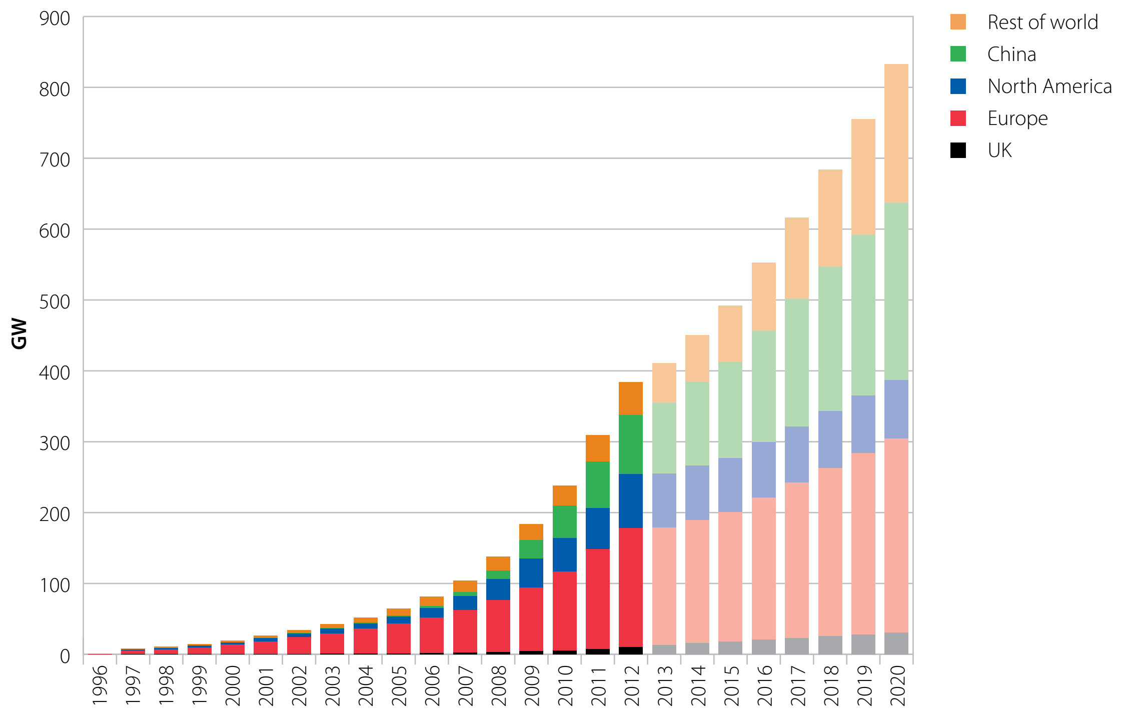
Source: CCC calculation based on www.transportpolicy.net and IEA emissions data.
Notes: Covers road transport only; excludes aviation and shipping.

Figure 2.6: Fuel efficiency/emissions standards for cars for selected countries (2000 to 2025)



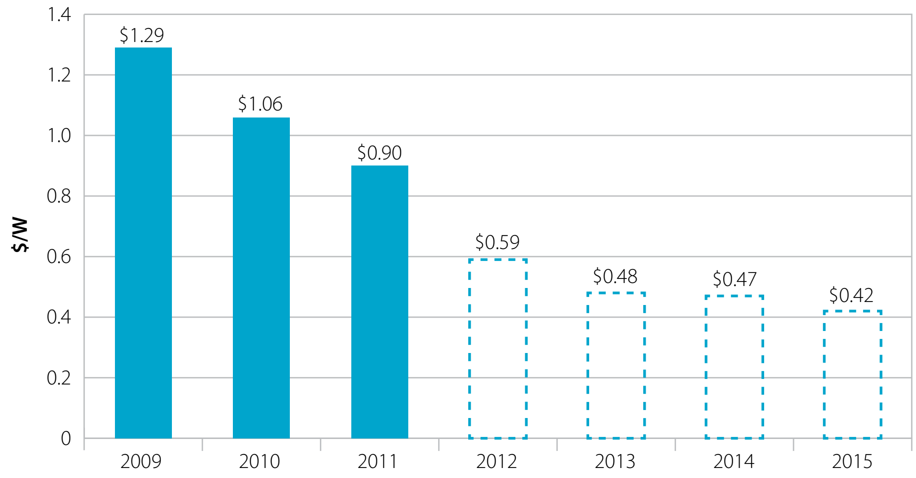
Source: The International Council on Clean Transportation (2013) www.theicct.org/info-tools/global-passenger-vehicle-standards
Notes: Solid lines reflect historical performance; dashed lines reflect enacted targets; dotted lines reflect proposed targets or targets under study. China's target reflects gasoline vehicles only. Mexico includes light commercial vehicles.

Figure 2.7: Global installed wind and solar capacity – actual (1996-2012) and projected (2013-2020)



Source: Historic installation data from BP Statistical Review of World Energy. Projections based on various national sources: 12th 5-year plan (China), EIA Annual Energy Outlook – Reference case (North America), National Renewable Energy Action Plans (Europe), CCC Next steps on Electricity Market Reform (UK), Rest of world based on trend growth.

Figure 2.8: Solar PV module production costs – actual and predicted (2009-2015)



Source: Greentech Media Research (2012).

(vi) Comparison of commitments in UK and other countries

The previous sections have shown that many developed and developing countries have made commitments to reduce emissions to 2020 and beyond, and are implementing policies to deliver these. These commitments have been made on a range of metrics and base years, making direct comparison to UK efforts more difficult. However, our analysis suggests many commitments are comparable in ambition to the UK's.

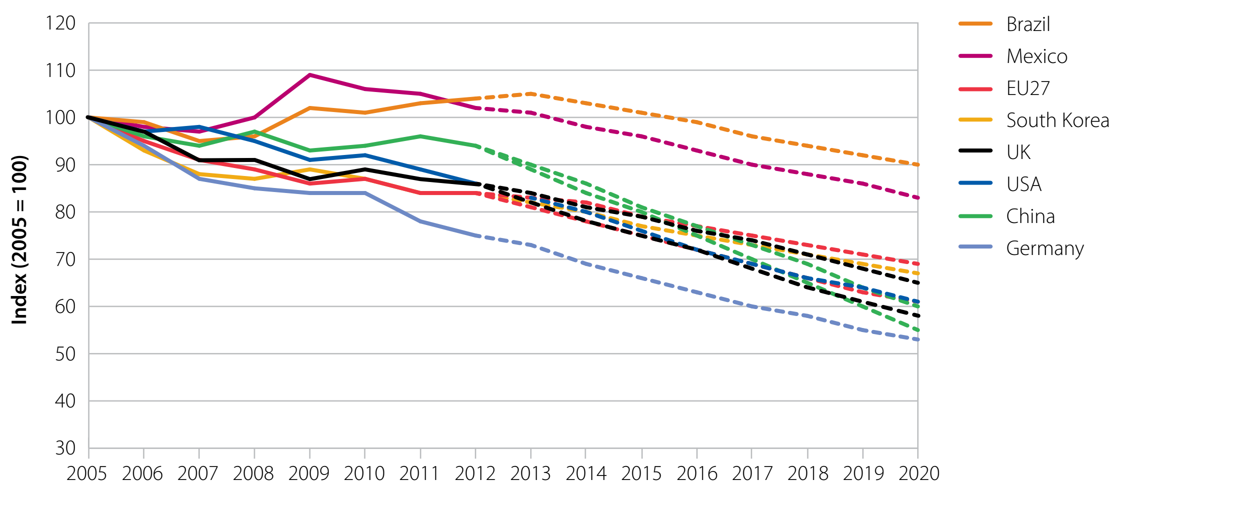
- **Absolute emissions.** Compared to 1990 levels the UK has similar targets to other developed countries (Table 2.1). Measured against 2005 levels some countries have more stretching commitments than the UK. This reflects the fact that UK emissions fell through the 1990s, requiring less effort to meet the 2050 target from a 2005 baseline.
- **Carbon intensity.** Some of the largest emitters made Copenhagen pledges in terms of carbon intensity (i.e. emissions per unit of GDP). Our analysis suggests that UK targets imply reductions in carbon intensity to 2020 comparable to other countries, including China and the US (Figure 2.9).
- **Long-term commitments.** The UK's 2050 target is based on emissions of around 2 tCO_2e per capita. Where country commitments to 2050 exist, these are generally on a comparable basis (Table 2.1): implied 2050 per capita emissions in the US, EU and Mexico are also all around 2 tCO_2e or less (e.g. 0.5-2.1 tCO_2 in the EU).

Table 2.1: Post-2020 commitments, selected countries

Country	Year	Commitment	Reduction in emissions		Implied 2050 per capita emissions (tCO_2e)
			vs. 1990	vs. 2005	
UK	2025	50% below 1990	50%	41%	
	2050	≥80% below 1990	≥80%	≥76%	2.1
Germany	2030	55% below 1990	55%	46%	
	2050	80-95% below 1990	80-95%	76-94%	0.8-3.3
EU	2050	80-95% below 1990	80-95%	78-95%	0.5-2.1
USA	2030	42% below 2005	33%	42%	
	2050	83% below 2005	80%	83%	2.6
Japan	2050	80% below 1990	80%	81%	2.2
Mexico	2050	50% below 2000	34%	56%	1.8

Note: Figures exclude international aviation and shipping for comparison purposes, even where these are included in the target (e.g. in the UK's 2050 target).
Source: Targets from various national sources. Emissions data from UNFCCC (www.unfccc.int). Population data from UN World Population Prospects 2012 (Medium fertility).

Figure 2.9: Carbon intensity reductions implied by 2020 pledges, selected countries (2005-2020)



Source: CCC analysis based on Ecofys (2012) and IMF (2013).
Notes: Reflects emissions produced per unit of GDP (PPP basis). Solid lines show historical outturn; dashed lines show low and high pledges where applicable.

In the next section we consider the extent to which national targets and policies are consistent with global emissions pathways to achieve the climate objective.

Summary. The UK is not acting alone. Many countries including China and the US are acting to deliver their Copenhagen pledges, with increased coverage of low-carbon measures around the world. This could provide the foundation for an ambitious global agreement beyond 2020.

4. Consistency of international actions with global emissions pathways

A key aim of this chapter is to determine whether international circumstances are such that our climate objective remains in play. This requires us to assess whether current action and countries' pledges are in line with feasible global emissions pathways that meet the climate objective.

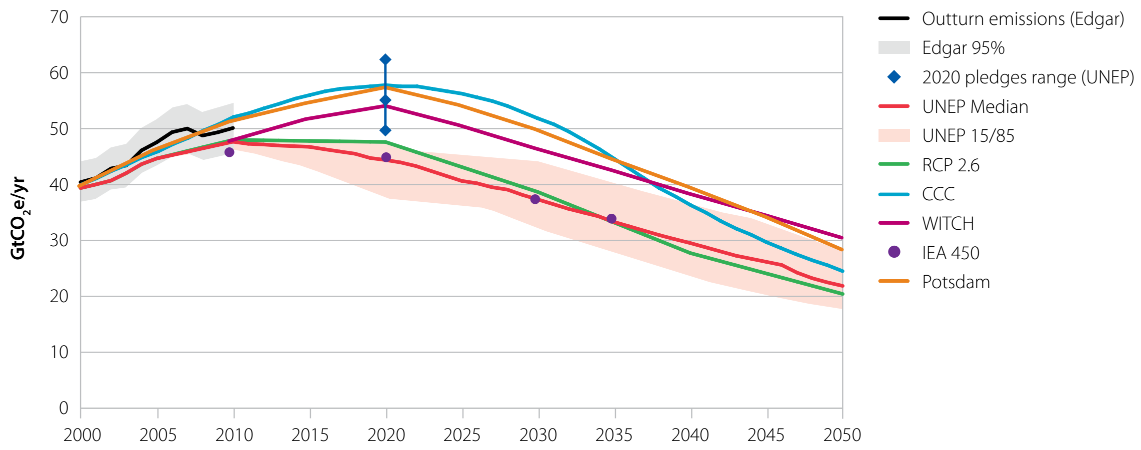
The emissions pathways in Chapter 1 fall within the range of Copenhagen Accord commitments and show the need for deep emissions cuts after 2020 in order to meet the climate objective (Figure 2.10).

Various studies consider the feasibility of pathways with deep emissions cuts consistent with climate objectives.

- **UNEP analysis**[12], published before the IPCC AR5 report, presents cost-effective pathways with lower emissions to 2020 than our Chapter 1 pathways and a more gradual reduction to 2050. The lower peaking of emissions in this scenario results in a gap between the cost-effective path and countries' Copenhagen pledges. The analysis suggests the gap can be bridged through rapid and concerted action. Failure to bridge the gap would mean higher peaking and a need for steeper emissions reductions post-2020, which would be a less cost-efficient path to meeting the climate objective.
- **The IEA 2°C ("450ppm") scenario** constructs a plausible energy pathway consistent with having a 50% chance of limiting global average temperature increase to 2°C. This involves energy-related CO_2 emissions peaking at 32 Gt before 2020, then falling to 22 Gt in 2035. Adding in other greenhouse gases puts this just below the high-end Copenhagen Accord commitments in 2020 and shows a similar trajectory to our pathways in Chapter 1. The IEA have published detailed analysis of how 2020 emissions cuts could be delivered in practice[13]. Almost three-quarters of the emissions saved are from energy efficiency in 2020, whilst in the longer term renewables, nuclear and CCS make the largest contribution to emissions reduction.
- **Other analysis.** A number of other studies assess the feasibility of meeting the 2°C target.
  - A recent study by Imperial College London[14] found it is possible to limit CO_2 emissions from energy use and industrial processes to a level consistent with a 2°C climate objective by 2050 with current technologies. This pathway has almost complete decarbonisation of the electricity sector across all regions, significant electrification of industry, transport and buildings, extensive deployment of energy efficiency and increased use of bioenergy.
  - Analysis based on the WITCH (World Induced Technical Change Hybrid) model[15] with concerted global action starting in 2020 suggests the climate objective can be met with a broad portfolio of mitigation options including nuclear and CCS. Emissions in this pathway peak in 2020.

12 UNEP (2012) 'The emissions gap report' http://www.unep.org/publications/ebooks/emissionsgap2012/
13 IEA (2013) *"Redrawing the energy-climate map"*.
14 Imperial College (2013) '*Halving global CO_2 by 2050: technologies and costs*' http://www3.imperial.ac.uk/climatechange/publications/collaborative/halving-global-co2-by-2050
15 See http://www.witchmodel.org/index.html

Figure 2.10: Copenhagen Accord commitments and global emission pathways consistent with our climate objective (2000-2050)



Source: UNEP (2012), IPCC, IEA, WITCH model, Luderer et al (2013), CCC.
Notes: Edgar 95% refers to 95% confidence interval around Edgar data. UNEP Median refers to median trajectory of a "likely" (>66%) chance of staying below 2°C. UNEP 15/85 refer to the 15th and 85th percentile ranges for this pathway. WITCH pathway is delayed action to 2020. IEA 450 is the IEA scenario for CO_2 and RCP for non-CO_2. Potsdam is 'Frag2020' from Luderer et al (2013).

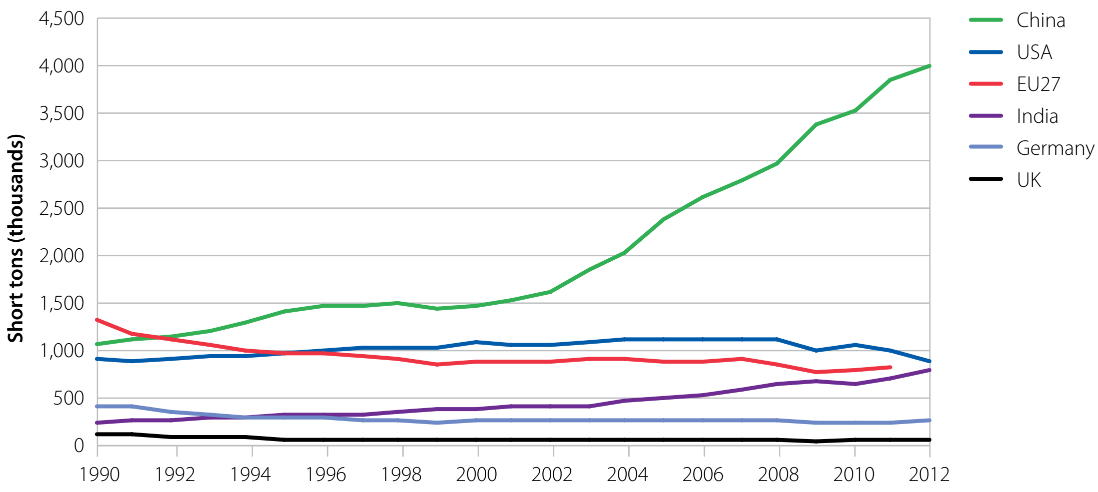
- Research by the Potsdam Institute[16], found that in a scenario with comprehensive emissions reductions starting after 2020 and full technology availability, warming could still be limited below 2°C with a likely (>66%) probability and with moderate economic impacts. The study highlights the higher costs and global temperature risks associated with delayed action.
- A study by the International Institute for Applied Systems Analysis (IIASA)[17] modelled different global energy pathways to meet climate change (to limit temperature increases to less than 2°C with a probability of at least 50%) and other goals such as energy access and security and health. These goals were met in 41 of the 60 pathways modelled, with emissions peaking around 2020 and declining towards zero in the latter half of the century.

These show that global emission pathways peaking around 2020 with steep reductions in the 2020s and beyond are feasible with current technology options and consistent with the climate objective. Later peaking risks higher costs, reliance on steeper reductions, unproven technologies and a lower level of emissions in 2100, and increases the risk of exceeding the 2°C target.

A number of energy market themes emerge from the various modelling exercises: current plans for coal generation pose a severe risk to meeting the climate objective and unabated coal can play only a limited role going forward; there is a transitional role for gas; and there needs to be an acceleration of investment in low-carbon technologies (Box 2.2):

16 Luderer et al (2013) op.cit.
17 IIASA (2012) 'Global Energy Assessment' http://webarchive.iiasa.ac.at/Research/ENE/GEA/rio_energyday.html

Figure 2.11: Coal consumption in selected regions (1990-2012)



Source: US Energy Information Administration Statistics.

- **Coal.** Coal use is high and continues to expand, with particularly strong growth in China (Figure 2.11). This growth will need to stop soon if temperature rise is to be kept to 2°C. Current plans demonstrate that this remains a major challenge, despite progress in the US and EU. Recent and planned additions of coal capacity also emphasise the importance of carbon capture and storage (CCS) to achieving steep emissions reduction.
- **Gas.** There is a transitional role for gas, being the least carbon-intensive fossil fuel. However, growth cannot continue indefinitely – there needs to be a move from investment in gas generation to low-carbon energy sources such that gas use peaks in the 2020s and then declines.
- **Low-carbon technologies/measures.** Deployment of low-carbon technologies needs to ramp up quickly from its relatively low level in order to stay within a 2°C global temperature limit. Energy efficiency has the most potential in the short-term, while renewables, CCS and nuclear will be needed to deliver deep cuts beyond 2020.

There will be significant global investment needs associated with this energy market transformation. Implementation of measures to support the next phase of transition from conventional fossil fuels to low-carbon technologies are not yet in place. Agreeing such approaches remains a major challenge for individual countries and for the international community collectively in the context of a global agreement.

Summary: The climate objective and the global emissions pathways to achieve it remain feasible, but very challenging. There is a limited global role for unabated coal going forward, and a transitional role for gas, and there needs to be an acceleration of investment in low-carbon technologies. Countries need to deliver Copenhagen pledges for 2020, and plan now for deep emissions cuts beyond 2020.

Box 2.2: Energy market themes consistent with our climate objective

Coal

- Use of coal is currently high and increasing, accounting for over a quarter of global energy demand and 43% of CO_2 emissions.
  - China is the world's largest consumer of coal, accounting for 47% of global consumption in 2011, followed by the US (14%), Europe (10%) and India (9%).
  - In the last decade global coal consumption increased by 53% (4.3% annually). Growth was fastest in China (147%).
- Going forward, pathways to keep temperature rise to 2°C suggest very limited room for coal expansion. For example, in the IEA's 2°C scenario:
  - Total coal demand peaks before 2020, with sharp falls thereafter of 2.8% annually to 2035. Coal's share of overall energy demand reduces to 16% by 2035, as coal is substituted by renewables and gas.
  - Coal use in the power sector peaks by 2020 just 5% higher than in 2010, after which it more than halves by 2035. This requires that net new build capacity is limited to 260 GW from 2010 to 2020. The IEA scenario envisages that the majority of this, 190 GW, would be added in China, with falling capacity in the US and EU to 2020 and beyond.
- While current plans for new coal generation in the US and Europe could be consistent with the climate objective, plans for coal use elsewhere pose a major challenge.
  - In the US, proposed emissions limits on new power plants effectively prevent new build of unabated coal. In the EU, limited new capacity is expected to be added to the power mix, with significant retirement likely under existing environmental regulations (e.g. 60% of current capacity is not compliant with the Industrial Emissions Directive). Although new coal is expected to be added in Germany (e.g. Dena[17] estimate 11 GW to be added by 2020), this will be more than offset by planned plant retirements (18 GW). In the UK several coal plants have either closed already under the Large Combustion Plant Directive or are due to before the end of 2015.
  - Significant new coal generation is being planned in China and India. The World Resources Institute (WRI)[18] estimate 1400 GW are being planned globally across 59 countries, with 76% in China and India. Not all of this would proceed to construction and operation, even under business as usual, and there will be some offsetting effect of existing plant closing. However, without further policies, it is likely to go beyond the 250 GW net additional capacity in the IEA 2°C scenario. Reducing the planned additions of coal capacity therefore remains a major priority and carbon capture and storage (CCS) is likely to be crucial in achieving steep emissions reductions after 2030.

18 Dena (2012) '*Integration der erneuerbaren Energien in den deutsch-europäischen Strommarkt*' http://www.dena.de/fileadmin/user_upload/Presse/Meldungen/2012/Endbericht_Integration_EE.pdf

19 World Resources Institute (2012) '*Global coal risk assessment: Data analysis and market research*' http://www.wri.org/sites/default/files/pdf/global_coal_risk_assessment.pdf

Box 2.2: Energy market themes consistent with our climate objective

Gas

- Gas is a major energy source, representing 21% of primary energy consumption and 20% of CO_2 emissions.
  - Demand is driven by the United States (accounting for 21% of consumption), Russia (14%), and the EU (16%).
- Demand for gas has risen by 36% over the past decade (3.1% annually), slightly slower than coal demand. Most of the growth has come from China (up 365%), India (up 165%) and the Middle East (up 100%).
- Globally, there is some scope for a transitional role for gas, being the least carbon-intensive fossil fuel, but ultimately gas needs to be replaced by low-carbon energy sources.
  - Under the IEA 2°C scenario gas demand continues to grow but at a much lower rate – around 0.6% per year – to 2035. Gas use without CCS in power generation initially increases to 2025, then declines, reflecting that it is still considerably more carbon-intensive than low-carbon alternatives.
  - Although there would be emissions reductions from near-term investment in gas rather than coal-fired generation, there is a need to move quickly from investment in any conventional fossil fuel to low-carbon technologies.
  - Recent discoveries of conventional gas fields (e.g. in Turkmenistan) and rapid expansion of US shale gas therefore only offer a short-to-medium-term role in a 2°C consistent pathway.

Low-carbon technologies/measures

- Renewables and nuclear technologies currently account for 19% of global energy consumption. Hydro and bioenergy in power and heat provide the bulk of renewable energy, whilst nuclear provides around 15% of current electricity demand.
- IEA's 2°C scenario sees a rapid increase in these technologies going forward, increasing their share of global energy demand from 19% in 2010 to 37% in 2030. CCS and energy efficiency also play a role.
  - Renewables, nuclear and CCS provide 42% of global energy by 2035 and nearly 80% of electricity generation, with hydropower and nuclear representing the largest shares. Deployment of CCS is highest in China, followed by America and India.
  - The greatest expansion of nuclear generation is in China and India, with capacity additions of 136 GW and 39 GW respectively by 2035. The EU and the US maintain shares at close to current levels.
  - Energy efficiency also has a role to play, particularly to 2020 when three-quarters of the emissions saved are from energy efficiency measures, largely due to reduced electricity demand in buildings and industry.

Investment requirement and regional impacts

- To achieve the 2°C consistent scenario, IEA estimate total global investment needs to be $140 tn over the period 2010-2050, of which $36 tn is additional.
- IEA estimate that two-thirds of global fossil fuel reserves cannot be commercialised in a 2°C world without significant CCS deployment. Since these reserves are concentrated in four regions – North America, the Middle East, China and Russia – CCS represents an important hedging strategy for these countries as it would preserve the economic value of these reserves on a low-carbon mitigation path.

5. Overview of international action and implications for the fourth carbon budget review

The fourth carbon budget review must identify what, if anything, has changed since our original advice was given. Our conclusion is that progress towards a global agreement has been slow but broadly in line with what was expected at the time the fourth carbon budget was set, with unanticipated progress in some countries, including major emitters.

The climate objective and the global emissions pathways to achieve the objective remain feasible but very challenging. The level of ambition in a new global deal will be an important determinant of whether challenges are addressed. This should build on commitments and action at the current level such that global emissions peak around 2020 and fall significantly by 2030 (e.g. our global emissions pathways assume at least a 10% cut on 2020 levels).

The climate objective remains an appropriate basis for policy, both because of the very significant costs and risks associated with dangerous climate change, and the role of the UK in securing an ambitious new global agreement. The UN has agreed to aim for such an agreement and this would be made less likely by a lowering of UK ambition in the fourth carbon budget.

We will therefore continue to use global emissions pathways which are consistent with achieving the climate objective, for example, which peak in 2020 with deep cuts thereafter such that emissions are roughly halved in 2050 (see Chapter 1).

To allow for the high degree of uncertainty about what will be agreed and delivered internationally, we will also consider alternative scenarios for a global agreement. For example, we will model scenarios in which global emissions peak after 2020 but the climate objective is still achieved, and in which emissions are cut but insufficiently to achieve the climate objective. These scenarios will allow us to explore the robustness of the fourth carbon budget across the range of uncertainty for international outcomes, and the extent to which flexibility is needed in approaches to meeting the budget.

We set out the specific scenarios and implications of these for carbon prices and 2050 emissions in Chapter 4.

We will continue to monitor progress toward a global deal to reduce emissions, focusing on the following questions:

- Does the climate objective remain feasible in light of international discussions and agreements?
- What are the implications of agreed emissions pathways for projected carbon prices and long-term emissions targets?
- What is an appropriate UK contribution to an agreed global emissions reduction, and what is the appropriate balance of domestic emissions reduction by the UK versus purchase of emissions reduction from other countries?

We will assess further progress to a global deal in our advice on the fifth carbon budget.

Summary: The climate objective and the global emissions pathways to meet it should be the basis for UK policy. International developments should continue to be closely monitored, with implications drawn for UK carbon budgets as appropriate.

Chapter 3: EU emissions pathways and targets

Introduction and key messages

Section 10 of the Climate Change Act requires that we consider EU circumstances when designing carbon budgets.

This reflects the importance of the EU in contributing to achievement of overall climate objectives; possible intra-EU competitiveness risks associated with any difference in the pace of emissions reductions in the UK and elsewhere in the EU; and the relationship between EU ambition and the carbon price used to design carbon budgets.

In addition, under the current accounting rules of the Climate Change Act the contribution of the traded sector, covering power generation and the energy-intensive sectors, to meeting carbon budgets is determined by the UK's share of the cap in the EU Emissions Trading System (EU ETS).

When we advised on the fourth carbon budget there was not yet an agreed EU path through the 2020s. Our approach was to design a budget to reflect the cost-effective path to the UK's 2050 target with manageable impacts (e.g. on fuel poverty and competitiveness), which would then be aligned with the EU path once agreed.

The Government agreed with this approach and scheduled a review for 2014.

Key developments since 2010 that we assess in this chapter are the publication by the European Commission of its 2050 emissions pathways, and subsequent EU discussions about a new 2030 emissions target.

We conclude that these developments are consistent with the assumptions underpinning the fourth carbon budget, which on this basis remains cost-effective with manageable impacts. There is therefore no legal or economic justification to change the budget because of EU circumstances at this time.

- New EC analysis of the cost-effective path to the EU's 2050 objective involves a reduction in UK emissions in 2025 that broadly matches the reduction required by the fourth carbon budget, increasing confidence that the budget does indeed reflect the cost-effective path.
- The fourth carbon budget is at the low end of the range of ambition currently being discussed on an EU 2030 package. If the Government successfully secures its stated objectives for a 2030 EU package then the budget would need to be tightened.
- While not the focus of this report, there have been no developments that would suggest competitiveness impacts associated with the fourth carbon budget are now not manageable. We will return to the issue of competitiveness in our December report when assessing the cost-effective UK path.

It is important to note that the fourth carbon budget was not premised on the EU increasing the ambition in its 2020 emissions reduction target from 20% to 30%; and that the default trajectory in the EU ETS is neither the agreed path through the 2020s, nor could it be the basis for the fourth carbon budget.

- The assumption on 2020 emissions underpinning the fourth carbon budget analysis is consistent with the current EU 2020 target for a 20% reduction relative to 1990. If a 30% target were to be agreed, which is the UK Government's objective, tightening of the budget might be justified.
- There is a default trajectory for the EU ETS to continue the slow rate of decline from the pre-2020 phase should the negotiations fail to agree a new package. A strategy of aligning to this now and then realigning later once an EU package is agreed would not be legal, practical or sensible:
  - It would amount to a change in the budget without a corresponding change in circumstances and would represent a significant departure from the cost-effective path to the 2050 target. As such, it would not meet the criteria under the Climate Change Act.
  - The precise level of carbon budget implied by the default trajectory is uncertain given that the detailed rules for calculating the UK share of the EU ETS cap in the 2020s are not yet known.
  - Such a strategy and the frequent changes in the budget that it entails would undermine investor confidence. Moreover, it would undermine credibility of the UK in EU negotiations.
  - It would not offer any benefits for competitiveness or a more favourable share for the UK when negotiating how EU-wide targets are split across countries.

It is essential that the UK continues to push for an ambitious EU 2030 package. The UK has an important role in these discussions, and an ambitious package is required as part of an effective global response to climate change.

We set out the analysis that underpins these conclusions in 4 parts:

1. Recap of assumptions on EU action underpinning the fourth carbon budget
2. Latest EC analysis on the path through the 2020s
3. Current EU discussions on the 2030 target and pathways through the 2020s
4. Implications for the fourth carbon budget

1. Recap of assumptions on EU action underpinning the fourth carbon budget

Under the current accounting rules of the Climate Change Act, the UK's share of the EU ETS cap defines emissions for the traded sector, covering power generation and energy-intensive industries. This means that budget compliance will be measured not in terms of gross emissions from the traded sector, but rather as net emissions after the purchase of allowances and offset credits in the EU ETS.

At the time the fourth carbon budget was set there was no agreed path for the EU ETS beyond 2020, with which the traded sector part of the budget could be aligned.

Although there is a default path in the EU ETS Directive, this was not the *agreed* path – it was always the case that there would be a process to agree EU ambition for 2030, including the EU ETS path – nor could it be the basis for the fourth carbon budget given the requirements in the Climate Change Act (Box 3.1).

In the absence of an agreed EU path, we designed the fourth carbon budget based on an assessment of the cost-effective path to the 2050 target in the Climate Change Act (i.e. to reduce emissions by at least 80% relative to 1990). The 2020 starting point for this path was consistent with the current EU 2020 target (20% reduction on 1990 levels) and the EU ETS cap for 2020 (Box 3.2).

We envisaged that the budget might be adjusted to reflect the EU ETS cap through the 2020s when agreed, depending on the level of the cap. The Government accepted this, and in setting the budget it also scheduled a review for 2014 to assess compatibility of the budget with the agreed EU path, should there be one by this time. For example, both we and the Government suggested that if the EU increased ambition for 2020 emissions reduction then a tightening of the budget might be appropriate[1].

While there is not yet an agreed path for the EU ETS through the 2020s, there is new evidence about what this might be. In sections 2 and 3 we consider whether this evidence is compatible with the path for traded sector emissions in the fourth carbon budget.

Summary: The intention was that the traded sector part of the budget would be aligned with the EU ETS cap once this was agreed. The assumption on 2020 emissions underpinning the budget is consistent with the currently agreed EU ETS cap for 2020. There was and is no agreed path through the 2020s for the EU ETS cap: the default trajectory in the EU ETS is not the agreed path, nor could it be the basis for the fourth carbon budget.

1 For example, we proposed a tighter '*Global Offer*' budget as a contribution to an effective global deal; the Government proposed a tighter budget under a 30% EU 2020 target in the December 2011 *Carbon Plan*.

Box 3.1: The default EU ETS trajectory for the 2020s

The default trajectory for the EU ETS cap was set in the revised EU ETS Directive in 2009, and requires that the cap continues to decline beyond 2020 at the current rate of reduction (i.e. 38 $MtCO_2e$ per year).

In advising on the fourth carbon budget, we considered whether the default path could be a suitable basis for the budget. We concluded that it was inadequate in the context of the EU and UK 2050 targets to reduce emissions and could not be the basis for the budget. The Government and the EC also concluded that the default trajectory was inconsistent with the 2050 targets.

- We were clear in our advice to Government and Parliament that a UK carbon budget reflecting the EU default path would not be compatible with requirements under the Climate Change Act. In particular, it would represent a significant departure from the cost-effective path to meeting the 2050 target in the Act, raising costs and risks of achieving this objective.
- The Government agreed with this advice, stating that the default trajectory associated with the 20% target was not consistent with the statutory 2050 target: "*The [default] trajectory is inconsistent with the UK meeting its 2050 target – net traded sector emissions by 2050 would require almost full decarbonisation in the non-traded sector (or significant purchase of ICUs) which is not feasible*".[2]
- The EC reached a similar conclusion in their analysis for the *Low-carbon Roadmap* when identifying the cost-effective EU path, which goes well beyond the default trajectory.

We also concluded that the default trajectory should not be considered as the agreed path for the EU ETS; it was always the case that there would be a process to agree an EU emissions reduction path through the 2020s.

- The default EU ETS trajectory has never been regarded as the agreed path through the 2020s.
- Neither was it ever the case that the move to an EU 30% emissions reduction target for 2020 would have triggered an agreed path: there is no EU ETS trajectory associated with the 30% target.
- Rather, it was envisaged that there would be a process to agree a path through the 2020s, although with no agreed schedule for this.

This process is now underway, and we assess its progress in section 3.

2 DECC (2011) *Impact Assessment of Fourth Carbon Budget Level*, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48080/1685-ia-fourth-carbon-budget-level.pdf

Box 3.2: Assumptions on UK traded sector emissions in 2020 compared to the UK share of the EU ETS cap

The fourth carbon budget was designed to reflect the cost-effective path to the 2050 target in the Climate Change Act (i.e. to reduce emissions by at least 80% on 1990 levels) subject to the impacts being manageable.

Our approach was to project UK emissions in 2020, and then to assess the cost-effective path through the 2020s, of which the fourth carbon budget period formed part.

Under the current accounting rules of the Climate Change Act, performance against the traded sector part of the budget – covering energy-intensive industries and power generation – will be judged against the UK's share of the EU ETS cap once this is known.

If the UK's share of the agreed EU ETS cap in 2020 were to be above the level assumed in designing the fourth carbon budget, this would raise questions about whether the budget could be achieved in practice under the current accounting rules (e.g. it could require greater effort in the non-traded sector than the feasible cost-effective level built into the budget).

However, our estimate of the UK's share of the EU ETS cap in 2020 is actually below the level assumed when designing the fourth carbon budget. In other words, the budget reflects a lower level of ambition than the current EU ETS cap in 2020. A move to a tighter EU ETS cap associated with a 30% greenhouse gas target for 2020 is therefore not required in order that the budget is achieved (Table B3.2).

See Box 3.3 in section 3 for more on how we estimate the UK share of the EU ETS cap.

Table B3.2: UK 2020 traded sector emissions assumed in fourth budget analysis compared to UK share of EU ETS cap under current and possible EU climate packages for 2020

	$MtCO_2e$ in 2020
UK 2020 traded sector emissions assumed in the fourth budget	205
Current UK share of ETS cap in "20% world"	165
Possible UK share of ETS cap in "30% world"	130

Note: Estimates have changed since the first three carbon budgets were legislated, when the expected UK shares of the ETS cap under 20% and 30% targets were 197 and 160 $MtCO_2e$ respectively. The level of UK emissions assumed in the fourth carbon budget analysis is calculated by summing the emissions for sources covered by the EU ETS in our Medium Abatement scenario from our 2010 advice.

Source: CCC calculations based on published EC information.

2. Latest EC analysis on the path through the 2020s

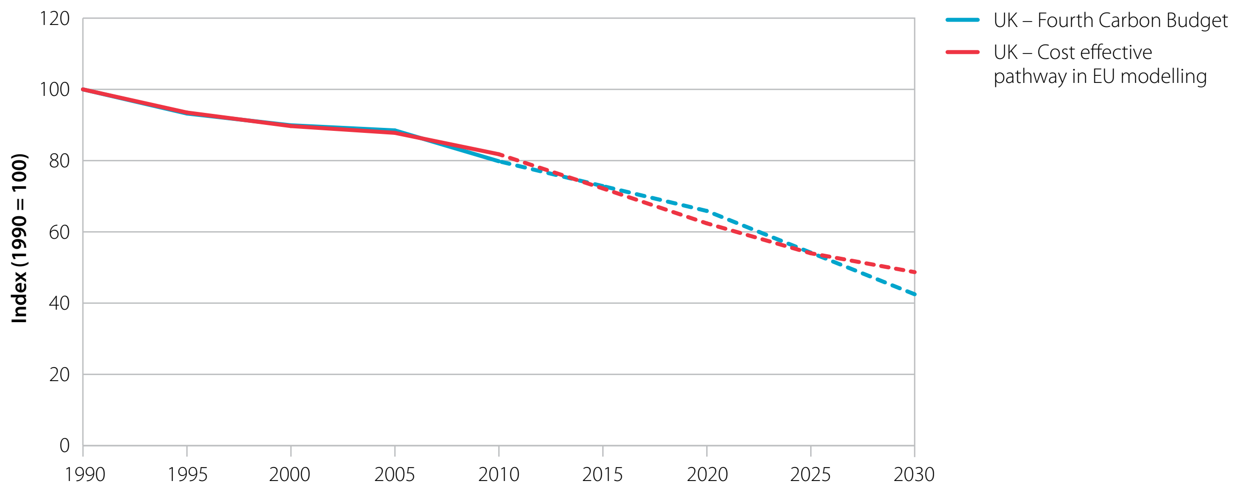
The EC Low-Carbon Roadmap[3] was published in 2011, after we had published our advice on the fourth carbon budget. It set out the cost-effective path to meet the EU objective of reducing GHG emissions by 80-95% by 2050 relative to 1990 levels. It concluded that the aim should be to achieve a 25% reduction in EU emissions in 2020, and a 40-44% emissions reduction in 2030.

In 2012, the EC published additional analysis based on the Roadmap which presented implications for emissions in each Member State[4]. This showed that the UK's share of the cost-effective EU path matches the UK's legislated fourth carbon budget very closely, and involves many of the same measures as the scenario that underpins the budget.

- The UK share of the cost-effective path in the EU analysis involved a 46% reduction in emissions in 2025 relative to 1990. This is the same reduction currently legislated in the fourth carbon budget (Figure 3.1).

3 EC (2011) *Roadmap for moving to a competitive low carbon economy in 2050*, http://ec.europa.eu/clima/policies/roadmap/documentation_en.htm
4 EC (2012) *Analysis of options beyond 20% GHG emission reductions: Member State results*, http://ec.europa.eu/clima/policies/package/docs/swd_2012_5_en.pdf

Figure 3.1: UK cost-effective pathways through the 2020s



Source: CCC (2010), "The Fourth Carbon Budget". EC report to DG Climate Action (2012), "Technical report accompanying the analysis of options to move beyond 20% GHG emission reduction in the EU by 2020: Member State results".
Notes: Includes international aviation to allow consistent comparison. Solid lines are outturn estimates, dotted lines are future scenarios.

- Both the EU analysis and the scenario underpinning the fourth carbon budget involve decarbonisation of the UK power sector to around 50 gCO_2/kWh, a significant roll-out of electric vehicles, substantial improvements in energy efficiency, and emissions reductions in industry and non-CO_2 greenhouse gases.

Summary: Analysis published by the EC since our original advice provides more confidence that the fourth carbon budget reflects the cost-effective path to the 2050 target. The budget would be closely aligned with an EU agreement based on the EC analysis.

3. Current EU discussions on the 2030 target and pathways through the 2020s

The EU's Green paper and the UK's negotiating position

Building on its Roadmap, the EC published a Green Paper[5] in March 2013, which highlighted the Roadmap's finding that the cost-effective path through 2030 would be a reduction of at least 40% in EU greenhouse gas emissions on 1990 levels.

The UK's response to the Green Paper was that the EU should:

- Adopt a minimum ambition to cut EU emissions by 40% in 2030 on 1990 levels, therefore reflecting the cost-effective path.
- Commit to increase ambition to a 50% cut in the context of an ambitious global agreement.

Discussions are currently taking place at the EU on the appropriate level of ambition to 2030, with the UK at the forefront of these negotiations. It is unclear precisely how long this

5 EC (2013) *A 2030 framework for climate and energy policies*, http://ec.europa.eu/energy/consultations/20130702_green_paper_2030_en.htm

process might take, and any agreement at the EU level would then need to be ratified by Member States.

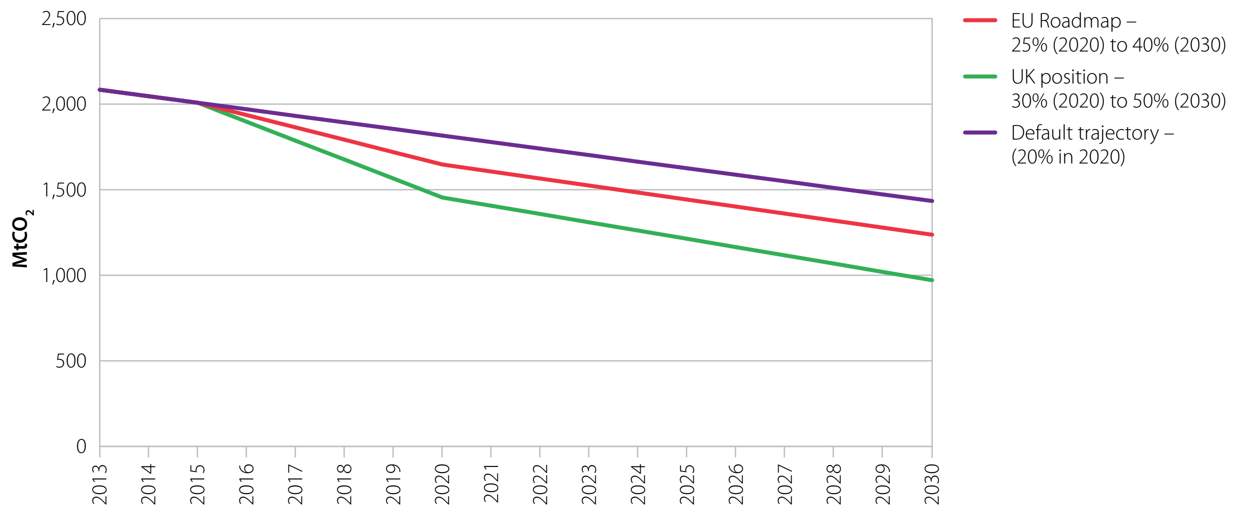
Consistency of the UK's fourth carbon budget with EU discussions on the 2030 target

In section 2 we showed the consistency of the fourth carbon budget with the cost-effective path identified by the EC for the economy as a whole.

We noted in section 1 that it is also important to assess consistency of the traded sector part of the budget with the UK's share of the EU ETS cap, given current accounting rules under the Climate Change Act.

The range of possible EU ETS trajectories is defined by the default path and the UK's negotiating position, with the path implied by the Roadmap in the middle (Figure 3.2).

Figure 3.2: Range for EU ETS caps to 2030



Source: CCC analysis based on published EC information.
Notes: Assumes any adjustment to 2020 target applies from 2015. Default trajectory falls at 38.3 $MtCO_2$ per year.

There are complexities in identifying the UK share of the EU ETS cap. Changes since our original advice suggest a lower UK share than previously expected (Box 3.3). As a result our analysis, based on the latest evidence, shows that the level of emissions estimated for the traded sector when designing the fourth carbon budget is at the low end of ambition of possible EU ETS caps (Table 3.1).

- If the Government were successful in achieving its negotiating position, the current fourth budget could have to be tightened (e.g. by around 150 $MtCO_2e$ to 1,800 $MtCO_2e$).
- If a 40% target were agreed for 2030, as suggested in the EU Roadmap, it could also be appropriate to tighten the budget.

- If there were a complete failure in the EU negotiations, such that the default trajectory is adopted, there would be a question of whether an upward adjustment to the budget would be appropriate (e.g. by up to 50 $MtCO_2e$), or whether this could be managed within existing flexibilities.

Summary: The fourth carbon budget is at the low end of ambition of emissions paths currently being discussed by the EU. If the UK Government achieved its negotiating position, then the budget could have to be tightened (e.g. by around 150 $MtCO_2e$).

Box 3.3: Calculating the UK share of the EU ETS cap

The UK's share of the EU ETS cap – which defines net emissions for the traded sector – is determined by two factors:

- The level of the overall EU cap.
- The proportion of the cap attributable to the UK. This in turn reflects the UK's share of auctioned allowances, allowances allocated for free to UK installations, and allowances claimed from the new entrant reserve by UK firms.

For Phases I to III of the EU ETS (covering the period to 2020) these factors can be accurately assessed given that they are determined by rules set out in the EU ETS Directive.

Beyond 2020 these factors will not be finalised for some time. For the fourth carbon budget period (2023-27) this therefore requires assumptions about the level of the EU cap and the likely UK share.

The evidence base for these assumptions has developed over time and with it the expected UK share of the cap:

- The final EU ETS cap for Phase III was published in September 2013 (2,084 $MtCO_2e$ in 2013, falling at 38.3 $MtCO_2e$ per year in the default pathway). This was a higher level, but with slightly quicker reductions, than expected in 2010 and 2011.
- The rules governing free allocation of allowances have also been refined over time – the EC has recently published the UK's share of free allowances for Phase III of the EU ETS (7.9%).
- Auction rules were set in the 2009 EU ETS Directive and have not changed. Therefore the UK's expected share of auctioned allowances has not changed significantly.

As a result, the expected UK share of the EU ETS cap over the fourth carbon budget has fallen. For example, under the default trajectory:

- The Government expected this to be 860 $MtCO_2e$ in its 2011 Impact Assessment for the fourth carbon budget.
- We expected this to be 790 $MtCO_2e$ in our letter to the Secretary of State earlier this year, based on the finalised Phase III cap and an assumed proportion of this for the UK (9.7%).
- We now expect this to be 740 $MtCO_2e$, based on the final cap and the latest EC data on free allowances in Phase III (implying a total UK proportion of 9.1%).

Under the latest evidence, the default trajectory is therefore much closer to the legislated budget than previously thought. The budget is less ambitious than would be implied under the pathway from the EC Roadmap or the Government's negotiating position, given that these would have a tighter EU ETS cap (Table 3.1).

The changes in the estimates also demonstrate the inherent uncertainty involved in projecting the EU ETS cap and the UK's share, suggesting that small adjustments may be better handled within other budget flexibilities (e.g. banking/borrowing, non-traded sector effort, credit purchase outside the EU ETS) rather than by formal changes to the legislated budget.

6 CCC 2013. '*Implications of European circumstances for the fourth carbon budget*'. http://www.theccc.org.uk/publication/implications-european-4th-carbon-budget-review/

Table 3.1: UK emissions in the fourth carbon budget period (2023-27) under different EU paths for the 2020s ($MtCO_2e$)

Scenario	Projected UK share of the EU ETS cap	Implied fourth carbon budget (covering both traded and non-traded sectors)[1]
No agreement – default EU ETS trajectory	740	2,000
Legislated fourth carbon budget[2]	**690**	**1,950**
Lowest ambition in EU Green paper – 20% (2020) to 40% (2030)	690	1,950
EU Roadmap – 25% (2020) to 40% (2030)	650	1,910
UK Government objective – 30% (2020) to 50% (2030)	550	1,810

Notes:
Estimates rounded to nearest 10 $MtCO_2e$. All scenarios assume 2013 EU ETS cap of 2,084 $MtCO_2e$ and total UK share of 9.1%.
1. Assumes non-traded sector emissions of 1,260 $MtCO_2e$ over the fourth carbon budget period, as in our original advice.
2. Our original advice on the level of the fourth carbon budget reflected the UK cost-effective emissions pathway, and did not make any specific assumptions on the EU ETS cap. For comparison the table reports emissions in sectors covered by the EU ETS: 690 $MtCO_2e$.

4. Implications for the fourth carbon budget

The fourth carbon budget review must identify whether the circumstances under which the budget was set have changed. Our assessment in this chapter is that EU developments have been in line with what was envisaged at the time the budget was set:

- We envisaged that there would be a process to agree a path for EU emissions reductions to 2030.
- This has moved forward, with cost-effective paths identified and discussions around the pathways underway.
- The currently legislated fourth carbon budget aligns with the low end of ambition of EU paths being discussed.
- While not the focus of this report, there have been no developments that would suggest competitiveness impacts associated with the fourth carbon budget are now not manageable. The analysis in our April 2013 report on competitiveness[7] shows that incremental competitiveness impacts of the budget are small and manageable under current policies; they would be very limited for the EU pathways currently under discussion. We will return to the issue of competitiveness in our December report when assessing the cost-effective UK pathway.
- Therefore, EU developments reinforce the current budget rather than provide a basis to change it.

7 CCC (April 2013), *Reducing the UK's carbon footprint and managing competitiveness risks.* http://www.theccc.org.uk/publication/carbon-footprint-and-competitiveness

Although uncertainty remains as to the outcome of discussions, it would be inappropriate to respond to that uncertainty by aligning now to the EU default trajectory and then realigning later to an agreed EU position for 2030. Such an approach would not meet the criteria under the Climate Change Act. It would undermine investor confidence without any benefits for competitiveness or UK contribution to the EU targets. Moreover, it would undermine credibility of the UK in EU negotiations.

- In relation to compliance with the Climate Change Act:
  - It would amount to a change in the budget without a corresponding change in circumstances; this is not allowed under the Act.
  - It would be inconsistent with the requirement in the Climate Change Act for carbon budgets to prepare for meeting the UK's 2050 target. The Government has also recognised this inconsistency.
  - It would be difficult to implement in practice. The precise level of carbon budget implied by the default trajectory is uncertain, given that the detailed rules for calculating the UK share of the EU ETS cap in the 2020s are not yet known.
- Frequent changes would reduce the certainty provided by carbon budgets and therefore undermine investor confidence.
- It would not help the position of energy-intensive firms in the UK at risk of competitiveness impacts given the EU already has a robust process in place to manage the competitiveness risks and the UK Government has set out compensation packages available to firms at risk of both direct and indirect impacts of climate change policies.
- It would not help the UK in getting a better deal in the EU effort sharing negotiations given the EU ETS rules are generally designed to be independent of commitments made by individual countries.
- It would severely undermine UK credibility in the discussions over the EU 2030 package. Given the important role of the UK in these discussions, it would reduce the likelihood of an outcome consistent with cost-effective routes to tackling climate change.

The economically sensible and legally compliant approach is therefore for the Government to continue to push for a strong and cost-effective EU package and not revise the fourth carbon budget at the current time on the basis of EU circumstances. We will continue to monitor these circumstances and identify any implications for carbon budgets as the EU process is resolved.

We will reflect the uncertainty around where current EU negotiations will end up through the carbon price projections that we use when analysing the cost-effective UK path in our full advice, to be published in December 2013.

- In addition to central projections which reflect the lowest-cost path to meeting the climate objective, we will model scenarios where the objective is met with delayed action, and where the objective is not met.
- Using this range of carbon prices will test the robustness of the fourth carbon budget across the uncertainty for EU outcomes, and identify the appropriate flexibilities in the approach to meeting the budget.
- We set out the carbon price scenarios we will use for our full advice in chapter 4.

Summary: EU developments have been in line with our original advice when designing the fourth carbon budget. On this basis therefore, it remains cost-effective with manageable impacts, and is at the low end of EU ambition currently being discussed around a 2030 emissions reduction target. There is no legal or economic basis to change the budget in respect of EU circumstances at this time.

Chapter 4: Global emissions pathways and carbon price projections in the fourth carbon budget review

Our assessment in the previous three chapters of climate science and the contexts at international and EU levels suggests that the climate objective underpinning the advice for the fourth carbon budget remains appropriate. It also suggests that required reductions in global emissions to achieve the objective are broadly similar to those previously assumed and remain feasible, if highly challenging.

We use global emissions pathways in several ways when designing carbon budgets (Figure 4.1):

- To assess the appropriate level of the UK 2050 target, which in turn informs the level of carbon budgets, based on early uptake of low-cost measures and investment to develop options to meet the 2050 target.
- To generate associated carbon price projections over the period to 2050, which in turn can be used to identify the cost-effective level of abatement under the carbon budgets.
- To assess the appropriate UK contribution to global emissions reductions, based on a top-down burden-sharing of international action.

The currently legislated budget reflects the first two approaches – cost-effective reductions in UK emissions on the path to the statutory 2050 target (i.e. to reduce emissions by at least 80% relative to 1990, consistent with the halving of emissions in our global pathways). In the context of a new global deal with international commitments for the UK, it may be appropriate to align the budget to the third approach; a new assessment of the appropriate budget level would be required once a new global deal has been agreed.

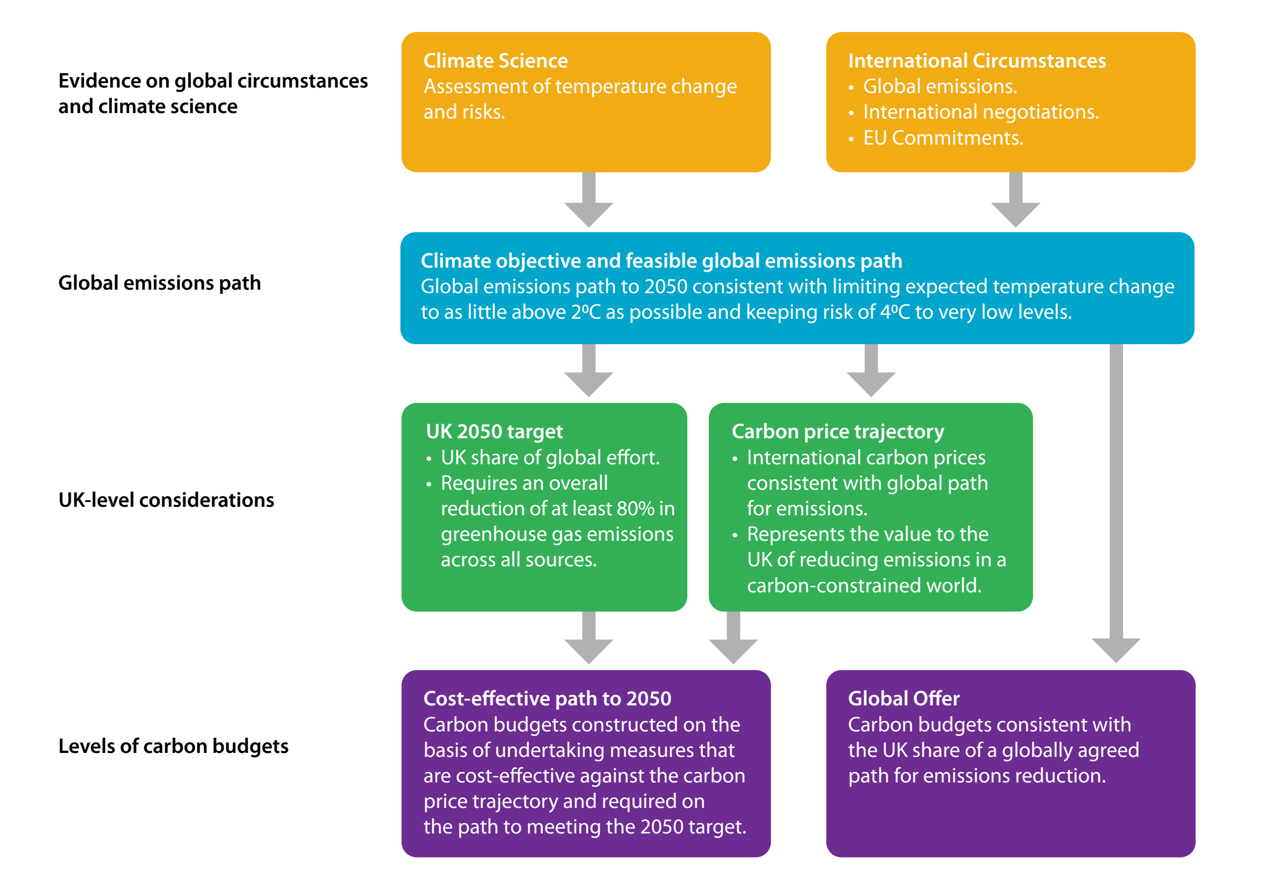
In this chapter we consider the appropriate carbon prices to use to determine the cost-effective level of abatement, given our assessment in Chapters 1-3.

Our conclusion is that the Government's range of carbon values are at an appropriate level and capture well the range of uncertainty in the global emissions path. Therefore, they are a suitable basis for informing the review of the fourth carbon budget.

We set out our analysis in four sections:

1. From global emissions pathways to carbon price projections and carbon budgets
2. Carbon prices for global emissions pathways that achieve the climate objective
3. Uncertainties over the global emissions path
4. Our approach to carbon prices for the fourth carbon budget review

Figure 4.1: From climate science and international circumstances to carbon budgets



1. From global emissions pathways to carbon price projections and carbon budgets

Definition of carbon prices

As set out by the Government's guidance on carbon valuation, the price of carbon reflects the marginal cost of abatement to meet a given carbon target. For example, a carbon price of £200/tCO_2e to achieve a global emissions reduction of 50% in 2050 means that the marginal cost to achieve this reduction is £200.

Carbon prices are generated in carbon markets, for example cap-and-trade systems such as the EU Emissions Trading System (EU ETS) and mechanisms that generate project-based carbon credits such as the Clean Development Mechanism. They can also be set directly as carbon taxes. As set out in Chapter 2, global coverage of carbon taxes and trading schemes is increasing (e.g. to now cover 20% of non-transport emissions), and links are beginning to be made between regions. Further coverage and integration of markets would be expected as a result of a new global deal.

Carbon price projections are generated using models that combine global emissions pathways with assumptions on the costs and availability of abatement options (e.g. marginal abatement cost curves). They are a proxy for what might result from carbon markets under certain assumptions, for example about integration of markets between regions.

How carbon prices can be used to inform emissions reduction strategies

Carbon prices are one input to determining the cost-effective abatement path to achieving climate objectives.

- For example, at the global level, an expectation of a very high carbon price in the future relative to the present might suggest that emissions reduction effort should be accelerated, finding a better balance of costs over time. In other words, in such a situation it would be economically sensible to abate by a greater amount in the near term at relatively low cost, while increasing the level of allowed emissions by an equivalent amount in the long term, when action is very expensive – this would deliver the same level of cumulative emissions at lower overall cost.
- At the national level, one measure of the economic benefit of an abatement measure in a carbon-constrained world is whether this costs less than the projected carbon price, that is whether it is a cheap way of contributing towards meeting an emissions constraint relative to paying for emissions reduction elsewhere. Alternatively, where such abatement goes beyond an emissions constraint, this offers opportunities to sell emissions credits to other countries at a profit.
  - This is currently clearest for sectors covered by the EU ETS, where installations have to surrender permits to cover their emissions and can buy fewer or sell more allowances if they reduce their emissions.
  - It also applies to some extent outside the EU ETS, where the UK has an overall target under the EU process, which permits credits to be purchased from, or sold to, other Member States to make up for a shortfall in domestic abatement, up to a limit of 5% of the country's allowed emissions.
  - As the world moves towards a more comprehensive global deal on emissions and as the coverage of carbon tax and trading schemes expands, carbon prices will become increasingly relevant across the economy.

How we used carbon prices in designing the fourth carbon budget

In our original advice on the fourth carbon budget, we used carbon price projections to identify cost-effective abatement from the set of feasible measures:

- Those costing less than the carbon price, across the lifetime of the investment.
- Those required to prepare for meeting the 2050 target, by reducing costs and increasing potential deployment rates of key technologies, thereby creating a wider range of options to reduce emissions in the long term. These may cost more than the carbon price in the 2020s, but are cost-effective when considered over the entire period to 2050.

Carbon price projections are therefore an important element of carbon budget design. It is important that the carbon price projections in the fourth carbon budget review reflect the range of uncertainty about global emissions pathways that we have identified in the previous three chapters.

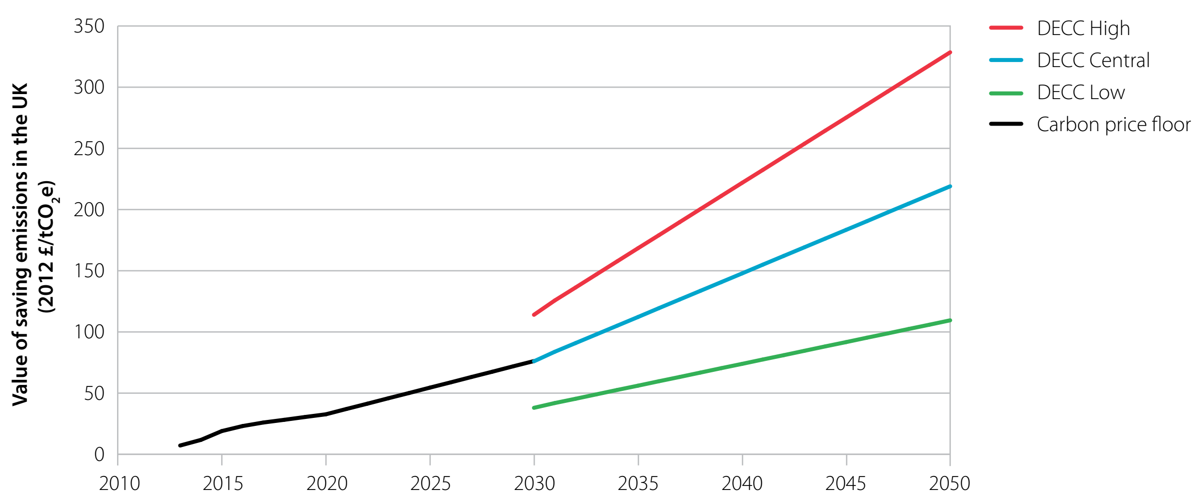
2. Carbon prices for global emissions pathways that achieve the climate objective

The advice on the fourth carbon budget used long-term carbon prices based on the Government's carbon appraisal values. These are projections of international carbon prices consistent with global emissions pathways that achieve the climate objective. There are three scenarios that reflect a range of estimates of the costs for global emissions pathways broadly consistent with the climate objective (Figure 4.2):

- **Central carbon values.** This represents a central view of expected technology costs, energy demands and fossil fuel prices, consistent with a reduction in global emissions to around 2 tCO_2e/capita in 2050. Prices are £76/tCO_2e in 2030, rising to £219/tCO_2e in 2050.
- **High carbon values.** Values are 50% higher, representing a world in which it is more expensive to achieve the same reduction in emissions. This could be because technology costs do not fall as anticipated, fossil fuel prices are lower than expected and/or energy demand is higher than expected.
- **Low carbon values.** Values are 50% lower, representing a world in which the emissions reductions are less costly. This could be due to greater cost reductions for low-carbon technologies, lower energy demands and/or higher than anticipated fossil fuel prices.

The DECC appraisal values from 2030 onwards represent the marginal abatement costs associated with meeting global emissions targets, assuming free trade in emissions. Their levels are consistent with the range of estimates in the literature, although our own analysis demonstrates that there is a risk of higher prices (see Box 4.1 and Section 3). For example, higher prices could ensue if key uncertain abatement options are constrained (e.g. bioenergy, carbon capture and storage – CCS) or if the world pursues a sub-optimal path involving late action or limits on trading.

Figure 4.2: The Government's carbon values



Source: DECC (2009) Carbon Valuation in UK Policy Appraisal: A Revised Approach; DECC (2013) Updated short-term traded carbon values used for modelling purposes.
Notes: DECC also publishes separate values for the traded and non-traded sectors for the period to 2030, which both converge on the same 2030 point as the carbon price floor trajectory of £76/tonne.

For the period prior to 2030, DECC has published three trajectories that all meet at its 2030 point (i.e. £76/tCO_2e):

- The traded sector appraisal values assume a £5/tCO_2e price in 2020. These are based on the current EU ETS cap without any further reductions assumed beyond 2020. These are therefore not consistent with global emissions pathways that achieve the climate objective. The expectation is that higher carbon prices would ensue if the EU agrees a more ambitious package.
- The carbon price floor is the Government's target trajectory resulting from the carbon price underpin, reaching £33/tCO_2e in 2020. This was in line with expected carbon prices under increased EU ambition at the time it was introduced, and implies a relatively steady growth in carbon prices from its introduction through to 2030. It is worth noting that the carbon price floor is primarily a policy instrument for delivering abatement towards meeting carbon budgets. It follows from estimates of the value of carbon, and is not a pre-requisite for use of carbon values in determining carbon budgets and identifying the appropriate mix of measures to reduce emissions.
- The non-traded appraisal values reach £65/tCO_2e in 2020, which is the estimated marginal abatement cost to deliver the ambition in the legislated carbon budgets in those sectors not covered by the EU ETS. These values are therefore an output of the carbon budgets, rather than a suitable input into assessing their levels.

The European Commission (EC) has also published a projection for carbon prices under the cost-effective path to 2050, as set out in its Low-Carbon Roadmap. These reach €25/tonne (i.e. £21/tCO_2e) in 2020 and €61/tonne (£49/tCO_2e) in 2030, for an EU emissions trajectory with a 25% emissions reduction against 1990 levels in 2020 and at least a 40% reduction by 2030 (see Chapter 3 for more detail on the EC Roadmap and possible EU emissions trajectories).

Box 4.1: Carbon prices from global modelling of emissions paths to meet the climate objective

The literature provides a range of estimates for the carbon price or marginal abatement cost implied by different paths for global emissions (Figure B4.1). The variation between studies for similar emissions paths results, at least in part, from the use of different methodologies and/or different assumptions.

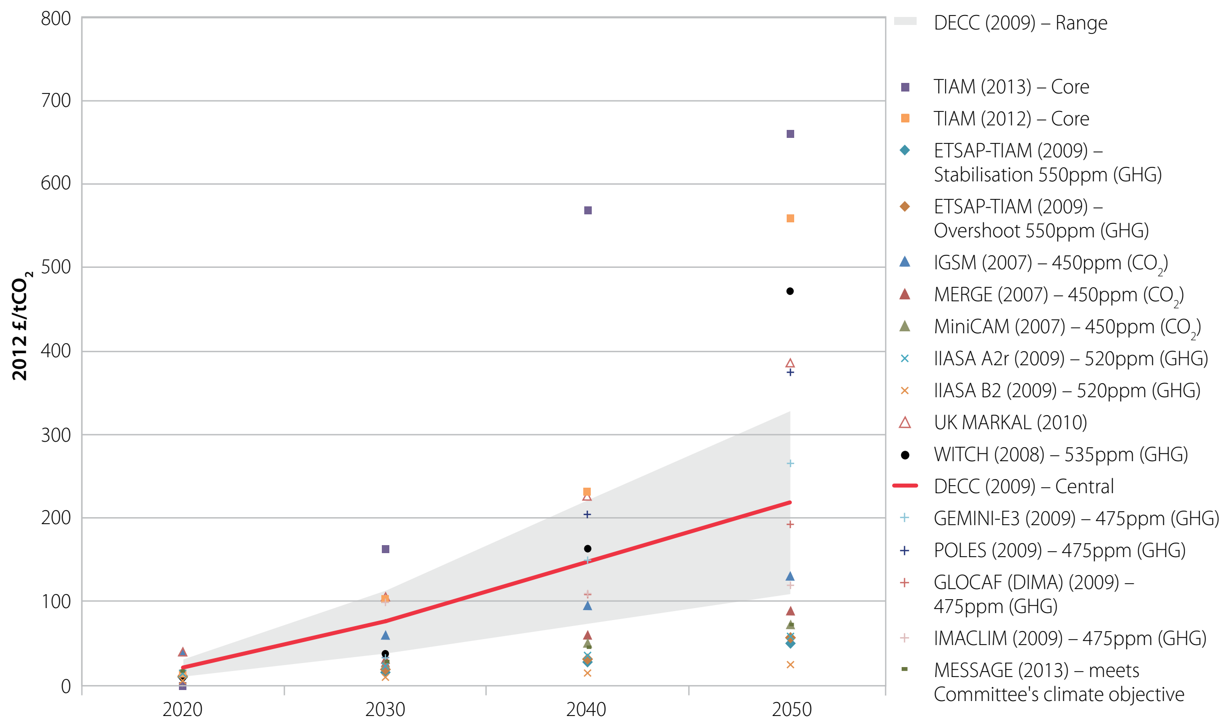
In particular, assumptions regarding the availability of sustainable bioenergy have a strong influence on the level of carbon prices implied by a given emissions path. Modelling for the Committee by University College London (UCL) using their TIAM-UCL model of the global energy system demonstrates this impact. Carbon prices in a run using the Committee's estimates of global sustainable bioenergy resources (as set out in our 2011 *Bioenergy Review)* are four times higher than those using UCL's standard bioenergy resource assumptions (these carbon prices are illustrated in Chart B4.2b in Box 4.2).

In our Bioenergy Review we concluded that it would be unsafe to assume any higher levels of bioenergy supply than our estimate of global sustainable resource. Since our resource estimate is towards the bottom end of the range in the literature, it follows that some of the carbon prices in the literature are lower than would be sensible to plan for.

These models also generally assume relatively benign assumptions regarding the timing of emissions reductions and the extent of international emissions trading. Weak early action and/or limits to trading could increase these required carbon prices considerably.

We conclude therefore that the DECC values are in line with credible estimates in the literature, with a risk that higher prices could ensue in practice if global warming is to be limited to 2°C within sustainable limits for bioenergy resource.

Figure B4.1: Carbon prices from global modelling of emissions paths to meet the climate objective



Notes: This chart shows carbon prices for scenarios which are similar to the Committee's climate objective, which implies stabilisation of Kyoto greenhouse gas concentrations at around 520 ppm, or of CO_2 at around 450 ppm. The core runs of the models can be described as follows: TIAM – meets the Committee's climate objective; ETSAP-TIAM – stabilises GHG concentrations below 550 ppm by 2100; IIASA (A2r and B2) – 520 ppm GHG concentration target in 2100; WITCH – has 535 ppm GHG concentration target in 2100; IGSM, MiniCAM, MERGE – have 450 ppm CO_2 concentration targets for 2100; GLOCAF – stabilise at GHG concentrations of 475 ppm with overshoot to 500 ppm; GEMINI-E3, POLES, IMACLIME – stabilise at GHG concentrations of 475 ppm; MARKAL – UK-only model meeting the 80% reduction target for 2050, consistent with the global climate objective. MESSAGE – global model with scenario meeting the Committee's climate objective. The DECC values plotted for the period pre-2030 are those for the carbon price floor. The shaded area surrounding the DECC Central carbon values is the Low-High range, defined as ±50%.

3. Uncertainties over the global emissions path

In Chapters 1 to 3 we noted uncertainties that exist in key areas. For example: in the climate science about climate sensitivity (Chapter 1); about what the international community will agree in terms of global emissions cuts (Chapter 2); about EU emissions pathways through the 2020s and beyond (Chapter 3).

These uncertainties imply an uncertainty over the future trajectory for carbon prices faced by the UK. We capture this by consideration of the following scenarios for global emissions reduction:

- **Core Pathway.** The climate objective is achieved with peaking of global emissions around 2020 followed by a halving by 2050 to 20-24 $GtCO_2e$.
- **Back-ended Pathway.** The climate objective is achieved but with later peaking of global emissions, offset by even lower emissions in 2050 than under the Core Pathway, such that cumulative emissions are the same.
- **Delayed Peaking.** Global emissions reduction is delayed, such that emissions peak a decade later, but global emissions are still reduced to 20-24 $GtCO_2e$ by 2050. Even if such a rapid reduction after 2030 were feasible, which is unlikely, the climate objective would be unattainable under many plausible assumptions for climate sensitivity.
- **Reduced Action.** Global emissions reduction is delayed, such that emissions peak a decade later, and 2050 emissions are 50% higher. This represents a further departure from achievement of the climate objective. It would not be met unless both climate sensitivity and additional feedbacks (e.g. from melting permafrost) turned out to be at the optimistic end of current assumptions.

We have developed carbon price projections for these scenarios using a combination of the Government's carbon values and the TIAM-UCL model[1], as well as a survey of the relevant literature (Box 4.2). Under our approach, the first three scenarios are within the range of the Government's carbon values; the last scenario gives rise to carbon prices below the lower end of the Government's carbon values (Figure 4.3):

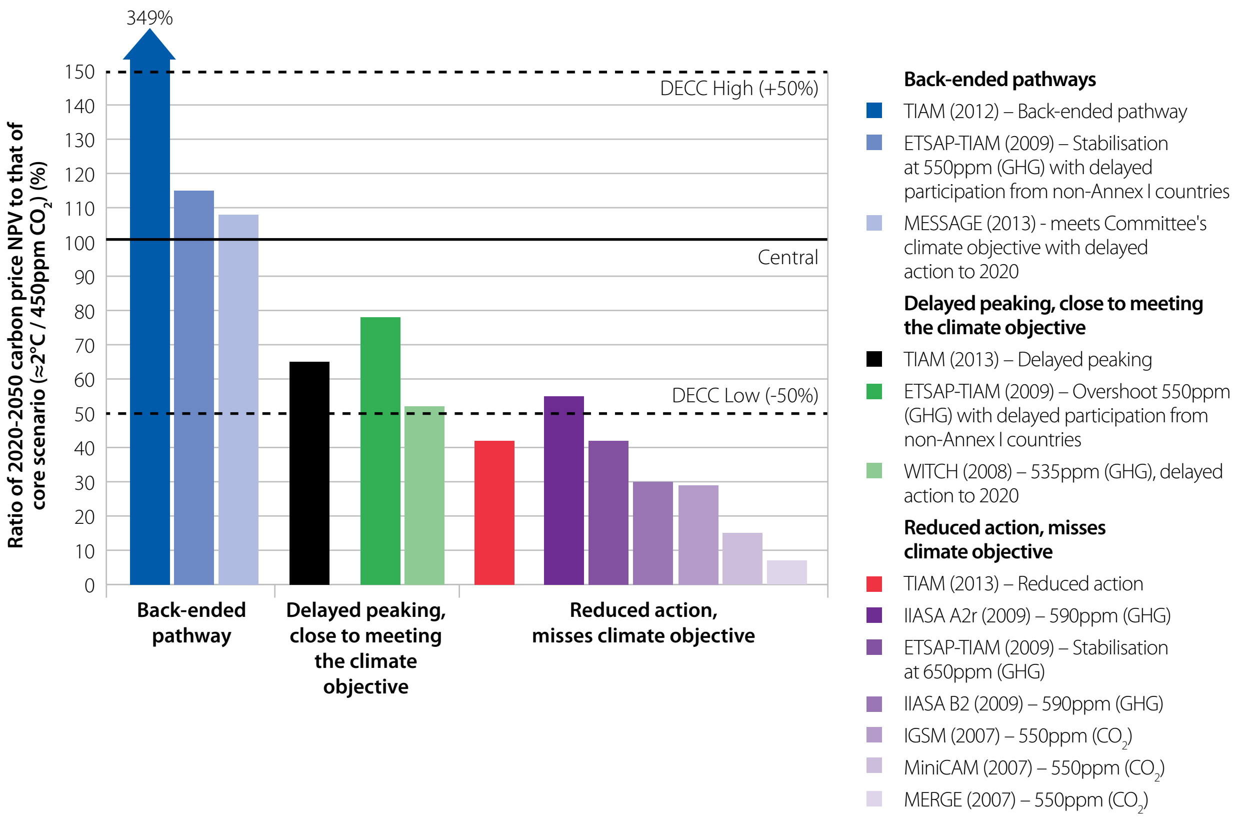
- The DECC carbon values are around the middle of the range for emissions paths, such as the Core Pathway, that are consistent with the climate objective.
- The Back-ended Pathway, which also meets the climate objective, is more expensive overall than the Core Pathway, as the additional emissions reduction in the longer term costs more than is saved by delaying the peak. TIAM modelling indicates that average carbon prices over the period 2020-50 would be over three times higher than those under the Core Pathway, given the extremely high prices required by 2050. This reflects the limited extent to which emissions reduction can be deferred while achieving the same level of cumulative emissions, and the greater costs of doing so – in reality such a pathway may simply not be plausible.

1 We commissioned the TIAM-UCL modelling in two parts: the first part was published alongside our report on International Aviation and Shipping in early 2012 (available from http://www.theccc.org.uk/publication/international-aviation-shipping-review/); the second part is published alongside this report.

- The TIAM modelling and wider literature show that carbon prices under the Delayed Peaking scenario might be up to 50% below those under the Core Pathway, on average between 2020 and 2050. This suggests that carbon prices in the DECC low scenario are broadly appropriate for looking at such an emissions path.
- The carbon prices implied by the Reduced Action scenario are on average around 70% below those in the Core Pathway and therefore fall outside the Government's range of carbon values, reflecting a substantial deviation from the climate objective and inconsistency with the UK's legislated 80% target for 2050.

We conclude therefore that the DECC carbon values provide a reasonable range for the potential carbon prices in a carbon-constrained world consistent with meeting the climate objective, and with plausible emissions paths that could result from international negotiations.

Figure 4.3: Carbon prices for emissions paths that deviate from the climate objective



Notes: This chart shows the ratio of the net present value (NPV) of core scenario carbon prices over the period 2020 to 2050 vs. other scenarios from the same models. The scenarios for the models are as follows (for TIAM see part 3 of this chapter): ETSAP-TIAM – core scenario stabilises GHG concentrations below 550 ppm from now to 2100; 'overshoot' scenario allows GHG concentrations to be higher than 550 ppm until 2100; 'delayed participation' scenario in which non-Annex I countries delay action with either a stabilisation or overshoot of 550 ppm; 'low ambition' scenario with stabilisation of GHG concentrations at 650 ppm. IIASA (A2r and B2) – core scenario has a 520 ppm GHG concentration target in 2100; 'medium ambition' scenario has a 590 ppm GHG concentration target. WITCH – core scenario has a 535 ppm GHG concentration target in 2100; 'delayed peaking' scenario has 535 ppm GHG concentration target with all action delayed to 2020. IGSM, MiniCAM, MERGE – core scenarios have a 450 ppm CO_2 concentration target for 2100; 'low ambition' scenarios have a 550 ppm CO_2 concentration target for 2100. MESSAGE (2013) – core scenario meets the Committee's climate objective, 'delayed scenario' meets the objective with no action pre-2020.

Box 4.2: TIAM modelling of emissions paths

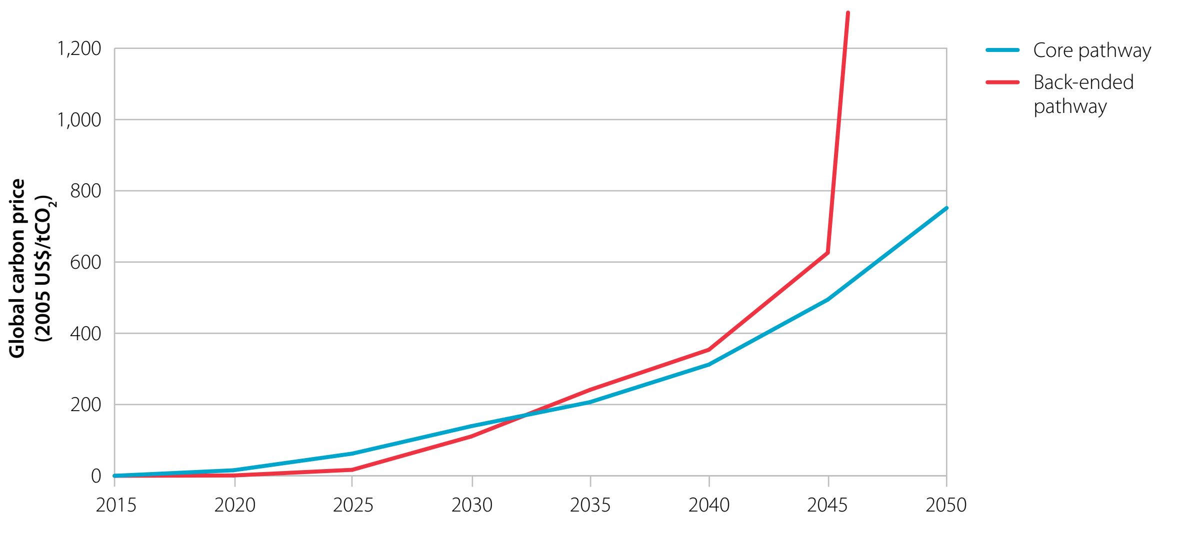
In order to examine the relative carbon prices implied by different emissions pathways, we commissioned University College London (UCL) to run their TIAM-UCL model of the global energy system. The modelling was done in two batches, in 2012 and 2013, using slightly different versions of the model and hence two different results for the Core Pathway were obtained (Figures B4.2a and B4.2b).

The results of the modelling show:

- **The Back-ended Pathway**, which meets the climate objective but with effort compressed into a shorter period before 2050, has carbon prices that are lower in the medium term but much higher later on as abatement becomes extremely expensive at the margin in reaching emissions in 2050 that are around 20% lower than under the Core Pathway.
- **The Delayed Peaking scenario** is associated with lower medium-term carbon prices. These prices then catch up with (and slightly overtake) those in the Core Pathway, as the scenarios converge on global emissions of around 2 tCO_2e/capita in 2050.
- **The Reduced Action scenario**, in which 2050 emissions reach 3 tCO_2e/capita in 2050, has carbon prices which remain some distance below those in the other two scenarios. However if CCS is not available then prices are similar to those in the Delayed Peaking scenario.

We have calculated the net present value (NPV) of these carbon price trajectories over the period 2020 to 2050. This falls by around 35% in the Delayed Peak scenario, and by around 60% in the Reduced Action scenario. This is a similar sensitivity to other analyses in the literature and suggests that the DECC range captures an appropriate level of uncertainty – see Figure 4.3.

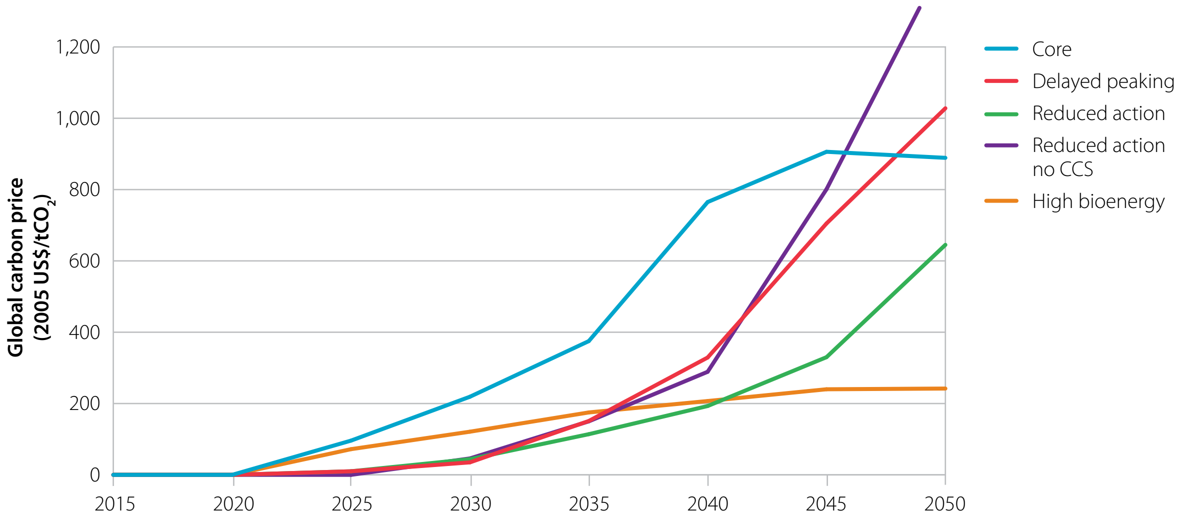
Figure B4.2a: TIAM-UCL runs in 2012



Source: University College London modelling for the CCC.

Box 4.2: TIAM modelling of emissions paths

Figure B4.2b: TIAM-UCL runs in 2013



Source: University College London modelling for the CCC.

4. Our approach to carbon prices for the fourth carbon budget review

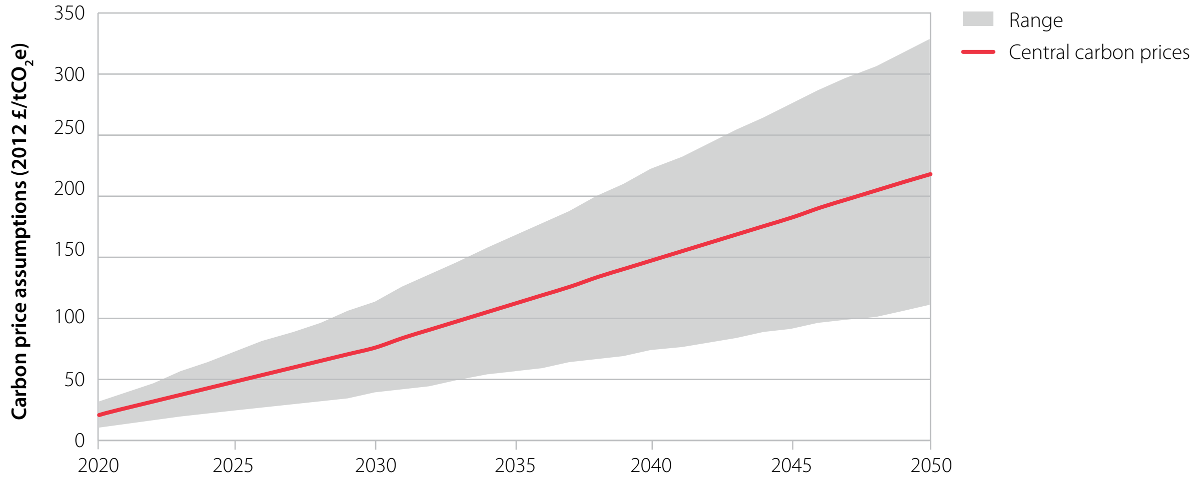
Carbon price projections are an important analytical tool which we use to identify cost-effective abatement options and emissions pathways in the UK through the 2020s. Our budgets are based on pathways which are cost-effective relative to the carbon price and on the path to meeting the 2050 target.

In setting our scenarios 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).

In our updated assessment of cost-effective abatement options, which we will publish in December 2013, we will use carbon values based mainly on the Government's projected values and range (Figure 4.4):

- For 2030 to 2050, we will use the full range of DECC carbon appraisal values. These have central levels of £76/tonne in 2030 and £219/tonne in 2050 (2012 prices), with low and high values 50% below and above the central levels.
- For the period prior to 2030, we will use the European Commission's projection of the 2020 carbon price consistent with the cost-effective path to an EU-wide emissions reduction of 80-95% by 2050. We therefore use the EC's value of €25/tonne in 2020 (£21/tonne), rising linearly through the 2020s and reaching DECC's appraisal value of £76/tonne for 2030. We will undertake sensitivity analysis using low and high values 50% below and above this central assumption (i.e. as in the Government's values post-2030).

Figure 4.4: Carbon prices used for the Fourth Carbon Budget Review analysis



Source: DECC (2009) Carbon Valuation in UK Policy Appraisal: A Revised Approach; EC (2011) Low-Carbon Roadmap.
Notes: Linear interpolation assumed between the EC point for 2020 and the DECC point for 2030, as in DECC methodology post-2030.

Sensitivity analysis across the range of possible carbon prices will allow us to test how robust the fourth carbon budget is 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, this would not be consistent with the climate objective or the UK 2050 target to reduce emissions by 80%, and would therefore not be an appropriate basis for the carbon budget analysis.

Summary: The Government's range of carbon values are at an appropriate level and appropriately capture uncertainty in the global emissions path. Therefore, they are a suitable basis for informing the review of the fourth carbon budget.

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