Building a low-carbon economy – the UK's contribution to tackling climate change

Committee on Climate Change
December 2008

Building a low-carbon economy – The UK's contribution to tackling climate change

The First Report of the Committee on Climate Change
December 2008

London: TSO

information & publishing solutions

Published by TSO (The Stationery Office) and available from:

Online
www.tsoshop.co.uk

Mail, Telephone, Fax & E-mail
TSO
PO Box 29, Norwich, NR3 1GN
Telephone orders/General enquiries: 0870 600 5522
Fax orders: 0870 600 5533
E-mail: customer.services@tso.co.uk
Textphone 0870 240 3701

TSO Shops
16 Arthur Street, Belfast BT1 4GD
028 9023 8451 Fax 028 9023 5401
71 Lothian Road, Edinburgh EH3 9AZ
0870 606 5566 Fax 0870 606 5588

TSO@Blackwell and other Accredited Agents

Published with the permission of Committee on Climate Change on behalf of the Controller of Her Majesty's Stationery Office.

© Crown Copyright 2008

All rights reserved.

Copyright in the typographical arrangement and design is vested in the Crown. Applications for reproduction should be made in writing to the Office of Public Sector Information, Information Policy Team, Kew, Richmond, Surrey, TW9 4DU.

First published 2008

ISBN 9780117039292

Printed in the UK for The Stationery Office.

75% recycled
When you have finished with this leaflet please recycle it

CONTENTS

FOREWORD

The Committee on Climate Change was appointed in 'shadow' form in March 2008, becoming a statutory committee on 1st December 2008 when the Climate Change Bill became law. Its core function is to recommend what the level of the UK's 'carbon budgets' should be. These budgets are established by the Climate Change Act and will define the maximum level of CO_2 and (potentially) of other greenhouse gases (GHG) which the UK will emit in each 5 year budget period, beginning with 2008-12.

The Climate Change Act requires the Government to gain Parliament's approval to a proposed level for the next three budgets, setting a trajectory of UK CO_2/GHG emissions over the next 15 years. The Committee is required to make recommendations on this basis.

This first report of the Committee on Climate Change therefore recommends UK carbon budgets for the three periods 2008-12, 2013-17 and 2018-22. In addition, it covers issues on which we are required to report by the Climate Change Act, or on which we have been asked by the Secretary of State to provide our opinion. These include:

- What should be the target for UK emissions reduction by 2050?

- Whether budgets should cover CO_2 emissions, or all greenhouse gas (GHG) emissions, including the relevant non- CO_2 gases

- How far CO_2/GHG emissions reduction should be achieved by domestic UK action, and what reliance on emissions reduction credits bought from other countries is acceptable?

- Whether and how international aviation and shipping should be included in the UK's targets and budgets

- And the implications of our recommended budgets for economic growth, energy security, the competitiveness of particular industrial sectors, fuel poverty, and for specific regions and devolved administrations.

The Committee's recommendations on the first of these issues – the target for 2050 – have already been presented in a letter to the Secretary to State delivered on 7th October 2008. We recommended that the UK should commit to reducing its GHG emissions by at least 80% below 1990 levels by 2050.

Part I of this Report sets out the detailed analysis which underpins that recommendation. Part II sets out our recommendations on the level of the first three budgets and the extent to which these should be addressed via domestic action versus through the purchase of bought-in credits from other countries. Part III explains our proposed approach to international aviation and shipping and to non-CO_2 gases, and Part IV covers wider economic and social considerations.

The essential task of the Committee can be summed up as providing advice on how fast the UK can and should progress towards a low-carbon economy and how it achieves that progress. In developing that advice, we have had to asses the technologies that are or might be available to deliver low-carbon energy and increased energy efficiency, the potential for consumer behaviour changes that reduce energy consumption and carbon emissions, and the likely effectiveness of the policies presently in place or potentially applicable in future. Around each of these there is significant uncertainty.

It is not therefore possible, nor is it the role of the Committee, to attempt to predict what the precise path to a low-carbon economy should entail either in terms of technologies or policies. Instead, our role is to recommend a path of emissions which is appropriate as a UK contribution to global climate change mitigation, and to identify whether that path is feasible at manageable economic cost, given the range of different technologies and policy levers which could be deployed.

This Report therefore sets out alternative ways in which emission reductions could be achieved, and assesses whether there are reasonable scenarios in which different combinations of actions would deliver the required emission reductions path. The analysis clearly shows that the required reduction path is feasible.

Once the recommendations of this Report have been considered by government and deliberated by Parliament, statutory budgets for the UK emissions of CO_2/GHG emissions will be set. One role of the Committee will then be to monitor actual progress in reducing emissions versus the budgets set. We will provide our first progress report to Parliament in September 2009. In addition we will need to provide advice to government on how to fine tune the level of the budgets in the light of the results of the Copenhagen negotiations on a global climate deal. We will also begin work soon on the analysis which will inform our recommendations for the fourth budget period (2023-27) which we will deliver by 2011. And there are a range of specific issues, identified at various points in the Report, where the tight timescales to which we have had to work have allowed only preliminary analysis and where we intend to do more detailed analysis over the coming year.

The progress we have made so far would not have been possible without the hard work and dedication of the members of the Secretariat and the whole Committee would like to express our thanks to them.

THE COMMITTEE ON CLIMATE CHANGE

Lord Turner of Ecchinswell is the Chair of the Committee on Climate Change and Chair of the Financial Services Authority. He has previously been Chair at the Low Pay Commission, Chair at the Pension Commission, and Director-General Confederation of British Industry (CBI).

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

Dr Samuel Fankhauser is a Principal Research Fellow at the Grantham Research Institute on Climate Change at the London School of Economics. He is a former Deputy Chief Economist of the European Bank for Reconstruction and Development and former Managing Director (Strategic Advice) at IDEAcarbon.

Professor Michael Grubb is Chief Economist at the UK Carbon Trust and Chairman of the international research network Climate Strategies. He is also senior research associate at Cambridge University and holds a visiting professorship at Imperial College. Previously he was Head of the Energy and Environmental Programme at Royal Institute of International Affairs, before joining Imperial College as Professor of Climate Change and Energy Policy.

Professor Sir Brian Hoskins, CBE, FRS is the Director of the Grantham Institute for Climate Change at Imperial College, London and Professor of Meteorology at the University of Reading. He is a Royal Society Research Professor and is also a member of the National Science Academies of the USA and China.

Professor Julia King became Vice-Chancellor of Aston University in 2006, having previously been Principal of the Engineering Faculty at Imperial College, London. Before that she held various senior positions at Rolls-Royce plc in the aerospace, marine and power business groups. In March this year she delivered the 'King Review' examining vehicle and fuel technologies that, over the next 25 years, could help to reduce carbon emissions from road transport.

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

Professor Jim Skea is Research Director at UK Energy Research Centre (UKERC) having previously been the Director of the Policy Studies Institute (PSI). He has also acted as Launch Director for the Low Carbon Vehicle Partnership and was Director of the Economic and Social Research Council's Global Environmental Change Programme.

ACKNOWLEDGEMENTS

The Committee would like to thank:

The team that prepared the analysis for the report. This was led by David Kennedy and included: Mark Bainbridge, Alice Barrs, Jenny Byars, Liz Cassidy, Ben Combes, James Davey, Kristofer Davies, Jamila Fattah, Sharon Gaisie, Ajay Gambhir, Neil Golborne, Sarah Guy, Rachel Hall, Julia Heard, Debbie Hemming, Edward Hogg, Richard Houston, David Joffe, Swati Khare-Zodgekar, David Lewis, Rachel Lund, Nina Meddings, Sarah Naghi, Stephanie Ockenden, Akshay Paonaskar, Nicholas Petersen, Michele Pittini, Niall Riddell, Stephen Smith, Caroline Spencer, Jonathan Stern, Kiran Sura, Mike Thompson, Claire Thornhill, Emily Towers, Mark Weiner, Katherine White.

A number of individuals for their support: Alex Bakir, Philippa Benfield, Brenda Boardman, Jonathan Brearley, Alon Carmel, Tom Corcut, Simon Dietz, Malcolm Ferguson, Federico Gallo, Vivienne Geard, Jonathan Gillham, Stephen Glaister, Laila Gohar, Phil Goodwin, James Hardy, Chris Holland, Chris Hope, James Hughes, Roger Lampert, David Lee, Mirko Licchetta, Jason Lowe, Margaret Maier, Alan McKinnon, Gemma Mills, Manuela Naessl, Robert Nicholls, Stephen Oxley, Vicky Pope, Stephen Prichard, Huub den Rooijen, Aliya Saied, Duncan Sinclair, Jamie Torrens, David Wilson, Damon Wingfield

A number of organisations for their support, including seconding staff, sharing modelling tools and data, and co-financing consultancy assignments including: British Energy, the Carbon Trust, Climate Change Capital, Climate Strategies, DECC, Defra, DfT, EdF Energy, the Energy Savings Trust, the Environment Agency, the Hadley Centre, Shell, the Office of Climate Change, the Rail Carbon Trajectory Working Group, Rothschild, UKERC, the Department of the Environment in Northern Ireland, the Scottish Government and the Welsh Assembly Government.

A wide range of around 1000 stakeholders who responded to our Call for Evidence and Commented on our Work Programme, and who attended our kick off events (London, Belfast, Cardiff and Glasgow), expert workshops, or met with the CCC bilaterally.

EXECUTIVE SUMMARY

Climate change resulting from CO_2 and other greenhouse gas emissions poses a huge threat to human welfare. To contain that threat, the world needs to cut emissions by about 50% by 2050, and to start cutting emissions now. A global agreement to take action is vital. But a global agreement will not be possible unless the countries of the rich, developed world provide leadership.

A fair global deal will require the UK to cut emissions by at least 80% below 1990 levels by 2050. The good news is that reductions of that size are possible without sacrificing the benefits of economic growth and rising prosperity. Technologies are available or with appropriate support could be developed which deliver low-carbon energy; opportunities to increase the efficiency with which we use energy are huge; lifestyle changes which will not undermine welfare can produce significant cuts in energy consumption. And many of the actions required to tackle climate change we should want to do anyway because these have economic, wider environmental and security of supply benefits.

But the potential will not be achieved without appropriate policies: financial incentives through carbon prices, taxes and subsidies; support for technology innovation; information and encouragement; and regulation when needed. The challenge is not the technical feasibility of a low-carbon economy but making it happen. Ensuring action will require strong leadership from government and a concerted response from individuals and businesses. It will require policy commitment to cutting emissions steadily over time, sticking on the path to an 80% reduction, and reacting to any diversion with new policies to get back on track. The UK's Climate Change Act makes that commitment, establishing a system of five year "carbon budgets". The Committee on Climate Change is charged with recommending the level of those budgets.

In this our first report, we begin by explaining why the UK should aim for an 80% reduction by 2050 and how that is attainable, and we then recommend the first three budgets that will define the path to 2022. Achieving this path requires strong policies; some of these are already in place, some need to be reinforced, and some new ones will be required.

But the path is attainable at manageable cost, and following it is essential if the UK is to play its fair part in avoiding the far higher costs of harmful climate change.

* * *

The key findings and recommendations of the report are set out below in three sections:

1. The 2050 target

2. The first three budgets

3. Wider social and economic impacts of budgets

1. THE 2050 TARGET

Box 1 sets out our summary findings and recommendations relating to the 2050 target. These are based on:

(i) Consideration of appropriate global and UK targets to reduce the risk of dangerous climate change.

(ii) Analysis of the technological feasibility of radical emissions cuts and the possible costs of achieving them.

Box 1 Summary findings and recommendations on the UK's 2050 emissions reduction target

- The UK should aim to reduce Kyoto greenhouse gas emissions by at least 80% below 1990 levels by 2050 (77% below 2005 levels). This would be an appropriate UK contribution to a global deal aiming to reduce Kyoto greenhouse gas emissions to between 20-24 billion tonnes by 2050 (about 50-60% below current global levels).
- The 80% target should apply to the sum of all sectors of the UK economy, including international aviation and shipping. To the extent that international aviation and shipping emissions are not reduced by 80%, more effort would have to be made in other sectors.
- The costs to the UK from this level of emissions reduction can be made affordable – we estimate between 1-2% of GDP in 2050 – with appropriate policies and given early action to put the UK on an appropriate path. Our estimates are the same order of magnitude as those provided by the Stern Review and other global and UK studies.

(i) Setting a 2050 target to avoid dangerous climate change

There is a very strong case for the UK to adopt a significantly more ambitious target than the 60% objective set in the 2003 Energy White Paper. There have been two key changes since this objective was set:

- Recent developments in climate science and in the analysis of potential impacts mean that the whole world should now be aiming for deeper reductions in GHG emissions than previously seemed appropriate.
- Latest evidence on emissions and atmospheric concentrations suggests that these are higher than was projected at the time that the 60% target was set. More radical and earlier action is therefore needed to achieve climate objectives.

The UK should strongly support a global commitment to cutting GHG emissions by at least 50% below current levels by 2050, with total global Kyoto GHG emissions between 20-24 billion tonnes CO_2e in 2050, and with further reductions to between 8-10 billion tonnes CO_2e required by 2100. Cuts of this scale would limit our central expectation of temperature rise by 2100 to as close to 2°C as possible, and reduce the risk of extremely dangerous climate change to very low levels (e.g. less than a 1% chance of 4°C temperature rise). CO_2e concentrations would peak at around 500ppm by the end of the century before falling towards 450ppm.

By 2050 the UK should reduce its Kyoto GHG emissions by at least 80% below 1990 levels (i.e. about 77% below 2005 levels). The appropriate UK share of a global emissions target involves ethical judgements and will be the subject of international negotiations. But we believe that it is difficult to imagine a global deal which allows developed countries to have emissions per capita in 2050 which are significantly above a sustainable global average. In 2050 the global average could be between 2.1 and 2.6 tonnes per capita, implying an 80% cut in UK Kyoto GHG emissions from 1990 levels.

The target should cover all Kyoto GHGs and all sectors including international aviation and shipping. To the extent that international aviation and shipping emissions are not reduced by 80% more effort would have to be made in other sectors.

The majority of the 80% cut will in the long term need to be achieved via domestic action. Free trade in emissions reductions certificates is desirable within a global deal since it reduces the total cost of reducing emissions and can provide a flow of finance to support emissions cuts in developing countries. But in the long term low cost opportunities to cut emissions in developing countries will diminish and radical reductions in emissions of developed countries will be unavoidable.

Over time, more information and analysis will become available which may suggest that the target should be adjusted. Our recommended targets reflect the best judgement on imperfect information and analysis available today. Over time better information will become available, and it may become appropriate to adopt a new target.

(ii) Achieving the 2050 target: technologies and costs

A range of technologies are available or can be developed which would:

- make the required emissions reductions possible
- cost the UK 1-2% of GDP in 2050.

Key points supporting each of these conclusions are set out below.

Low-carbon technologies

There exists a range of technologies in power, buildings and industry, and transport that could deliver the required emissions reduction.

Decarbonisation of the power sector is key to achieving emissions reduction targets. A number of technologies exist that could in combination deliver required emissions reductions:

- **Renewable generation could make a significant contribution to power sector decarbonisation, both globally and in the UK:**
  - Wind generation is a proven form of low-carbon power generation, the costs of which have fallen fourfold since the 1980s and are likely to continue to fall given further scope for technology innovation. Despite the inherent intermittency of wind power supply, wind generation could make a significant contribution to total global electricity generation, and be a major source of electricity in the UK (e.g. 30% by 2020 and more beyond), particularly in combination with new energy storage and load balancing technologies such as smart metering.
  - Solar power is expected to become increasingly cost competitive, particularly in sub-tropical sunny regions, although low yields are likely to keep costs in the UK high.
  - The economics of tidal range (i.e. Severn Barrage type) power generation depend crucially on the discount rate assumed; this technology also has potential wider environmental impacts (e.g. for biodiversity) which should be considered. Other forms of tidal and wave power are at an earlier stage of development and not currently cost competitive, but may become so with technological development. Across the world marine power is likely to count for only a small share of electricity generation, but the opportunity in the UK is likely to be higher.

- Biomass power generation – in particular co-firing with fossil fuels in CCS plants – may become economic in future. But if concerns about bioenergy production cannot be overcome via new technology developments, the role of appropriate biomass use in power generation may be limited given other opportunities to use bioenergy where either transformation losses are lower (e.g. heat) or where alternative low-carbon energy sources are less likely to be available (e.g. aviation).

- **Nuclear power is cost competitive with conventional fossil fuel generation:** This is true even when decommissioning costs and possible fuel price increases due to increased uranium demand are allowed for. The main constraints on nuclear deployment are likely to be the feasible build rate, which is limited by the supply of technically competent nuclear specialist engineers and demanding regulatory frameworks. The Committee recognises that there are also concerns about the long-term sustainability of nuclear waste storage and about the possible implications of an extensive global nuclear power industry for nuclear military proliferation. But if these risks are in principle acceptable – a judgment which is beyond our remit – the Committee believes that the economic case for nuclear power deployment is strong.

- **CCS generation is an essential technology for reducing global emissions, but needs to be developed rapidly.** CCS will always be more expensive than conventional fossil fuel generation because of the additional process steps involved. But it is a technically feasible solution and best estimates suggest that it is likely to play a major role in a cost-efficient global abatement strategy. It is now essential to invest in projects which demonstrate the effectiveness of various CCS technologies in large-scale installations, and which identify the feasible timescales and likely costs of extensive deployment.

Investment in a combination of these technologies in the UK would help to reduce power generation emissions from current levels of around 550 gCO_2/kWh to well below 50 gCO_2/kWh in 2050. It would also support decarbonisation of other sectors, namely heat and transport, where there is scope for introduction of low-carbon electricity based technologies and notwithstanding technical challenges that this would pose for design of the power system.

Emissions reductions in buildings and industry can be achieved through energy efficiency improvement and the introduction of new technologies. In the near term, there is major scope for significant emissions reductions (electricity and heat related) through energy efficiency improvement and through relatively minor changes in behaviour that have minimal consequences for welfare. Further emissions cuts will require the introduction of new technologies based on electricity (e.g. heat pumps, storage heating) and the use of sustainable biomass. In industry, application of new technologies to reduce emissions (e.g. CCS in cement and steel) is likely to be feasible and economically viable.

Transport emissions cuts through introduction of new technologies will be required:

- The carbon efficiency of vehicles using fossil fuels can be increased by 30-40%. But there are absolute physical limits to what can be achieved through these improvements and, given underlying demand growth, efficiency improvements will not themselves be sufficient to reduce carbon emissions to the extent needed.

- Electric vehicles combined with the decarbonisation of electricity generation could lead to a dramatic reduction in emissions from cars and light vans. Investments in recharging infrastructure, and improvements in battery technologies are however required to unlock this potential. And further innovation would be necessary before this technology could be applied to more challenging transport segments such as HGVs.

- Hydrogen could become a feasible source of energy for some transport modes and could play a major role if improvements in battery technology are slow. But hydrogen vehicles are not as close to commercial deployment as electric, with significant challenges remaining in relation to hydrogen infrastructure, storage, and safety, and the durability and cost of fuel cells.

- Biofuels have a potentially important role in reducing transport emissions. The extent to which this will be the case in practice is currently unclear, given uncertainties over quantities of sustainable biofuels that will be available. A clearer picture will emerge however as sustainability safeguards and new generations of biofuels are developed.

Economic cost of meeting an 80% target in the UK

The costs of meeting the 80% target are affordable and should be accepted given the consequences and higher costs of not acting. Our modelling suggests that the least-cost path is likely to entail a major contribution from energy efficiency improvements in both buildings and surface transport between now and the mid 2020s, the radical decarbonisation of power generation by 2030, and the increasing application of electricity to surface transport from 2015 onwards and to heat production from the 2020s onwards. It indicates that meeting the UK target of an 80% cut can be achieved at a cost in the order 1-2% of GDP in 2050. This order of magnitude is consistent with cost estimates from the Stern Review and the IPCC and with various UK studies. The Committee recommends that it is accepted given the consequences and much higher costs of not acting.

2. THE FIRST THREE BUDGETS

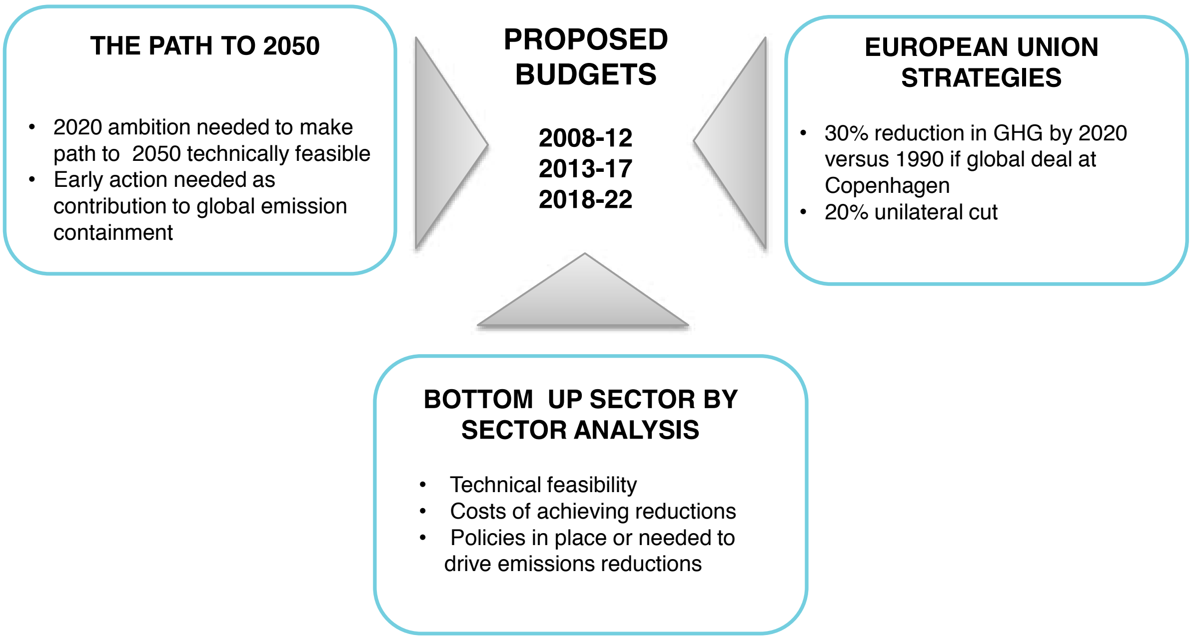
In determining the appropriate level for the first three carbon budgets covering the period 2008-22 we have considered three factors (Figure 1):

1. The implications of the 2050 target for the appropriate trajectory over the next fifteen years, and appropriate contributions by the UK to required global emissions reductions in 2020.

2. The implications of EU targets for emissions reductions to which the UK is already committed.

3. A bottom up sector by sector analysis of feasible emissions reductions, likely costs, and the policies required to ensure that they are achieved.

Figure 1: Factors considered in setting the first three carbon budgets



Source: CCC

Box 2 presents our summary findings and recommendations, which we explain below in two subsections:

(i) The proposed level of the first three budgets.

(ii) Our sector by sector assessment of feasible emissions reduction.

Box 2: Summary findings and recommendations on budgets for the period 2008-2022

- We follow the EU framework and propose two sets of budgets, one to apply following a global deal on emissions reductions ('Intended' budgets), and the other to apply for the period before a global deal is reached ('Interim' budgets).
- The budget should apply to all Kyoto greenhouse gases.
- The Intended budgets require an emissions reduction of 42% in 2020 relative to 1990 (31% relative to 2005). The Interim budget requires a 34% emissions reduction in 2020 relative to 1990 (21% relative to 2005). Intended and Interim budgets are summarised in table 1.

Table 1 GHG budgets for the UK for 2008-2022

		Budget 1 (2008-2012)	Budget 2 (2013-2017)	Budget 3 (2018-2022)
Interim budget ($MtCO_2e$)	Traded sector	1233	1114	1011
	Non-traded sector	1785	1704	1559
	Non-traded sector CO_2	1304	1235	1103
	Non-traded sector non-CO_2	481	469	456
	Total	3018	2819	2570
Intended budget ($MtCO_2e$)	Traded sector	1233	1009	800
	Non-traded sector	1785	1671	1445
	Non-traded sector CO_2	1304	1201	989
	Non-traded sector non-CO_2	481	469	456
	Total	3018	2679	2245

Source: CCC
Note: The traded sector comprises energy-intensive firms in the European Union Emissions Trading Scheme (EU ETS). The non-traded sector comprises residential, commercial, small industrial and transport sectors. Non-CO2 gases are Kyoto greenhouse gases apart from carbon.

- International aviation and shipping should be part of the UK's climate strategy but should not be explicitly included in the budget given unresolved issues related to allocating emissions at the national level. The Committee proposes, however, to report annually on progress reducing emissions in these sectors.
- Our proposed budgets can be feasibly reached through energy efficiency improvement in buildings and industry and fuel efficiency improvement in road vehicles, combined with a significant shift towards renewable and nuclear power generation and renewable heat.
- To deliver feasible emissions reductions, strengthening of existing policies and development of new policies – at the EU, UK and national [within UK] levels – will be required.
- The Government should not plan to purchase offset credits (e.g. CDM) to meet the Interim budget. More generous use of offset credits, however, would be appropriate in transitioning from the Interim to the Intended budgets.
- The cost of meeting proposed budgets is less than 1% of GDP in 2020, and potential competitiveness issues for energy-intensive industries can be addressed through appropriate design of the policy framework.
- There will be potential costs for the fuel poor which can and should be addressed through design of the policy framework.

(i) The proposed level of the first three carbon budgets

Budgets should include all Kyoto GHGs, for three reasons**:** it is all GHGs rather than just CO_2 that cause climate change; the UK's international commitments are in terms of GHGs; and including non-CO_2 GHGs provides additional options for meeting budgets. There is some measurement uncertainty regarding the level of non-CO_2 emissions, but the Committee concludes that this is manageable.

International aviation and shipping should not be included in budgets, but there need to be clear strategies to achieve emissions reductions, and the Committee's annual reports of progress against budgets should be accompanied by reports on international aviation and shipping. These sectors are important from a climate change perspective and should be covered by the UK's climate strategy and ideally by global agreements. There are, however, complexities that currently make it difficult sensibly to allocate international emissions to the national level. We therefore recommend that budgets should not include international aviation and shipping. But the level of ambition in budgets for other sectors should ideally reflect likely progress in reducing emissions in these sectors, and other mechanisms to drive emissions reduction in aviation and shipping should be in place. The Committee's annual reports on progress in these sectors should keep under review whether at any time it does become appropriate to include either sector within the budget process.

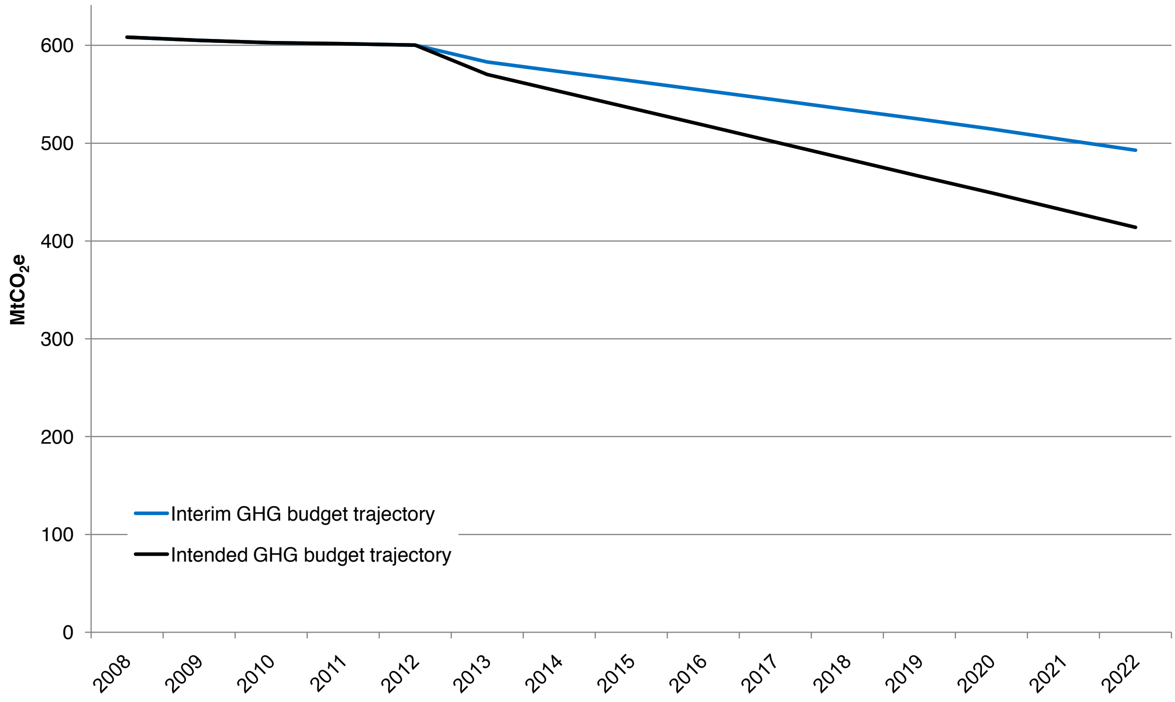
The appropriate budgets for the UK should reflect the outcome of the Copenhagen and any subsequent negotiations on a global treaty, and should be in line with the EU approach:

- The Intended budget, which should apply once a global deal has been reached, would require a reduction in 2020 of 42% in GHG emissions below 1990 levels, which is equivalent to 31% below 2005 levels; this translates to required emissions reductions of 175 $MtCO_2e$ in 2020

- The Interim budget, which the UK would be committed to even in the absence of a global deal, would require a reduction of 34% in 2020 from 1990 levels, which is equivalent to 21% below 2005 levels; this translates to required emissions reductions of 110 $MtCO_2e$ in 2020.

The allowed emissions under these budgets are shown in Figure 2.

Figure 2 Annual allowed emissions for the UK 2008-2022, consistent with the proposed GHG budgets



Source: CCC

Meeting budgets is feasible given power sector decarbonisation, energy efficiency improvement in homes, buildings and industry, and emissions reductions in transport. Some of the required emissions reduction can be achieved at negative cost and would therefore save money for households and businesses. A significant part of the required emissions reduction can be achieved at a cost below the likely carbon price within EU ETS, which we project to be around £40/tCO_2 in 2020 in a central scenario. But some significant abatement options cost more than the carbon price, and would not be pursued if the objective were simply to minimise the cost of meeting a 2020 emissions reduction target. We believe, however, that it is important to pursue these options to foster technology innovation and to ensure that the UK is on the path to meeting the 80% target in 2050.

Strengthening of the policy framework will be required. The current policy framework will deliver some of the required emission reductions. But strengthening of existing policies will be needed if they are to deliver the full abatement potential we have identified. New policies will also be needed to support deployment of renewable heat and to reduce emissions from road vehicles. In addition, there is a range of other areas where new policies will have to be considered (e.g. to support widespread solid wall insulation, and the application of plug-in hybrid technologies to vans).

There should be no limit on the use of credits bought from the rest of Europe (i.e. EUAs) to meet the budgets, but the use of offset credits (e.g. CDM) should be tightly controlled, particularly to meet the Interim budget:

- The Committee recognises the benefits of carbon markets, which can help achieve emissions reductions at least cost and drive emissions reductions in developing countries. But we believe that it is essential for rich developed countries to achieve significant domestic reductions to drive the development of required low-carbon technologies and to be on the path to meeting the deep domestic emissions cuts that will be required in the longer term.

- Limits on the use of credits from other European countries (European Union Allowances [EUAs] in EU ETS) are neither feasible nor necessary: as long as emissions reductions happen somewhere within Europe, the technologies of a low-carbon economy will be developed. The overall policy imperative is simply to ensure that overall emissions caps within EU ETS are sufficiently tight.

- But the use of offset (e.g. CDM) credits bought from outside Europe should be limited.

  – In respect to the EU ETS, the purchase would be by private companies under rules set at the European level. These envisage limited purchase in the "no global deal" scenario, but with a significant proportion of the additional effort following a global deal being purchased as offset credits. The Committee supports this approach.

  – In the non-traded (i.e. non EU ETS) sectors, however, purchase of offset credits would be by Government. The Committee recommends that there should be no planned purchase of offset credits to meet the Interim budget, but that if the Intended budget is adopted after a global deal, the incremental non-traded sector effort required could be achieved by purchasing offsets up to the limit proposed within the EU's framework.

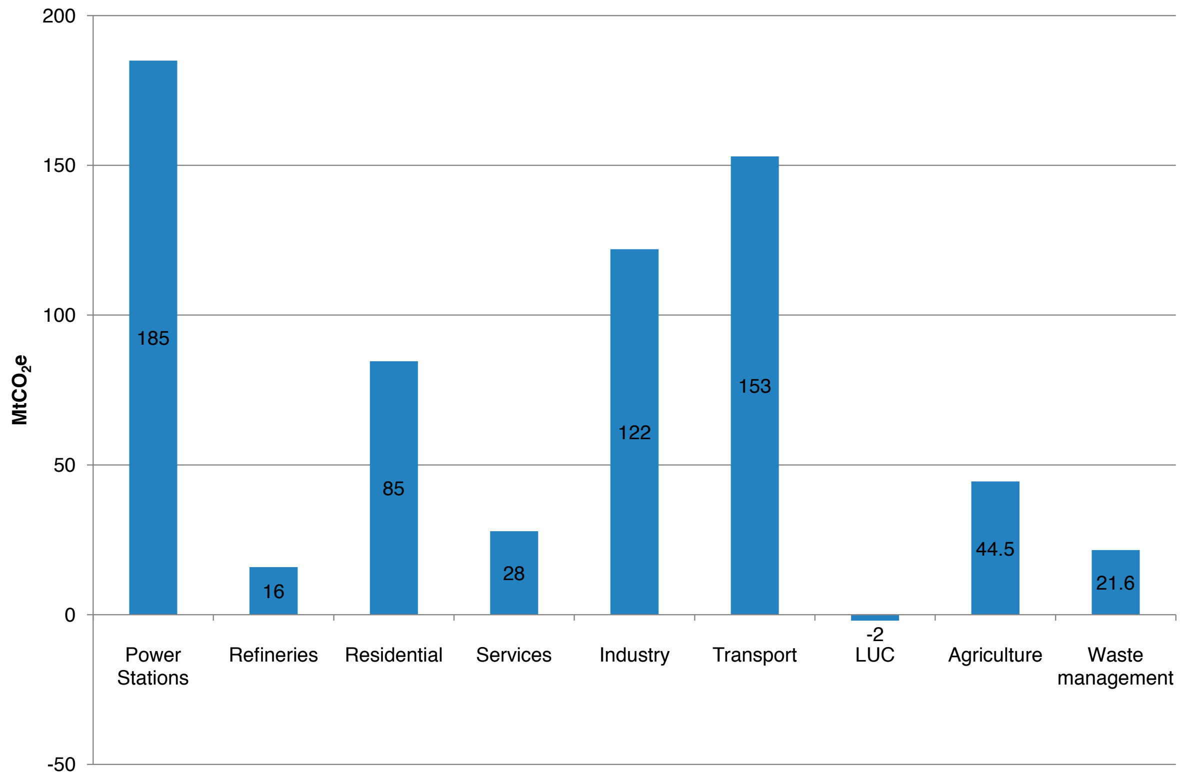
The overall result of these recommendations would be that in the Interim budget case, less than 10% of required emissions reductions would come from purchase of offset credits, with the remaining 90% coming domestically or from elsewhere in the EU. In the Intended budget case, domestic effort would be higher, but up to 20% of the required emissions reduction could be achieved through offset credit purchase.

The cost of meeting budgets is less than 1% of GDP in 2020. This cost is due to the impact of higher energy prices, net of any increases in income due to energy efficiency improvements. The 1% figure can be compared to annual growth forecast to be above 2% on average across the three budget periods, which will result in an economy that is about 30% larger than now in 2020; the cost of meeting budgets would be equivalent to losing half of one year's growth. The Committee's view is that this cost should be accepted given the consequences and costs of not acting.

(ii) Feasible emissions reductions

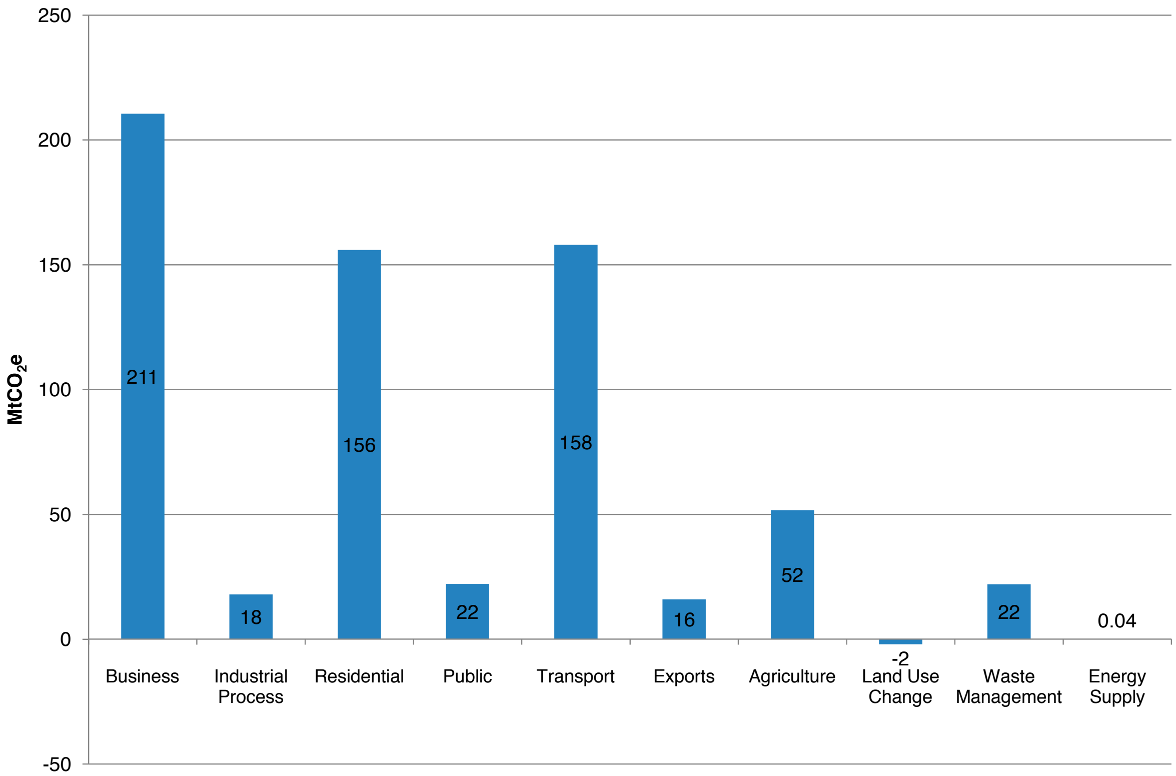
Current UK emissions are shown in Figures 3 and 4. We have assessed the potential to reduce these emissions sector by sector, looking at technical feasibility, at the costs of achieving reductions, and at the policies either in place or required to achieve emissions reductions. In particular, we have considered scope for decarbonising power generation, reducing emissions from energy use in buildings and industry, and reducing emissions from domestic transport.

Figure 3 UK 2006 GHG emissions presented by DECC source sector category



Source: DECC

Figure 4 UK 2006 GHG emissions presented by DECC end use sector category



Source: DECC

Decarbonising the power sector

The UK has a major opportunity to achieve significant progress towards the decarbonisation of electricity generation in the first three budget period. This comes because around a third of UK electricity generation capacity – in particular, coal generation capacity – is scheduled to be retired in the next 15 years. It is important that this opportunity is grasped given the almost full decarbonisation of the power sector required by 2030, and the likely need to apply electricity to an increasing set of activities (e.g. in heat production and transport) to meet the 2050 target.

A range of economically viable low-carbon generation technologies will be available in the first three budget periods:

- The costs of onshore and offshore wind should be accepted given the significant emissions reduction potential that these technologies offer in the first three budget periods, and scope for driving down costs through wider deployment.

- Analysis suggests that nuclear new build is justified on economic grounds in the first three budget periods. If the feasible pace of deployment of wind power is less than currently envisaged in the Government's draft Renewable Energy Strategy, and if concerns about waste storage can be addressed, nuclear power deployment should be accelerated to fill this gap.

- CCS may be demonstrated to be economic towards the end of the first three budget periods. The contribution of CCS during the first three budget periods, however, is likely to be limited given that this technology has not yet been demonstrated at the appropriate scale.

Various policies will be required to support deployment of these technologies. The creation of a clear carbon price signal within the EU ETS over the first three budget periods is a priority for driving electricity sector emission reductions, but additional policy levers will be required:

- The financial support and non-financial (i.e. relating to planning and transmission) policy measures of the draft Renewable Energy Strategy are vital;

- the extension of the EU ETS beyond 2020 is essential to support investment across the range of low-carbon generation technologies;

- and CCS projects to demonstrate this technology at scale are of key importance.

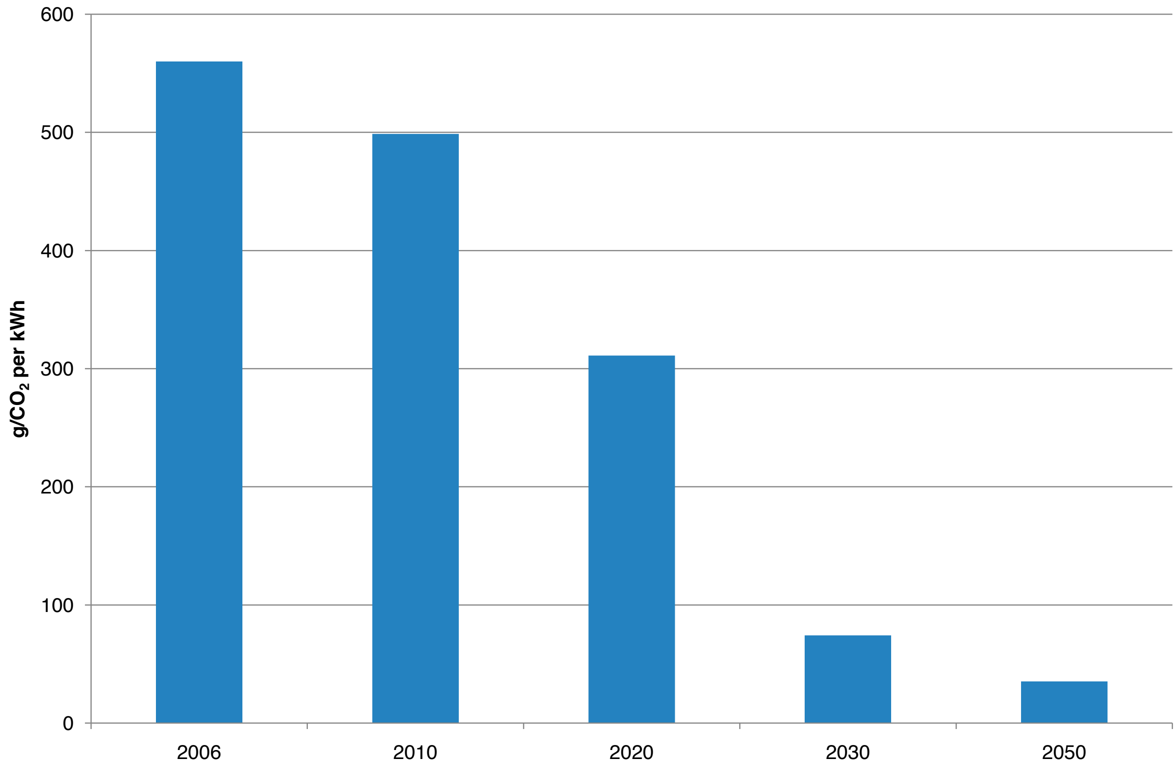
Conventional coal-fired power generation should only be built on the expectation that it will be retrofitted with CCS equipment by the early 2020s. Given reasonable estimates of likely carbon prices in the 2020s, it is unlikely that conventional coal-fired generation will be economic even if no other policy levers are in place. But there is a danger that uncertainties about future carbon prices could result in investments that lock the UK in to carbon intense generating plant. There is therefore a strong case for buttressing the carbon price lever by establishing a clear and publicly stated expectation that coal-fired power stations will not be able to generate unabated beyond the early 2020s.

One way to achieve this would be to establish a requirement that coal-fired power stations cannot be built beyond a certain date without CCS (say 2020), that those built before that date will be given a deadline for retrofitting CCS (say in the period 2020-2025), or that plants which choose not to retrofit should be allowed to generate for a very limited number of hours. Alternatives could be (i) to set emissions standards (i.e. company specific ceilings on the g/kWh emissions from power generation) implying the need for CCS retrofit in the 2020s to any conventional plant added over the next ten years, and ensuring that overall progress towards decarbonisation of electricity was in line with the required path to 2030 and beyond, and (ii) to establish a floor price within the EU ETS. These and other possible options warrant further consideration.

Power sector emissions reductions of 40% below 1990 levels are realistically achievable by 2020. These emissions reductions would result if renewable generation can be increased to 30%

of the total, which would require a similar pace of deployment over the next 12 years to what has been achieved on average in Germany over the last ten years, and a slower pace to that which has been achieved in Spain. Alternatively, a slightly lower level of renewables with some nuclear new build would deliver the same emissions reduction of around 50 $MtCO_2$ in 2020. In either scenario, average carbon intensity would fall by 2020 in line with what is required on the longer term path to full decarbonisation by 2050, shown in Figure 5.

Figure 5 CO_2 intensity per kWh of electricity generated, 2006-2050



Source: CCC

Energy use in buildings and industry

The use of energy is often not subject to the professional management of costs. As a result, there appears to be scope for significant energy efficiency improvement at a cost to the economy and to individuals which is low, nil, or indeed negative (i.e. where upfront investment would be quickly repaid and give a good return). This is particularly true in the residential sector, but also in commercial sectors of the economy where energy costs are a small proportion of total costs. In practice however, there are numerous barriers which prevent theoretically attractive opportunities from being implemented (e.g. due to lack of information, hidden costs, hassle factors, etc.). Conversely there is a wide range of possible options for the micro-generation of electricity which are technically possible but high cost. We make a crucial distinction therefore between theoretical technical potential, cost-effective potential, and realistic potential[1].

Significant emissions cuts through relatively low cost energy efficiency measures in homes are realistically achievable. By 2020:

- In the residential sector there is technical potential to reduce emissions by almost 40$MtCO_2$ through energy efficiency improvement and lifestyle changes. Over half of these reductions would result from measures whose cost is negative or nil, with the remainder achievable at a cost less than our forecast carbon price of £40/tCO_2.

1 Theoretical potential is defined as abatement potential that could be achieved absent any barriers to uptake of measures. Cost-effective potential is abatement potential that costs less per tonne of carbon saved than the projected carbon price. Realistic potential is technical potential adjusted to reflect any barriers to uptake of measures and ways that these might be addressed by the policy framework.

- Our assessment of realistic potential suggests that a reduction of 9-18 $MtCO_2$ could be achieved from existing buildings, with an additional 4 $MtCO_2$ from new buildings.

- Delivering this would, however, require some development of the policy framework to provide stronger incentives under the Supplier Obligation (which requires energy companies to implement energy efficiency measures in the residential sector) and the tightening of appliance standards.

Significant emissions cuts through more expensive renewable heat measures in the residential sector are realistically achievable and should be pursued. The development of renewable heat sources (mainly biomass but also heat pumps) and of micro-generation (solar photovoltaic) could save up to 65 $MtCO_2$ in 2020 but at a much higher cost per tonne saved than for energy efficiency improvements. Our assessment of realistic potential suggests a much lower reduction of up to 10 $MtCO_2$ in 20202. Delivering this potential is desirable in the context of meeting our proposed budgets and 2050 target. It will require development of new policies, in particular to support wider deployment of renewable heat through a range of price and non-price measures.

There is significant scope for cutting emissions in non-residential buildings and industry. By 2020:

- In non-domestic buildings there is technical potential to reduce emissions by 11 $MtCO_2$ through zero or negative cost energy efficiency improvements, of which we believe 5-9 $MtCO_2$ can realistically be saved. In addition, we estimate a realistic potential to save up to 2 $MtCO_2$ via higher cost abatement actions involving renewable heat and micro-generation.

- In industry, there is only limited technical potential (7 $MtCO_2$) to save CO_2 at zero or negative cost, but the majority of this (4-6 $MtCO_2$) should be realistically achievable.

- Over 50% of emissions from commercial buildings and 95% of emissions from industry are covered by strong binding policy levers which will support delivery of emissions reductions. The Committee recommends, however, that new policies should be considered to unlock emissions reductions in those firms currently not covered by these binding levers.

Reducing domestic transport emissions

Deep emissions cuts in road transport can be achieved through improved fuel efficiency of new cars and vans in the first three budget periods. This opportunity arises from the potential intensification of energy efficiency improvement in internal combustion engines and application of a range of non-powertrain measures (e.g. improved aerodynamics), the potential to deploy new technologies (e.g. plug in hybrid and pure electric cars and vans), and from potential changes in purchase behaviour (e.g. encouraging consumers to buy slightly smaller more fuel efficient cars). A robust framework will, however, be required to deliver emissions reduction potential:

- Unlocking the full potential for emissions reductions from cars of up to 12 $MtCO_2$ will require a legally binding EU target that carbon emissions of new cars should be no more than 100 gCO_2/km in 2020, together with ambitious interim targets. Given an EU framework, delivering this in the UK will require a range of domestic policy measures (e.g. awareness raising, fiscal levers).

- Unlocking the full potential of at least 3$MtCO_2$ in vans will require a legally binding framework at the EU level supported by domestic measures.

Significant potential for emissions reductions exists through changed driver behaviour, modal shift and better journey planning. The Committee has not carried out detailed analysis of the opportunity to reduce surface transport emissions via demand side measures (i.e. measures which reduce kilometres travelled or modal shift to less carbon intensive transport [e.g.

rail rather than car]). But indicative estimates suggest a potential to deliver cuts of up to 10 $MtCO_2$ in 2020, if a range of levers (e.g. better information, driver training) are deployed. The Committee will assess the potential for more significant reductions as part of our future work programme.

Reducing emissions of non-CO_2 greenhouse gases

We have identified scope for significant emissions cuts in agriculture and waste:

- **In agriculture,** a preliminary analysis has indentified realistically achievable abatement potential of up to 15 $MtCO_2e$ in 2020 through a range of measures around livestock and soils. These exclude both controversial hi-tech options (e.g. the use of Ionophores) and scope for changed consumer behaviour (e.g. eating less carbon intensive types of meat). Analysis of opportunities in agriculture is at an early stage and the policy framework for delivering abatement is undeveloped. The Committee intends to do further work on this sector and urges the Government to consider the policies available to drive emissions reduction.

- **In waste,** our assessment is that there is around 5 $MtCO_2e$ realistically achievable emissions reduction in 2020 (e.g. through increased levels of Anaerobic Digestion which converts gases from waste to biogas that can be substituted for fossil fuels). There is already a policy framework in place at national and international levels that should unlock at least some of this potential. This could be strengthened through introduction of new policies to support renewable heat, including through the use of biogas from waste.

Economy wide emissions reductions to meet budgets

We have aggregated our sectoral assessments of emissions reduction potential to three economy wide scenarios which we label Current Ambition, Extended Ambition and Stretch Ambition.

- **The Current Ambition scenario** includes identified measures which would cost less per tonne than the forecast carbon price, and/or which are covered by policies already in place; the scenario includes cautious estimates of emissions reductions from these measures. It includes significant progress towards low-carbon electricity generation, and some progress on improving fuel efficiency in new cars.

- **The Extended Ambition scenario** incorporates more ambitious but still reasonable assumptions on the penetration of energy efficiency improvements and a number of measures which would cost appreciably more per tonne of carbon abated than the predicted carbon price, but which are important stepping stones on the path to 2050. It is broadly in line with policies to which the government and/or EU is committed in principle, but where precise definition and implementation of policy is still required. It includes, for instance, a significant penetration of renewable heat, more radical energy efficiency improvement in cars and vans, and some lifestyle changes in homes and transport.

- **The Stretch Ambition scenario** adds further feasible abatement opportunities for which at the moment no policy commitment is in place, including more radical new technology deployment and more significant lifestyle adjustments.

Achieving the emissions reductions in our Extended Ambition scenario would ensure that the UK meets the domestic reductions required in the Interim and Intended budgets. This would be complemented by purchase of offset credits by firms in the EU ETS, and by possible Government purchase of offset credits to achieve the higher emissions reduction needed under the Intended budget. The Stretch Ambition scenario therefore includes measures which could compensate for a shortfall in delivery of measures in the Extended Ambition scenario or which could be pursued as an alternative to the purchase of offset credits.

3. WIDER SOCIAL AND ECONOMIC IMPACTS OF BUDGETS

The Committee is required under the Climate Change Bill to consider a range of wider economic and social impacts from budgets including competitiveness, fuel poverty, security of supply, and differences in circumstances between the regions of the UK; we now briefly consider each of these in turn.

Competitiveness impacts can be mitigated through appropriate design of the policy framework. These impacts are potentially important for a small number of globally competitive energy-intensive industries. Imposing a carbon price on these industries could in principle result in carbon leakage, with relocation of production to other countries. This risk could, however, be mitigated through one of three policies: the introduction of border carbon price adjustments, the free allocation of permits to selected sectors, or the possible future negotiation of global sectoral agreements. The Committee notes that the EC will make a proposal to mitigate the risk of emissions leakage in the context of the revised EU ETS.

Carbon budgets would not undermine sustainability of public finances. There are a number of specific significant fiscal impacts of carbon budgets, some positive and some negative. Revenue from auctioned permits in EU ETS could reach £8 billion by 2020, but losses of fuel duty could amount to £4 billion. Overall the impact may be positive in 2020 but mildly negative in earlier years. This reinforces the importance of progressing as rapidly as possible to auctioning rather than free allocation of EU ETS permits.

Fuel poverty impacts should be addressed through energy efficiency improvement and income transfers or social tariffs. Higher energy prices required to meet carbon budgets will increase the number of fuel poor households (i.e. households who have to spend more than 10% of income to reach a defined minimum level of energy consumption). This impact could be partially offset, however, through energy efficiency improvement amongst fuel poor households, and more fully offset through income transfer or social tariffs. The Committee's view is that fuel poverty impacts should be mitigated, and our analysis suggests that this could be achieved at manageable cost. Further work is required to understand the most appropriate delivery mechanism.

Security of supply impacts from intermittent generation can be managed, and the achievement of a lower carbon economy will provide a hedge against price volatility:

- In principle, the intermittent nature of wind generation could pose issues for security of supply. In practice, this can be managed through having adequate back-up capacity available to increase generation at short notice. Intermittency is therefore an issue of cost rather than security of supply. Issues of market design and incentives may however need to be addressed to ensure that adequate investment in back-up capacity takes place.

- More generally, increasing levels of low-carbon power generation and energy efficiency improvement will reduce exposure to volatile oil and gas prices, and mitigate the risk of sustained high price periods and possible supply interruptions, thus providing economic benefits in addition to climate change benefits.

There is an opportunity to cut emissions in all the nations of the UK, and an important role for national authorities in delivering emissions reductions:

- Significant opportunities exist across all the sectors – power, buildings, industry transport and agriculture – in each of Northern Ireland, Scotland and Wales, but with some variation. National authorities have an important role to play in unlocking this potential given the balance of reserved and devolved powers.

- Wider social and economic effects, notably competitiveness and fuel poverty, are more important in some regions than at the national average level, but as we noted above these potential impacts can be mitigated through appropriate design of the policy framework.

* * *

Deep emissions cuts in the UK are required both over the next fifteen years and in the period out to 2050 as part of a wider global emissions reduction effort. Realistically achievable emissions reductions are sufficient to meet the required objective. And the cost of these emissions cuts is manageable. The challenge now is for the Government to strengthen the policy framework and for individuals and businesses to respond. Meeting this challenge is vital if we are to avoid dangerous climate change and the significant consequences and costs that this would involve.

PART I:

THE 2050 TARGET

We have been asked by the Secretary of State to advise on the UK's 2050 emissions reduction targets; the two chapters in this part of the report set out our recommendations in response to this request and the underpinning analysis.

In **Chapter 1: Setting a 2050 target**, we first consider the 60% emissions reduction target adopted by the UK in the 2003 Energy White Paper in the context of advances in scientific understanding of climate change since that time. We next provide an assessment of damages from climate change and propose a decision rule. We consider a range of possible global emissions reductions in the context of this decision rule, and conclude that global emissions reductions of at least 50% in 2050 are required if risks of dangerous climate change are to be kept at acceptable levels. We argue that a UK emissions reduction of 80% is an appropriate contribution to a 50% global cut.

In **Chapter 2: Meeting a 2050 target**, we set out why we think meeting an 80% target is feasible and affordable. We start with a high level analysis of the technologies likely to be available to deliver new low carbon energy sources and to drive energy efficiency improvements, and draw on analysis from the International Energy Agency which illustrates how these technologies might be combined to deliver global emission cuts of about 50% by 2050. We then summarise the results of detailed modelling of the UK energy system to 2050 which shows that emissions cuts of 80% and above are feasible and affordable at a cost in the range 1-2% of GDP.

CHAPTER 1:

SETTING A 2050 TARGET

Prior to the Climate Change Act the UK Government set an objective to reduce UK CO_2 emissions by at least 60% relative to a 1990 baseline by 2050. The Government asked the Committee to consider whether a more stretching objective should be set and whether the objective should be expressed in terms of CO_2 alone or all Kyoto greenhouse gases[1] (GHGs). This chapter considers what targets are required at a global level to avoid or mitigate harmful climate change, and what would be an appropriate UK share of the global target. Chapter 2: *Meeting a 2050 target* considers the costs entailed in achieving the proposed global and UK targets.

Our conclusion is that the minimum UK 2050 objective should be to achieve a reduction of 80% versus a 1990 baseline, and that the objective should be expressed in terms of the CO_2 equivalent of Kyoto GHGs. Our analysis in Chapter 2 suggests that such an objective is attainable at a manageable economic cost. This UK objective would be a reasonable contribution to a global objective of cutting GHG emissions by 50% or more below current levels. This global objective, with further reduction beyond 2050, would aim to keep central estimates of global average temperature rise by 2100 close to 2°C, and reduce the chances of extreme climate change (e.g. a more than 4°C rise in temperature by 2100) to a very low level. A consequence of even a 2°C rise is that adaptation policies, in the UK and across the world, are essential.

If future scientific analysis suggests that the probability of extreme climate change is higher than presently envisaged, or that the human welfare consequences of climate change are significantly greater than currently assessed, it may be appropriate to increase the reduction objectives further at a later date. Furthermore, if emissions grow at a faster rate or emissions peak later than we have assumed then the world will have to make more stringent emission cuts to meet our climate objectives.

The evidence and arguments which support these recommendations are set out in the following sections.

1. Developments since the Royal Commission on Environmental Pollution (RCEP) proposed the 60% objective in their 2000 report.

2. Our approach to setting objectives.

3. Setting a global climate objective.

4. Setting global emissions reduction objectives.

5. Appropriate UK contribution to the global target.

6. Responding to developments in science and future emissions growth: possible future adjustments to objectives.

As background to the chapter, Box 1.1 opposite explains the differences between alternative figures for emissions used in this and other reports.

1. Kyoto GHGs are the major long-lived greenhouse gases covered by the Kyoto Protocol: carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, hydrofluorocarbons and perfluorocarbons. Other shorter-lived agents arising from human activity also affect climate, such as ozone and aerosols

Box 1.1 Types of emissions and data sources

GHG emission figures can vary considerably because of differences in the sectors covered, gases included and as a result of measurement uncertainties. Major emissions databases include the Global Carbon Project (http://www.globalcarbonproject.org), the Climate Analysis Indicators Tool (CAIT, http://cait.wri.org) and the Emissions Database for Global Atmospheric Research (EDGAR, http://www.mnp.nl/edgar/). These draw on source material covering four main types of emissions:

- **CO_2 emissions from fossil fuel use.** Arising from the use of fuels such as coal, oil and natural gas, emission estimates are reasonably consistent and up-to-date across a range of sources including the International Energy Agency (IEA), the US Energy Information Administration (EIA), and the Carbon Dioxide Information Analysis Center (CDIAC) at the US Department of Energy.
- **CO_2 emissions from other industrial processes**. Various industrial activities (aside from fossil fuel use) involve emission of CO_2, such as cement production. Estimates of these emissions are also available from CDIAC.
- **CO_2 emissions relating to land-use**. Forests and soils around the world represent a huge natural stock of carbon. As large areas are being deforested and used as agricultural or urban land, this stock is decreasing and adding to net CO_2 emissions. Measurement of the global flux of CO_2 from these activities is difficult and is a large source of emissions uncertainty. Estimates are widely based on a study by Houghton covering the 1980s to 1990s[2], however another study by DeFries et al.[3] suggests land-use emissions less than half of these values. The Intergovernmental Panel on Climate Change (IPCC) uses the mean of the two studies[4].
- **Kyoto GHG emissions**. The Kyoto Protocol covers emissions of CO_2 along with other major long-lived GHGs emitted from a range of activities: methane, nitrous oxide, sulphur hexafluoride, hydrofluorocarbons and perfluorocarbons. Countries participating in the UNFCCC process submit official figures for these emissions, but records only extend back to 1990 and many countries have never submitted national communications. Uncertainties in global emissions of these non-CO_2 GHGs are thought to be potentially very large.

2 Houghton, R. A. (2003) *Emissions (and Sinks) of Carbon from Land-Use Change*. Report to the World Resources Institute from the Woods Hole Research Center.
3 DeFries, R.S., et al. (2002) Carbon emissions from tropical deforestation and regrowth based on satellite observations for the 1980s and 1990s. *Proc. Natl. Acad. Sci. U.S.A.*, 99 (22), 14256–14261.
4 Solomon, S., et al. (eds.) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK, Cambridge University Press. p518.

1. DEVELOPMENTS SINCE THE RCEP PROPOSED THE 60% OBJECTIVE

The UK's objective of a 60% reduction by 2050 was proposed by the RCEP in its report 'Energy– the changing climate' published in 2000. RCEP proposed that the global objective should be to prevent the concentration of CO_2 in the atmosphere exceeding 550 parts per million (ppm), and it believed that a UK cut of 60% was a reasonable UK contribution to this global objective. It referred to modelling results which suggested that a 550ppm target was compatible with a global mean temperature increase (versus pre-industrial levels) of 2.3°C by 2100 and 2.9°C by 2200.

Since the Commission's report, however, developments in climate science suggest the need for a significantly tighter global objective, whilst trends in emissions and concentrations suggest the need for earlier and more radical action by the developed world in particular.

- **Developments in climate science** over the last decade have increased awareness of the danger of severe and self reinforcing climate change.
  - Work on the carbon cycle in particular has highlighted the danger that global warming will reduce the rate of absorption of atmospheric CO_2 by terrestrial carbon sinks, such as forests, and the oceans. These currently absorb around half of all manmade CO_2 emissions[5]. However, as temperatures increase, the effectiveness of sinks is predicted to decline. For any given level of manmade emissions, this would result in a higher long-term increase in CO_2 concentrations and hence temperatures.
  - Increasingly models have looked at the warming caused by all GHGs, including non-CO_2 gases. The RCEP reported results were based on CO_2 only. These suggested that 550ppm of CO_2 alone would produce an eventual global mean temperature increase of around 2.9°C. The latest Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) shows that this CO_2 concentration, if taken as a CO_2-only target, would produce an increase of about 4°C when the impact of other GHGs is taken into account (Table 1.1).
  - It is now realised that atmospheric pollution is likely to have masked about 0.3°C to 0.5°C of the GHG warming that would otherwise have occurred this century[6]. As GHG concentrations continue to rise but air quality improves, so even more warming can be expected.
  - The reduction in the summer Arctic sea ice in recent years has been at the high end of model predictions. Also the summer melt of the Greenland ice sheet has accelerated. These observations have led to new concerns about the pace of climate change, particularly as it affects Arctic ecosystems, possible methane release from melting permafrost and high rates of sea level rise.
  - There is now a greater understanding of the range of potential climate change impacts, their regional variation and the possibility of abrupt or irreversible changes (Box 1.2). Local climate systems will be affected in different ways depending on a range of factors such as changing temperatures, precipitation patterns, sea level rise, extreme weather events, deglaciation and ocean acidification. The poorest regions will be most affected by climate change, in part because of low adaptive capacity. Aggregate market studies have suggested that the potential beneficial effects of small temperature increases in some temperate zone countries will exhaust at lower temperature increases than previously estimated. These analyses also suggest greater damage once temperature increases become significant.

---

5 Solomon, S., et al. (eds.) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK, Cambridge University Press. p516.

6 Stott, P.A., et al. (2006) Observational constraints on past attributable warming and predictions of future global warming. *J. Clim.*, 19, 3055–3069.

Table 1.1 Classification of recent stabilisation scenarios according to different concentration targets

CO_2 concentration (ppm)	CO_2e concentration (ppm)	Global mean temperature increase above pre-industrial at equilibrium (°C), using "best estimate climate sensitivity"	Peaking year for CO_2 emissions	Change in global CO_2 emissions in 2050 (% of 2000 emissions)	No. of assessed scenarios
350-400	445-490	2.0-2.4	2000-2015	-85 to -50	6
400-440	490-535	2.4-2.8	2000-2020	-60 to -30	18
440-485	535-590	2.8-3.2	2010-2030	-30 to +5	21
485-570	590-710	3.2-4.0	2020-2060	+10 to +60	118
570-660	710-855	4.0-4.9	2050-2080	+25 to +85	9
660-790	855-1130	4.9-6.1	2060-2090	+90 to +140	5

Source: Adapted from IPPC Working Group III Fourth Assessment Table 3.5
Note: Equilibrium temperatures assume a climate sensitivity of 3°C and are different from expected global mean temperatures in 2100 due to the inertia in the climate system.

Box 1.2 Update of the IPCC's 'Reasons for Concern'

The IPCC's 'Reasons for Concern' were first published in its Third Assessment Report (TAR), 2001. Since then, the trend of developments in scientific understanding suggests the need for a more ambitious global objective. An update by the IPCC notes the following conclusions:

- There is new and stronger evidence of observed impacts of climate change on unique and vulnerable systems, with increasing levels of adverse impacts as temperatures increase.
- There is new evidence that observed climate change is likely to have already increased the risk of certain extreme events such as heatwaves, and it is more likely than not that warming has contributed to the intensification of some tropical cyclones, with increasing levels of adverse impacts as temperatures increase.
- The distribution of impacts and vulnerabilities is still considered to be uneven, and low-latitude, less-developed areas are generally at greatest risk due to both higher sensitivity and lower adaptive capacity; but there is new evidence that vulnerability to climate change is also highly variable within countries, including developed countries.
- There is some evidence that initial net market benefits from climate change will peak at a lower magnitude and sooner than was assumed for the TAR, and it is likely that there will be higher damages for larger magnitudes of global mean temperature increases than was estimated in the TAR.
- The literature offers more specific guidance on possible thresholds for initiating partial or near-complete deglaciation of the Greenland and West Antarctic ice sheets.

Source: IPCC Working Group III Fourth Assessment (2007) p781

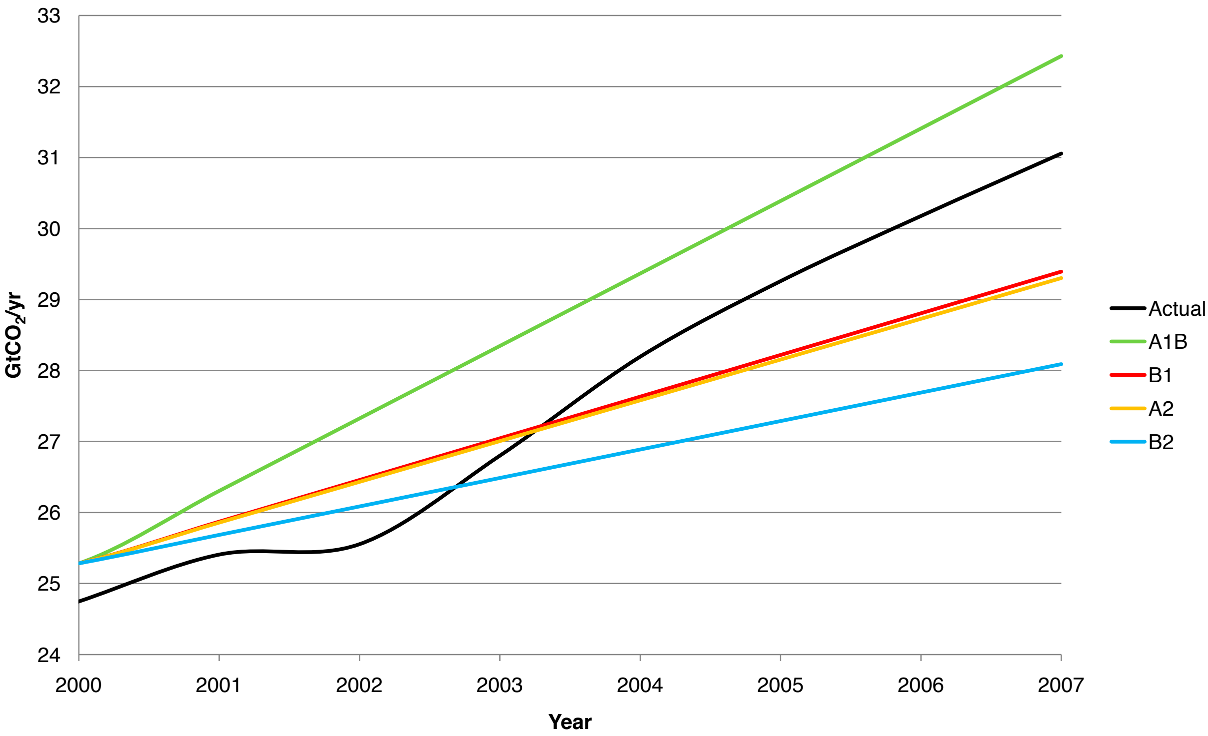
The implication of recent developments in climate science and in the analysis of potential impacts is that the whole world should now be aiming for lower levels of GHG emissions in 2050 than previously seemed appropriate. In addition:

- Latest emission and concentration trends show significant increases. The growth rate of fossil fuel-based CO_2 emissions has increased from around 1% per annum in the 1990s to over 3% per annum during 2000-2006[7]. This reflects the acceleration of global economic growth, averaging 2.4% in the 1990s but 3% from 2000 to 2007, driven in particular by the growth of China and India. Growth has also become more carbon intensive[8] as China in particular has developed heavy industry and built coal-based electricity generation capacity. As a result, CO_2 emissions have been at the top end of the range of scenarios the IPCC considered (Figure 1.1) and concentrations of CO_2 in the atmosphere have continued to grow (Figure 1.2).

The implication of the latest trends in emissions and concentrations is that more radical reduction is needed, and sooner, to achieve climate targets. Developed countries can no longer design their mid-century targets on the assumption that a large proportion of the world will continue to emit per capita far lower levels. More radical developed country targets need to be combined with agreements which also commit developing countries to limit their emissions.

There is therefore a very strong case for the UK to adopt a significantly more stretching target than seemed appropriate when the 60% objective was initially proposed.

Figure 1.1 Global carbon dioxide emissions (excluding those relating to land-use) compared to the scenarios included in the IPCC Special Report on Emissions Scenarios (2000)

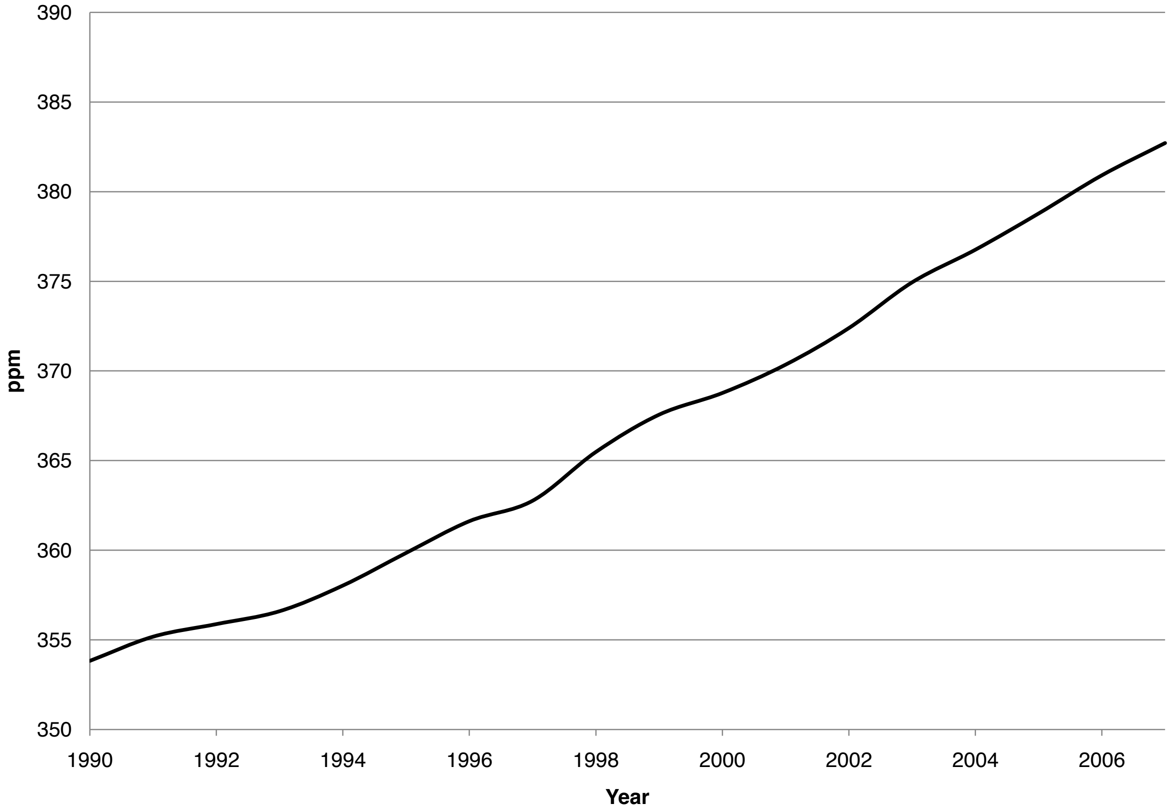


Source: IPCC Special Report on Emissions Scenarios (2000) and Global Carbon Project. Errors around actual emissions are about 5%.

7 Canadell, J. G., et al. (2007) From the cover: contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks. *Proc. Natl*. Acad. Sci. U.S.A., 104, 18866–18870.

8 Raupach, M. R., et al. (2007) Global and regional drivers of accelerating CO_2 emissions. *Proc. Natl*. Acad. Sci. U.S.A., 104, 10288–10293.

Figure 1.2 Global annual averages of atmospheric CO_2 concentration in parts per million (ppm).



Source: NOAA/ESRL (www.esrl.noaa.gov/gmd/ccgg/trends/)

2. OUR APPROACH TO SETTING OBJECTIVES

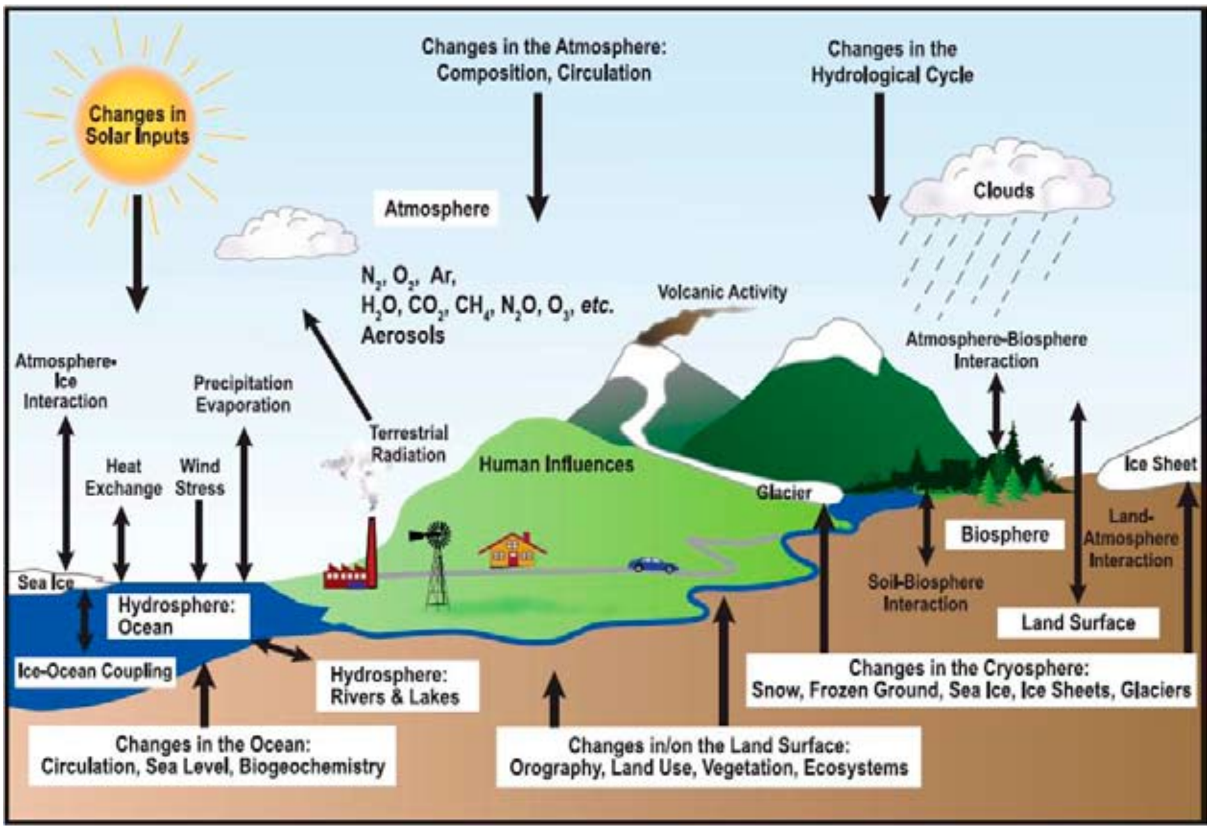
The ultimate aim of global climate policy is to avoid harmful impacts on human welfare which could arise from an increase in global mean temperature and associated changes in regional climates around the world. Global mean temperatures are being strongly increased by manmade emissions. In setting a global emissions target, we therefore have to reach a judgement on the trade-off between the economic costs of reducing emissions and the harmful welfare costs arising from climate impacts caused by further emissions.

The challenge is that the relationship between emissions and impacts is determined by a number of complex climate mechanisms. Three complexities in particular need to be recognised.

- **Feedback loops within the climate system**. The climate system consists of a number of interacting processes which climate models attempt to incorporate in their future projections (Figure 1.3). As GHG concentrations cause temperatures to rise, feedbacks are generated which amplify the initial warming. Climate processes which cause an overall feedback can be divided into two categories:
  - Those that determine the overall temperature response to a given increase in GHG concentrations. Three main processes play a role here. First are atmospheric changes, where warming alters the temperature structure of the air allowing it to carry more water vapour, itself a potent GHG. Second are changes to cloud processes, and third is the melting of snow and ice causing the Earth's surface to become less reflective and thus absorb more heat. The overall strength of this temperature feedback is often measured as 'climate sensitivity'.
  - Those that further alter GHG concentrations in response to climate change. In particular, carbon cycle feedbacks are likely to add to CO_2 concentrations and have been incorporated into the latest model projections as mentioned in Section 1.

  Current uncertainties in all the above processes, along with the natural variability of the climate system, give rise to differences in the exact degree of warming projected by models. Additionally, other feedback processes have been suggested such as release of natural methane stores from northern wetlands or (more speculatively) from oceans, but are less certain and so are not currently incorporated. It is therefore possible as temperatures rise that the climate system could show new and altered feedback processes, not included in current model projections, which could make it more difficult to stabilise concentrations and temperatures.

Figure 1.3 Schematic of climate system components



Source: IPCC Working Group I Fourth Assessment FAQ 1.2 Figure 1.

Note: An increasing number of these components are being added to climate models as interactive features, some of which have a major influence on global average temperatures. In particular, clouds, ice, atmospheric temperature structure and water vapour content all play a role in determining the warming due to an increase in GHG concentrations from human activities. The carbon cycle, which helps regulate atmospheric GHG concentrations, involves interactions of the land, biosphere and ocean with the atmosphere. Volcanic activity exerts an occasional climate cooling.

- **Potential climate system irreversibilities**: Beyond certain thresholds, the global climate system may trigger changes which, while not necessarily feeding back strongly into increased global mean temperature, could be irreversible (at least for centuries or millennia) and which could have huge regional climate or human welfare effects. There are good scientific reasons to believe, for example, that beyond some temperature thresholds the Greenland and West Antarctic ice sheets will commence irreversible melting. These would, after centuries, eventually increase global sea level by up to 12m. Beyond some level, the pattern of major ocean currents (the meridional overturning circulation) could change dramatically with huge implications for regional climate (e.g. much less warm in northern Europe and warmer in the South Atlantic and the Tropics) even in the absence of further global temperature increases. A range of other potentially irreversible changes has been suggested[9]. There are, therefore, levels of climate change which the world should seek with very high probability to avoid, but it is very hard to predict where the thresholds for many of these irreversible events lie.

9 Lenton, T. M., et al. (2008) Tipping elements in the Earth's climate system. *Proc. Natl. Acad. Sci. U.S.A.*, 105 (6), 1786-1793.

- **Nonlinear and regional effects on human welfare:** The impacts of climate change on human welfare are not simply related to global mean temperature increase but depend on important consequences such as extreme weather events, regional sea level rise, precipitation and rates of change. As global temperature rises, harmful human welfare effects are likely to increase. But the relationship of adverse human welfare effects to regional changes is highly likely to be strongly 'non-linear' for example a 4°C rise is highly likely to be much more than twice as harmful as a 2°C rise. A relatively small rise in global temperature (e.g. 1°C) is likely to be manageable with adaptation efforts in most regions, and indeed it is possible that in some temperate regions the human welfare effects of small increases could be positive. Once higher increases are experienced, positive effects are likely to disappear and negative effects to accelerate, with the potential to adapt declining as temperatures increase. Furthermore, the poorest regions will be most affected by climate change. Several developing countries in Africa and South Asia are likely to be hit especially hard in part because of low adaptive capacity. This raises significant equity issues, especially since these regions are not responsible for the bulk of historic emissions.

In order to establish an emissions reduction target we need to judge what level of global mean temperature increase should be seen as 'dangerous' and therefore ideally avoided, and what level is so dangerous that it must be avoided with very high probability: Section 3 provides the rationale for this judgement which needs to reflect consideration of potential climate irreversibilities and non-linear human welfare impacts. In addition we need to assess estimated probability distributions of the temperature rise for different emission reduction trajectories: Section 4 presents an analysis of these distributions which rests on modelling the complex feedback loops within the climate system. A key judgement to be made is how low to define the acceptable probability of 'dangerous' and of 'extremely dangerous' climate change.

Two final features of our approach should be noted.

- A focus on all GHGs not CO_2 alone. When considering the long-term aim of global climate change mitigation, all GHGs are important, since all play a role in driving climate change. We therefore believe that long-term global policy objectives, and the UK's 2050 objective, should be expressed in terms of all Kyoto GHGs not CO_2 alone. The separate issue of how short- and medium-term budgets should deal with non-CO_2 GHGs is addressed in Chapter 9: *Non-CO_2 greenhouse gases.*

- A focus on temperature impacts by 2100, and use of the 'versus pre-industrial average' convention.

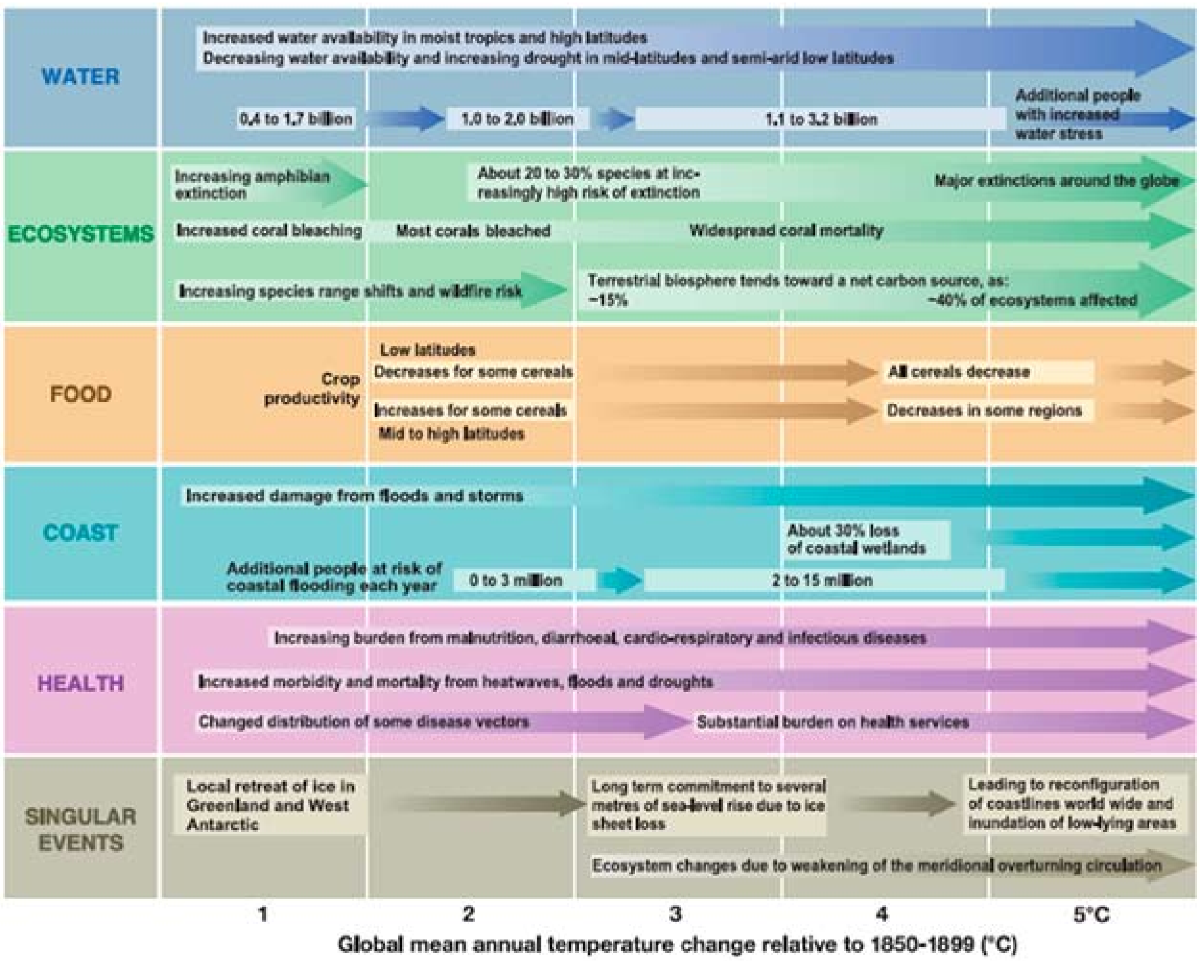
  – The global mean temperature impact of manmade emissions will continue and increase over a very long time. Even if concentrations of GHGs in the atmosphere were stabilised by 2050 or 2100, global mean temperature would take many decades to approach a new equilibrium. Beyond 2100, however, uncertainties about the long-term behaviour of the climate system, and the ability of the human race to adapt or to manage climate change by means yet unknown, are huge. We have therefore chosen to focus our analysis on possible temperature increases by 2100, rather than on stabilised concentrations and final equilibrium temperatures. Some additional warming is likely to occur after 2100; however this will be much less pronounced for trajectories with stronger emissions reduction this century.

  – The other presentational choice that needs to be made relates to the base year for defining temperature increases. Figures used in reports on climate change often switch between expressing temperature increase versus the pre-industrial average, versus a 1960-90 average, versus 1980-2000, or 1990-2000. There is no correct approach, but there is a value in consistency. We have therefore chosen to express temperature change figures versus the pre-industrial average, and where we have used figures or data drawn from, for instance, IPCC reports, we have when necessary adjusted the scale to allow this consistent approach.

3. SETTING A GLOBAL CLIMATE OBJECTIVE

This section considers desirable global temperature objectives expressed as a maximum degree Celsius rise by 2100 versus pre-industrial levels. Our conclusion is that ideally global policy should seek to avoid a mean global temperature rise of more than 2°C. Given emissions and concentration increases which have already occurred, and given the uncertain relationship between emission levels and temperature increases, however, it is not now possible to ensure with high likelihood that a temperature rise of more than 2°C is avoided. There is a significant probability that the world will enter the danger zone of increasing human welfare impact. We therefore recommend that the objective should be to limit our central expectation of temperature rise to 2°C, or as close as possible. In addition we propose an additional rule which is to reduce the risk of extremely dangerous climate change to very low levels (e.g. less than 1%). We have made the judgement that 4ºC this century would be this 'extreme danger' threshold.

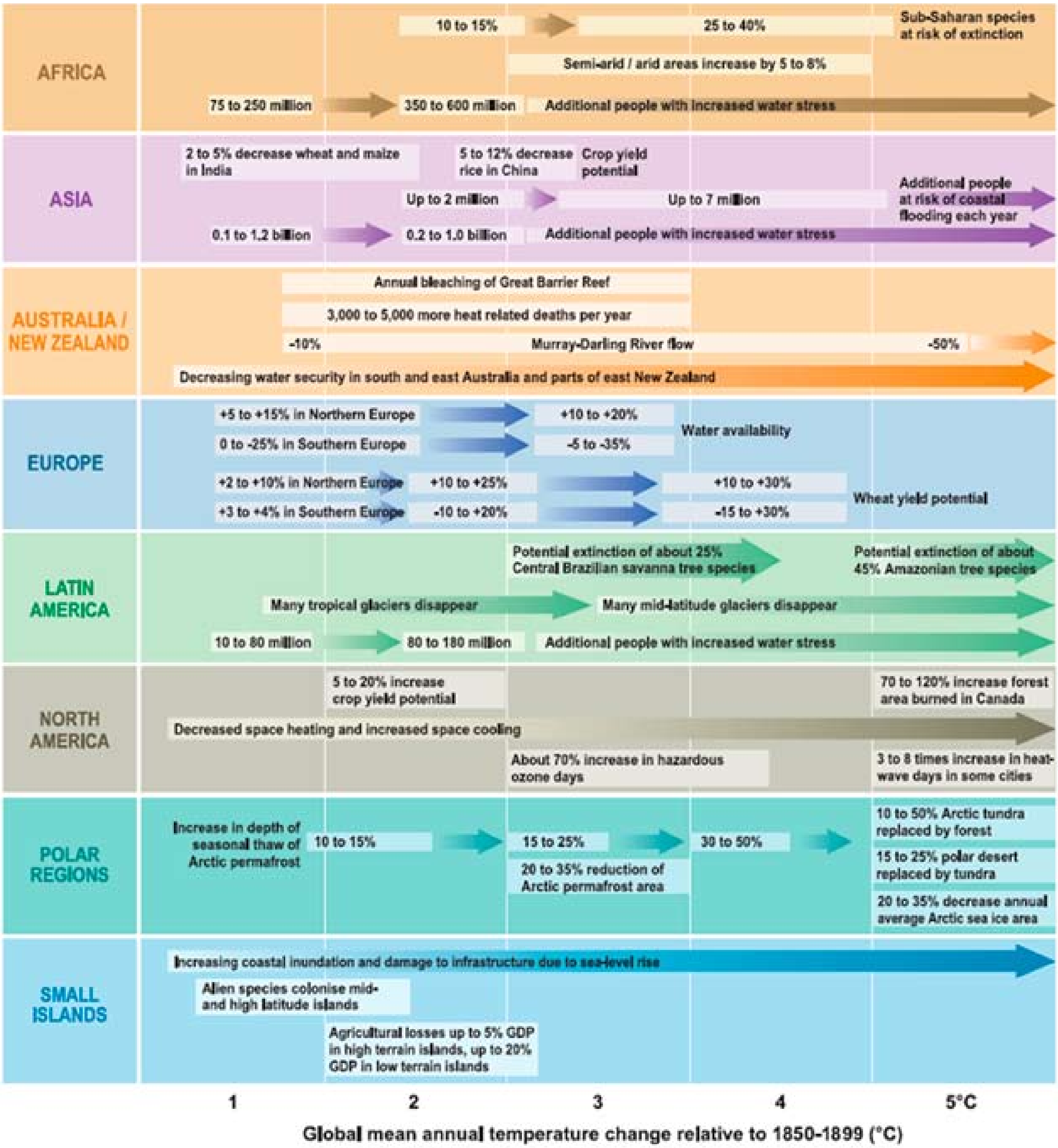
Figure 1.4 Examples of global impacts projected for changes in climate (and sea level and atmospheric CO_2 where relevant) associated with increases in global average surface temperature in the 21st century.



Source: Redrawn from IPCC Working Group II Fourth Assessment (2007) Table 20.8. Temperature increases are taken relative to 1850-1899; to convert to changes relative to 1980-2000, subtract 0.5°C.

Note: Edges of boxes and placing of text indicate the range of temperature change to which the impacts relate. Arrows between boxes indicate increasing levels of impacts between estimations. Other arrows indicate trends in impacts. All entries for water stress and flooding represent additional impacts of climate change relative to the conditions projected across the range of SRES scenarios A1FI, A2, B1 and B2.

Figure 1.5 Examples of regional impacts



Source: Redrawn from IPCC Working Group II Fourth Assessment (2007) Table 20.9

Our conclusions draw on the analysis of the IPCC Fourth Assessment report on 'Impacts, adaptation and vulnerability", which sought to identify how ecosystem and human welfare detriments will increase as a result of climate change. This analysis does not point to one specific danger point, but it does suggest a range of increasingly harmful effects, along with some severe regional consequences and elevated probabilities of irreversible shifts, as temperatures rise. Summary figures presented by the IPCC illustrate the overall picture of risks, accounting for the range of possible future socioeconomic trends and assuming no adaptation (Figures 1.4 and 1.5).

The impacts are considered along six different dimensions.

- **Water**: Climate change is likely to amplify precipitation patterns around the world, so that wet regions will generally get wetter and dry regions drier. The combination of these changes with a growing world population will lead to more people suffering water shortages, with a projected 1 to 2 billion people at risk for a warming of around 2°C. In addition, precipitation is projected to become more variable so that longer droughts will be interspersed with heavier rainfall. This means that even if average water availability does not change, it could become more difficult to manage water resources and flood risks will increase, especially in river basins where up to 20% of the world's population live. Warming will also lead to retreating glaciers and reduced snow cover in mountain regions, sources which are currently relied on for freshwater by over one-sixth of the world's population. Areas particularly at risk of water stress include Southern Africa, the Andes, Asia, Australia, Mediterranean Europe and Western USA.

- **Ecosystems**: Extinctions of species are of particular concern because they are irreversible. Many ecosystems are facing a range of pressures due to human activity, with climate change a contributing factor[10]. However, as a direct result of climate change, 20% to 30% of plant and animal species assessed so far would face a 'commitment to extinction'[11] for a temperature rise of 2°C to 3°C. Further increases in warming could lead to major loss of species. Systems at particular risk include tundra, mountain and Mediterranean-type systems, mangroves and coral reefs, all with significant knock-on consequences. As an example, coral reefs are home to around a quarter of marine species, making them important for biodiversity, tourism, shoreline protection and a critical protein source in the developing world. Reef mortality is closely linked to rising ocean temperatures, with the Great Barrier Reef and Caribbean reefs predicted to be bleached and overrun with algae within a few decades. Recent attention has also been given to ocean acidification, which occurs as a direct result of increased atmospheric CO_2 concentrations. Acidification is expected to make it more difficult for marine organisms to form shells, with negative consequences across the food chain.

- **Food**: The impacts of climate change on crop production are projected to differ markedly by region. Positive impacts for food supply in temperate zones could be experienced as a result of increasing CO_2 concentrations and local warming of about 1°C to 3°C depending on the crop. In low latitudes, however, where the climate is seasonally dry and a high fraction of GDP depends on agriculture, falling productivity is likely even for very low global temperature increases. Beyond a global average 3°C increase, world food production is projected to fall. Increased flooding and drought is also likely to put crops at risk. Areas facing a particular threat to food security and income include Africa, Asia and Latin America. Continued changes to the distribution of fish species are expected to have adverse impacts on fisheries.

- **Coasts**: Large settlements and concentrations of infrastructure are often situated on coasts, such as those on the Eastern seaboard of the US or the mega-deltas of Bangladesh and Eastern China. Many small islands are also very exposed to changes in sea level. The IPCC estimated global average sea level rise of up to 59cm above 1980-1999 levels by the end of this century, based on model results which did not include possible rapid melting of large ice sheets in Greenland and West Antarctica. This would lead to heightened risk of inundation during storms, and freshwater supplies becoming increasingly contaminated with salt. Up to 3 million people could be at risk of coastal flooding for a 2°C global temperature rise, depending on the rate at which coastal populations continue to increase and the level of adaptation that occurs, with poor communities more exposed through their limited adaptive capacity. More recently, other studies have suggested that a global rise of 1.6±0.8m by 2100 may be more realistic[12,13].

10 Reid, W. V., et al. (2005) Ecosystems and Human Well-being: Synthesis. In: *Millennium Ecosystem Assessment*. Washington DC, Island Press. pp14-17

11 'Commitment to extinction' denotes the long-term inability of a species to sustain itself, due to changes in its current habitat and a lack of suitable adjoining habitats to which the species can migrate.

12 Rohling, E. J. (2008) High rates of sea-level rise during the last interglacial period. *Nat. Geosci.*, 1, 38-42.

13 Pfeffer, W. T., et al. (2008) Kinematic constraints on glacier contributions to 21st-century sea-level rise. *Science*, 321(5984), 1340-1343.

- **Health**: Despite some benefits, such as fewer deaths from cold exposure, climate change is likely to have a net negative impact on human health. Increases in deaths, diseases and injuries from heatwaves, floods, storms, fires and droughts are predicted, as well as problems associated with poorer air quality in urban areas. Reduction in crop productivity in low latitudes will increase levels of malnutrition. Changes to temperature and rainfall patterns will alter ranges of infectious diseases, which will become less prevalent in some areas and more so in others. For example, 39-62 million more people in Africa could be exposed to malaria for a global rise of 2.5°C to 3.5°C[14]. Overall health impacts will be critically dependent on available levels of education, healthcare and infrastructure, however climate change will make it harder for the Millennium Development Goals to be attained.

- **Singular events**: Rather than steadily varying impacts, these are major shifts in the Earth system which may occur past some threshold and which may be effectively irreversible. The possible melting of the Greenland and West Antarctic ice sheets are good examples of this. Models suggest that Greenland could start irreversible melting as a result of sustained global warming of 1.9°C to 4.6°C. Factors governing melting of the West Antarctic ice sheet are less well understood, and recent observations have shown rapid local losses from both ice sheets, highlighting the inadequacy of current models. If significant melting were to occur, the resulting sea level rise would be very slow (taking several centuries to reach equilibrium, as with the rise from warming oceans) but could be up to 12m for complete deglaciation.

Specific regions are likely to experience a combination of impacts leading to a threshold for dangerous change which may be different from the global average. For example, the record losses of Arctic summer sea ice are occurring faster than predicted by most IPCC models[15]. As well as causing further local warming and melting by making the region less reflective to sunlight, these ice losses put many species at risk, including marine birds and polar bears, as well as indigenous human cultures. Many ecosystems in mountain regions are also at particular risk to a low level of warming, because this will push the habitable zone to higher and higher altitudes until land area runs out. Another region which could experience a critical limit is Amazonia, where rainforest could be replaced by savannah through drought and wildfires. The Amazon is the world's largest tropical forest, currently acting as a net absorber of atmospheric CO_2 on the scale of around 370-1400 megatonnes of CO_2 per year ($MtCO_2$), and is home to about 20% of the world's species[16]. A temperature rise beyond 3°C to 4°C could, according to some estimates[17], alter the local climate enough to prompt large parts of the forest to die back, turning the region into a net carbon source. Despite this regional complexity, the IPCC draws some general conclusions, shown in Box 1.3.

14 Tanser, F.C., et al. (2003) Potential effect of climate change on malaria transmission in Africa. *Lancet Infect*. Dis., 362, 1792-1798.
15 Stroeve, J., et al. (2007) Arctic sea ice decline: faster than forecast. *Geophys. Res. Lett.*, 34, L09501.
16 Parry, M. L., et al. (eds.) *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK, Cambridge University Press. p604.
17 Lenton, T. M., et al. (2008) Tipping elements in the Earth's climate system. *Proc. Natl. Acad. Sci. U.S.A.*, 105 (6), 1786-1793.

Box 1.3 Summary conclusions of an IPCC assessment of key vulnerabilities to climate change

- Some observed key impacts have been at least partly attributed to anthropogenic climate change. Among these are increases in human mortality, loss of glaciers, and increases in the frequency and/or intensity of extreme events.
- Global mean temperature changes of up to 2°C above 1990-2000 levels would exacerbate current key impacts, such as those listed above, and trigger others such as reduced food security in many low-latitude nations. At the same time, some systems such as global agricultural productivity could benefit.
- Global mean temperature changes of 2°C to 4°C above 1990-2000 levels would result in an increasing number of key impacts at all scales, such as widespread losses of biodiversity, decreasing global agricultural productivity and commitment to widespread deglaciation of Greenland and West Antarctic ice sheets.
- Global mean temperature changes greater than 4°C above 1990-2000 levels would lead to major increases in vulnerability, exceeding the adaptive capacity of many systems.

Source: IPCC Working Group II Fourth Assessment (2007) p781

Note: Pre Industrial global average temperatures were 0.6°C below 1990-2000 level

What none of this analysis can provide is a definitive and obvious maximum temperature target. But the Committee believes that a reasonable judgement, looking at this evidence, is that the global danger zone starts above about 2°C, and that global policy should aim to keep central estimates of temperature increases below this danger zone. However, it is no longer possible with certainty, or even with high probability, to avoid this danger zone. Average mean global temperature is already about 0.8°C above pre-industrial levels[18], and even if concentrations of GHGs could be fixed at 2005 levels, the world could be committed to a long-term eventual warming of 2.4ºC (1.4ºC to 4.3ºC)[19]. The world therefore needs to plan strategies for adaptation to temperature increases of at least 2ºC. But it should also, we believe, aim to reduce to very low levels (e.g. less than 1%) the dangers of exceeding 4°C.

The consequences of such a rule for required global emission trajectories are considered in Section 4. In Section 6 we consider how objectives of this sort, and the related emission targets, should be adjusted in the light of new information becoming available over time.

18 Solomon, S., et al. (eds.) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK, Cambridge University Press. p36

19 Ramanathan, V. & Feng, Y. (2008) On avoiding dangerous anthropogenic interference with the climate system: Formidable challenges ahead. *Proc. Natl. Acad. Sci. U.S.A.*, 105 (38), 14245-14250.

4. SETTING GLOBAL EMISSIONS REDUCTION OBJECTIVES

Given the above climate targets, we need to consider a range of specific GHG emissions trajectories defined by the different emission levels each year, and estimate possible resulting temperature increases. In using these to design appropriate global policy it is important to note that the temperature increase by 2100 is primarily a function of the total emissions over the period, rather than the level of emissions in 2050 alone.

The number of different emissions scenarios which could be modelled is infinite. We therefore need to choose a manageable number of trajectories which together cover the range of likely desirable policies. We do this by varying three parameters: the year at which we assume that global emissions peak, the pace of emissions reduction achievable thereafter, and the ultimate emissions floor. In each case the path of emissions before peaking is assumed to follow a baseline scenario. CO_2 emissions include those relating to land-use as well as those from fossil fuels and industrial processes, and emissions of other relevant gases are also accounted for (see the Technical Appendix for further details). We have analysed eight trajectories.

- Trajectories with global emissions peaking in 2028, and with subsequent reductions in total CO_2 emissions of 1.5% per annum, 2% per annum, and 3% per annum (these are labelled trajectory 2028:1.5%, 2028:2%, and 2028:3%). Other GHGs are reduced at consistent rates (Figure 1.6).

- Trajectories with global emissions peaking in 2016 and with subsequent reductions in total CO_2 emissions of 1.5%, 2%, 3%, and 4% (labelled 2016:1.5%, 2016:2%, 2016:3%, 2016:3%low, and 2016:4%low[20]). Other GHGs are reduced at consistent rates (Figure 1.7).

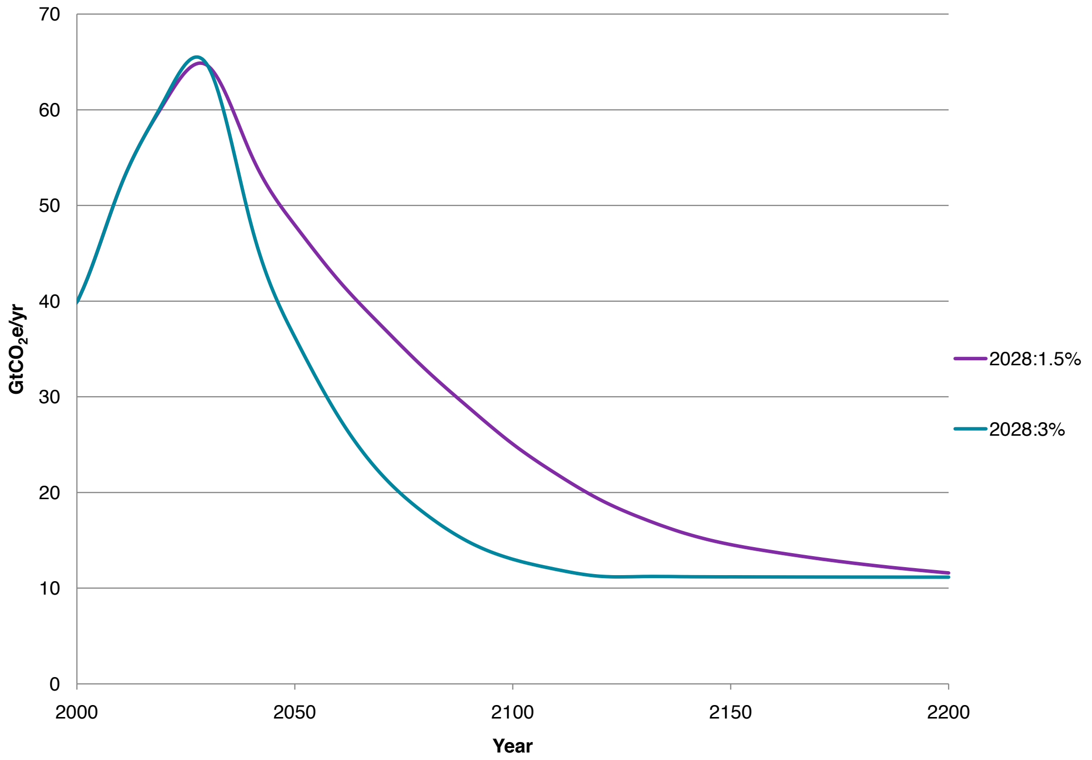
The Committee has drawn on model analysis to estimate probability distributions of temperature increases for each trajectory[21]. Results suggest that a trajectory peaking around 2016 and with a subsequent emission reduction rate of 3% or more is required to meet the climate objectives we set out in Section 3 above.

- **Trajectories with emissions peaking in 2028**: None of the three trajectories considered here would keep atmospheric GHG concentrations below 550ppm of CO_2 equivalent by the end of the century, according to central model estimates (Figure 1.8), and all would give a global average warming of 2.5-2.8°C this century. Even the most aggressive subsequent annual reduction rate of 3% would leave a 3% chance of exceeding a severely dangerous 4°C (Figure 1.9). We do not therefore believe that a global policy which leaves emissions peaking as late as 2028 is adequate.

- **Trajectories with emissions peaking in 2016**: Here all the trajectories except a 1.5% annual reduction after 2016 would keep concentrations below 550ppm of CO_2 equivalent, according to central model estimates (Figure 1.10). Only reductions at 3% or 4% per year would limit the chance of reaching 4ºC to very low levels, with central model estimates indicating a 2.2°C temperature rise this century from the 2016:3% trajectories, and a 2.1°C rise from 2016:4% low. Even in these cases it should be noted that the chances of exceeding 2°C by 2100 would be 63% and 56% respectively, according to our model distributions (Figure 1.11).

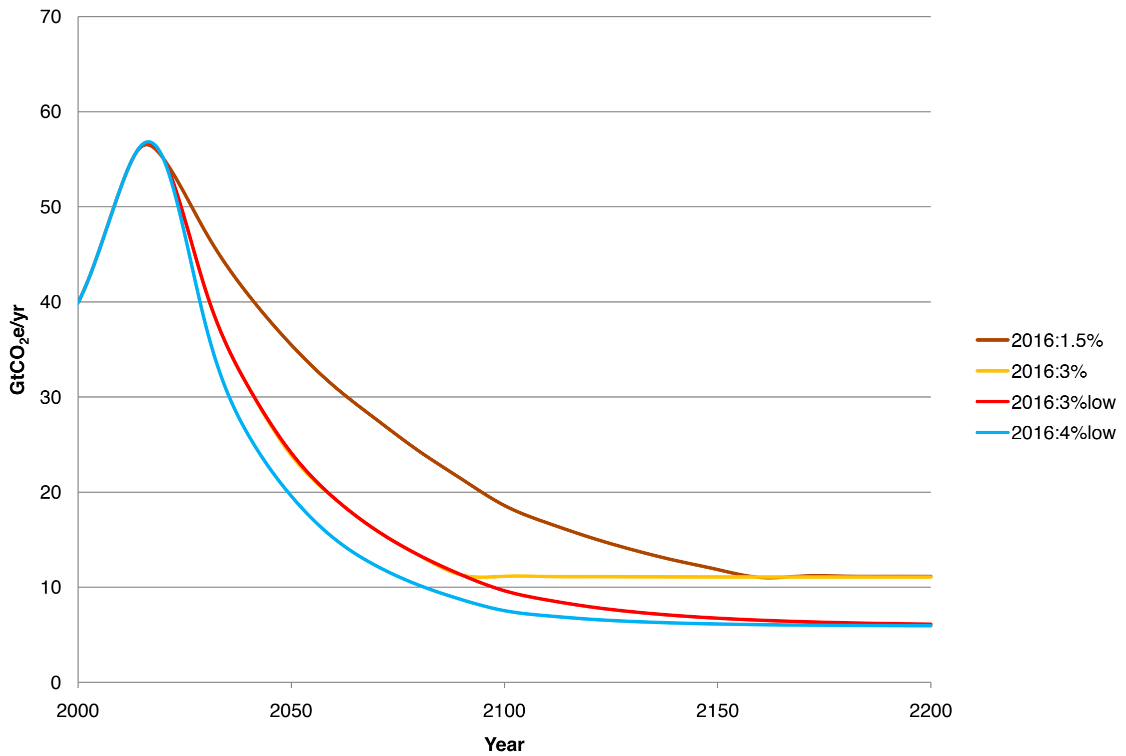
20 2016:3%low and 2016:4%low are distinguished by their lower ultimate emissions floor.
21 The MAGICC climate model is used here (www.cgd.ucar.edu/cas/wigley/magicc/) with a distribution of climate sensitivity taken from Murphy, J.M., et al. (2004) Quantification of modelling uncertainties in a large ensemble of climate change simulations. *Nature*, 429, 768–772.

Figure 1.6 Global emissions reduction trajectories peaking in 2028



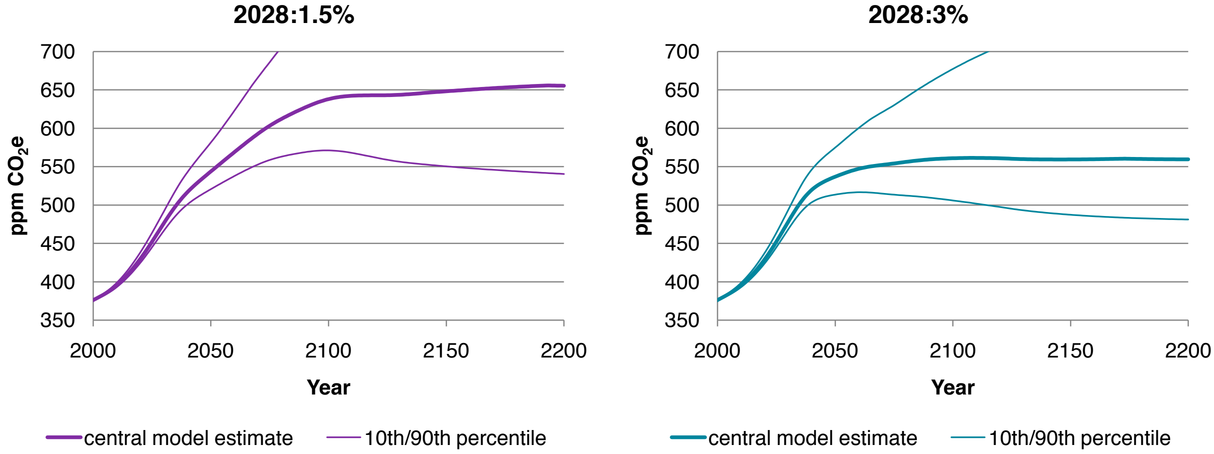
Note: Three possible future global emissions trajectories have been analysed, all peaking in 2028. After peaking, CO_2 emissions (including those relating to land-use) are reduced by 1.5%, 2% or 3% annually until a floor is reached (only 1.5% and 3% trajectories shown here). Kyoto GHG emissions are plotted here on a CO_2-equivalent basis. For further information, see Technical Appendix.

Figure 1.7 Global emissions reduction trajectories peaking in 2016



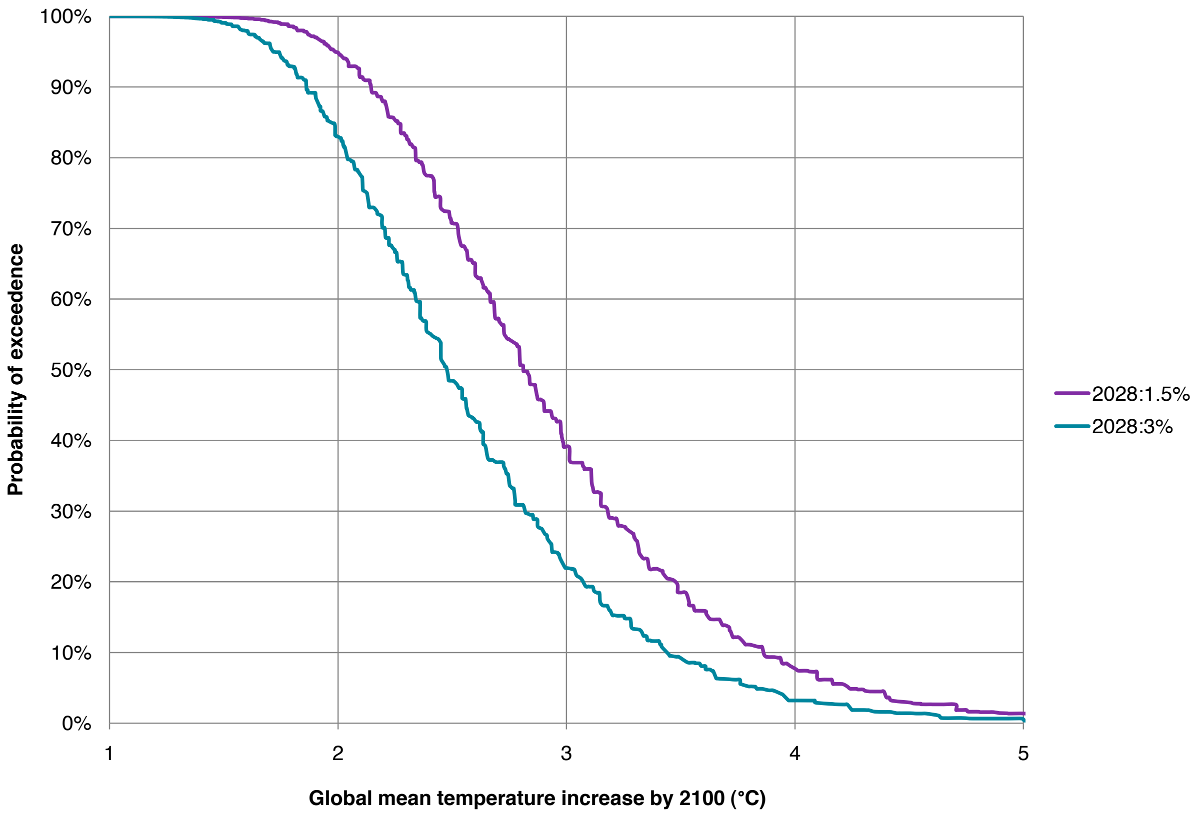
Note: As with Figure 1.6, but with trajectories peaking in 2016 and subsequent CO_2 reduction rates ranging from 1.5% to 4% annually. 2016: 3% shares an ultimate emission floor with most other trajectories, whereas 2016:3%low shares a lower floor with 2016:4%low, denoting a world were strong efforts are made to reduce emissions. Both trajectories with 3% reductions yield the same emissions in 2050 and have very similar climate effects out to 2100; however they illustrate the effect of ultimate emissions levels on temperatures in the 22nd century. For further information, see Technical Appendix

Figure 1.8 CO_2-equivalent atmospheric concentrations for emissions trajectories peaking in 2028



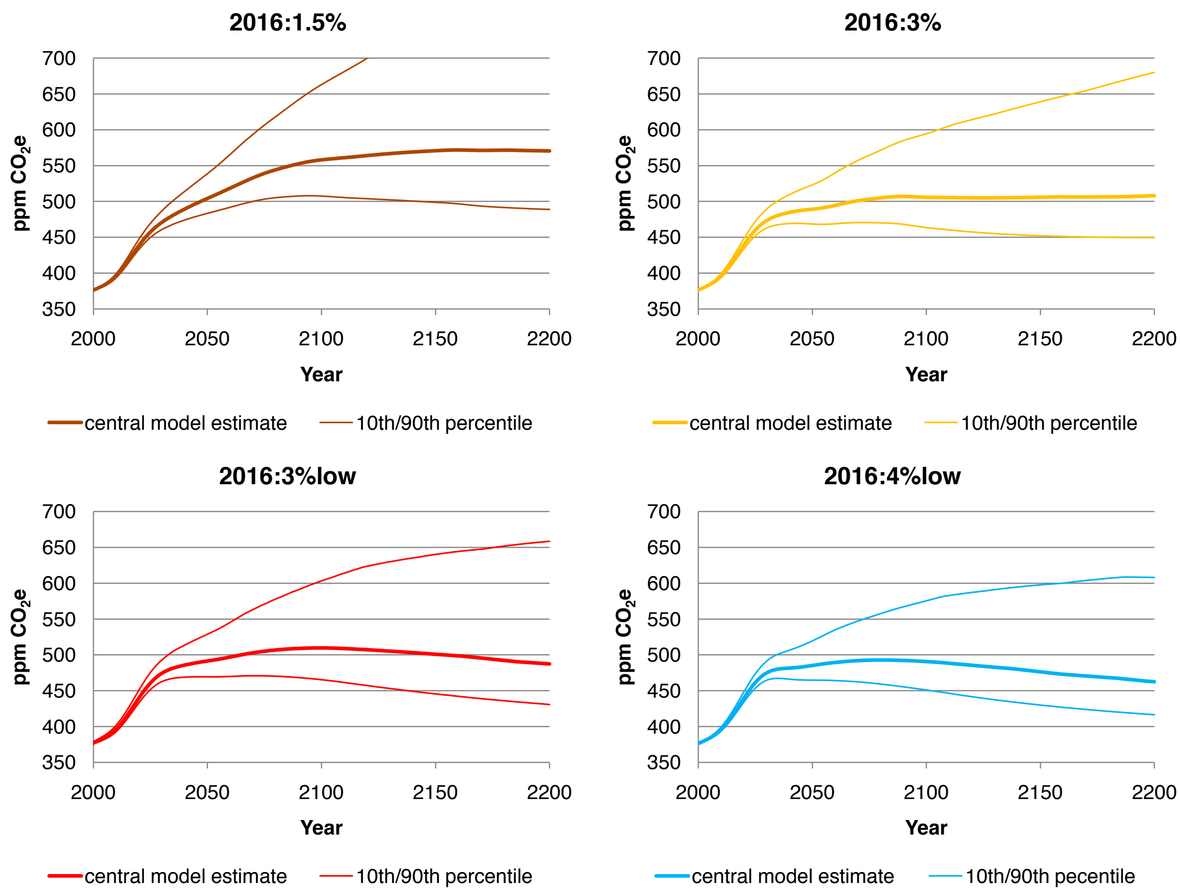
Note: Total CO_2-equivalent atmospheric concentrations (including Kyoto GHGs, ozone and aerosols) are given in parts per million (ppm) for emissions trajectories 2028:1.5% and 2028:3%. Upper and lower thin lines show the 10th and 90th percent bounds of model response, whilst the thick central line represents the central model estimate

Figure 1.9 Probabilities of exceeding a given global mean temperature increase by 2100 for emissions trajectories peaking in 2028



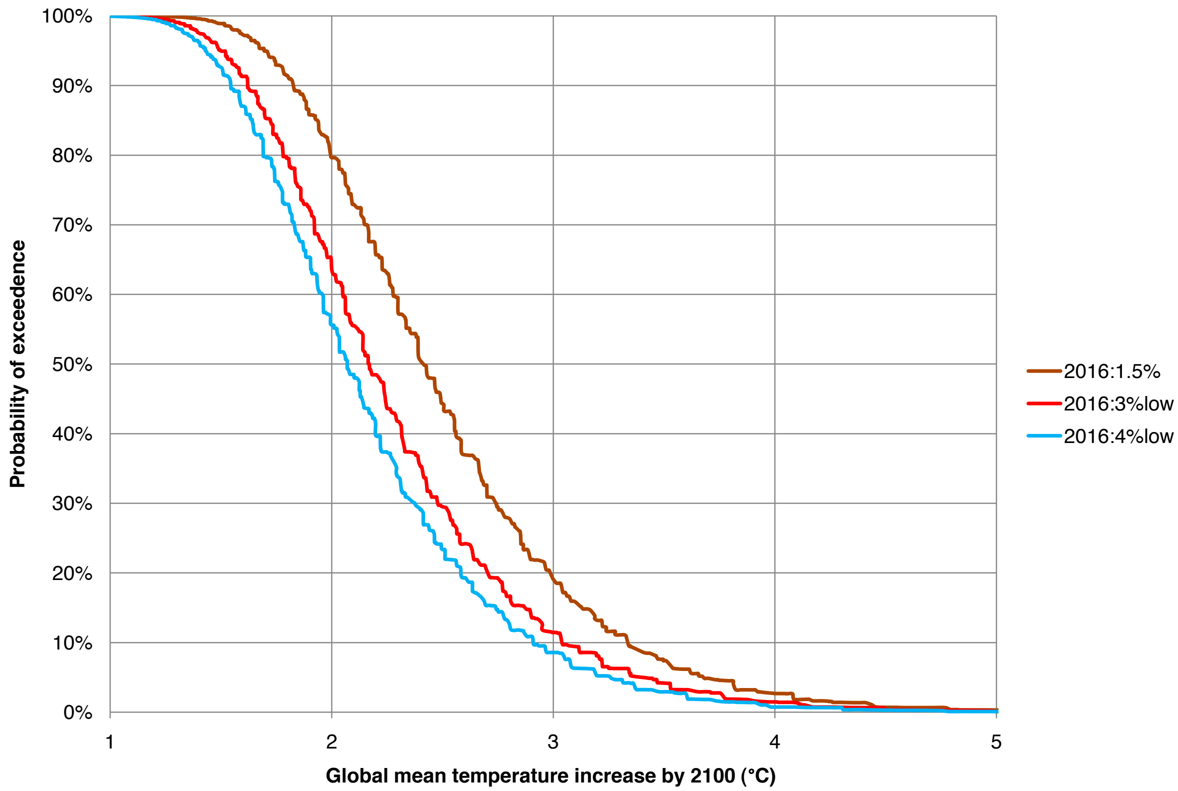
Note: Curves show the range of model outputs for given global temperature increase (relative to pre-industrial) in 2100, for the emissions trajectories peaking in 2028, given climate model parameters outlined in the Technical Appendix.

Figure 1.10 CO_2-equivalent atmospheric concentrations for emissions trajectories peaking in 2016



Note: Total CO_2-equivalent atmospheric concentrations (including Kyoto GHGs, ozone and aerosols) are given in parts per million (ppm) for emissions trajectories 2016:1.5%, 2016:3%, 2016:3%low and 2016:4%low. Upper and lower thin lines show the 10th and 90th percent bounds of model response, whilst the thick central line represents the central model estimate.

Figure 1.11 Probabilities of exceeding a given global mean temperature increase by 2100 for emissions trajectories peaking in 2016



Note: Curves show the range of model outputs for given global temperature increase (relative to pre-industrial) in 2100, for the emissions trajectories peaking in 2016, given climate model parameters outlined in the Technical Appendix. Both 2016:3%low and 2016:3% give very similar probabilities at 2100.

- **Consistency of findings with other model analyses**: Other investigations into the emissions reduction required to limit the risk of exceeding 2°C have come to a range of broadly consistent conclusions. One recent study showed that peaking in 2010 to 2015 followed by a 3% reduction in fossil fuel CO_2 emissions would give a 25% to 75% probability range of exceeding 2°C[22]. Our results are in broad agreement but are at the less optimistic end of this range (63%), reflecting the fact that we have accounted for the observed higher growth of emissions up to peaking. In the supporting material for this report we show how, for the same level of emissions in 2050, more rapid emissions reduction prior to 2020 can reduce the probability of exceeding 2°C. Both our trajectories and those in the above study suggest that GHG concentrations will have to overshoot an acceptable long-term level and then fall before temperatures have reached equilibrium. Stronger action would be required if it is assumed that overshooting is not acceptable. For instance, another study shows that long-term stabilisation at 450ppm of CO_2 equivalent without overshooting (leaving a roughly 50% probability of exceeding 2°C) will require a 6.5% annual reduction in fossil fuel CO_2 emissions given current emissions growth[23]. Others have recommended an 80% global reduction by 2050 relative to 1990, in order to further reduce the risks of exceeding 2°C[24].

Given the inherent uncertainty of these estimates the choice of appropriate desirable trajectory is necessarily judgemental. But the Committee believes that it is a reasonable judgement that the objective should be to achieve a global commitment to a peak of emissions within the next ten years, with a subsequent reduction of all CO_2 emissions at 3% per annum or more, accompanied by similar effort for other GHGs (the feasibility and cost of this reduction is considered in

22 Meinshausen, M., et al. (2006) Multi-gas emissions pathways to meet climate targets. *Climatic Change*, 75 (1-2), 151-194.
23 Anderson, K. & Bows, A. (2008) Reframing the climate change challenge in light of post-2000 emission trends. *Phil. Trans. R. Soc. A*, 366 (1882), 3863-3882.
24 Parry, M., et al. (2008) Climate policy: Squaring up to reality. *Nat. Rep. Clim. Change*, 2, 68-71.

Chapter 2). This would imply a global level of Kyoto GHG emissions of between 20 and 24 gigatonnes[25] on a CO_2-equivalent basis ($GtCO_2e$) in 2050 compared with a 1990 level of about 36 $GtCO_2e$ and an estimated current level of about 48 $GtCO_2e$. A global reduction of about 34% to 46% below 1990 levels and of 50% to 59% below current levels are therefore likely to be required to meet the global climate objectives we proposed in Section 3 above (Table 1.2). This is broadly in line with the commitments made at the G8 meetings at Heiligendamm and Hokkaido, which committed the G8 nations to a broad 50% reduction without specifying the precise base year.

It is important to note, however, that while discussion of a global deal tends to focus on emissions in 2050, two other considerations are also important:

- The climate impact of our preferred trajectories depends primarily upon the cumulative emissions profile. Cumulative emissions between 1990 and 2050 for the trajectories recommended here are 2,420 $GtCO_2e$ to 2,540 $GtCO_2e$, of which we estimate around 780 $GtCO_2e$ has been used already.

- In addition, the climate impact of our preferred trajectories depends upon further emission reduction beyond 2050: emissions should fall to between 8 $GtCO_2e$ and 10 $GtCO_2e$ by 2100, with a cumulative budget between 2051 and 2100 of 590 $GtCO_2e$ to 760 $GtCO_2e$. Should emissions not fall further beyond 2050 then the climate outcomes set out in this section will not be achieved.

Table 1.2 Global 2050 emissions target, in terms of Kyoto GHG emissions, arising from trajectories 2016:3%, 2016:3%low and 2016:4%low

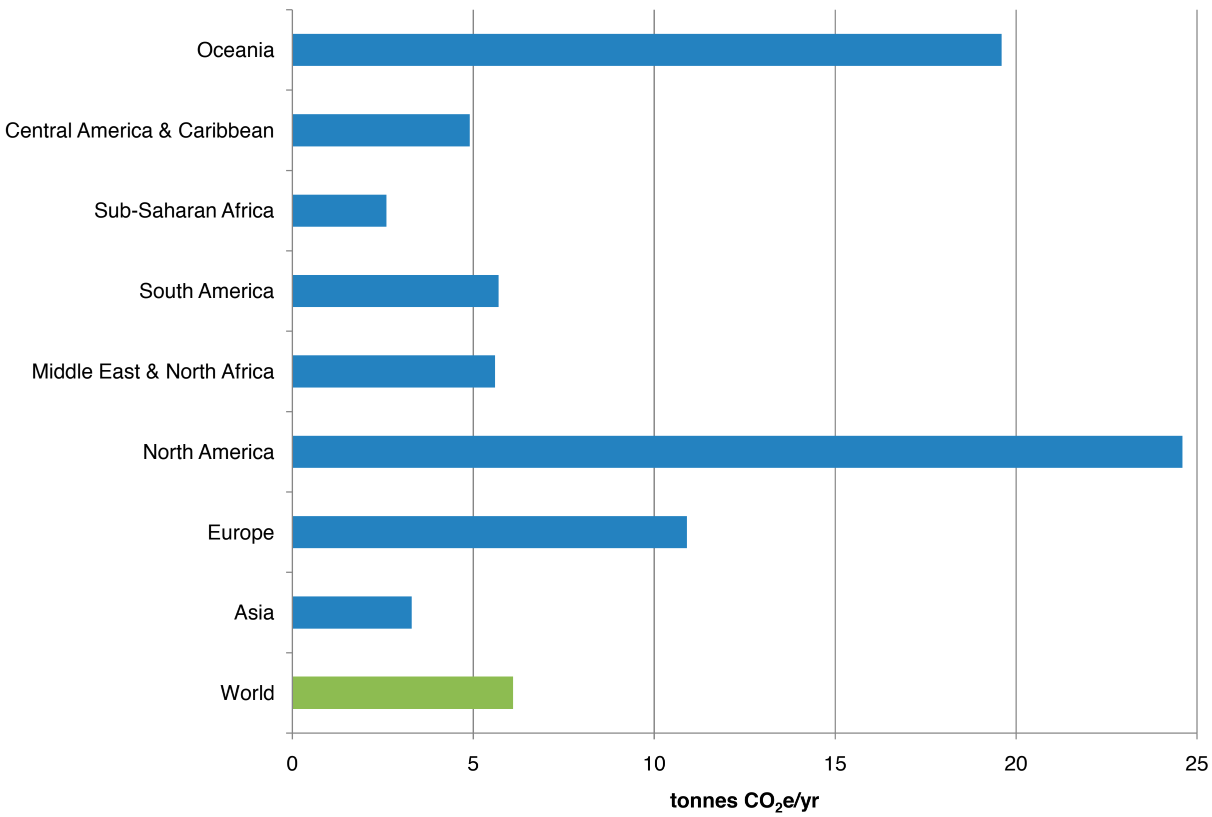
Emissions trajectory	Kyoto emissions ($GtCO_2e$/yr)			2050 emissions cut, relative to baseline year	
	1990	2007	2050	1990	2007
2016:3% / 2016:3%low	36.1	48.1	23.9	34%	50%
2016:4%low	36.1	48.1	19.6	46%	59%

25 One gigatonne is equal to one billion tonnes (or one thousand megatonnes)

5. APPROPRIATE UK CONTRIBUTION TO THE GLOBAL TARGET

The UN Framework Convention on Climate Change established the principle that all countries should share responsibility for reducing global emissions but that the level of reduction has to reflect the different circumstances of each country. This is both because initial per capita emissions are hugely different (Figure 1.12) and because different countries have very varied income levels and therefore different capacities to afford new technology deployment. This principle of 'common but differentiated responsibilities' has been reflected in numerous different proposals for the burden-sharing approaches which should be used to allocate emission targets between countries (Box 1.4). Some of these proposals (e.g. the Multistage Approach) are concerned with the practical transition details of achieving a global deal; some (e.g. Tryptych) are essentially amalgams of different underlying approaches.

Figure 1.12 Emissions of Kyoto GHGs (excluding those relating to land-use) per head of population in the year 2000, broken down by region as well as the world average

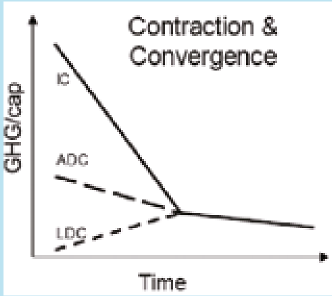


Source: CAIT

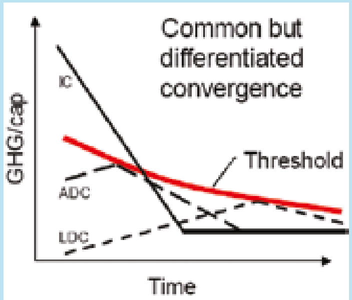
Box 1.4 Burden-sharing methodologies[26]

Multiple approaches exist for determining the level of national emissions reductions required as part of an international effort. Most assume that the level of GHG emissions per capita (GHG/cap) for Industrialised Countries (ICs), Advanced Developing Countries (ADCs) and Less Developed Countries (LDCs) will converge in the long term.

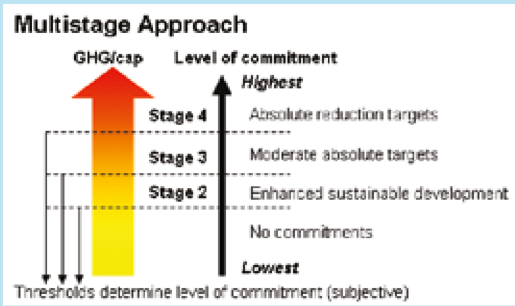
Per capita convergence[27]
All countries participate and agree on a path for future global emissions and a long-term stabilisation level for GHG concentrations – contraction. From this a global per capita emissions target is set which all countries have to converge to within a given time period.



Common but differentiated convergence[28]
Similar to the above whereby a global per capita emissions target is set and all countries have to converge to this level within a given time period. However, Annex 1 countries have to begin convergence immediately but convergence for individual non-Annex 1 countries starts from the date when their per capita emissions reach a certain percentage threshold of the global average.



Multistage
Multistage consists of several stages with differentiated types and levels of commitments. Each stage has a stage-specific commitment with countries graduating to higher stages when they exceed certain thresholds (e.g. certain level of per capita emissions). Countries take on binding commitments and targets when they reach the minimum threshold for stage 1.



Triptych[29]
Triptych considers country-specific differences in the source of emissions and emission reduction potentials in setting emissions targets. Emissions allowances are calculated for various sectors (industry, energy, domestic, agriculture and waste) which can take a variety of forms (production efficiency, per capita emissions) and these are then aggregated to obtain a national target. Individual sector targets are not binding, only the national target is binding.

Intensity
The intensity target is expressed as dynamic variable where emissions are a function of GDP. This approach affords participating countries the flexibility to pursue cost-effective emissions reduction but requires that economic development takes place in a carbon efficient way.

26 Höhne, N., et al (2007) Factors underpinning future action. 2007 update. DEFRA.
27 See for instance Agarwal A and S. Narain (1991), Global warming in an unequal world, Centre for Science and Environment, New Delhi. Meyer A (2000), Contraction & convergence. The global solution to climate change. GCI (2005), GCI Briefing: Contraction & Convergence, Global Commons Institute. Welsch, H (1993) A CO_2 agreement proposal with flexible quotas. Energy Policy, 21, 748–756.
28 Höhne et al. (2006), Common but differentiated convergence (CDC), a new conceptual approach to long-term climate policy *Climate Policy*
29 Blok et al. (1997), The Triptique approach. Burden differentiation of CO_2 emission reduction among European Union member states

But there is a fundamental difference in principle between approaches which assume broadly equal per capita emissions in the long term and those which are based on GDP carbon intensities.

- **Equal per capita emissions**: The simplest approach is to assume that in the long-term every person on the planet is entitled to an equal share of GHG emissions. If the world in total is to reduce emissions to a range of 20 $GtCO_2e$ to 24 $GtCO_2e$ by 2050, this would imply a per capita allowance of between 2.1 to 2.6 tonnes CO_2-equivalent (assuming a global population in 2050 of about 9.2 billion[30]). A global deal on this basis would require that the UK reduces emissions to something like 146 $MtCO_2e$ to 180 $MtCO_2e$[31] compared to a 1990 baseline of 797 $MtCO_2e$ – this includes bunker fuels used for international aviation and shipping and emissions relating to land-use. This implies cuts of between 78% and 82% versus the 1990 baseline. Two variants of this basic principle can then be considered:
  - In the first, per capita convergence, different countries with different per capita starting points, all immediately begin to converge towards the equal long-term per capita target. Richer countries, with currently higher per capita emissions, need to cut more, but all countries which are already above the long-term sustainable average need to start reduction immediately, and developing countries never emit more per capita than the declining developed country level.
  - In the second 'common but differentiated convergence' it is accepted that developing countries will for some considerable time continue to grow per capita emissions, and will for a period of time move above the declining per capita level of the developed countries. Although all countries end up at the same level of per capita emissions, developed countries need to reduce their emissions more quickly to allow for higher growth in other countries. This reflects the argument that developing countries will need to go through periods of relatively carbon intensive growth similar to those which developed countries passed through, and (in some variants) that developed countries should accept responsibility not only for their current emission levels but for their historic emissions.

Either of these variants could allow departures from the precise per capita rule to allow for differences in regional climate or natural resources (e.g. differences in the need for heating or in the supply of clean hydropower), but such adjustments are unlikely to produce radically different figures.

- **Declining GHG intensity of GDP**: A quite different approach aims to achieve cuts in the GHG intensity of GDP, with each country committing to reduce emissions per unit of national income. A richer country might have a higher level of emissions per capita than the global average in the long term, as long as the GHG intensity of its economy is falling at an appropriate pace.

30 UN medium variant projection of population in 2050 drawn from the UN World Population Database, 2006. The UN projections range between 7.8 and 11.9 billion people. Clearly if population is higher than anticipated here then each person's allowance will be lower.

31 Assumes a UK population of 69 million, UN medium variant projection.

The choice between these two principles is in part an ethical one and in part a pragmatic issue –what global deal is possible? It is not part of the Committee's remit to propose a specific methodology for the purposes of international negotiations. Nor do we make a judgement about which methodology is ethically preferable to another. But the Committee's opinion is that it is difficult to imagine a global climate deal which is either pragmatically achievable or fair which does not involve the UK and other developed countries reducing their emissions, over the long-term, to a per capita level which if applied across the world would be compatible with a our climate objectives, that is just over 2 tonnes of CO_2-equivalent per capita. The argument that this should be accepted as a target for developed countries is further reinforced by Lord Stern's point that it is difficult to identify developing countries which in 2050 are likely to run their economies with emissions far below 2.1 to 2.6 tonnes per capita, and that if there are not major economies with emissions significantly below the global average, there cannot be countries significantly above.[32]

Given the range of reduction required under the different burden-sharing methodologies the Committee therefore recommends that the UK's 2050 objective should be to reduce its emissions of GHGs at least 80% below the 1990 baseline.

32 Stern, N. (2008), Key elements of a Global Deal on Climate Change, London School of Economics.

6. RESPONDING TO DEVELOPMENTS IN SCIENCE AND FUTURE EMISSIONS GROWTH: POSSIBLE FUTURE ADJUSTMENTS TO OBJECTIVES

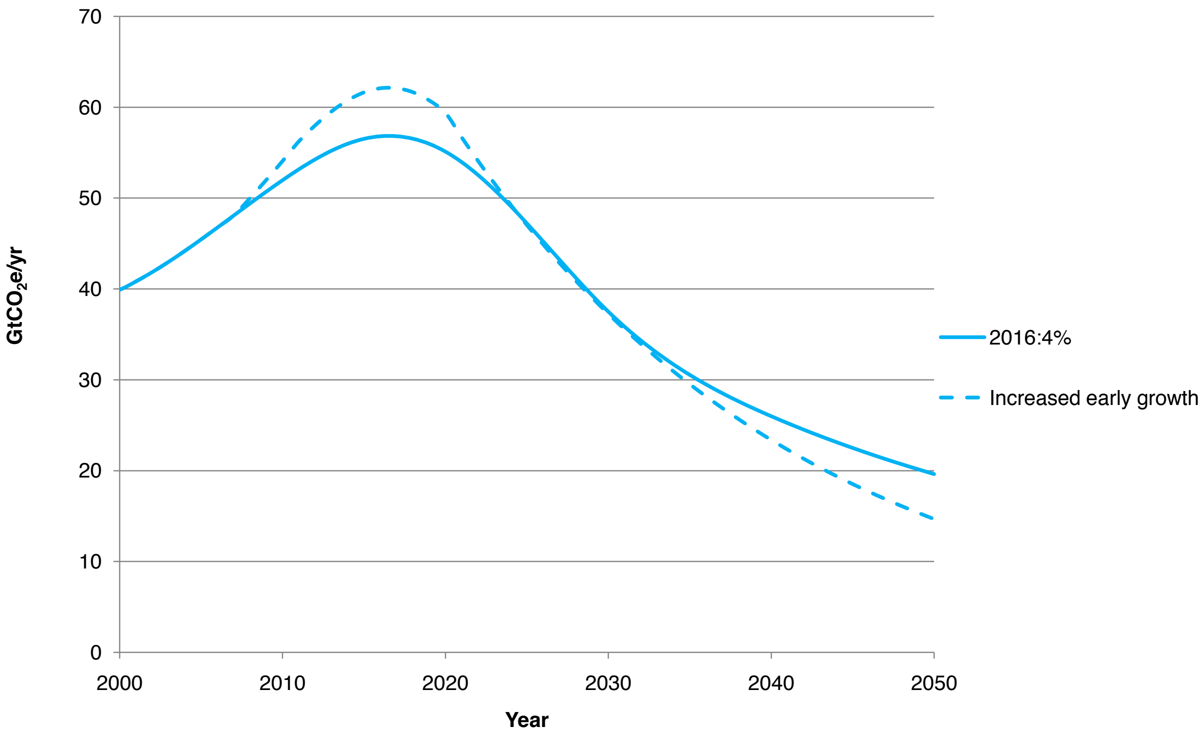
In Section 3 we stressed the uncertainty surrounding the judgements that need to be made concerning both the global and local human welfare impacts of increasing temperature and the chances that increasing temperatures produce irreversible physical shifts or intensifying climate feedback effects. In Section 4 we stressed the inherent difficulty of defining an emissions trajectory to meet any given climate objective, given that the most that science can provide is probability distributions of future temperature effects which are themselves uncertain estimates. Our recommendation that the UK's 2050 objective should be to reduce emissions by at least 80%, therefore, reflects the best judgement based on imperfect information and analysis available today. Over time, more information and analysis will become available which may suggest the need to adjust the target. In particular:

- Estimates of the probability that the world will exceed a point of 'extreme danger' (e.g. 4ºC) could increase or decrease, or judgements on where a point of 'extreme danger' lies could change. This could be a result of developments in climate modelling and/or because of actual temperature trends: if by 2030, for instance, temperature increases are running ahead of present mean expectations, the estimated probability that the world will exceed 4°C by 2100 will almost certainly also increase. If this does occur, it will be appropriate to increase targeted emission reduction for 2050 and/or to commit to further significant reduction in the second half of the century. The aim should be at any time to keep the probability of exceeding a defined 'extreme danger' threshold in the future below a very low level (e.g. less than 1%).

- Estimates of the likely adverse global and local human welfare impacts of different levels of temperature increase may also change as more information becomes available. By 2030, for instance, we may have evidence that the impact of a 2°C warming is either more harmful or less harmful than we currently believe. This too may make adjustments in long-term targets appropriate.

- Actual achieved emissions could diverge from our modelled trajectories. If, for instance, emissions do not peak in 2016 but continue to rise, or if emissions increase at a faster rate than anticipated before the peak, then the probability of keeping below a given temperature will be reduced. To maintain these probabilities cumulative emissions from now to 2050 will need to be in line with those implied by the recommended targets, and overshoots in the early years will need to be matched by more rapid reduction later. In this case Kyoto gas emissions in 2050 would need to be lower than 20-24 $GtCO_2e$ (Figure 1.13).

Figure 1.13 An example of the effect of a revised trajectory on 2050 emissions targets



Note: If emissions grow at a different rate (as shown) or peak at a different time, then the chances of limiting global mean temperatures rely on conserving the cumulative emissions budget. So for deviation from a global trajectory of 2016:4%low, any increased early growth will have to be offset by a lower 2050 emissions target in order to conserve the cumulative emissions budget.

From today's vantage point, however, the Committee believes that an 80% cut by 2050 is appropriate as part of a global deal to halve emissions from current levels. It is highly likely to be required to reduce, but not by any means remove, the harmful effects of climate change. And it is highly likely to be achievable at a manageable cost. The next chapter sets out our assessment of that cost.

CHAPTER 2:

MEETING A 2050 TARGET

Chapter 1: *Setting a 2050 target* recommended that the UK should support a target to reduce global Kyoto Greenhouse gases (GHGs) by about 50% between now and 2050. Global emissions should fall to 20-24 $GtCO_2e$ in 2050. Compared to our estimate of business as usual this implies abatement of up to 56 Gt in 2050, of which 48 Gt could come from lower fossil fuel CO_2 emissions with the remainder coming from reduced land-use and non-CO_2 emissions. As part of this global deal, we also recommended that UK GHG emissions should fall to 80% below 1990 levels by 2050. This chapter considers the feasibility and cost of achieving these objectives. It also identifies some implications for the feasible path to 2050 – where the UK will need to be in 2020 or 2030 if it is to meet the 2050 target – and it considers the possible role of international emissions trading in achieving the UK's long-term target.

It does not set out a single recommended technology path. It is not the role of the Committee to recommend a particular balance between different technologies – for example nuclear versus renewable electricity generation – nor indeed can anyone define now the appropriate balance given uncertainty over future technological developments. Instead, the focus of this chapter is on identifying whether there exists a portfolio of different technological options which makes it likely that our recommended emissions reduction can be achieved at a manageable economic cost.

The conclusions we reach are:

- A combination of existing technologies, and those currently under development, could deliver the required global emissions reduction at an economic cost of 1-3% of GDP in 2050 in line with the conclusions of the Stern Review. The UK could achieve an emissions reduction of 80% below 1990 levels at a cost of 1-2% of GDP in 2050. These estimates are based on engineering estimates of costs. Neither estimate takes into account GDP costs caused by changes in economic structure.

- It is likely that a key feature of the future optimal path will be the almost complete decarbonisation of electricity generation, and the extension of electricity to a wider range of energy end uses (in particular transport and heat). This implies that rapid progress on electricity decarbonisation is vital.

- While international trading of emissions credits can usefully reduce the cost of mitigation, over the long term it is highly likely that the vast majority of the UK emissions reduction will need to be achieved domestically (e.g. a UK commitment to an 80% reduction may well require a UK domestic reduction of over 75%).

- It is therefore essential that the 2020 target (i.e. the target for the third budget), and the extent to which the UK relies on bought emission credits in meeting that target, are designed to be compatible with radical domestic emissions reduction by 2050.

The chapter has five sections.

1. Technologies available to drive emissions reduction

2. A possible global path to a 50% reduction: technologies and costs

3. A possible UK path to an 80% reduction: technologies and costs

4. The role of international emissions trading: valuable but supplementary

5. Implications of the path to 2050 for the 2020 target and the first three budgets.

1. TECHNOLOGIES TO DRIVE EMISSIONS REDUCTION

It is not the role of the Committee to recommend a particular mix of technologies to be deployed. And the Committee has not conducted nor commissioned primary research into alternative technologies which would enable us to reach independent conclusions about technological feasibility and cost. But to support our recommendation for the 2050 targets set out in Chapter 1, we need to satisfy ourselves that they are likely to be achievable at a manageable cost. We have therefore relied on published expert opinion on the status, likely prospects, and costs of different technological options. This section represents the summary conclusions of that review.

Five features of the analysis should be noted:

- We have drawn heavily on the International Energy Agency's (IEA) *Energy Technology Perspectives 2008*, which has been developed in support of the G8 Plan of Action, and which provides a synthesis of expert views. This report provides information on the development status of each technology, current and future possible cost trends, and any physical limits to the feasible scale of deployment (e.g. given inherent limits to resource supply or the existence of supply bottlenecks). In particular we have drawn upon the IEA BLUE Map scenario[1] which shows how 48 Gt of CO_2 abatement could be delivered in 2050. We have supplemented this analysis with UK-specific data to identify which technologies are likely to be more or less relevant to the UK.

- We refer in this section to international estimates of costs expressed in US dollars. One notable feature of cost estimates is that where a technology requires large-scale physical construction (e.g. for electricity power plant) UK cost estimates are almost always significantly higher than global estimates. This reflects higher construction costs, but also higher costs and time involved in land acquisition and planning procedures, reflecting higher population density than in for instance the US. These differences between the UK and global cost estimates, however, are seen in all technologies (wind as much as nuclear as much as new fossil fuel plant) and global estimates of the **relative** cost of different technologies are largely applicable to the UK. In Section 3 of this chapter *"A possible UK path to an 80% reduction"*, and in Chapters 3 to 13 of the report, we use UK-specific cost estimates to calculate the cost to the UK of our recommended targets.

- Cost estimates for many technologies (and in particular those relevant to electricity generation) have risen significantly over the last three years. The cost of fossil fuel based generation has increased dramatically as a result of price rises for coal, gas and oil. But the cost of low-carbon technologies has also increased, with large rises in the cost of wind turbines and of solar photovoltaic cells, and significant cost overruns in new build nuclear reactor investments. These increases have resulted from a combination of increases in material costs (e.g. steel, which in turn is driven by fossil fuel prices), skill shortages and by bottlenecks in supply chains. It is therefore crucial to distinguish between short-term cost increases and long-term cost trends, and to ensure that relative cost comparisons do not mix, for instance, nuclear cost estimates from 2004 with wind estimates from 2008, or vice versa.

1 IEA (2008), *Energy Technology Perspectives*, International Energy Agency. *Paris*. The BLUE Map scenario explores the energy implications of a reduction of global greenhouse gas emissions to 50% of current levels by 2050.

- The take up of low-carbon technologies depends, in part, on the age profile of the existing capital stock and the remaining asset life. Typically, many energy-intensive assets are long-lived (Table 2.1) and this can lead to slow rates of technology diffusion for low-carbon technologies. However given that investments in long-lived assets are sunk costs a high-carbon price may make it more economic to scrap these assets prematurely. The global analysis carried out by the IEA, and the UK analysis, both allow premature capital scrapping.

- The focus of this section, and of the modelling results presented in Sections 2 and 3, is on technological options to reduce fossil fuel CO_2 emissions, excluding consideration of behavioural changes (e.g. persuading people to fly less, use smaller cars, or increase the temperature at which air conditioning is set). To the extent that behavioural changes are likely, the cost of achieving radical emission cuts would be lower than those we present in this chapter[2]. The potential role of behavioural changes in driving emissions reduction in the UK in the first three budget periods is considered in Chapters 3 to 13. We believe there is significant potential but not sufficient to make behavioural change an alternative to radical energy efficiency improvement and investment in low-carbon energy sources.

The overall challenge faced is illustrated in Figure 2.1. This shows the reduction in CO_2 emissions required in the UK from power generation, transport[3], and the provision of heat to meet an overall 80% GHG target. CO_2 emissions from these sectors will need to fall by more than 80% if non-CO_2 gases and emissions from international aviation and shipping cannot be cut by 80%. Emissions can be reduced by using low-carbon energy sources and by improving energy efficiency.
We therefore cover the relevant technologies under four headings and then identify some key implications.

(i) Decarbonising electricity generation

(ii) Energy efficiency in the use of electricity

(iii) Transport: more efficient vehicles, new fuels and demand containment

(iv) Heat: energy efficiency and new energy sources

(v) Summary and implications

2 Our UK MARKAL analysis reported later in the chapter will include some behavioural changes because it allows the demand for energy services to vary with the costs of meeting them. The IEA analysis assumes that demand for energy services is fixed across all its scenarios.

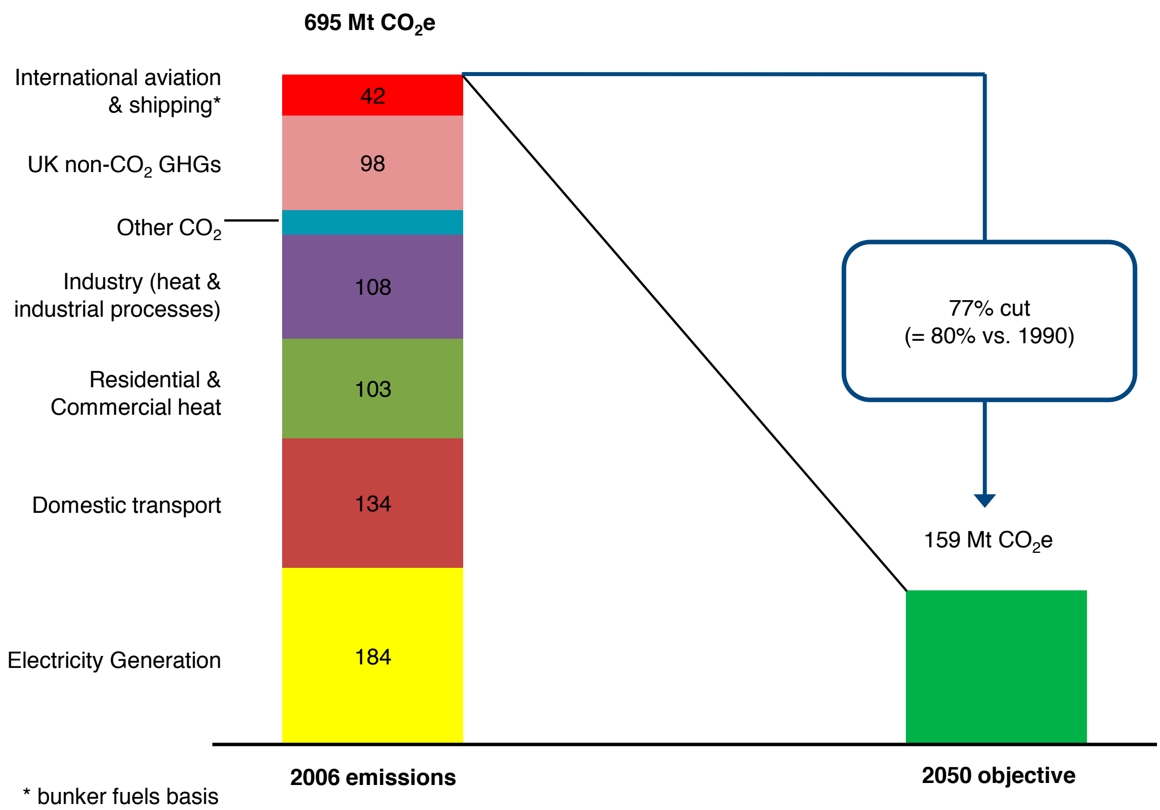
3 The transport sector includes domestic aviation. For a discussion of abatement opportunities in aviation and shipping, see Chapter 8.

Table 2.1 Typical service life for energy-consuming capital goods

Type of asset	Typical service life (years)
Household appliances	8-12
Automobiles	10-20
Industrial equipment/machinery	10-70
Aircraft	30-40
Electricity generation plants	50-70
Commercial/industrial buildings	40-80
Residential buildings	60-100

Source: Jaffe, A. Newell, R. and Stavins, R. (1999) energy-efficient technologies and climate change policies: issues and evidence, *Resources for the future climate issue brief no 19*, Washington, DC.

Figure 2.1 The scale of the challenge



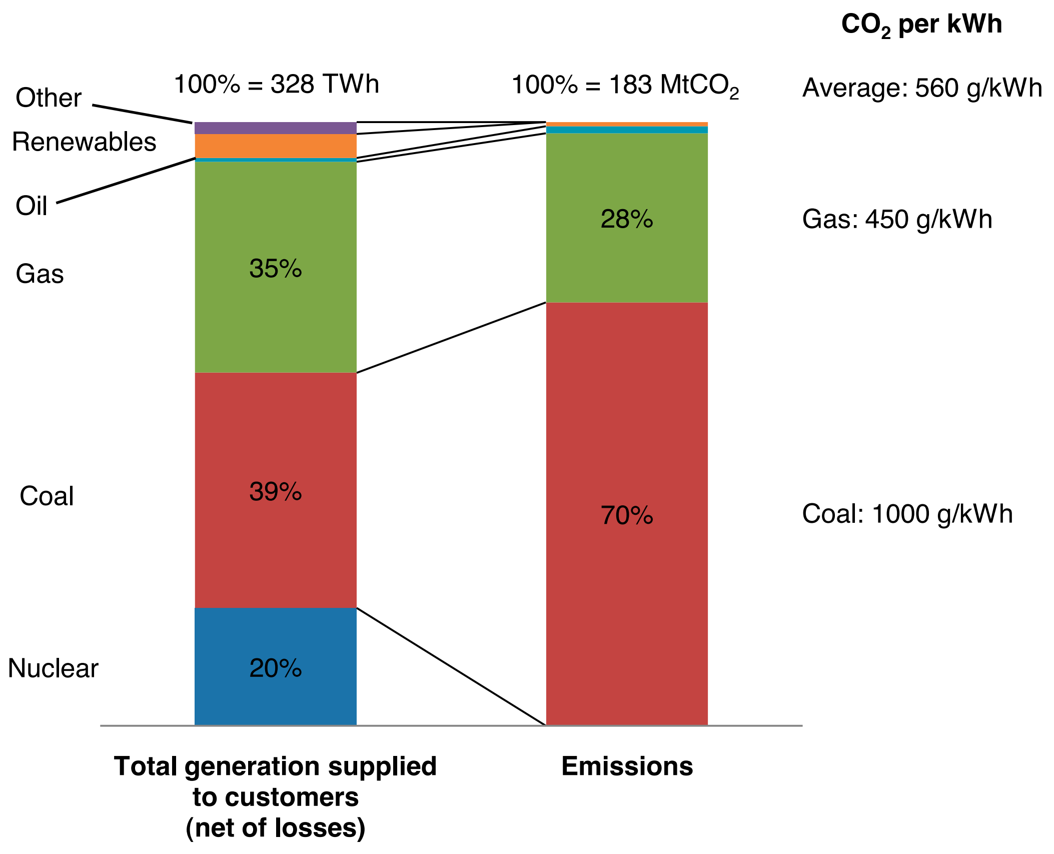
Source: UK National Atmospheric Emissions Inventory (2008).

(i) Decarbonising electricity generation

Over 18,000 TWh (18000 billion kWh) per annum of electricity is produced globally, emitting around 11 $GtCO_2$.[4] The UK currently generates close to 400 TWh of electricity per annum[5], with associated emissions of 183Mt of CO_2 in 2006 (Figure 2.2). Around 70% of these emissions derive from coal generation, which produces about 850g of CO_2 per kWh generated; nuclear and renewable related emissions are trivial, about 5-20g/kWh[6]. The challenge in electricity generation is to achieve a radical reduction in grams of CO_2/kWh. To achieve this decarbonisation, a range of technologies are already or are likely in the future to be available (Table 2.2).

In the short term, lowest cost mitigation is likely to involve either fuel switching between fossil fuels (using gas rather than coal), improving the efficiency of fossil fuel generation, or deploying proven low-carbon technologies with costs already fully or close to competitive with fossil fuels (primarily nuclear, wind on the best sites, and hydro). In the longer term, a wider range of renewable technologies is likely to be cost effective, and carbon capture and storage could play a major role. Table 2.3 summarises the IEA assessment of the current relative cost position and of the possible position in the longer term.

Figure 2.2 UK power sector generation and emissions, 2006



Data for 2006, from the Digest of UK Energy Statistics (2008) and the National Atmospheric Emissions Inventory (2008)

Note: Generation and CO_2 from centralised generation only.

4 IEA (2008), Op. cit., p 83-85.

5 Total generation in 2006 was 395 TWh, with 328 TWh reaching consumers. The remainder was either used by power generators or lost in transmission/distribution.

6 While the emissions of wind and nuclear generation at the point of use are zero, emissions during their construction mean that over their life-cycle such sources of generation can be considered to have a small level of associated emissions, in the range 5-20 gCO_2/kWh. For more detail, see the Nuclear Power Generation Cost-Benefit Analysis for the 2007 Energy White Paper.

Table 2.2 Power generation technologies in existence or under development

Category	Technology
Improvements to conventional fossil fuel efficiency	e.g. Ultra-supercritical coal plant
Technology already deploying on significant scale & close to competitive	• Nuclear • Wind
Renewable technologies already available, with current costs significantly above competitive levels	• Solar PV • Biomass (Combined heat and power / dedicated power generation)
Renewable technologies at the demonstration stage	• Concentrated solar power • Wave • Tidal
New (not yet deployed) clean fossil fuel	Carbon capture and storage (CCS)

Table 2.3 Estimates of power generation costs by technology type: current and future

	US¢/kWh	
	Current	Future
Coal	2.5-6	depends on fuel costs
Gas	4-6	depends on fuel costs
CCS	n/a	premium of 2-4
Wind	Onshore: 6.5-13.5 Offshore: 7.5-11	5.3-8 in 2015 25% reduction by 2020
Nuclear	3-7.5	no significant reduction
Solar PV (areas of good irradiation)	30-35	9-12 by 2030 5-7 by 2050
Concentrated Solar Power	12.5-22.5	3.5-6
Wave and Tidal	15-30	4-8
Biomass	6-18	5-12 by 2050

Source: IEA (2008).

We consider below the potential importance and cost of the major technologies and reach a summary conclusion on the prospects for decarbonisation.

Conventional fossil fuel generation: Even without the application of carbon capture and storage (CCS), the carbon efficiency of fossil fuel generation can be improved significantly by the application of best technology available today or likely to be available in the future (Figure 2.3). The average efficiency of coal-fired power plants operating in 1992 to 2005 was 35%; best available plants can achieve 47%; and ultra super critical plants may in the future achieve 55%[7]. Average efficiencies of gas-fired plants range from 33% in Russia to 49% in western Europe, and the best available combined cycle plants can achieve 60%[8]. Best practice carbon efficiency could therefore come down to around 700 g/kWh for hard coal, and 350 g/kWh for gas[9]. Switching from coal to gas can also achieve a significant one off reduction in emissions. Improving the fuel efficiency of conventional fossil fuel plants will therefore be an important element in a global abatement strategy. But there are immovable limits to what can be achieved through these improvements: without CCS, fossil fuel generation cannot achieve the radical improvements in carbon efficiency which will be needed.

Nuclear power: Nuclear power is a long established and proven low-carbon technology, with further improvements in efficiency and safety likely to be achieved by a new generation of reactors. It will be an important and cost-competitive option for decarbonisation, but there are constraints on the feasible scale of deployment (Figure 2.4).

- Cost estimates from a wide variety of sources suggest that it is highly likely to be cost competitive with fossil fuels once a significant carbon price is in place, and may be competitive even without a carbon price if fossil fuel prices are at the levels seen in mid-2008. This assessment seems to be robust even if account is taken of decommissioning and waste disposal costs, and even allowing for the recent cost increases and overruns (e.g. at the new plant being built at Olkiluoto in Finland). Typical cost estimates for nuclear have increased over the last four years from about 3 to 5 cents per kWh to 6 to 8 cents per kWh, but costs of fossil fuel generation and wind power have also increased significantly in that period, keeping the relative position unchanged.

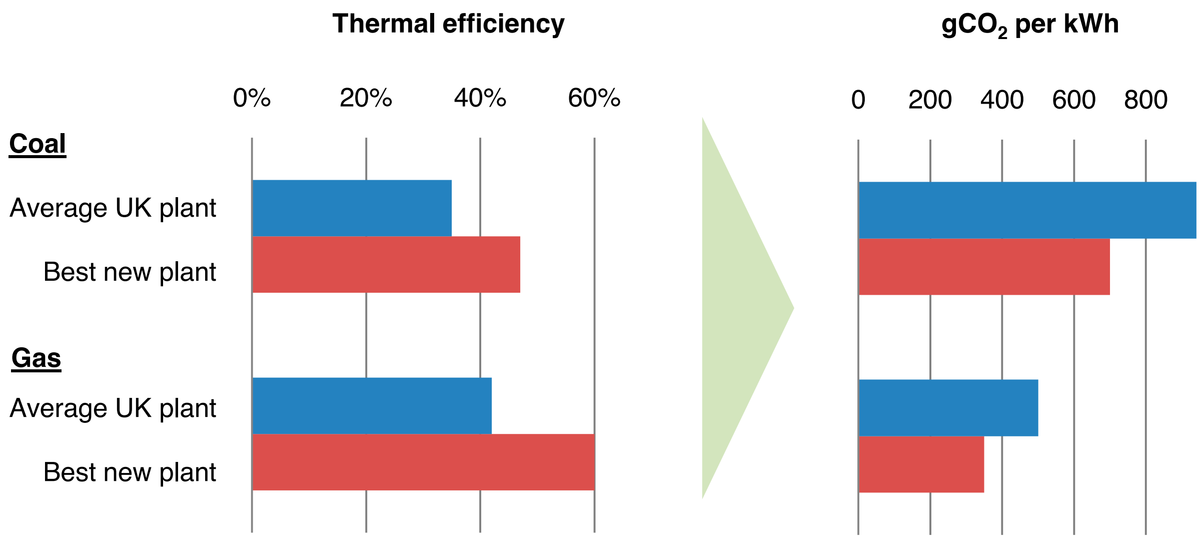
- Supplies of fuel do not place serious constraints on the feasible growth of nuclear power, given proven and likely uranium supplies, alternative potential fuel sources, and in the longer term the potential for fast breeder fuel recycling.

- Instead the binding constraint on nuclear's contribution to decarbonisation seems likely to be the feasible pace of nuclear plant construction, given limits to the supply of technically competent engineers and companies, and given the importance of tightly controlled planning, licensing and safety inspection regimes. Given these constraints, even the IEAs high nuclear BLUE scenario does not envisage nuclear contributing more than 35% of global electricity by 2050[10], and many estimates suggest considerably less.

Whether nuclear power should be deployed to the maximum extent possible is of course a contentious issue: opposition in principle is based on concerns about weapons proliferation (civil to military leakage) and the environmental consequences from the long-term disposal of high-level waste. The Committee recognises that these concerns raise political issues which go beyond our remit. But if nuclear power is acceptable in principle, it is likely to be a cost-effective low-carbon technology playing a significant role in decarbonisation. However, it is not in itself a sufficient solution.

7 IEA (2008), Op. cit., p255/7.
8 IEA (2008), Op. cit., p256/7.
9 IEA (2008), Op. cit.,p257.
10 IEA (2008), Op. cit., p85.

Figure 2.3 Improvements to fossil fuel plant efficiency and impact on emissions intensity[11]



Sources: Digest of UK Energy Statistics and IEA (2008).

Figure 2.4 Constraints on the feasible scale of nuclear deployment

Manufacturing capacity

- Significant constraints to rapid expansion. Bottlenecks caused by few suppliers with long order backlogs. Particularly in the areas of large reactor pressure vessels, supplies of nuclear grade pumps, valves and heat exchangers (NEI, 2007).

Skills

- Large share of workforce close to retirement. Nuclear education had declined, although some signs of a recent turnaround (IEA, 2008).

Supplies of fuel

- At 2004 levels of demand for uranium, conventional reserves could meet demand for 270 years.
- Use of fast-breeder reactors in the future would increase this by a factor of 50 (NEA, 2005).

=> Fuel supplies are not a major constraint

Waste management

- 1 GW light water reactor produces 25 tonnes of spent fuel per year. IEA growth rates would imply up to 31,250 tonnes of spent fuel per year in 2050.
- Commercial reprocessing plants in France, UK and Russia can handle 5,000 tonnes per year.
- Deep geological disposal seen as safe route, but no such facility yet exists.

Public Policy

- Environmental concerns.
- Nuclear proliferation – reducing the potential for diverting nuclear fuel into weapons programmes.

Nuclear could supply 23% of global electricity in 2050 under the IEA BLUE Map scenario

Sources: IEA (2008), Nuclear Energy Institute (2007), Manufacturing Capacity assessment for new US nuclear plants, NEI, Washington DC and Nuclear Energy Agency (2005), Uranium 2003: Research, production and demand, Report no 6098, OECD/NEA, Paris.

11 Emissions intensity figures are unadjusted for losses, unlike those in Figure 2.2.

Wind power: Wind power is a robust, proven technology which can make a significant contribution to decarbonisation at an acceptable cost, particularly in the UK. But there are important limits to the contribution that it can make.

- Global wind power deployment has grown rapidly in recent years and costs have fallen fourfold since the 1980s due to learning curve effects and increases in turbine size. As a result onshore wind at the best sites has reached a cost per kWh broadly competitive with fossil fuels if fossil fuel prices are at mid-2008 levels[12].

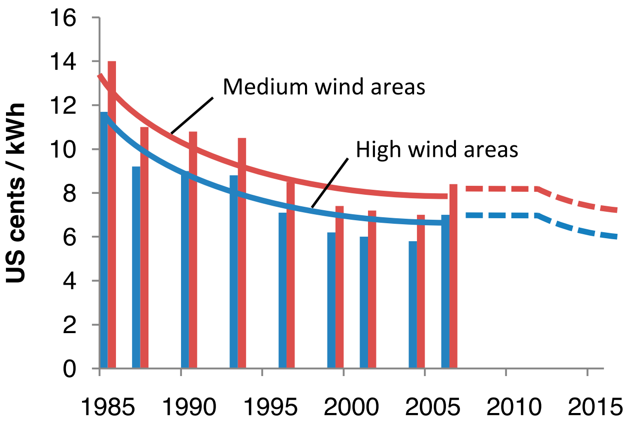
- Over the last three years this trend of decreasing costs has been temporarily reversed as increases in material cost (steel and concrete) and supply chain bottlenecks in production have driven sharp increases in turbine and installation costs (Figure 2.5). Supply bottlenecks may prove to be particularly severe in the initial years of significant offshore deployment. Over the long-term, however, the IEA anticipates that the trend of cost reduction will be resumed, but without the dramatic falls of the last twenty years. Gradual improvements in aerodynamic design and turbine size will continue to increase yield: operational and maintenance costs will come down gradually as reliability is improved and wear and tear reduced, whilst effective lifespan may increase. The IEA estimates that learning curve effects might run at 10% (i.e. a doubling of cumulative capacity installed produces a 10% cost decline) and that offshore investment cost per MW installed might fall by a third between now and 2050. This is likely to make wind power more competitive at sites which are currently less attractive.

- The feasible scale of wind power deployment varies hugely by region in line with the inherent wind resource[13]. Across the world, the IEA anticipates in its BLUE Map scenario that wind could deliver 12% of all the electricity by 2050[14], but in the UK the percentage could be significantly higher. Theoretical estimates of the total potential contribution of wind power in the UK suggest that offshore and onshore wind combined could potentially supply 88 TWh/year[15] by 2020, over 20% of current UK electricity demand.

- The inherent intermittency of wind power, however, brings its own challenges for widespread deployment even in a wind-rich country like the UK. The cost implications of intermittency (which include system balancing costs, increased transmission capacity and the requirement for backup) are manageable, although they can vary considerably from system to system and depend on the proportion of generation that is intermittent. While typical global costs are estimated to add around 1 to 1.5 cents/kWh to generation costs, UK-specific estimates are in the range 1-2p/kWh for a 25-30% share of wind generation[16] (see Chapter 5: *Decarbonising electricity generation* for more detail). But the need for backup generation when the wind is not blowing, which on a least-cost basis would probably be fossil fuel based, means that other technologies will also be required to achieve radical decarbonisation.

12 The OPEC basket price exceeded $100 per barrel during this period, peaking at over $140 in July 2008, www.opec.org/home/basket.aspx.
13 See for example www.windatlas.dk for wind resource maps of Europe.
14 IEA (2008), Op. cit., p85.
15 Sinclair Knight Merz (2008), Quantification of Constraints on the Growth of UK Renewable Generating Capacity.
16 Range based on 2008 estimates by Carbon Trust, SKM and Redpoint.

Figure 2.5 Cost trends in wind generation



Evolution of wind power costs

- Over the past 2-3 decades there has been a steady decline in the costs of wind generation, due to learning effects
- In recent times, high demand for turbines and bottlenecks in supply have caused a substantial increase in turbine prices
- The previous declining cost trend is likely to reinstate in future, with the major factor in declining wind generation costs likely to be increasing turbine size

Source: IEA (2008).

Solar power: In the long run, solar power technologies enjoy enormous inherent advantages, and it is possible that by the late 21st century solar power will play a very major role in a low-carbon economy at a minimal cost penalty. Its role in the UK emissions reduction programme, however, is likely to be more limited, at least for several decades and perhaps permanently.

- Solar energy can be converted to electrical energy via two different categories of technology: solar photovoltaics (PV), which directly convert solar energy to electrical energy; and Concentrated Solar Power (CSP), which uses direct sunlight to generate heat that is used to operate a conventional power cycle (e.g. a steam turbine). In addition solar thermal energy can be captured directly to heat water or air (this is considered in subsection (iv) below).

- Solar energy enjoys huge inherent long-term advantages. Solar energy reaching the earth each day is around 10,000 times current total human energy consumption: as a result, the land area requirement for solar energy to meet a large proportion (and in the long run perhaps all) human energy needs, even at already feasible energy yields, is relatively small. Both solar PV and CSP for instance could theoretically meet all 2050 global electricity needs with a land use of less than 0.4% of global land surface area[17]. This compares very favourably with for instance biofuels. In its solar PV form, moreover, the technology can use roof space in urban areas. It is deployable on a small as well as a large scale. When locally deployed, it cuts out transmission and distribution requirements and cost; and it is totally clean and noiseless. For these reasons solar technology deployment is uncontroversial, raising none of the environmental concerns which create opposition to wind or nuclear deployment. And the challenges of intermittency and imperfect predictability, while present, are significantly less important than for wind.

- Globally, at today's costs neither solar PV nor CSP are competitive without large subsidy but there is potential for dramatic cost reduction in both.
  - Solar PV today is far from being cost competitive. Estimates vary widely, but all estimates are several times the cost of producing electricity from fossil fuels, nuclear, or wind. Over the last three years, moreover, costs have increased significantly as a result of severe bottlenecks in manufacturing and in silicon purification. But unlike wind and nuclear there are strong reasons for believing that radical cost reductions will be achieved, either

17 Based on 1KW$_P$ PV delivering 750 kWh/yr and 120 W$_p$ covering 1m^2. IEA baseline power demand of 50,000 TWh/yr would require 554,822 km^2 or 745km by 745 km.

via the improvement of the existing crystalline silicon technology, or via next generation technologies, such as thin film (Table 2.4). The IEA anticipates that if scale deployment is driven by appropriate incentives, costs could fall to 5¢/kWh in sunny regions by 2050[18], making solar PV by then cost competitive with fossil fuels, nuclear and wind.

– Concentrated solar power (CSP) has lower current cost, with plants under construction expected to generate electricity at between 12.5 and 22.5¢/kWh[19]. The IEA cite research which suggests that in sunbelt countries, it could prove the lowest cost solar solution even in the long term, with costs possibly falling to 3.5¢/kWh by 2050[20].

Table 2.4 Generations of photovoltaics and potential for cost reductions

Type of photovoltaic technology	Market prospects
Crystalline silicon	Well-established technology, but limited further cost reduction potential
Thin film	Expected to achieve signficant market penetration by 2020-2030
Third generation devices	Expected to achieve significant market share from 2030 onwards, with a cost of 5-7 US¢/kWh by 2050

Source: IEA (2008).

- Given these characteristics and cost potential, it is possible that in the very long term solar power will be the most important of all the new technologies. But it will take several decades to achieve the required cost reductions, and even in the long term the role of solar power generation within the UK could well remain small. CSP is unlikely to be a feasible option except in the lower latitude sunbelt (i.e. southern Spain and North Africa) but not northwest Europe. It may however be possible for solar thermal-based electricity to be generated in this sunbelt and transmitted to Europe via high voltage DC lines[21]. And while solar PV does produce electricity even on cloudy days at middle latitudes, yields in the UK are likely to be less than half of that achieved in southern Spain, and this translates directly into an inversely proportional (e.g. two times) increase in cost per kWh. Estimates of solar PV costs in the UK do not therefore suggest that it will become close to cost competitive, at least for many decades.

18 IEA (2008), Op. cit., p375.
19 IEA (2008), Op. cit., p383.
20 IEA (2008), Op. cit., p384.
21 IEA (2008), Op. cit., p379.

Tidal and wave power: At the global level, tidal and wave power could make a useful but still minor contribution to renewable energy production, but in the UK the potential is proportionally far more important. Three different categories of marine power need to be distinguished (Table 2.5).

Table 2.5 Tidal and wave power: technology status

Technology	Source of power	Generating technology	Status of technology
Tidal range: - Tidal barrage - Tidal lagoon	Rise and fall of tides within tidal estuaries	Classic hydro-electricity turbines	Mature: utilises long established technology used in river and dam based hydro electricity and installed in tidal range setting at La Rance since the 1960s
Tidal stream	Fast running tidal currents (e.g. between island and mainland)	3 variants: - Horizontal axis turbines - Vertical axis turbines - Reciprocating hydrofoils	Clearly workable in principle but still in development and demonstration Significant learning curve effects still to come Major installation challenges in offshore marine environment
Wave	Wave oscillations at sea or as waves hit coast	5 main technology types: - Oscillating wave surge convector - Attenuator - Overtopping device - Oscillating water column - Point absorber	At demonstration stage Major uncertainties about best specific technology variant

Sources: IEA (2008); Sustainable Development Commission (2007), Turning the Tide; Carbon Trust (2006), Future Marine Energy.

- **Tidal range power,** which exploits the rise and fall of the tide in estuaries. This energy can be harnessed using either a tidal barrage (a dam across the estuary) or tidal lagoons (barriers which enclose a particular area within the estuary). In either case, the electricity generating process uses the mature technology of water driven turbines, as used for over a century in the hydro-electricity industry: this technology has been applied in a tidal barrage setting at La Rance in France for several decades. There are therefore neither technological uncertainties, nor significant opportunities for future cost reduction via learning curve effects. Instead, the crucial issues relate to the costs of construction after taking account of measures to offset local environmental impacts, and the appropriate discount rate to use for extremely long-lived projects (>100 years). Redpoint's analysis for Department of Energy and Climate Change (DECC) suggested a possible cost for a Severn Barrage of 11p/kWh, but analysis by the Sustainable Development Commission suggests that this could be below 5p/kWh if a social discount rate of 3.5% real is used, rather than a full commercial rate of 10% real.

- **Tidal stream power,** which derives kinetic energy from fast-flowing tidal currents. The electricity generating process here can either utilise turbines similar in form to those used in classic hydro projects or tidal barrages (i.e. circular turbines mounted horizontally), or a variety of alternative structures (e.g. reciprocating hydrofoil). Uncertainties over the best generating system design, together with the challenges of installation, maintenance and transmission connection in difficult offshore marine environments, place tidal stream at an earlier stage of technology development than tidal barrage. Significant learning curve effects are possible and necessary to make tidal stream power economic: the Carbon Trust estimated that early tidal stream plants might generate electricity at about 9-18p/kWh and that learning curve effects might reduce this to 5-7p/kWh.[22] The IEA suggests that costs of 4.5–8 US¢/kWh might be possible by 2050.[23]

- **Wave power,** which captures energy from wave movement, either out at sea or as waves hit the coast. There are a wide range of possible generating devices which are quite different in form from those familiar from classic hydro generation. Significant development work is still required to identify the most effective variants and the technology is still therefore at demonstration stage, with cost estimates necessarily uncertain. Redpoint estimates for 2020 suggest possible costs of 11.5p/kWh (i.e. significantly above tidal barrage costs even if a full commercial discount rate is used), but IEA estimates suggest as low as 4.5–9 US¢/kWh will be possible as early as 2030.

Across the world, the potential wave power resource is far greater than tidal range or tidal stream resource, with the latter highly dependent on specific geography. The IEA BLUE Map scenario envisages only a small role for wave and tidal power combined by 2050, providing only around 1% of global electricity generation. If other technologies were more expensive than envisaged, a far larger role for wave and tidal would be possible, but on present estimates alternative low-carbon technologies (wind, solar, nuclear and CCS) are likely to play much larger roles. In the UK, however, wave and tidal may play a far more important role. The Severn estuary is among the most attractive locations in the world to deploy tidal power technologies, and could generate up to around 5% of UK electricity needs; and the UK's theoretical potential wave resources are about 50% of the total European resource.

The potential role of a Severn Barrage is discussed in Chapter 5. The role of tidal stream and wave is likely to be small in the first three budgets, but could expand significantly thereafter.

Carbon capture and storage: The application of CCS[24] to fossil fuel electricity plants is highly likely to be an available and necessary element within the overall global abatement strategy. But urgent action is needed to demonstrate and prove the technology at production scale, and uncertainties about cost and feasible pace of deployment mean that CCS cannot be seen as a sufficient solution in itself, but one among a range of technologies which must be pursued in parallel.

- There is a range of different processes by which CO_2 can be captured in electricity generation (or in hydrogen production or CO_2-emitting industrial processes such as iron and steel or cement production). Each of these is clearly feasible: there are no fundamental research breakthroughs required. CO_2 transportation and storage underground are also clearly feasible, and have been used for many years in oil field management; however there is some risk of leakage. Each element of the CCS system has been demonstrated at non-trivial scale, although none involve capture from a coal-fired power plant (Figure 2.6). And while there are some uncertainties about how complete a solution CCS can be, estimates from the IPCC[25] suggest capture rates of 85-90%, resulting in emissions reduction of at least 80% versus a non-CCS plant for new-build plant[26] (Table 2.6), while such reductions may be lower for retrofit to existing plant. These figures suggest that capture rates for coal CCS plants may not be sufficient to bring emissions below 50g/kWh. However, the rate of CO_2 capture may eventually depend on the level of the carbon price, with higher rates of capture possible at additional cost, should the plant configuration and logistics allow. While these figures suggest that oxy-fuel and pre-combustion CCS plants are likely to have lower emissions, post-combustion

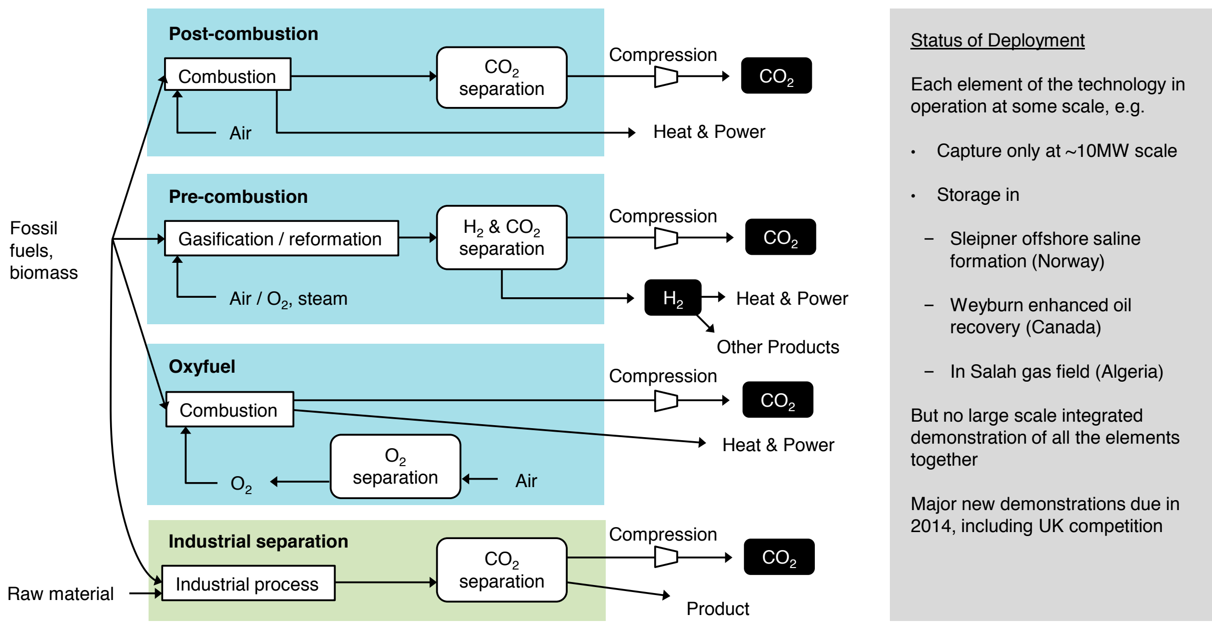
22 Carbon Trust (2006). Future Marine Energy.
23 IEA (2008), Op. cit., p400.
24 Carbon capture and storage involves the capture of CO_2 from a large-scale stationary power source or industrial emission process, its transportation via pipeline or ship and injection into suitable underground geological layers.
25 Rubin, E., et al. (2005) IPCC Special Report on Carbon Dioxide Capture and Storage, IPCC.
26 The capture process requires heat, in order to regenerate the solvent used to capture the CO_2 and to provide the steam required by the capture process. This heat is would generally be diverted away from use to generate electricity, resulting in a reduction in plant efficiency and a consequent increase in the CO_2 produced per kWh electricity generation, before capture. Because of this, the reduction in emissions vs. a non-CCS plant is not as great as the quoted capture rate.

technology will be essential for retrofit of coal plant currently being built, especially in India and China.

- Unlike nuclear and renewable technologies, which under optimistic assumptions might in future deliver electricity more cheaply than fossil fuels, adding CCS to fossil fuel plants must add cost. But reasonable estimates suggest a modest cost penalty. The IEA presents estimates that CCS could add 2-4¢/kWh to new gas and coal-fired generation costs[27]. Estimates for the UK suggest costs of around 2-3p/kWh. These costs primarily arise from reduced thermal efficiency and the engineering cost of CO_2 capture; in addition transportation, storage and monitoring costs and the costs to cover residual emissions are relatively small (Figure 2.7). There are also costs entailed in purchasing emissions credits to cover residual emissions; in the long run, in which we might expect a carbon price considerably higher than today's, co-firing of biomass in coal CCS plants could potentially be used to eliminate these residual emissions.

- The feasibility of CCS depends also, however, on the availability and capacity of potential CO_2 storage sites. Calculations by the IPCC suggest that total of world geological storage facilities (primarily saline aquifers) have a capacity of 1700–11000 $GtCO_2$. Given that the BLUE scenario envisages up to 10.4 Gt of captured CO_2 per annum by 2050[28], total storage is unlikely to be a significant constraint, at least this century. But regional variation in the availability of storage sites will have a significant impact on costs and implementation challenges. Due to its large and now significantly depleted offshore oil and gas fields the UK is relatively well placed for deployment of CCS (Figure 2.8).

Figure 2.6 Carbon capture and storage: technology status



Source: IPCC (2005).

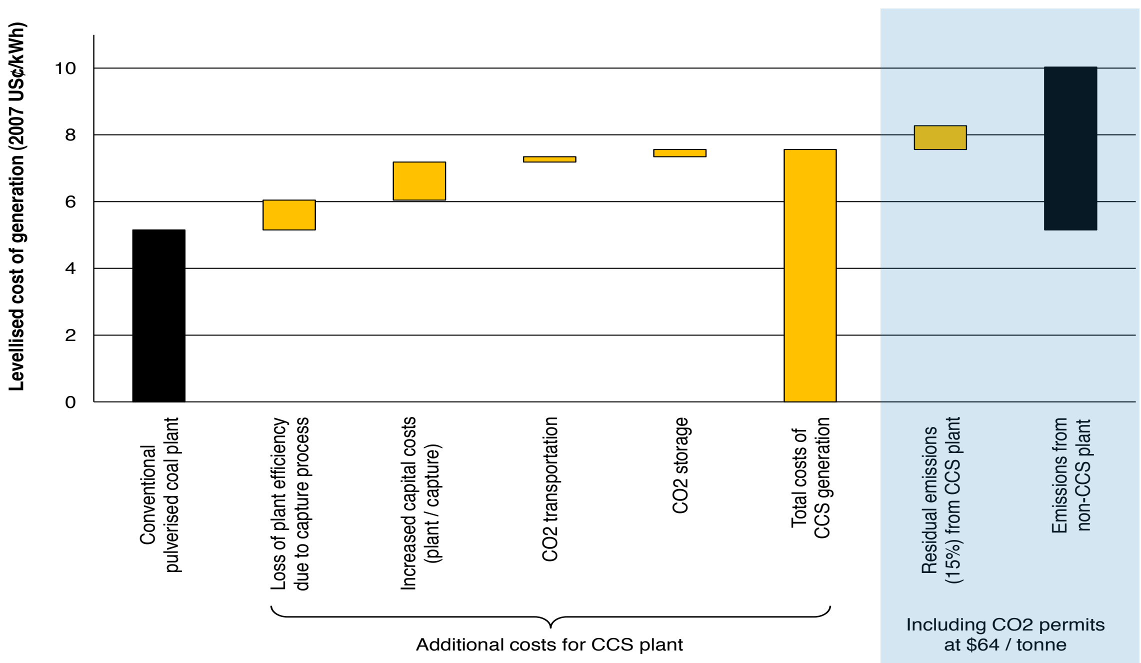
27 IEA (2008), Op. cit., p270.
28 IEA (2008), Op. cit., p69.

Table 2.6 Capture rates and emissions for different types of CCS plant

Type of CCS plant		Feasible capture rates	Increased energy requirement	Reduction in CO_2 vs. non-CCS plant	Residual CO_2 emissions
Coal	Pre-combustion	85-91%	14-25%	81-91%	70-150 g/kWh
	Post-combustion	85-90%	24-40%	81-88%	90-150 g/kWh
	Oxy-fuel	91-94%	18-43%	88-92%	73-86 g/kWh
Gas	Post-combustion	85-90%	11-22%	83-88%	40-66 g/kWh

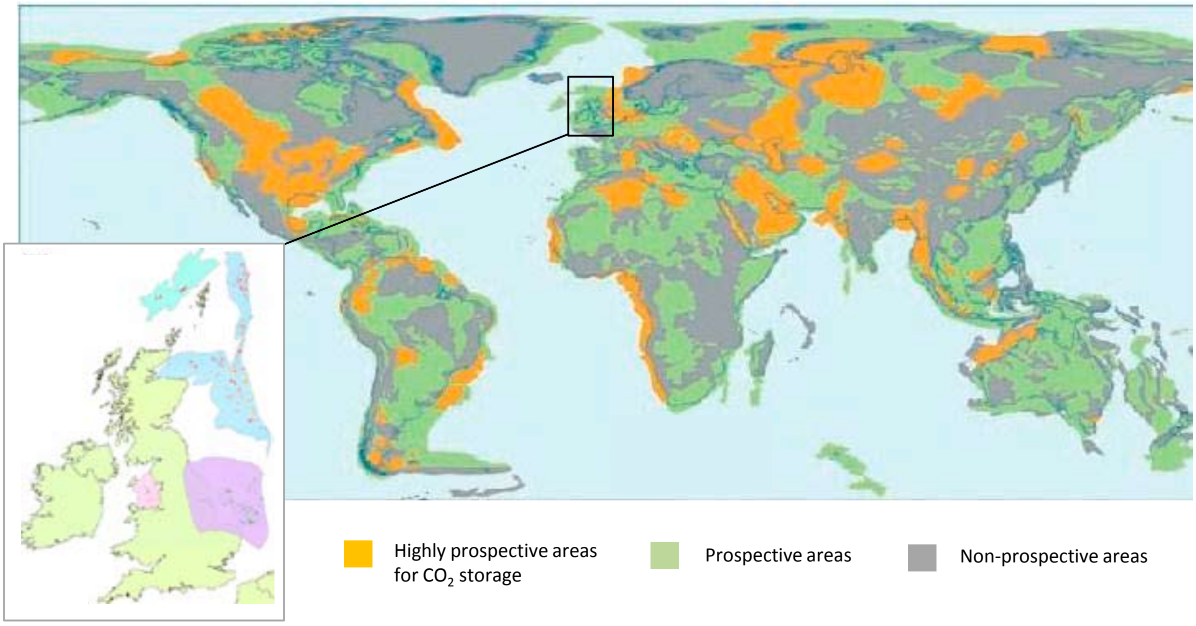
Source: IPCC (2005).

Figure 2.7 Composition of the cost premium for a new-build post-combustion coal CCS plant in 2020



Source: Calculations based on data from IPCC (2005), and using the 2020 coal price from the DECC central fossil fuel price scenario.

Figure 2.8 CO_2 storage sites: global and UK



Sources: British Geological Survey; Bradshaw, J. and Dance, T. (2004) Mapping geological storage prospectivity of CO_2 for the world's sedimentary basins and regional source to sink matching. Proceedings of the 7th International Conference on Greenhouse Gas Technologies, Vol. 1 pp 583-592.

- CCS is therefore almost certain to play an important role in the decarbonisation of electricity and industrial processes, discussed in subsection (iv) below. It will need to play that role given the rapid growth of coal-fired generating capacity in China and India. The IEA BLUE Map scenario envisages fossil fuels with CCS producing 26% of global electricity in 2050[29]. But it cannot be a sufficient solution in itself. It has not yet been demonstrated on large production scale and cost estimates are therefore uncertain. If it requires the construction of pipelines, it may be subject to local opposition and planning delays similar to those that hold up nuclear and wind deployment. And if many countries simultaneously attempted to deploy CCS on a large scale, it would be highly likely to be subject to the similar supply bottlenecks and cost increases to those that have recently been observed in nuclear, wind and solar PV.

Biomass: Biomass is organic material grown, collected or harvested for energy use. It can play a role in reducing CO_2 emissions in three applications: a) as a fuel source in power generation, either on its own or co-firing; b) as a fuel source for heat, either alone or in combined heat and power (CHP) applications; or c) as a feedstock to produce liquid biofuels or hydrogen for transport. We therefore discuss its role in subsections (iii) and (iv) as well as here.

Presently, total biomass use is uncertain but it probably accounts for around 10% of energy consumption[30]. Most is consumed in developing countries as traditional, non-commercial, biomass for domestic cooking and heating. However it currently provides about 1% of power generation globally and by 2050, with a supportive policy environment this could increase significantly. However concerns over its impact on wider sustainability and food supply objectives could limit its use. It is therefore essential that biomass is used as efficiently as possible; this probably implies its use in direct heat production (where transformation losses are small) or in applications (e.g. aviation fuel) where no alternative low-carbon fuels are available.

29 IEA (2008), Op. cit., p85.
30 IEA (2008), Op. cit., p308.

The costs of using biomass in power generation are uncertain, as there is wide variation in the cost and performance of plants. The IEA estimate current costs at 6-18 cents/kWh and suggest that costs could fall to 5-12 cents/kWh by 2050[31]. Although expensive compared to the current cost of fossil fuel power generation, biomass power generation becomes cost competitive under the carbon price envisaged in the BLUE Map scenario ($200/t$CO_2$ in 2050); if used for combined heat and power generation, efficiency and competitiveness improve significantly. The IEA anticipate biomass could sustainably provide about 6% of power generation by 2050 under its BLUE Map scenario[32].

Managing electricity supply and demand: electrical storage, smart metering and pricing. Each of the technologies discussed above could contribute to reducing the carbon intensity of electricity generation. But other than biomass and CCS, all the technologies are also likely to change the temporal relationship between electricity supply and demand. Electricity demand naturally varies significantly by season, day of the week, and time of day. But nuclear plants are most efficiently run on a continuous basis, and renewable electricity supply varies in line with the wind, tide, wave, and solar conditions. Achieving the full potential of low-carbon energy sources and minimising any additional costs incurred in moving to a low-carbon economy therefore depends also on a range of technologies which make it possible to shift the timing of electricity demand.

If nuclear and renewable energy are deployed sufficiently to make a major difference to CO_2 emissions, but without any change in the time specificity of electricity demand, a significant cost penalty will result. New nuclear build, combined with installation of sufficient wind capacity to meet the UK's objective (discussed in Chapter 5) of generating 30-35% of its electricity from renewable sources would mean that on some summer nights there would be more generation from wind and nuclear than demand[33]. These potential periods of excess capacity increase the costs of nuclear or wind power per unit of output, and at least under current UK electricity market rules, make it less likely that both wind power and nuclear would be developed simultaneously on a purely commercial basis.

These problems can be significantly mitigated, however, through developments in technology and in the use and pricing of electricity which can significantly reduce the time-specificity of electricity demand. Three categories of development will play a role:

- Improvements in technologies for the central storage of electricity, or for converting surplus electricity into potential energy to be used to generate electricity at peak periods (Table 2.7). A variety of technologies exist, and technological development is likely to improve the effectiveness of these central storage mechanisms, but it is not clear that fundamental breakthroughs can be achieved.

- Instead it may be more likely that major change results from developments which improve energy storage at the decentralised level, whether as electricity in car batteries, as warmth in better insulated houses, or as sustained low temperatures in freezers and refrigerators.

  – In subsection (iii) below, and in Chapter 7: *Reducing domestic transport emissions*, we suggest that it is possible that the decarbonisation of surface transport will be driven by electrification of cars and vans; if this does occur, it will create a major new demand for electricity which is not time-specific, and which could be met by overnight charging, using otherwise surplus overnight capacity.

31 IEA (2008), Op. cit., p311.
32 IEA (2008), Op. cit., p67,85.
33 The issue of intermittency and potential tension with nuclear during the first 3 budget periods is also discussed in Chapter 5 and Chapter 13: *Security of Supply*.

- In subsection (ii), and in Chapter 6: *Energy use in buildings and industry* we discuss the significant potential to improve residential home energy efficiency via better insulation and the possibility that, as electricity generation is decarbonised, electricity should play a greater role in home heating, whether in traditional electrical storage heater form, or via the use of ground or air source heat pumps. But the more efficiently homes are insulated, the less the electricity demand needs to be specific to a certain time of day, given that heat generated at one time of day (e.g. overnight, or whenever, say, tidal power is producing electricity) is still keeping the house warm at another.
- And there is already untapped potential to run fridges and freezers whenever other demand for electricity is least, given the high insulation levels already achieved in cold appliances.

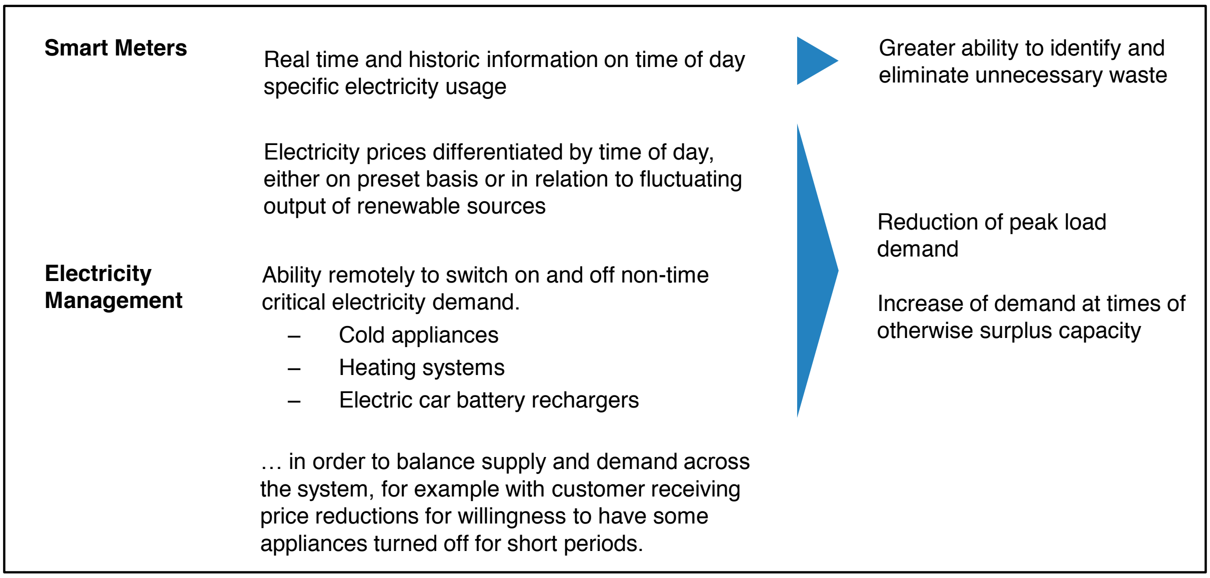
• There is therefore potential to shift electricity demand from current peaks, bringing it closer into line with the natural pattern of low carbon supply. Achieving this shift, however, is likely to require the use of price incentives, significantly varying the price of electricity to the end consumer according to time of use. This requires the roll-out of smart metering and energy management devices, which are already technologically feasible (Figure 2.9).

Table 2.7 Electricity storage options: current status and potential

Storage technology	Status / potential role
Pumped hydro storage	Established technology, provides fast-response peaking power. Requires appropriate geography.
Fly-wheels	Relatively mature. Small-scale devices, offering high power but low total energy storage. Often used in uninterruptible power supplies.
Compressed air	Large-scale compressed air storage can occur in underground storage reservoirs, if suitable geological formations are available. Smaller-scale options also under development.
Flow cells	Under development. Relatively high (around 30%) energy losses, but can be fully charged and discharged without problems and can be used for long-term storage.

Sources: DTI (2004) Status of electrical energy storage systems, Parliamentary Office of Science and Technology (2008) Electricity Storage.

Figure 2.9 Smart meter and electricity management capabilities and impact



Source: CCC analysis.

Summary conclusions on electricity generation: As already stressed, it is neither necessary nor possible to define in advance the precise mix of different technologies used to reduce emissions. But the range of different technologies available make it highly likely that it will be possible to almost entirely decarbonise electricity generation by mid century.

Globally, over the next ten to fifteen years, nuclear and renewables (in particular wind) and improvements in the efficiency of fossil fuel generation are likely to play the greatest role: beyond 2020, carbon capture and storage may become an important technology and in the long term solar power may play a very major role (Figure 2.10).

By 2050 the IEA BLUE Map scenario suggests that CO_2 emissions per kWh could be reduced by as much as 86%[34], with larger reductions possible in OECD countries (Figure 2.11). And while it is likely that this decarbonisation will entail higher electricity generation costs than the world would face in a non-carbon-constrained world, IEA estimates that the cost penalty could be small, with low-carbon electricity sources potentially available at only a few cents per kWh more than fossil fuel sources (as outlined earlier, in Table 2.3).

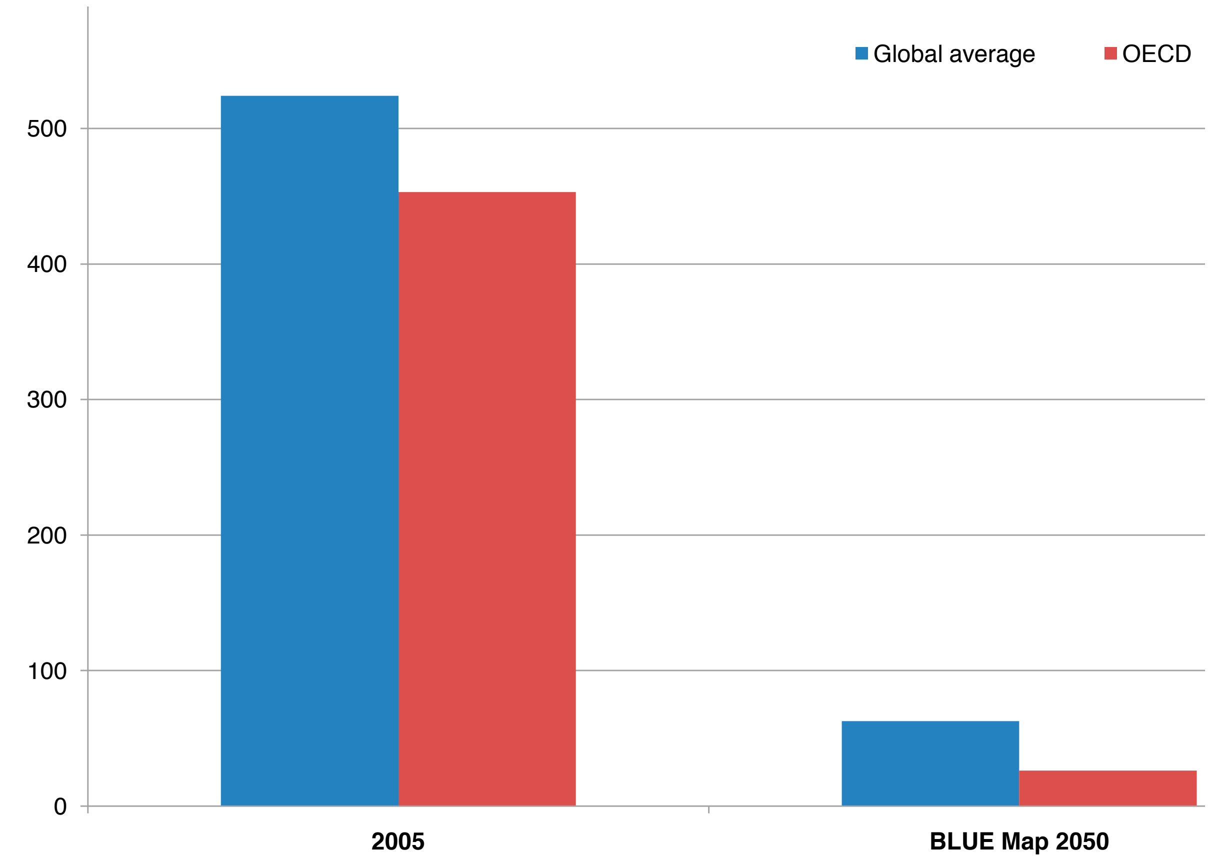
34 IEA (2008), Op. cit., p90.

Figure 2.10 Overall judgement on global deployment of electricity technologies

Long-Term Vision	Possible Timing	
A precise mix of technologies applied cannot be predicted, but... ... given the portfolio of different possible technologies ... it is highly likely that electricity generation can be almost totally decarbonised (i.e. <50 g/kWh) … at a 'modest' cost penalty, i.e. 0-4p per kWh, not tens of pence per kWh	**2010s:**	Shift from coal to gas in some regions Increasing application of efficient conventional fossil fuel technologies (CCGT, ultra supercritical coal) Increased deployment of nuclear Major deployment of wind in countries with natural resources Steady but still small proportion niche role for solar PV, solar thermal, biomass Demonstration of CCS technology
	2020s:	Continued roll out of nuclear and wind Large scale deployment of CCS Possible large-scale deployment of solar PV and solar thermal particularly in naturally sunny countries Possible roll-out of wave and tidal in countries with natural resource Steady increase in biomass use, particularly in CHP and cofiring / possibly CCS

Source: CCC analysis.

Figure 2.11 Global CO_2 emissions per kWh in power generation, 2005 and 2050



Source: IEA (2008).

(ii) Energy efficiency in the use of electricity

In the very long run the decarbonisation of electricity generation may be so close to complete that efficiency improvements in the use of electricity will be of secondary importance to carbon abatement, while still being important to cost minimisation. But radical decarbonisation (e.g. to less than 50 g/kWh) might take until 2030 or 2040 in OECD countries, and till much later in the century in developing countries. It is therefore essential in the meantime that maximum improvements are made in the efficiency with which electricity is used, both in residential and commercial buildings and in manufacturing processes.

Residential and commercial buildings: Across the world the percentage of electicity used in residential buildings and the service sector is just under 50%[35]. Globally, electricity demand in this sector could increase by 2.5% per annum in the absence of attempts to reduce emissions. There are, however, major opportunities to offset this growth via the application of existing and emerging technologies relevant to each major category of electricity (Table 2.8):

Table 2.8 Energy efficiency opportunities in the use of electricity

End-use technology	Efficiency opportunities
Air conditioning	Modern efficient technologies could reduce electricity consumption, for example by up to 38% at negative cost in the EU.
Lighting	Global shift from incandescent to compact fluorescent bulbs would reduce electricity consumption by 18% at negative cost. Longer-term shift to LED lighting could provide further radical improvements.
Appliances	Potential for a cost-effective efficiency improvement of at least 25%, more in developing countries.

Source: IEA (2008).

- In air conditioning, which in much of the world is, and will increasingly be, a major driver of electricity demand, there exist major opportunities to reduce cooling requirements by the better design of commercial and residential buildings to achieve natural cooling. In addition, best practice equipment efficiencies are 4-5 times higher than the least efficient equipment. The deployment of more efficient Information and Communications Technologies (ICT), appliances and lighting could reduce incidental heat and therefore the demand for cooling in many buildings.

- In lighting, an overlapping set of new technology developments could reduce electricity demand (watts per lumen of light produced) to a fraction of current levels in residential homes, and to a significantly lower level (e.g. 10 to 50%) in commercial buildings. Initial steps will entail transitions to higher efficiency ballasts and fluorescent tubes in commercial buildings and from incandescent to compact fluorescent lighting in residences. In the longer term, LED technologies are likely to deliver radical improvements in both. In addition better management of lighting, via the application of movement sensitive or light sensitive switches, could significantly reduce the amount of lighting demand currently wasted in unused rooms.

- Major improvements can be made in the energy efficiency of household appliances. The IEA reports that most regional and national studies conclude that the technical potential exists for 30-60% of further energy efficiency improvements in appliances[36].

35 IEA (2008), Op. cit., p120.
36 IEA (2008), Op. cit., p544.

- And major opportunities exist to improve efficiencies in ICT and other equipment, whether by reducing power demands while in use, by better management to eliminate power needs when not in use or, in the long run, via the development of new low energy materials.

Overall the IEA estimates that it might be possible to reduce building-related electricity demand in 2050 by 35%[37] below the baseline level via the application of these technologies.

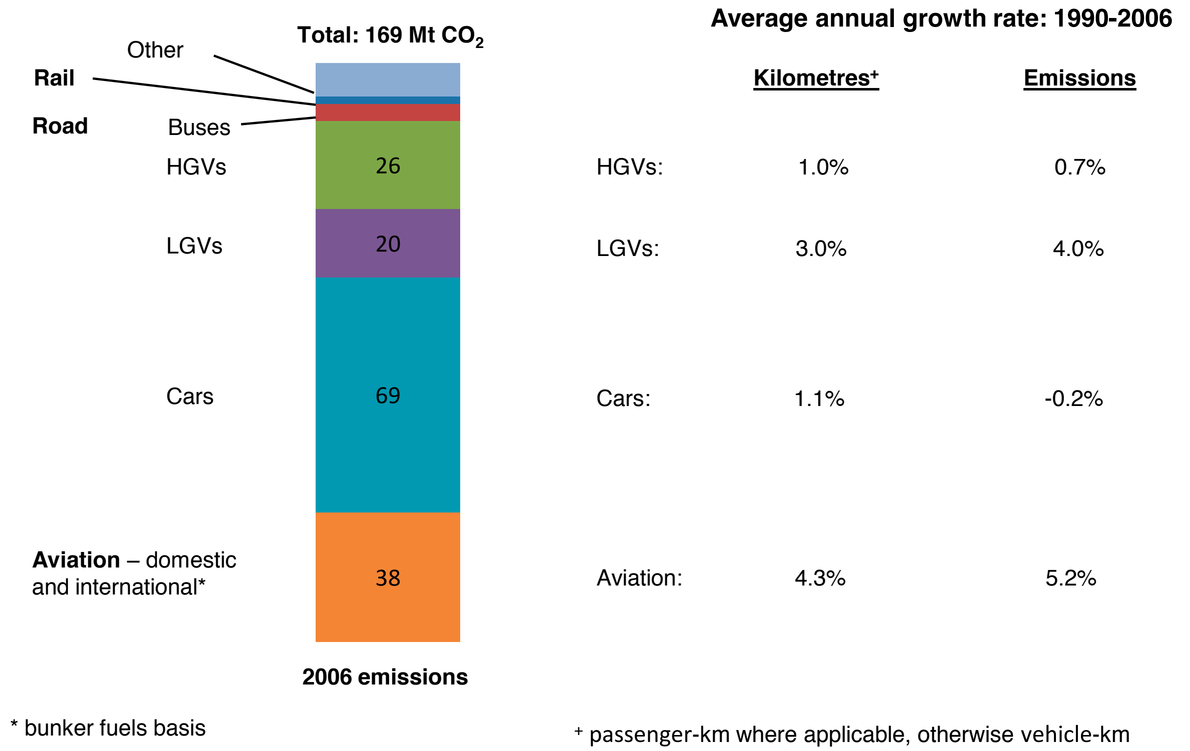
Industrial processes: Electricity is used throughout manufacturing industry to drive machinery, and in addition is very intensively used in specific industrial processes such as electric arc steel production and aluminium smelting. The opportunities to reduce demand in the intensive use areas are less than in commercial and residential buildings: this reflects the strong existing focus on energy efficiency in industries where energy is a significant element within the cost base. However, opportunities in general manufacturing are significant, with major improvement potential via the application of, for instance, variable speed drive technologies. Overall the IEA estimates that improvements in efficiency could reduce electricity demand in industrial processes in 2050 by 18%[38] versus the baseline. These estimates may fail to capture the possibility of radical changes in production technology or the impact that high-carbon prices will have on overall economic structure (i.e. the balance of consumer demand between goods and services and the balance of demand for low- and high-carbon goods).

(iii) Transport: more efficient vehicles, new fuels and demand containment

Emissions from transport account for around 30% of UK CO_2 emissions and 23% of global energy-related CO_2 emissions[39]; in the UK they are growing at around 1% per annum, with aviation emissions in particular on a fast upward path (Figure 2.12). Globally since 1990 transport CO_2 emissions have increased by 36%[40], with road traffic emissions growing particularly rapidly. This reflects the high income elasticity of demand for mobility. It is therefore essential that transport emissions are cut well below business as usual, through energy efficiency, the development of new low-carbon energy sources, and through measures which constrain demand without denying developing countries the welfare benefits of mobility.

37 IEA (2008), Op. cit., p105 – also includes reductions from agriculture, fishing and "other non-specified" sectors.
38 IEA (2008), Op. cit., p107
39 IEA (2008), Op. cit., p425.
40 IEA (2008), Op. cit., p425.

Figure 2.12 UK emissions from transport



Sources: UK National Atmospheric Emissions Inventory (NAEI); Department for Transport data.

More efficient vehicles: In road transport there exist major opportunities to reduce grams of CO_2 emitted per km through energy efficiency improvements even if the fuel source remains petrol or diesel. IEA estimates suggest that advanced engine technologies and improvements in tyres, aerodynamics, lights and appliances could increase petrol and diesel fuel efficiencies of LDVs[41] by up to 47% and by over 50% if hybrid technologies are used to capture energy lost in deceleration and braking (Table 2.9).

Improved aircraft design, meanwhile, could increase the energy efficiency of a new aircraft introduced in 2025 by as much as 35-45% relative to an average new production aircraft in 2006 through improvements in engine and airframe technology, while continuing to use aviation kerosene as the fuel (Table 2.10).

But there will eventually be absolute physical limits to what can be achieved by these energy efficiency improvements, and given the underlying growth of demand, energy efficiency itself would be unlikely to stabilise global transport emissions let alone cut them significantly. New low-carbon energy sources are also therefore essential.

41 Light duty vehicles include cars, sport-utility vehicles and small vans.

Table 2.9 Opportunities for efficiency improvements in petrol/diesel vehicles

	Gasoline			Diesel		
	Conventional	Advanced	Hybrid	Conventional	Advanced	Hybrid
Non-engine improvements (tyres, aerodynamics etc.)	1.5-13%	1.5-13%	1.5-13%	1.5-13%	1.5-13%	1.5-13%
Light-weight materials	10-11%	10-11%	10-11%	10-11%	10-11%	10-11%
Engine system improvements	5.5-9%	19-28%	8-11%	20-26%	22-30%	12-15%
Hybrid system	-	-	16-18%	-	-	15-17%
Overall improvement vs. base gasoline vehicle	**14-27%**	**28-45%**	**40-52%**	**30-43%**	**32-47%**	**40-55%**

Source: adapted from IEA (2008)

Table 2.10 Opportunities for efficiency improvements in aviation

Technological improvement	Efficiency improvement of new aircraft coming into service by 2025
Airframe	20-30%
Engine	15-20%
Operations / Air Traffic Management	10-15%

Source: Qinetiq (2008), Aviation CO_2 emissions abatement potential from technology innovation. Report to the CCC.

New transport fuels. There are three main energy sources or carriers which are likely to play a major role in reducing carbon emissions from transport: electricity, hydrogen and biofuels.

- **Electric vehicles** are far more efficient than internal combustion engines at converting energy inputs to kinetic energy within the vehicle. As a result, even if electricity is generated from coal, total grams per km travelled could be slightly lower for electric cars than for petrol cars; if electricity is gas generated the grams per km are significantly lower; as electricity is decarbonised through the technologies described in subsection (i) above, the advantage becomes large (Figure 2.13). As we decarbonise electricity, there could therefore be a huge opportunity to decarbonise road vehicles (Figure 2.14)[42].

  Electric cars are also fully capable of competing with petrol or diesel cars in speed or acceleration. The sole but important challenge is the size, weight and cost of batteries. Even the most advanced batteries available today can achieve energy densities only a small fraction of those of gasoline or diesel (Figure 2.15). However significant progress is being made with, for instance, lithium-ion batteries now achieving several of the performance objectives set by the US Advanced Battery Consortium (e.g. power discharge rate and power density) but with costs still significantly too high to make electric cost cars cost-competitive (Figure 2.16).

42 This figure represents the CO_2 emissions resulting from the use of a hydrogen fuel cell car, assuming that the hydrogen is produced via the electrolysis of water; there are alternative methods of hydrogen production.

Provided the cost penalty is accepted, however, electric propulsion is already close to being a realistic option for cars and light vans for users who do not need long distances between recharge. Investments to provide recharging infrastructure will be essential to support market growth, but major schemes are already under consideration or being launched in, for instance, Denmark, Israel and Australia (Figure 2.17).

As a result, some major manufacturers are planning product launches over the next few years (Figure 2.18) and reasonable scenarios (discussed in Chapter 7) suggest a significant percentage of new cars in Europe will be fully electric by 2020. The IEA's BLUE Electric Vehicle scenario envisages that 90% of all light duty vehicles (cars and vans) and an increasing share of heavier vehicles could be electric by 2050[43], reducing global emissions by over 4 Gt on a well-to-wheels basis relative to baseline[44]. On best present estimates this would likely come at a higher cost than other abatement actions. The IEA analysis suggests that the marginal abatement cost of electric vehicles could lie between \$200-500/tCO_2, compared with the costs of decarbonising power generation of up to \$50/tCO_2[45]. But it would still leave the total cost of required global abatement (across all sectors) at a few percentage points of GDP (see Section 2 for details) and these costs might fall significantly if technological progress and economy of scale effects were greater than currently assumed.

Electric vehicles are therefore likely to be a feasible route to a dramatic reduction in emissions from cars and light vans. Limitations to battery technology and thus to the possible range between recharging are however likely to make it more difficult to electrify HGVs, at least for several decades. Batteries are still less likely to be a feasible energy source for aircraft, even in the very long-term, due to their weight. Low-carbon liquid fuels with a higher energy density, such as biofuels or hydrogen, may therefore be essential in HGVs, buses and ships, and will certainly be essential for aviation.

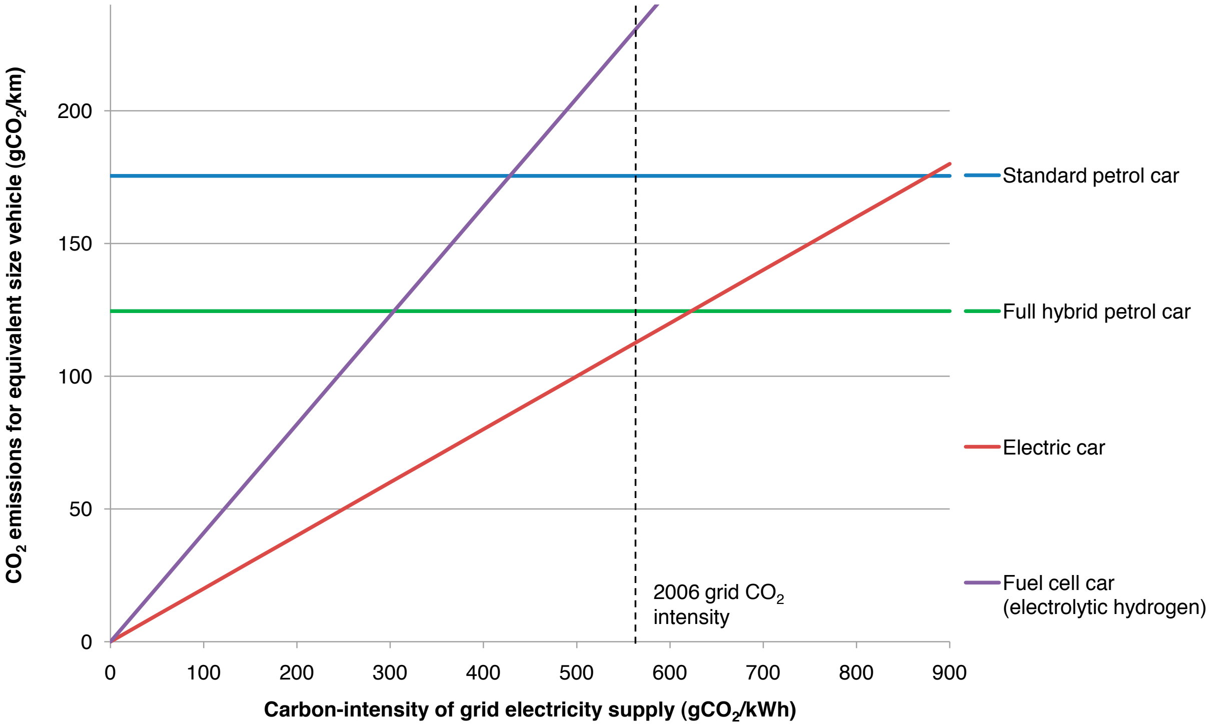
Figure 2.13 Carbon efficiency of electric versus internal combustion engine vehicles

	Power station efficiency Fossil fuel input => electrical energy		**Car engine / motor efficiency** Energy input => kinetic energy		**Overall efficiency** Fossil fuel input => kinetic energy output	**gCO_2 per km for equivalent car**
Internal combustion engine	n/a		26%	=	26%	**167**
Electric car (electricity from gas CCGT)	~50%	x	90%	=	45%	**79**
Electric car (electricity from wind / nuclear)	*no direct fossil fuel input but some CO_2 emissions embedded in construction*					**1-4**

Source: CCC calculations.

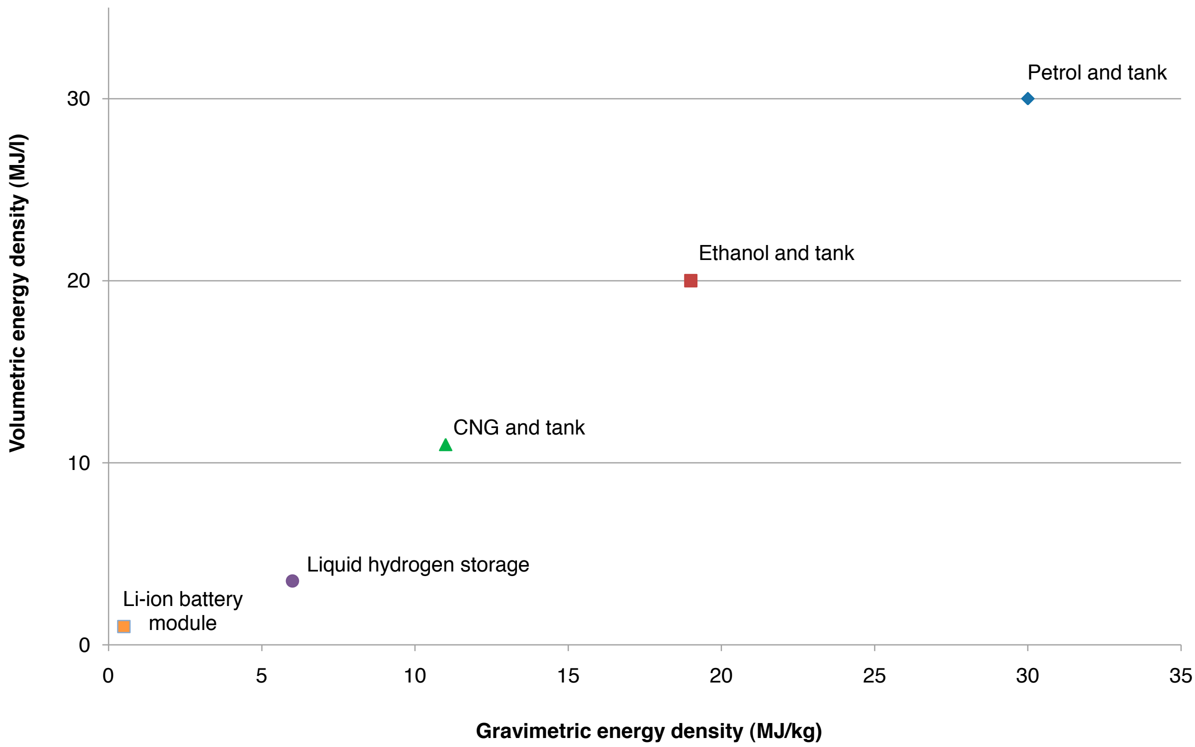
43 IEA (2008), Op. cit., p93.
44 IEA (2008), Op. cit., p96.
45 IEA (2008), Op. cit., p81 and p98.

Figure 2.14 Effect of electricity decarbonisation upon emissions from electric and hydrogen vehicles



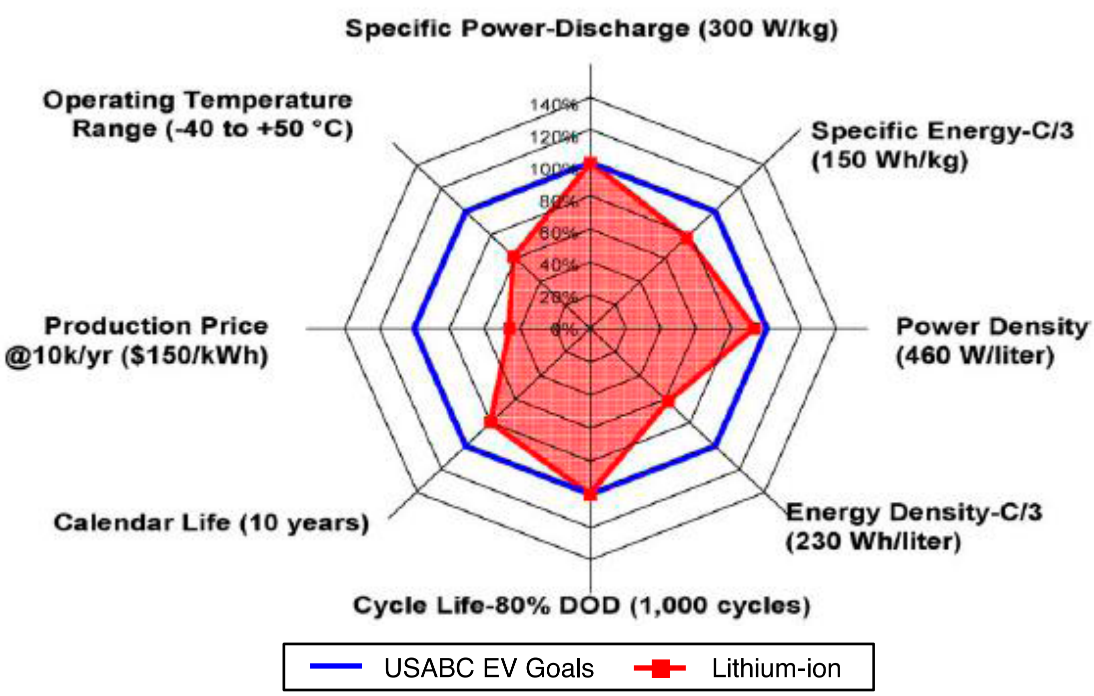
Source: CCC calculations.

Figure 2.15 Energy density of different transport fuels



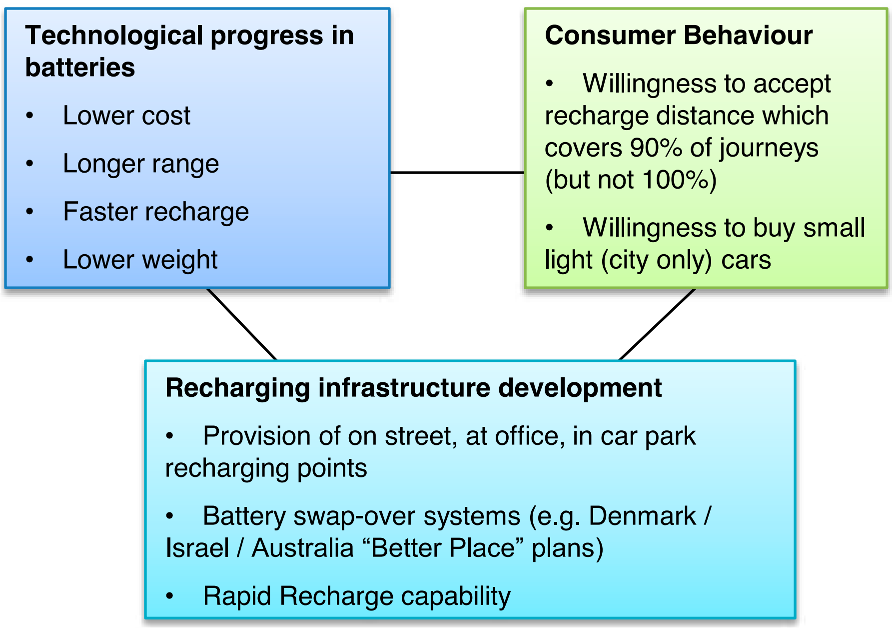
Source: Royal Society of Chemistry (2007) Fuelling the future.

Figure 2.16: Performance of lithium-ion batteries relative to industry targets



Source: Chalk and Miller (2006) Key challenges and recent progress in batteries, fuel cells and hydrogen storage for clean energy systems. *Journal of Power Sources*, 159(2006) 73-80.

Figure 2.17 Key drivers of electric vehicle uptake



Sources: CCC analysis.

Figure 2.18 Major electric vehicle product launches expected

	Present Product Offers	Product Landmarks Planned (2010-11)
Plug-in Hybrids	[some Toyota Prius cars have been modified to become plug-in hybrids]	**Toyota have accelerated planned launch date of Prius Plug-In to 2010** – Range 15 km electric **GM volt planned for 2010** – Range 65 km electric
Pure Electric	**G-Wiz. Micro-Car (2-seater)** – Cost £10,000 – Range 80 Km – Top speed 50 mph **Tesla Roadster (luxury sports)** – Cost £58,000 – Range 350 km – Top speed 125 mph	Electric car launches by – **Nissan** – **Subaru** – **Mitsubishi** – **Think**

Sources: Company websites; www.whatgreencar.com.

- **Hydrogen vehicles.** Hydrogen is not in itself an energy source but an energy carrier. The hydrogen needs to be produced either via electrolysis, in which the carbon efficiency depends on the grams per kWh of the electricity generation process; from biomass, which may compete with other sectors for finite sustainable resource; or from fossil fuel based processes, in which case the CO_2 emissions resulting from its production depend on the extent of carbon capture and storage achieved (Table 2.11). The hydrogen can then be used as a fuel within vehicles, either at relatively high efficiency in fuel cells–an electro-chemical device that converts hydrogen to electricity, used to drive an electric motor–or in less efficient hydrogen internal combustion engines. The efficiency advantage of fuel cells means that they are the likelier long-term solution.

  Provided therefore that it can be produced in a low-carbon manner, hydrogen could well become a feasible fuel for some transport modes and could play a major role if improvements in battery technology are disappointingly slow. But hydrogen vehicles are not as close to commercial deployment as electric, with significant challenges remaining in relation to hydrogen storage and the durability and cost of fuel cells. The lack of a hydrogen infrastructure is also a major inhibitor, although this is likely to prove less of a barrier for buses and other fleet vehicles that fuel at a central depot than for private vehicles. In aviation, even if implementation difficulties could be overcome, the emission of water vapour from hydrogen powered aircraft flying at high altitude would have a harmful greenhouse effect[46].

  The role that hydrogen may play is therefore uncertain. But technological progress may make it an important technology in HGVs, buses and ships, and potentially in other modes if its progress outstrips that of electric vehicles. The IEA BLUE Map scenario envisages that by 2050 hydrogen vehicles could account for 25% of the global HGV fleet[47].

46 See Chapter 8 for a discussion.
47 IEA (2008), Op. cit., p429.

Table 2.11 Options for hydrogen production

Method of hydrogen production	Associated CO_2 emissions (gCO_2 / kWh)
Electrolysis – renewable or nuclear electricity	7-9
– grid electricity	depends on electricity g/kWh (see Figure 2.14)
Natural gas – steam methane reforming (SMR)	92
– SMR with CCS	35
Coal gasification with CCS	48
Biomass – woody biomass	10-14

Source: Concawe et al (2007) Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context v2c, for the EU Joint Research Centre.

- **Biofuels**. Technologies have already been developed for producing biodiesel or bioethanol from a variety of crops. Initial products (labelled first generation) have utilised natural oils, fruits and sugars, which can be converted easily to biodiesel and bioethanol. Second generation technologies will be able to use a variety of processes to derive biofuels from biomass material with a lower calorific value, using bio-wastes and fast-growing crops grown on marginal land, using the whole plant rather than just the edible part. Third generation fuels (e.g. those derived from algae) are in the early stages of development. Cars, vans and HGVs can all be powered by biofuels, and biokerosene for aviation can be produced from biomass using a Fischer-Tropsch process.

  Biofuel production costs are currently higher than for conventional fossil fuels, and carbon abatement via biofuels could conversely be higher cost per tonne saved than for instance electricity decarbonisation. But the IEA BLUE Map scenario foresees the possibility of biofuels accounting for 26% of transport fuel demand in 2050[48].

  The key issues in respect to biofuels therefore relate not to technical feasibility, nor to cost, but to the full impact of biofuel production on GHG emissions (taking into account land use changes) and to concerns that biofuel production could compete with food production for scarce agricultural land. Some of these concerns are likely to be overcome by the development of second generation biofuels, but as the Gallagher Review has recently set out, there may still be limits to the types of land which biofuels can be produced on without causing harmful environmental or social side-effects (Table 2.12).

  The precise role of biofuels within an optimal carbon abatement strategy is therefore unclear. Bioenergy production overall (for all uses, not just transport) is almost certain to play a significant role in reducing emissions, but the issues which the Gallagher Review has highlighted suggest some limits to that role. It is therefore essential that bioenergy is used as efficiently as possible and in the applications where alternative decarbonisation options are unavailable or very expensive. Aviation could well be one such application; HGVs may be another.

48 IEA (2008). Op. cit., p94.

Table 2.12 Sustainability issues with different generations of biofuels

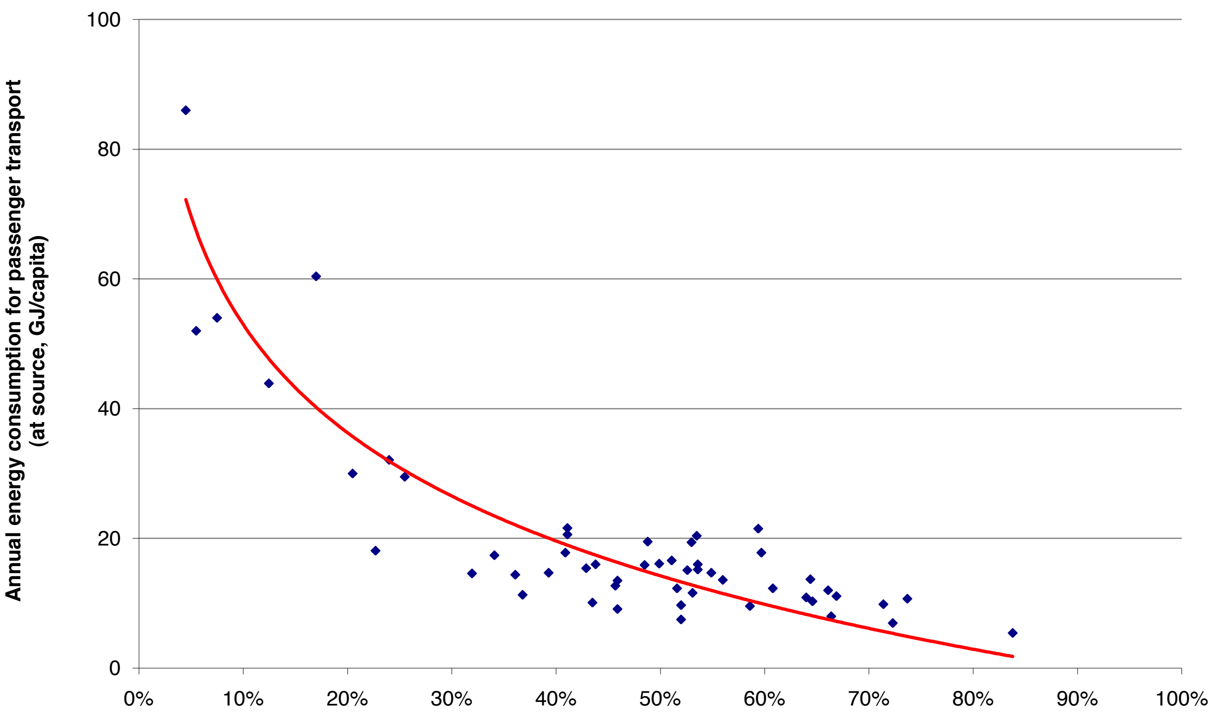
Biofuel generation	Sustainability concern
1st generation: biofuels from food crops	• Competition with food production • Low net GHG emissions saving vs. conventional fuels
2nd generation: e.g. ligno-cellulosic ethanol, Fischer-Tropsch diesel	Need to use wastes / residues, or ensure that genuinely marginal land is used for growing feedstocks

Source: Renewable Fuels Agency (2008) The Gallagher Review of the indirect effects of biofuels production.

Influencing the level and modal balance of demand. This chapter focuses primarily on the application of technologies to drive energy efficiency improvements and to deliver low-carbon energy sources, and does not consider changes in consumer behaviour that could limit demand for energy. To the extent that consumer behaviour may change the costs of achieving radical emissions reduction at the global level can be lower than those discussed in Section 2. The UK cost estimates in Section 3 attempt to take behavioural change into account by allowing the demand for energy services to vary with the cost of meeting them. But in the area of transport, it is important to note that demand is hugely influenced not only by individual consumer behaviour, but by societal decisions relating to land use planning, urban design and transport infrastructure investment (e.g. road and rail networks). City, suburban and intercity transport networks can be designed to deliver individuals' demand for mobility in ways which have dramatically different implications for carbon emissions. Energy consumption for passenger transport varies greatly according to the percentage of journeys made by different transport modes (Figure 2.19). And there is no necessary reason why increasing prosperity should mean an increasing share of higher-carbon private transport if cities are designed to facilitate public transport mobility (Figure 2.20).

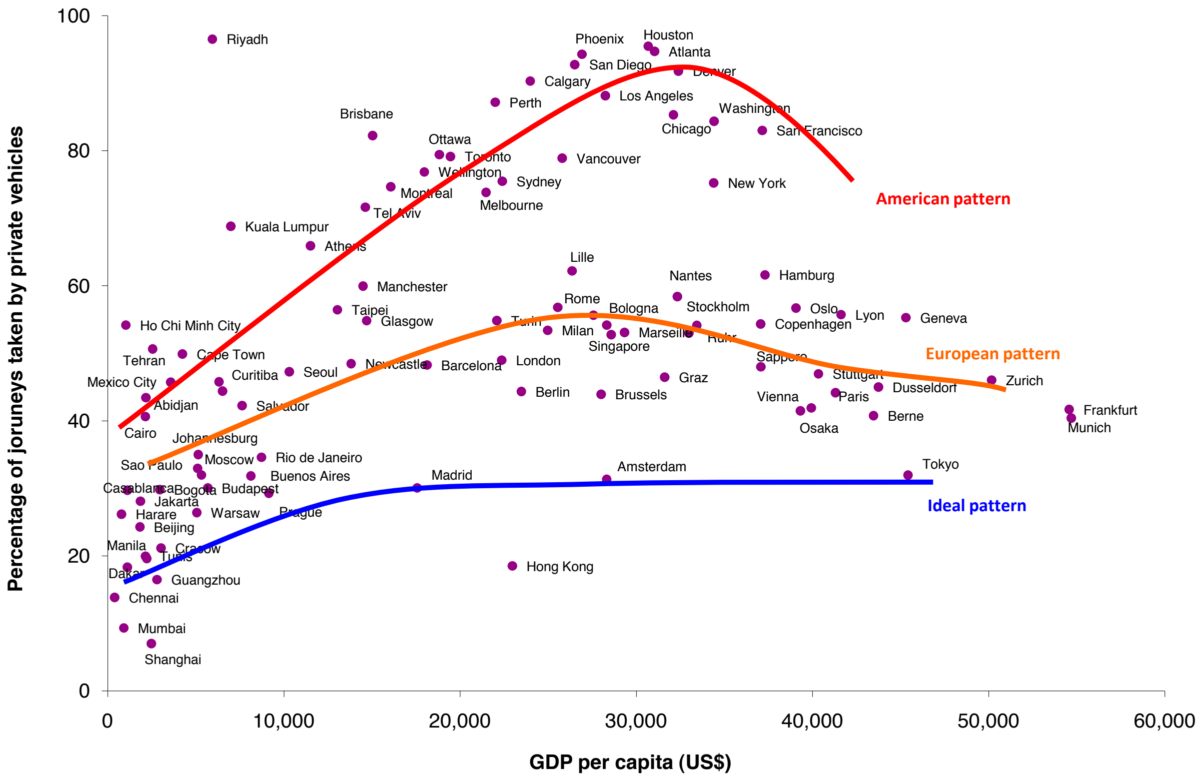
In transport therefore more than in any other sector, non-technology-based options to reduce emissions will be important.

Figure 2.19 Variation in city energy consumption with transport mode



Source: IEA (2008) and International Association of Public Transport (2006), Mobility in Cities Database, Courtesy of SYSTRA.

Figure 2.20 Use of private and public transport in cities of varying prosperity levels



Source: IEA (2008) and International Association of Public Transport (2006).

(iv) Heat: energy efficiency and new energy sources

At the global level the production of heat accounts for around 55% of final energy use (in addition in hot countries there is considerable and growing energy demand for coolness, i.e. air conditioning: this was considered under subsection (ii) above). Two categories of heat demand can usefully be distinguished: demand for moderate temperature heat for space and water heating and demand for heat (sometimes at very high temperatures) in industry. In both there are likely to be major opportunities to reduce emissions, but on different timescales and using different technologies.

Space and water heating in residential and commercial buildings: In the short term emissions reduction will come mainly from improvements in insulation and boiler efficiency: in the longer run, new sources of energy – including low-carbon electricity – could play an increasing role.

- Major improvements are possible in the insulation of buildings, radically reducing the required energy input to maintain comfortable space temperatures. 'Passive house' or ultra low energy use standards for new build homes – with efficient roof, wall and window insulation – can cut space heating energy requirements by up to 80% versus typical existing housing stock[49]. Improvements in existing buildings are more difficult to achieve, but major opportunities still exist (these are discussed in more detail in relation to the UK in Chapter 6).

49 IEA (2008), Op. cit., p555.

- Major improvements can also be achieved in the efficiency of gas boilers (and in some countries, coal and oil boilers) used in residential and commercial buildings. Latest condensing gas boilers can achieve thermal efficiencies of up to 90%, versus less than 75% for the typical installed stock, thus reducing grams of CO_2 per kWh of heat produced by around a sixth. Clearly, however, there is an absolute limit beyond which further improvement will become impossible.

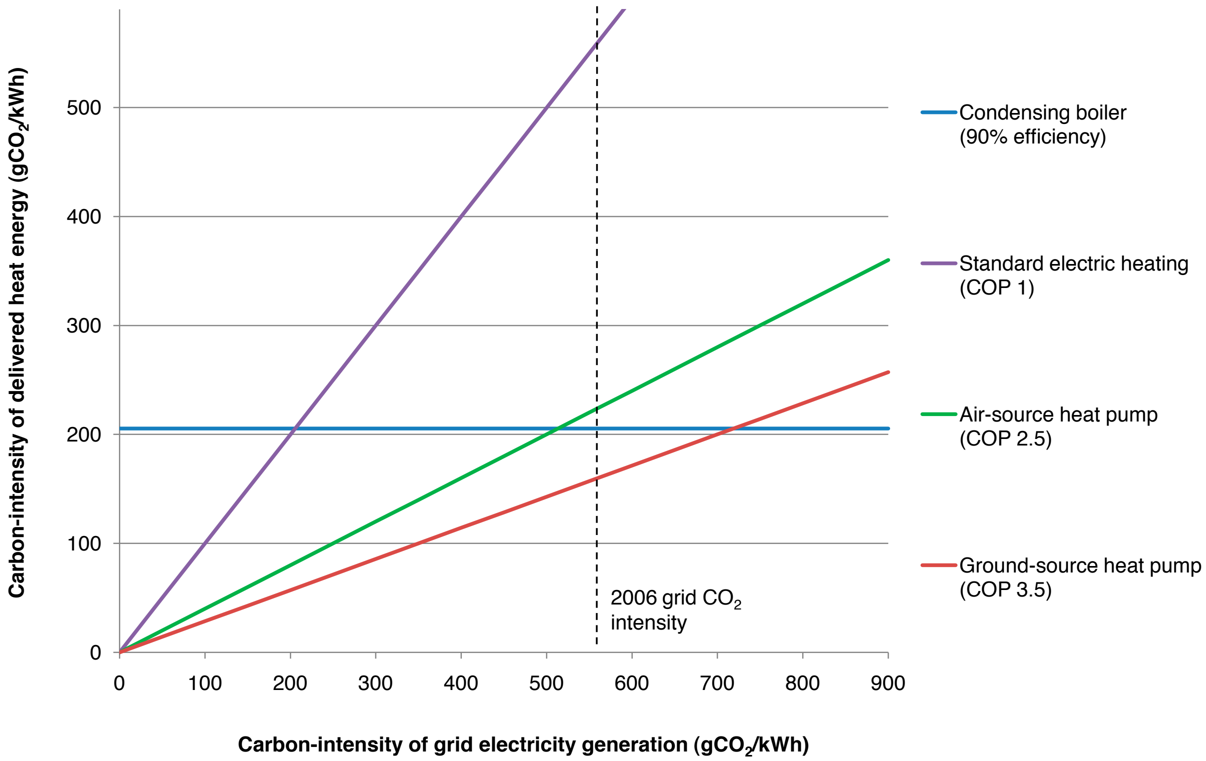
- Insulation improvements have less potential to reduce energy use in water heating: but solar thermal water heating is a fully proven low-carbon technology, which is likely to play a major role, particularly in sunny climates. The full potential of solar thermal systems has not been reached in most IEA countries, due to relatively high capital costs and long pay-back periods. The US has an R&D goal of halving the cost of energy produced by a solar hot water system to 4¢/kWh; this would be substantially below US retail electricity prices and below the retail price of gas in the UK.

- As electricity is decarbonised, it is likely that low-carbon electricity can be used to replace fossil fuels in space and water heating. Once the carbon intensity of electricity falls below about 200g/kWh it will be more carbon efficient to provide hot water and space heating with electricity than with gas burned in a condensing boiler, even using established technology such as electric bar or storage heaters (Figure 2.21). But far greater efficiency is possible with the use of heat pump technology. Ground-source heat pumps can deliver three to four times as much usable heat energy as they require in electricity input. The potential efficiency of air-source heat pumps is slightly lower (two to three times) but they can be deployed in many buildings (e.g. in dense urban areas) where ground source heat pumps are impractical. Either variant of heat pump can therefore already, even at the existing average UK carbon-intensity of electricity, deliver heat energy more carbon efficiently than gas. As electricity generation is decarbonised this advantage will become very large. In addition, biomass-based heat production is likely to play a role in locations where storage constraints are not severe and where natural resource exists.

Taking all of these options into account, the IEA's BLUE Map scenario envisages that emissions from residential and commercial buildings (almost all of which is devoted to the production of heat) could be reduced by around 60% versus business as usual by 2050[50].

50 IEA (2008), Op. cit., p78.

Figure 2.21 Carbon efficiency of heat pumps compared to conventional technologies



Source: CCC calculations.

Heat in industry: Heat is an essential input to industrial processes such as iron and steel production, non-metallic minerals (in particular cement), chemicals and petrochemicals, and pulp and paper. Together these four sectors account for 75% of global industry's direct[51] (i.e. non electricity related) emissions of CO_2, the vast majority of which results from the burning of fossil fuels to produce heat.

There are a range of opportunities to improve the efficiency of industrial processes to reduce heat demand without changing the energy source, or to reduce the carbon intensity of the energy source by switching from coal to gas in locations where this is feasible (Table 2.13). But given the professional management already devoted to reducing energy input costs, and the inherent requirement for heat in some industrial processes to achieve essential chemical or physical transformations, it is likely that the percentage reduction opportunity will be smaller than in the building sector. To achieve a radical decarbonisation (e.g. the envisaged reduction of emissions by 60% versus the baseline in the IEA's BLUE Map scenario[52]) will almost certainly therefore require the substitution of biomass for fossil fuel energy sources and/or the application of carbon capture and storage at major industrial sites (as well as at power stations as discussed in subsection (i) above).

51 IEA (2008), Op. cit., p482.
52 IEA (2008), Op. cit., p474.

Table 2.13 Opportunities for energy efficiency in industry

Industrial sub-sector	Efficiency opportunities
Iron & Steel	Deployment of best available technologies (BATs), especially for blast furnaces, would save 17% of emissions globally
Non-metallic minerals (cement, glass, ceramics etc.)	Cement dominates this sector; switching to dry-rotary kilns for cement production would save 12% of emissions
Chemicals & Petrochemicals	Deployment of BATs would save 25% in ammonia production. Membrane technologies may reduce emissions from various separation processes considerably in the future
Pulp & Paper	Biomass residues are commonly used for energy generation; efficiency improvements (e.g. advanced paper drying technologies) would free up scarce bioenergy resources

Source: IEA (2008).

(v) Technologies to drive emissions reduction: summary and implications

The subsections above have illustrated that there are likely to exist a wide range of technologies that can drive the decarbonisation of electricity generation, of transport energy sources, and of heat production. Together (as Sections 2 and 3 below will illustrate) they make it likely that the world and the UK can achieve the emissions reduction recommended in Chapter 1 at an acceptable economic cost.

They also suggest that:

- In the initial 10-15 years, emission reductions are most likely to be achieved through steps towards the decarbonisation of electricity production, from improved efficiency in electricity use, from improved fuel efficiency in petrol and diesel engines, and from improvements in insulation and boiler efficiency in homes and commercial buildings.

- In subsequent decades, almost total decarbonisation of electricity generation is likely to become possible, including through the application of carbon capture and storage. But in addition, it is likely that decarbonised electricity will then be applied to a widening set of uses, in particular in surface transport (through electric vehicles) and in water and space heating.

- It is therefore possible, despite the potential for improved efficiency in electricity use, that successful strategies to reduce carbon emissions in line with Chapter 1 recommendations will, in some countries, involve increases rather than decreases in electricity supply versus business as usual scenarios.

The implication of this is that the decarbonisation of electricity generation is almost certainly more important to successful emission reduction than the current contribution of electricity generation to total emissions would suggest.

2. POSSIBLE GLOBAL PATH TO A 50% REDUCTION: TECHNOLOGIES AND COSTS

Chapter 1 concluded that an appropriate global strategy should aim for a reduction of emissions of all Kyoto GHGs to about 20-24 Gt per annum by 2050, which would require a reduction of about 50-60% below the current level. The technology options described above in Section 1 make it likely that this reduction can be achieved at a cost of 1-3% of global GDP in 2050, in line with the estimates produced by the Stern Review. This section summarises the evidence which lies behind these estimates, covering in turn:

(i) A possible global technology path to 2050

(ii) Possible global costs

(i) A possible global technology path to 2050

We have made it clear that it is not possible or necessary to define in advance the precise mix of technologies which will be deployed to achieve global emissions abatement. That path will be determined by future developments in technologies and costs, which cannot be predicted. But it is possible to make a reasonable assessment of whether there are a variety of different technological scenarios which could deliver required emissions reduction at acceptable cost. The IEA has assessed a number of scenarios consistent with the technological possibilities described in Section 1 above. These scenarios suggest that an emissions reduction of the required magnitude is attainable.

- The IEA's analysis covers fossil fuel based emissions of CO_2 and therefore excludes consideration of land use related CO_2 emissions and of non-CO_2 GHG emissions from, for instance, waste management and agriculture. Emissions reduction in these other sectors is important, but analyses of possible abatement costs is in general less advanced compared to fossil fuel based CO_2. The IPCC estimate of potential, on which we have drawn, may underestimate the opportunity to cut emissions via reduced deforestation and afforestation, as its estimates only extend to 2030[53]. But despite the uncertainty it is clear that reduction in fossil fuel CO_2 emissions will have to account for the great majority of all abatement. One reasonable scenario using the IPCC figures for non-CO_2 and land-use changes could foresee at least 56 Gt of abatement below baseline levels in 2050, with 48 Gt of this arising from reduction in fossil fuel CO_2 (Table 2.14).

- The IEA describes a number of scenarios by which this could be achieved. This BLUE family of scenarios contains several variants reflecting for instance, different possibilities for the relative importance of electric and hydrogen vehicles in reducing transport emissions, and different balances between renewables, nuclear and CCS in decarbonising electricity. But the broad shape of the scenarios can be understood by one particular variant, labelled BLUE Map. This describes a technically feasible reduction of 48 $GtCO_2$ versus the baseline in 2050 (Figure 2.22).

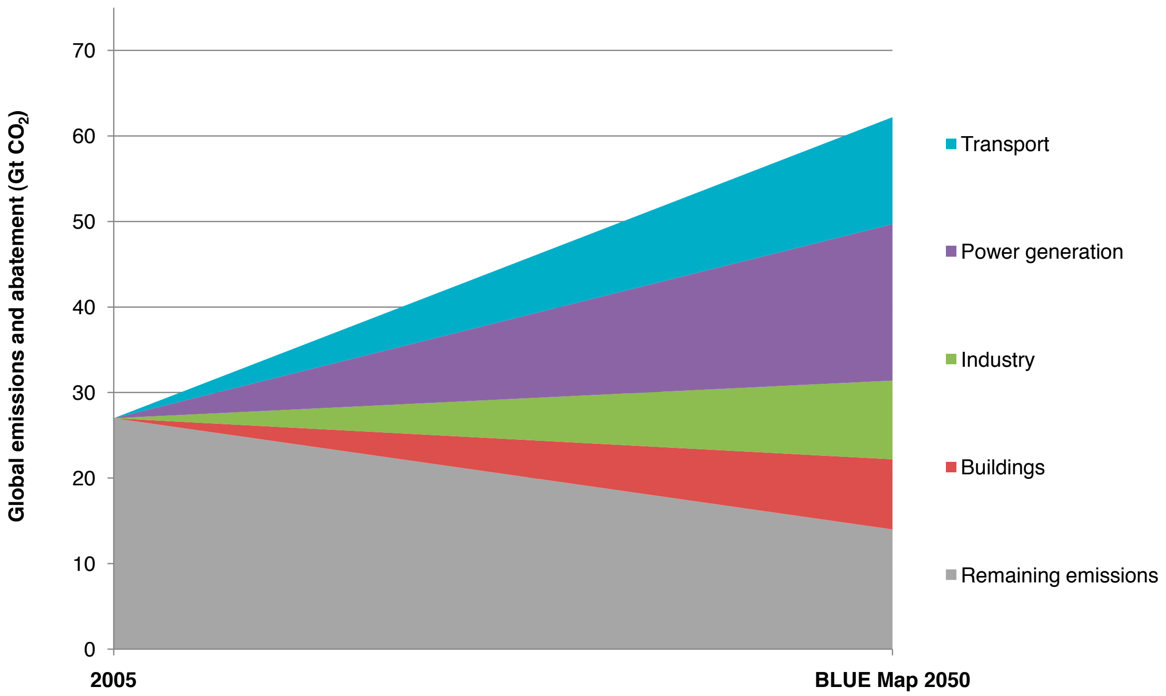
53 In addition to the difference in timescale estimates of non fossil fuel abatement potential are also highly uncertain. For example, IPCC 4AR WGIII (p632) suggests that forestry can deliver 1.3-4.2Gt of abatement in 2030 assuming a carbon price of less than $100 per tonne of CO_2. The estimates are derived from regional bottom-up studies, which take into account barriers to implementation. Other top-down models, which incorporate simplified forestry options as an input to generate least-cost mitigation scenarios, produce higher estimates of potential abatement–up to 14Gt in 2030.

Table 2.14 Global abatement scenario – potential sources of 2050 abatement

Sources of emissions	Abatement ($GtCO_2e$)
Fossil fuel CO_2 (*Source: IEA*)	48
Industry non-CO_2 (*Source: IPCC*)	0-1
Waste and Agriculture (*Source: IPCC*)	5
Forestry CO_2 (*Source: IPCC*)	3
Total	56-57

Source: IEA (2008) and Barker T., et al (2007) Climate Change 2007: Mitigation Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, UK. Cambridge University Press.

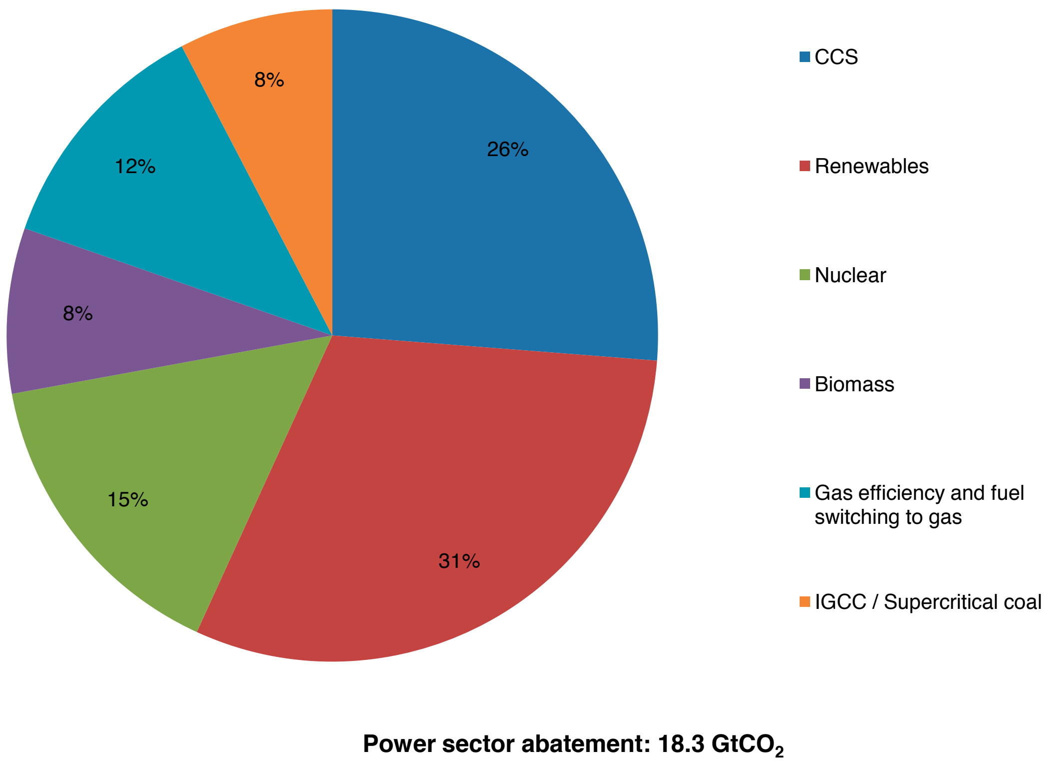
Figure 2.22 CO_2 abatement from IEA BLUE Map



Source: IEA (2008).

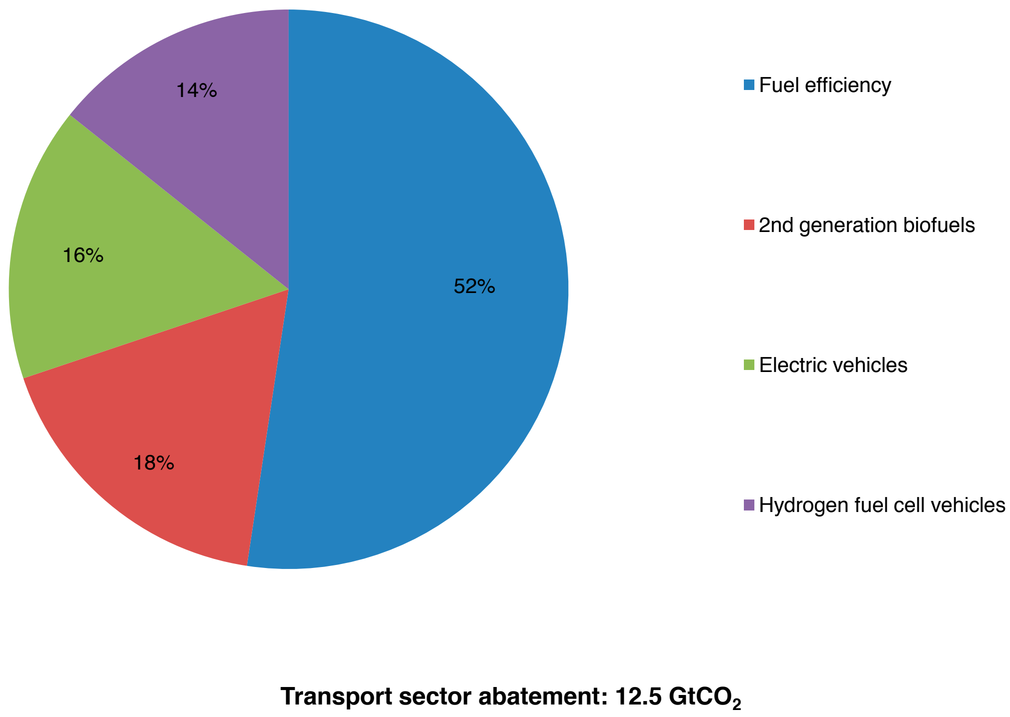
- In 2050 the BLUE Map scenario has the following features:
  - Decarbonisation of electricity generation makes the biggest single contribution – 18.3 Gt – through a balanced combination of renewables, nuclear, CCS, improved carbon efficiency and fuel switching (Figure 2.23). Other variants of the BLUE scenario illustrate different energy mixes which meet the same goal (e.g. more nuclear, more CCS or more renewables).
  - Significant decarbonisation of the transport sector with a role for fuel efficiency, hydrogen and electric vehicles and second generation biofuels (Figure 2.24). In the BLUE Map scenario, hydrogen, electricity and biofuels all have a role to play: alternative IEA scenarios illustrate that it is possible that one or other of these technologies might dominate.
  - A reduction of 9.2Gt in industry, with improved fuel efficiency and the application of CCS at industrial plant level playing major roles (Figure 2.25).
  - Abatement of 8.3 Gt in buildings, with improvements in insulation and the efficiency of electricity use the largest contributors (Figure 2.26).

Figure 2.23 Global power generation abatement in 2050 (IEA BLUE Map scenario)



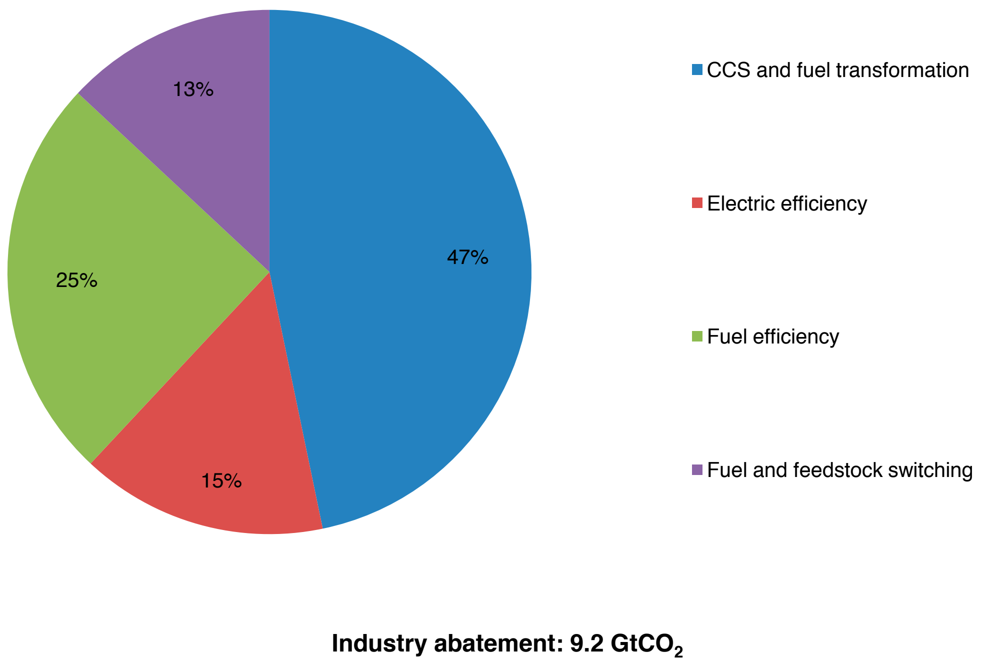
Source: IEA (2008).

Figure 2.24 Global transport abatement in 2050 (IEA BLUE Map scenario)



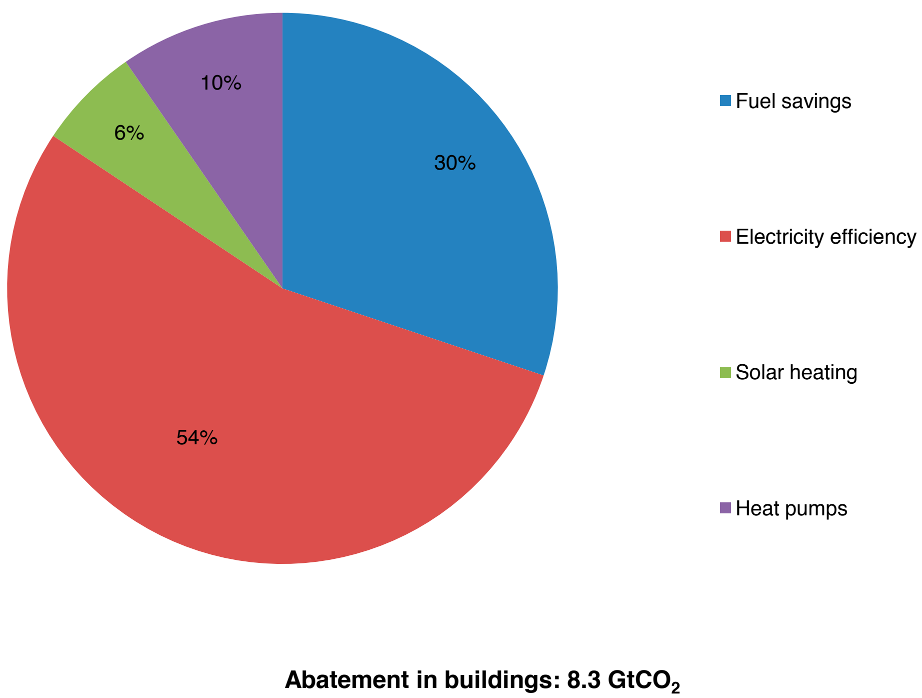
Source: IEA (2008).

Figure 2.25 Global industry abatement in 2050 (IEA BLUE Map scenario)



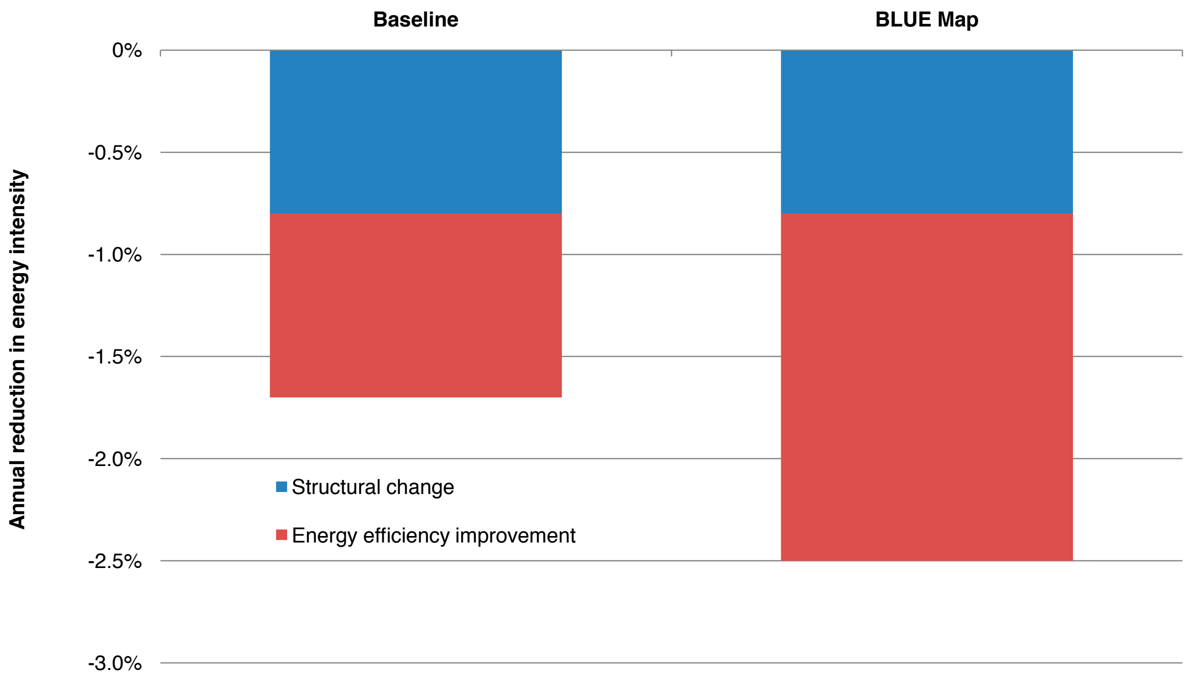
Source: IEA (2008).

Figure 2.26 Global buildings abatement in 2050 (IEA BLUE Map scenario)



Source: IEA (2008).

Figure 2.27 Annual reduction in energy intensity, global, 2005-2050



Source: IEA (2008).

The scenarios are of course only indicative. But they are built on a comprehensive assessment of already available technologies and of reasonably likely technological developments, with no assumption that there will be fundamentally new technological breakthroughs of an unpredictable type. They therefore provide reasonable assurance that, when combined with efforts to reduce other GHG emissions, a path to a 50% global reduction is achievable, reinforcing other analysis which reaches similar conclusions (e.g. the Stern Review).

(ii) Possible global costs

Some of the abatement opportunities pursued–particularly those which depend on energy efficiency improvements–will produce benefits that offset their costs and in some cases indeed will make economies more cost efficient and therefore richer. And it is possible that the pace of technological progress and the impact of cumulative investment in new technologies may make some new sources of energy as cheap as, or cheaper than, fossil fuels. But it is also clear that the pace of energy efficiency improvements required, which is significantly faster than achieved in the Baseline scenario (Figure 2.27) will necessitate investments that entail additional cost. And reasonable current estimates suggest that low-carbon sources of energy are likely to add some cost above that of high-carbon sources: it must, for instance, be the case that the deployment of CCS will increase the cost of fossil fuel based power generation.

The estimates produced by the IEA however, reinforce the findings of previous analyses that the total abatement costs are likely to be small relative to global GDP.

- Under its BLUE Map scenario, about 15 Gt per annum of abatement could be achieved at zero cost or less (i.e. a net benefit to the economy). Marginal cost of abatement would then rise to somewhere in the range of \$200 to \$500/tCO_2 by 2050 in order to achieve a required reduction of 48 Gt of CO_2 in 2050. The total resource cost[54] implied by the IEA analysis, while very large in dollar terms, ranges between 0.8 and 2.4% of global GDP in 2050 depending on the carbon price assumed. This only includes the costs of abating fossil fuel CO_2 emissions (Table 2.15). If we assume that the average cost of abating other emissions is the same as the IEA average abatement costs, then this increases total cost by one sixth to 0.9-2.8% GDP[55].

- We also ran our emissions trajectories and the SRES A1B scenario through the PAGE2002 integrated assessment model (IAM) and the Global Carbon Finance (GLOCAF) model developed by the Office of Climate Change. PAGE2002 suggested that approximately 44-48 Gt of CO_2 abatement could be delivered for a cost of 1-2% of global GDP in 2050. The GLOCAF model estimated that the costs of abating up to 55 Gt of GHG in 2050 could reach 3.3% of GDP if trading is allowed; unlike the IEA model, GLOCAF has no negative cost abatement options.

- These findings are consistent with analysis undertaken by Anderson (2006) for the Stern Review[56], which indicated a potential cost range from minus 1% of global GDP (i.e. a net benefit) to plus 3.5% for a reduction of 43 Gt of CO_2. The Garnaut Climate Change Review estimated that a 450ppm CO_2e overshooting scenario would cost between 2.3% and 4.0% of GDP[57] in 2050 depending on whether the GDP measure used is based on market exchange rates or purchasing power parities. Compared to the literature, they used a high estimate of business as usual emissions in 2050 which required over 80 Gt of abatement in 2050.

- Others[58] model a trajectory which allows CO_2e concentrations to rise to 500ppm before falling to 450ppm in 2150. This concentration trajectory–which is similar in shape to that produced by the most ambitious emissions reduction scenario set out in Chapter 1–leads to a cost of about 1.2% of GDP in 2050 with trading[59]. Another study[60], which also allows concentrations to overshoot 450ppm CO_2e before returning back down to it, estimates costs to be 2% of GDP in 2050[61]. More detailed analysis[62], using a range of baselines, shows that costs for this trajectory fall within the range of 1-3% of GDP in 2050. Higher baselines, such as SRES A1B, were at the top of this range. This analysis assumes full emissions trading.

---

54 These estimates do not include any second order effects–such as changes to GDP caused by a change in the use of production factors.

55 IEA average costs range between \$38/tCO_2 and \$117/tCO_2 for fossil fuel CO_2 emissions. The IPCC estimate that non-fossil fuel CO_2 emissions can be abated for a marginal cost of less than \$100 t/CO_2. The average cost of abating these emissions in the IPCC will be lower than this.

56 Anderson, D. (2006) Costs of finance of carbon abatement in the energy sector.

57 Garnaut Review (2008), Economic Modelling paper no 6, October 2008. They assume that abatement of industrial process and land use change emissions can be achieved at zero cost. Whilst some zero (or lower) cost measures are possible, IPCC 4AR WGIII (2007) suggests that most measures will involve a cost.

58 Den Elzen M and M Meinhausen (2005), Meeting the EU 2°C climate target: global and regional emission implications.

59 This cost estimate is derived for the CPI+tech case. The baseline produces a similar level of emissions in 2050 to the A1B baseline and requires similar levels of abatement in 2050 to our more aggressive emission reduction scenarios.

60 Van Vuuren et al (2007), Stabilising Greenhouse Gas concentrations at low levels: an assessment of reduction strategies and costs, Climate Change (2007) 81:119-159.

61 This is based on the SRES B2 baseline which has lower GHG emissions in 2050 compared to the A1B baseline.

62 Van Vuuren et al (2006), Stabilising Greenhouse Gas concentrations at low levels: an assessment of options and costs, MNP Report 500114002/2006.

The Committee therefore believes that it is reasonable to assume that the costs of the global emissions reduction recommended in Chapter 1 lie between 1 and 3% of GDP in 2050. And while all analyses suggest a wide range of uncertainty about the precise cost, the logic for believing that the order of magnitude is at most a few percentage points of GDP is robust. Globally, total expenditures of the energy sector are about 7.5% of GDP[63], and there exist a range of technologies which are likely to be able to deliver energy at costs which, while higher than fossil fuel alternatives, are more likely to be 0 to 50% more expensive than several times more expensive. The cost of mitigation must therefore be a few percentage points of GDP rather than, say, tens of percentage points. This implies that the world can almost certainly achieve a 50% reduction of emissions below current levels while sacrificing less than one year's economic growth out of the next 42.

The Committee agrees with the Stern Review that these costs of mitigation are substantially lower, and pose less of a threat to economic growth and human welfare, than the damage costs of uncontrolled climate change. We believe that the costs of climate change can to a significant extent be avoided through the recommended emissions reduction. To test this judgement we used the PAGE2002 IAM, which we calibrated with new scientific and economic evidence from the IPCC's 4th Assessment Report and other studies (see technical appendix). Our analysis shows that the emissions reduction scenarios set out in Chapter 1 would generate significant net benefits. The Committee is aware that this type of modelling involves many embedded assumptions and considerable uncertainties. Our approach to judging the desirability of the emissions reduction strategy which we recommended in Chapter 1 does not therefore rest on IAM results. Rather we believe that the dangers of significant climate change set out in Chapter 1, and in particular the danger of self-reinforcing feedback loops and irreversible effects, can reasonably be judged to be so great that if they can be avoided by a small sacrifice of GDP they should be. We believe that the case for action is clear.

63 Van Vuuren et al. (2007), Op. cit.

3. POSSIBLE UK PATH TO AN 80% REDUCTION: TECHNOLOGIES AND COSTS

In Chapter 1 we recommended that the UK's reasonable share of a global deal to cut emissions by 50% by 2050 would entail a cut in UK emissions (all sectors and all Kyoto GHGs) of 80% below 1990 levels by that date. Analysis suggests that cuts of this magnitude are technically feasible at an economic cost in 2050 in the range of 1 to 2% of GDP.

We have used the MARKAL model to conduct this analysis. The model (described in Box 2.1) incorporates assumptions on costs for a wide range of technologies and enables us to search for a least-cost optimisation path, and to investigate the implications for cost if a particular technology option (e.g. CCS) were not available as the base case assumes. The model covers CO_2 emissions for almost all sectors of the economy, but it does not cover international aviation nor non-CO_2 GHGs. Nor, as discussed in Chapter 8: *International Aviation and Shipping* and Chapter 9: *Non-CO_2 gases in agriculture, waste and industry*, do we have alternative sources which enable us to model emissions reduction in aviation or non-CO_2 with as much detail and certainty that is possible in the MARKAL model.

We therefore need to make assumptions about the scale of abatement which might be possible in those other sectors and gases. Figure 2.28 shows a reasonably cautious scenario, in which emissions from international aviation remain at the proposed allocation under Phase 3 of EU-ETS (5% below the average of 2004-06 emissions), shipping follows the same pattern, while non-CO_2 emissions fall by 70% relative to 1990 levels. It may be that these assumptions are pessimistic given the technology options discussed in Chapters 8 and 9, but if they were the limit of emissions reduction in these sectors, CO_2 emissions in non aviation would have to be cut by 89% against 1990 levels in order to achieve an overall GHG cut of 80%.

We have therefore used MARKAL to model the feasibility and the costs of scenarios for both 80% and 90% cuts in UK energy and industrial process CO_2 emissions. The 80% scenario represents a situation in which non-CO_2 and International Aviation and Shipping are able to contribute their full share to achieving the 80% overall target, while the 90% scenario represents a situation in which less can be achieved in these other sectors. We set out below:

(i) Possible technology paths

(ii) Possible costs of domestic action.

The potential reduction in costs which could be achieved via international trading are discussed in Section 4.

Box 2.1 The MARKAL model

The analysis of pathways to, and costs of, meeting ambitious targets for CO_2 abatement over the period to 2050 has been undertaken using the UK MARKAL (MARKet ALlocation) model. MARKAL is a least-cost optimisation model of energy use, representing the entire energy system, from primary energy resources through to demands for energy services (e.g. passenger-kms driven). The model is rich in technological detail, both on costs and other characteristics such as lifetime and efficiency, with assumptions drawn from multiple sources and extensively peer-reviewed.

The model imposes a cap on overall CO_2 emissions, allowing trade-offs between abatement measures in different parts of the energy system (e.g. electricity generation, transport, heat) to be examined. The representation of entire energy chains allows the model to choose combinations of primary energy resources and technologies to minimise the cost of meeting energy service demands (e.g. using wind energy to generate electricity to power battery electric vehicles). Where constraints on primary energy (e.g. biomass) supply exist, insights can also be gained on the best use of this finite resource.

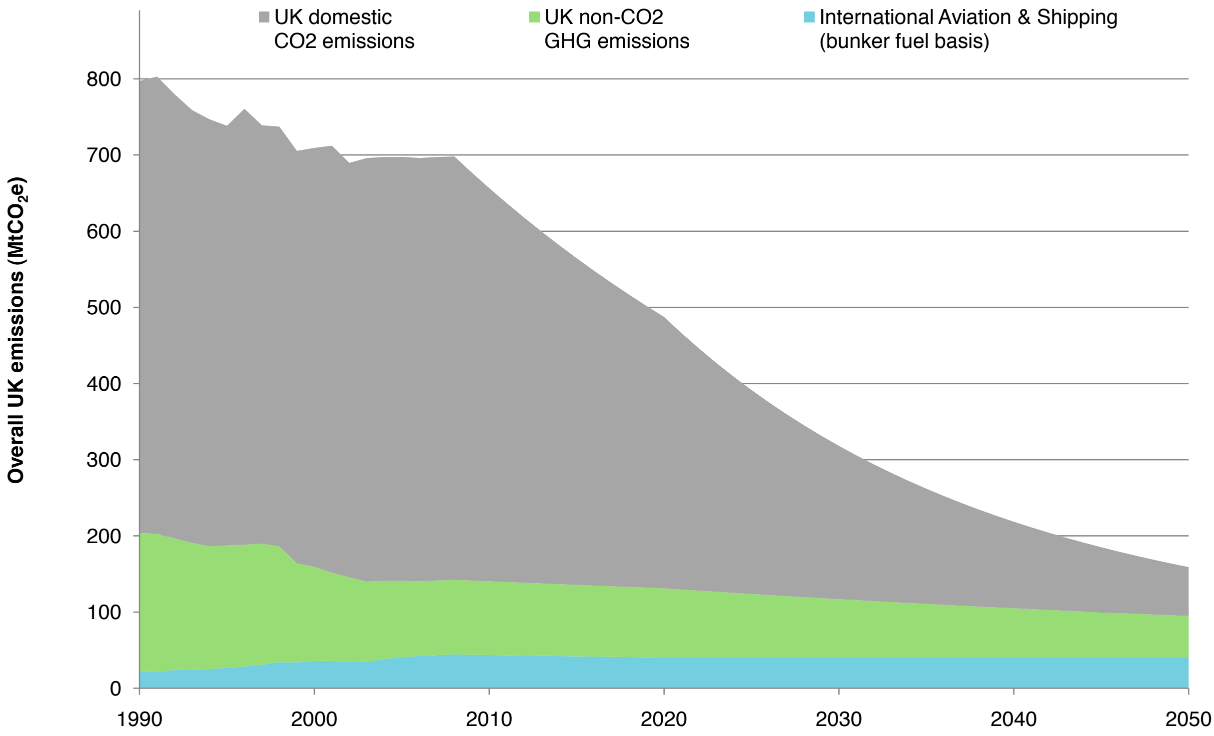
As an optimisation model, MARKAL's results represent the least-cost solution to meeting energy service demands under the emissions constraints imposed. Hence, it provides an indication of what could be achieved under optimal policy and decision-making; by definition, deviation from this optimal solution will tend to increase overall costs. As well as providing results regarding the total and marginal costs of meeting different emissions path, the model provides outputs that describe how the energy and transport systems might evolve, with regard to the technologies and fuels that would be used over the period to 2050.

MARKAL's optimisation implicitly assumes perfect foresight out to 2050. Clearly, such foresight is impossible, so we have not used the model to specify a precise path, but to establish that such a path can exist and how much it could cost. There are also limitations in MARKAL's representation of temporal and spatial variations in energy supply and use, implying that some scenarios will be more reliant on the increased flexibility in demand management discussed earlier in this chapter.

Multiple versions of MARKAL exist and it is used in many regions internationally. We have used the latest update to the UK MARKAL model: MARKAL Elastic Demand (MED). In MED demands for energy services are allowed to change in response to changes in costs of meeting them. In addition to the introduction of the Elastic Demand element, two further innovations were used in this modelling: the use of offset credits and emissions allowances in meeting abatement targets, to examine the importance of carbon trading in meeting targets; and the use of a two-stage optimisation, in order to limit the foresight of the model and gain insights into the implications of decisions in the period to 2020.

The modelling for CCC has been undertaken by AEA Energy & Environment, and reviewed by King's College London, who developed the UK MED version.

Figure 2.28 Implications for domestic UK CO_2 emissions to 2050 of achieving less than 80% reduction in other emissions categories



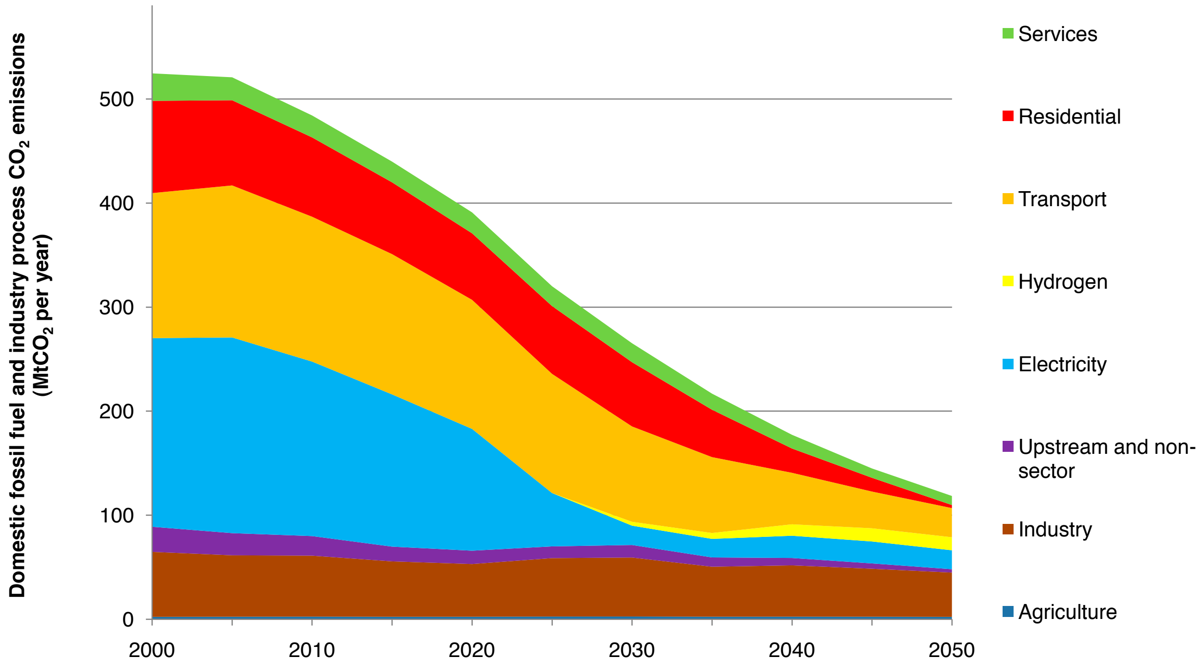
Source: NAEI and CCC calculations.

(i) Possible technology paths

Both the 80% reduction case and the 90% alternative illustrate the pattern which Section 1 (v) above suggested might be implied by the technology options available (Figures 2.29 and 2.30).

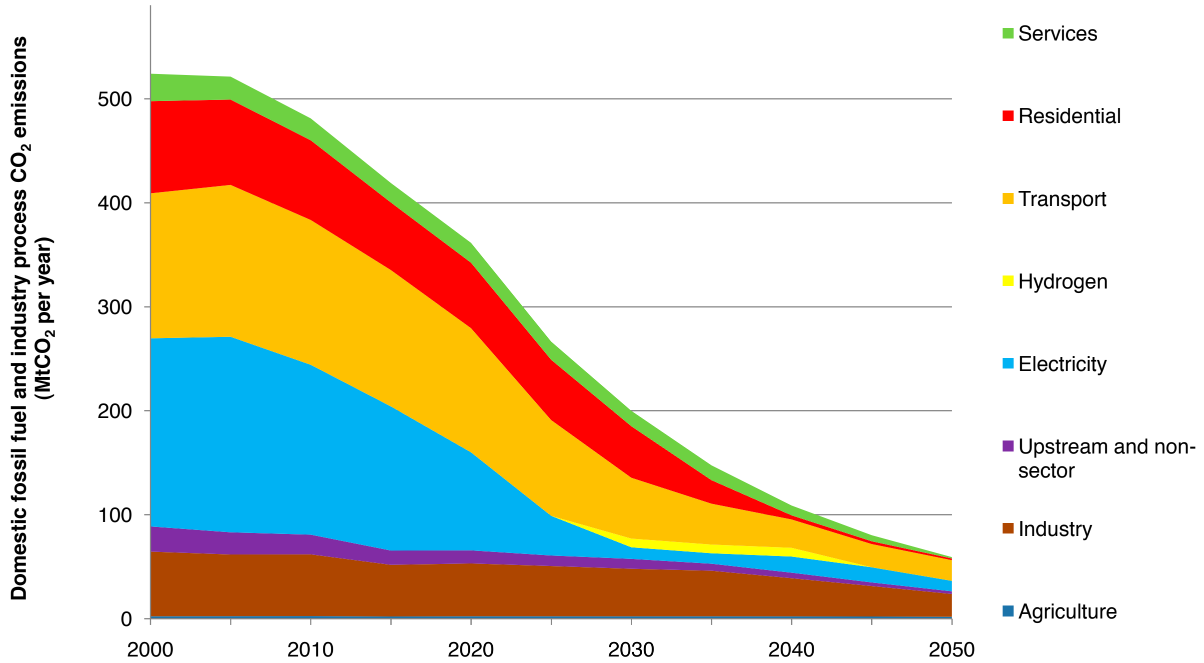
- In both scenarios the most dramatic early reduction occurs via the decarbonisation of electricity generation, which needs to be close to complete by 2030, with g/kWh below 70 by 2030 in the 80% scenario and below 40 in the 90% scenario (Figure 2.31), falling further to 35 and 20 respectively by 2050.
- Important early progress is also made in the residential sector via improvements in home insulation and improved efficiency of electrical appliances, lighting and ICT, and in the transport sector via the rapid improvements in the fuel efficiency of petrol and diesel vehicles.
- From the 2020s onwards, decarbonised electricity is increasingly used to drive further significant abatement in the car and light van subsectors of transport (via plug-in hybrid and battery electric vehicles) and in residential heat-related emissions.
- As a result electricity demand, having first been reduced through energy efficiency measures, is likely to increase significantly (Figure 2.32). If all technologies are available this additional electricity is supplied from a combination of nuclear, renewables (predominantly wind), and fossil fuel plants with CCS. This path implies very significant investment in new low-carbon generating capacity, and given that there are limits to the pace at which capacity can be added, provides a rationale for early action.

Figure 2.29 UK sectoral CO_2 emissions to 2050 on an 80% emissions reduction path (MARKAL)



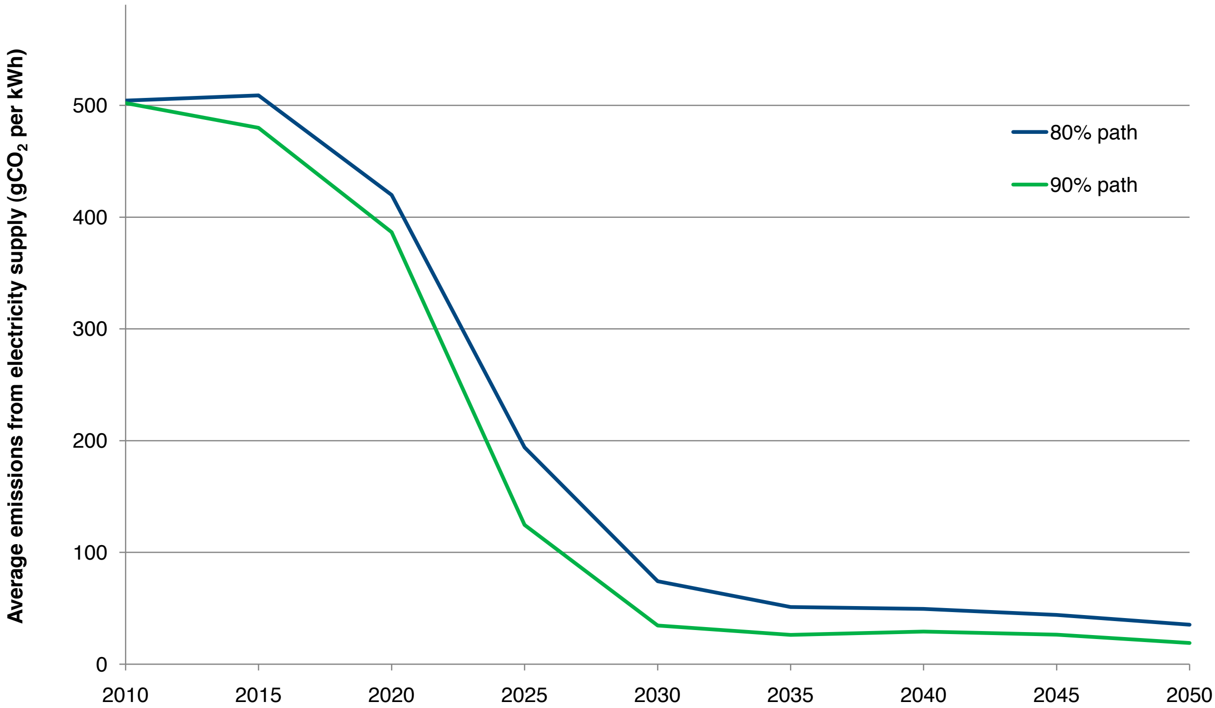
Source: MARKAL modelling based on CCC assumptions (2008).

Figure 2.30 UK sectoral CO_2 emissions to 2050 on a 90% emissions reduction path (MARKAL)



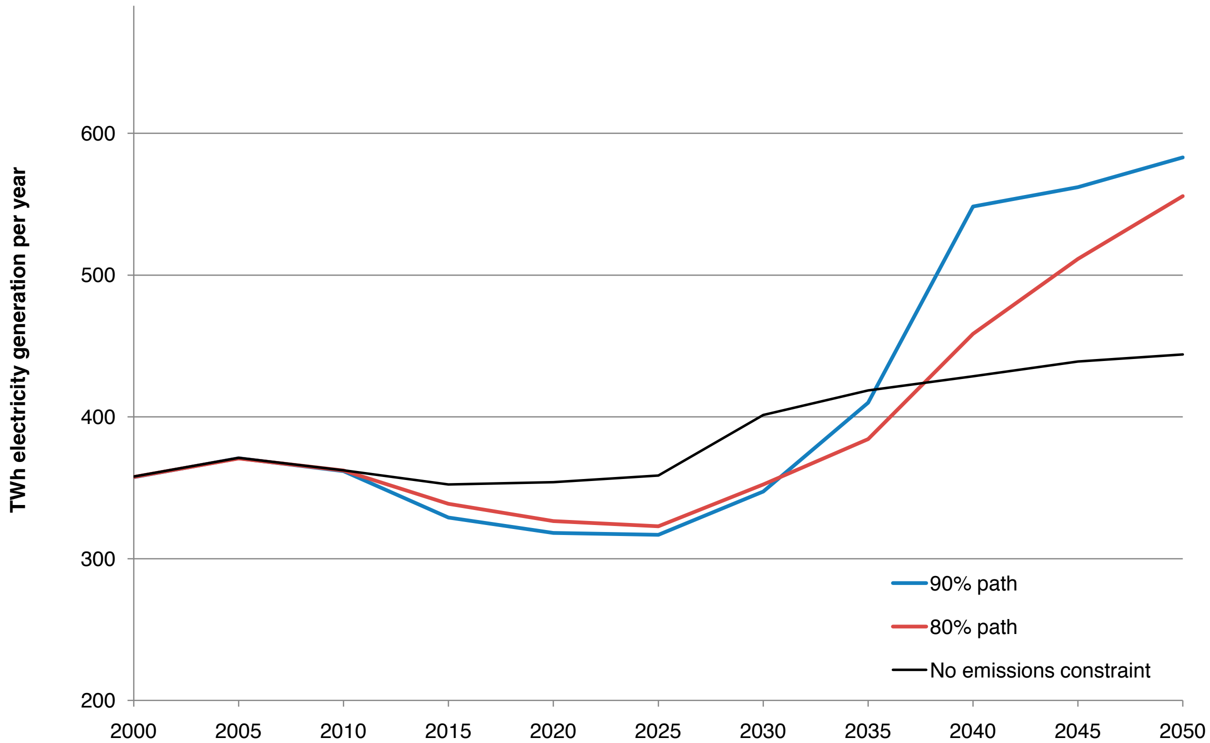
Source: MARKAL modelling based on CCC assumptions (2008).

Figure 2.31 Carbon-intensity of UK electricity generation under 80% and 90% emissions targets for 2050 (MARKAL)



Source: MARKAL modelling based on CCC assumptions (2008).

Figure 2.32 Aggregate generation under various emissions trajectories, 2000-2050 (MARKAL)



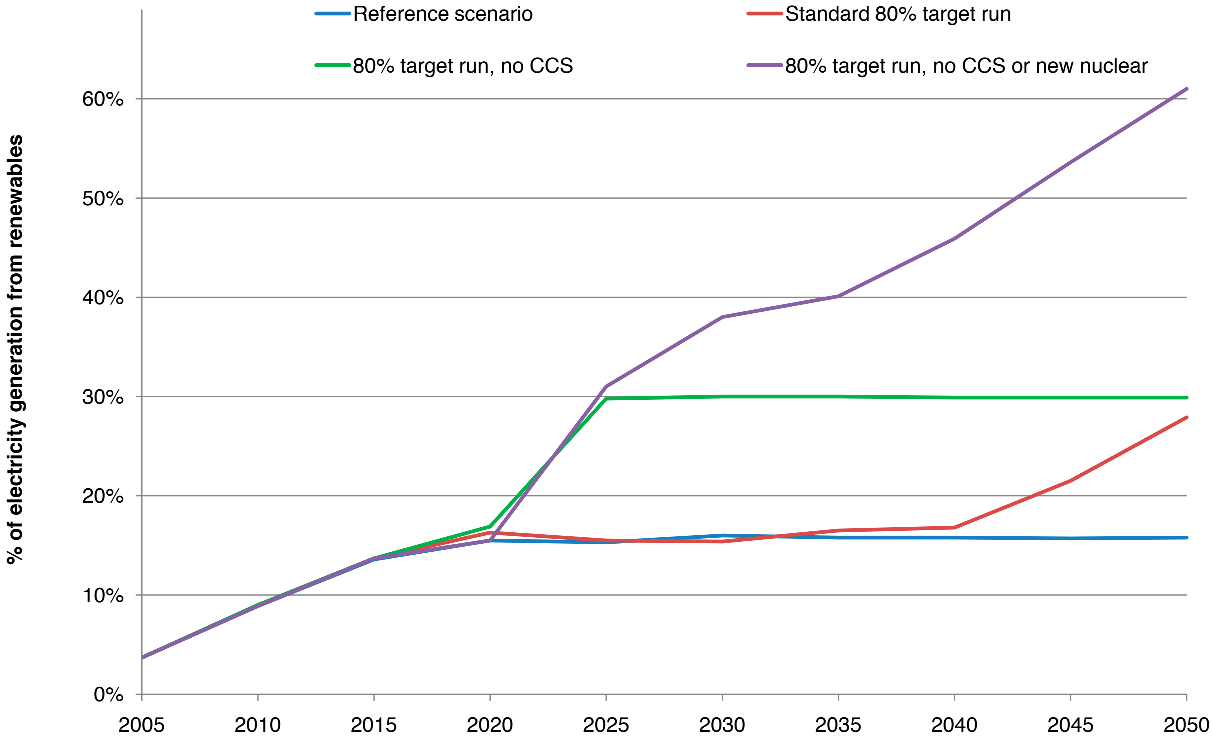
Source: MARKAL modelling based on CCC assumptions (2008).

The model also enables us to consider what might happen if key technologies were not available or if society chose not to deploy them.

- CCS is currently not a proven technology at full commercial scale. If it were unavailable at reasonable cost, the MARKAL model suggests that a huge expansion of nuclear power would be the least-cost option, but that renewables would also need to expand to 30% of supply by 2025 (Figure 2.33).

- If nuclear as well as CCS were not available, the model suggests that 80% or even 90% reductions would still be attainable, but at substantial additional cost, and with greater energy demand reduction (either price-induced or via life-style change).

Figure 2.33 Proportion of electricity generation coming from renewable sources under different scenarios, 2005-2050 (MARKAL)



Source: MARKAL modelling based on CCC assumptions (2008).

And it allows us to understand the consequences of choosing to invest in particular technologies:

- The Government has committed to an EU target that the UK will produce 15% of all its energy from renewable energy sources. Meeting this target is likely to require that 30% or more of total electricity generation comes from renewable sources in 2020, because the heat and transport sectors are less well placed to contribute to achieving this target. We have modelled a situation where there is 32% renewable electricity from 2020. In this scenario, MARKAL suggests that although there is a modest cost premium in the 2010s to achieve the CO_2 targets with this higher level of renewables, this does not add significantly to the costs of meeting longer-term emissions targets.

- We have also modelled a situation where there is significant investment in conventional coal-fired technology in the period to 2020, and where this cannot subsequently be retrofitted with CCS technology. MARKAL suggests that beyond 2020, this new-build coal plant is marginalised in the electricity system and is not dispatched at all beyond 2030. It is cheaper to strand this plant and to invest in new low-carbon capacity. The implication is that there is a very limited role for conventional coal-fired generation, and that the only rationale for adding conventional coal-fired capacity in the period to 2020 can be with a view to this being retrofitted with CCS.

Finally, the model enables us to consider the difference between 80% and 90% reductions in domestic CO_2 emissions. While the patterns of abatement are broadly similar, the key differences are:

- The model suggests that a 90% emissions reduction is achievable, but requires earlier and deeper progress in the reduction of power sector emissions and the earlier application of electricity to reduce emissions in the transport and heat sectors.

- Apart from its use in CCS power plants, natural gas features less in the 90% scenario, being displaced by lower-carbon options in power generation (nuclear and renewables), heat supply (biomass and low-carbon electricity) and hydrogen production (low-carbon electricity).

- Moving from an 80% to 90% abatement scenario, there is a reduction in the demand for energy services in response to a higher marginal cost of abatement and implied carbon price.

These technology paths should only be considered as indicative, with precise paths to be chosen in the light of evolving technological possibilities and costs, and of the availability of policy levers which can drive different categories of energy efficiency and new energy source deployment. Practical issues relating to the availability of policy levers are considered in Chapter 3 when we look at appropriate 2020 targets and in Chapters 5 to 7 which look at specific sectors.

But the two key conclusions can be drawn: first that 80% to 90% cuts in domestic CO_2 emissions are feasible: second that the radical decarbonisation of the electricity generation by 2030 is vital. There are no feasible scenarios which assume a more than trivial level of conventional (non CCS) fossil fuel plant on the system after the mid 2020s.

(ii) Possible costs

MARKAL modelling suggests that a reduction of 80% or more in domestic CO_2 emissions is feasible at manageable economic cost, even if no international emissions trading is possible.

- Our central scenario is based on oil, gas and coal prices from the Department of Energy and Climate Change (DECC) central fossil fuel price scenario[64], representing a world in which the global oil price is in the range $65-75 per barrel in real terms out to 2030.

- In our analysis of costs we have constrained the model not only to achieve various levels of reduction by 2050, but also to achieve various intermediate levels of reduction. This informs our Chapter 3 discussion of the appropriate budgets for the first three budget periods. The analysis suggests that a reduction of 80% to 90% in domestic CO_2 emissions by 2050 might reduce 2050 GDP by between 1% and 1.5% versus the MARKAL reference case.

- These estimated costs do not increase significantly if CCS is not available, with the model assuming that cost-competitive nuclear power can expand instead. But the costs do increase significantly if neither CCS or nuclear are available, reaching 2% of GDP in the 80% target case, but 3% in the 90% case.

64 Update to present the latest fossil fuel price assumptions following the January 2008 Call for Evidence. DECC, May 2008.

- In the high-high fossil fuel price scenario, which sees the oil price rise to $150 per barrel in real terms by 2015 and stay at that level thereafter, estimated costs of meeting emissions reduction targets fall as cost penalties of low-carbon technologies are eroded.

- These costs do not, however, cover emissions from international aviation and shipping or of non-CO_2 GHGs. Analysis of these sectors is at a less detailed stage but initial results suggest that the overall 80% target could be met at a cost of around 1.7% of GDP in 2050[65]. This is within the range of global estimates produced by the IEA, when we make allowance for non-CO_2 abatement.

Our conclusion is therefore that our recommendation for an 80% cut in the UK's GHG emissions below 1990 levels by 2050 is achievable at a relatively small cost to GDP, and that costs can be appreciably reduced by keeping all technology options for electricity generation open: renewables, nuclear and CCS.

65 Based on MARKAL results of runs including international aviation and assuming that abatement in sectors not covered can be undertaken at a similar average cost.

4. THE ROLE OF INTERNATIONAL EMISSIONS TRADING: VALUABLE BUT SUPPLEMENTARY

International trading of emissions reduction certificates can significantly reduce the cost of emissions reduction at both the global and UK level. And by creating financial flows from developed to developing countries it may help create a consensus for a global deal. But the vast majority of the 80% reduction in the UK emissions to be achieved by 2050 will have to take the form of domestic cuts.

- The case for free international trading within capped global emissions reduction targets is sound (the issue of the appropriate use of international credits in the period before a fully capped system exists – i.e. offset credits – is discussed in Chapter 3). Three possible drivers of emissions trading can usefully be distinguished:
  - Differences in production technologies, which make it possible to reduce emissions at lower cost in one country than another. These differences are likely to be evened out over time by the global flow of capital and technology. Opportunities for lower cost abatement via trading to exploit these differences are therefore likely to become small over the long term.
  - Differences in income between countries and people. These will result in higher income people or countries buying the right to a higher level of emissions from certain activities (e.g. flying) by income transfer to poorer people/countries. In the very long run these differences may reduce (at least between countries) if income convergence occurs, but they are likely to remain significant in 2050.
  - Inherent differences in natural geography and climate, which may result in different demands for heat, or create different opportunities for renewable energy production (e.g. solar) different potential to reduce emissions via land use changes such as reforestation. These differences are permanent.

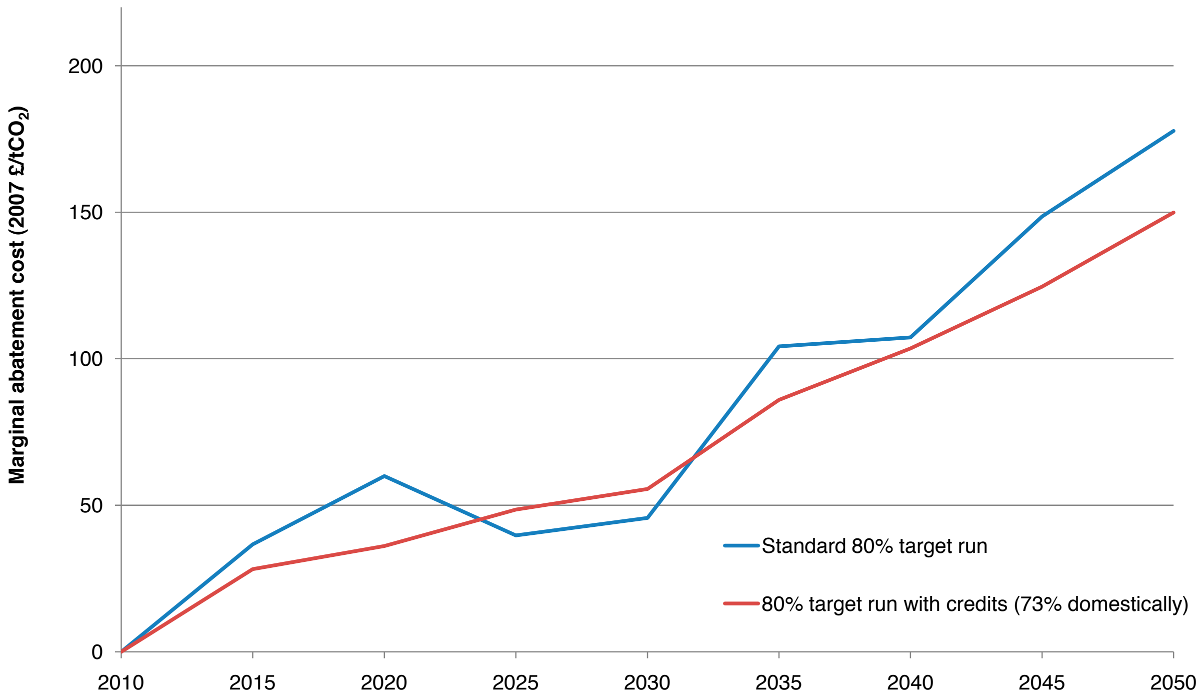
Emissions trading could cut the total cost of any given emissions reduction path by making it possible for some of that reduction to be achieved at lower cost outside the UK.

- Modelling by the Office of Climate Change suggests that free international trading could lower the cost of delivering 48 Gt of abatement of GHGs from around 4% of global GDP to 2% in 2050. This level of effort is broadly consistent with our 2016: 3% scenario set out in Chapter 1. The modelling also illustrates that the importance of international trading as a proportion of all abatement achieved will fall over time. In 2020, 2.5 Gt of CO_2e might be traded if the world were pursuing a least-cost path to emissions reduction; by 2050 trading volumes might be slightly lower even though total abatement versus business as usual would by then need to have risen. This reflects the diminishing importance of the category one driver of trading (differences in production technologies) mentioned above. Free international trading would still be very important to the reduction of costs because some countries would by then face very high marginal costs of abatement. But the vast majority of developed country emissions cuts by 2050 would need to be achieved in the domestic economy.

- These global findings are consistent with the MARKAL results for the UK.
  - Openness to trade could make a difference to the marginal cost per tonne of abatement in 2050: in the 80% case it might cut the marginal cost of abatement from £170 to £150 per tonne (Figure 2.34).
  - But it is important to note that in the long term the vast majority of abatement will have to be achieved via domestic action. The model suggests that for an 80% domestic CO_2 emissions reduction, 73% is likely to be most cost-effectively achieved domestically. This reflects the fact that by then the price of international emissions reduction credits is likely to be very high, since all countries will need by then to be on a strong downward emissions path and will therefore already have exploited low cost abatement opportunities.

This analysis implies that (i) free international trading within a fully capped global system is desirable; (ii) international emissions trading could make an important difference to the cost for the UK of making a major contribution to global emissions reduction; (iii) but the level of domestic abatement achieved in the first three budget periods needs to be high enough to place the UK on a realistic path to achieve the vast majority of the 80% cut by 2050 within the UK.

Figure 2.34 The effect of emissions trading on marginal costs of abatement (MARKAL)



Source: MARKAL modelling based on CCC assumptions (2008)

5. IMPLICATIONS OF THE PATH TO 2050 FOR THE 2020 TARGET AND THE FIRST THREE BUDGETS

There are three implications that we can draw from the path to 2050 for the 2020 target and first three budget periods:

- Early decarbonisation of the power sector is a priority. Policies in the first three budget periods should lay the foundations for widespread decarbonisation, and possible use of electricity to decarbonise other sectors, through the 2020s. Investment in low-carbon generation and technology development (e.g. CCS) are priorities.

- Policies in the first three budget periods should foster development of a range of options for abatement in power and other sectors.

- Given that emissions reduction in 2050 will largely have to be achieved through domestic effort, it is important to make significant progress in domestic emissions reduction during the first three budget periods, and that the strategy for meeting budgets does not place too much reliance on the purchase of credits.

We consider these implications in more detail in Chapter 3: *The first three budgets*.

PART II:

SETTING AND MEETING THE FIRST THREE BUDGETS

We are required under the Climate Change Bill to advise on the first three carbon budgets covering the periods 2008-12, 2013-17 and 2018-22. In this part of the report we set out analysis on the appropriate level of carbon budgets and our assessment of feasible emissions reductions. We do this in five chapters, covering our budget proposals, carbon markets, power generation, energy use in buildings and industry, and transport.

In **Chapter 3: The first three budgets,** we consider the appropriate emission reduction to be achieved over the first three budget periods in CO_2 only, adding analysis of non-CO_2 GHGs in Chapter 9: *Non-CO_2 greenhouse gases*.

We consider three factors: (i) the emissions required over the next 15 years to put the UK on a path to an 80% reduction by 2050; (ii) the implications of the commitments which the European Union has made to reduce greenhouse gas emissions by 20% unilaterally and by 30% if a global deal is agreed at Copenhagen; (iii) the emissions reductions which can be achieved sector by sector at manageable economic cost, given available technologies and policy levers. Sectoral emissions reductions scenarios (considered in more detail in Chapters 5-7) are aggregated to assess the cross-economy potential, and compared with the emissions reductions required by the first two factors.

Based on this analysis, we propose an approach to budget setting which, like the EU targets, is contingent on the outcome of the Copenhagen negotiations. We propose that the UK's Intended budget, if there is success at Copenhagen, should be based on a cut in CO_2 emissions of 40% below 1990 levels. Before there is a global deal, an Interim budget, with a 29% cut relative to 1990 levels, should be followed. We propose however that the reduction in non-traded sector emissions in the Interim budget should be achieved entirely via domestic reductions: this will make it possible to move to the Intended budget while still containing total purchase of offset credits within acceptable limits.

In **Chapter 4: Carbon markets and carbon prices**, we consider the role of carbon markets and other policy instruments in providing incentives for emissions reduction. We also consider the role of carbon prices in indicating where in the economy emissions reduction effort should be focused. And we consider the pros and cons of purchasing emissions reduction credits from other countries. We also present our price forecasts for offset credits and European Union Allowances. In the subsequent chapters we then use our central case estimate of £40/tCO_2 in 2020 as one among a number of criteria for determining which measures should be included in carbon budgets.

In **Chapter 5: Decarbonising the power sector,** we identify a significant opportunity for emissions reductions given the need for investment in new generating capacity in the second and third budget periods. We consider the economics of low-carbon power technologies and argue that there is a range of relatively inexpensive options for reducing emissions. We suggest that the carbon price will play a key role in driving investment in low-carbon electricity, but that other policies are also essential. These include: financial support (e.g. for CCS demonstration), appropriate planning and transmission frameworks for renewable generation and an appropriate policy stance towards investments in conventional coal capacity. We conclude by setting out scenarios in which emissions are reduced by more than 50% in 2020 relative to 1990.

In **Chapter 6: Energy use in buildings and industry**, we identify emissions reduction potential from improvements in energy efficiency, from consumer behaviour change and from the deployment of microgeneration and renewable heat. We consider in turn opportunities in residential buildings, in non-residential buildings and industry. And we distinguish between potential that is technically available, and the realistically achievable potential taking into account implementation constraints and the way that these might be addressed through appropriate policies. We conclude that there is significant potential for emissions reductions across different types of buildings and in industry at a price less than £40/tCO_2. We also conclude that achieving the significant potential for renewable heat will be more costly, but that it should be pursued given the need to achieve the overall reductions required and to develop new technologies.

In **Chapter 7: Reducing domestic transport emissions**, we consider opportunities for emissions reduction in surface transport, looking at both supply side and demand side measures. We set out analysis that shows significant potential for emissions reductions through technology innovation in cars and vans which could be unlocked given legally binding and ambitious EU frameworks supported by domestic policy instruments. We show that some of the options for emissions reductions may appear expensive when compared with the forecast carbon price, but argue that these are justified in the context of meeting our 2050 target and given the need to drive new technologies. On the demand side, where our analysis is at an earlier stage and our conclusions therefore more tentative, we nevertheless identify that there is likely to be significant potential to reduce emissions by changing driver behaviour, better journey planning and a shift to lower carbon transport modes.

CHAPTER 3:

THE FIRST THREE BUDGETS: SUMMARY ANALYSIS AND RECOMMENDATIONS

This chapter sets out our recommendations on the appropriate level of the UK's carbon budgets for the first three budget periods, 2008-12, 2013-7 and 2018-22[1].

The Government has asked the Committee to recommend the level of these budgets, subject to a legally binding constraint that the emissions reduction by 2020 must be at least 26% relative to 1990 ('2020' meaning for these purposes the annual average during the 2018-2022 budget period). The Committee has also been asked to recommend the balance of emissions reduction effort[2] between the 'traded' sectors (covered by the European Union Emission Trading Scheme (EU ETS), and comprising power generation and energy-intensive industry) and the 'non-traded' sectors (residential, service and transport sectors, and industrial sectors outside EU ETS); and the proportion of emissions reduction which should be met by purchasing credits from overseas.

Carbon budgets are central to the framework for realising emissions reductions. They set the overall level of ambition for these reductions, and the sectors of the economy where effort should be focused. And the analysis used to develop carbon budgets can inform the types of policies that may be appropriate to unlock emissions reduction potential. Once set, carbon budgets provide a mechanism for monitoring emissions reduction performance, and for shaping any response should targets be missed. Monitoring of progress against carbon budgets will be the subject of the Committee's annual reports to Parliament, as required under the Climate Change Act, with our first report being due in September 2009.

Two key decisions need to be made about the coverage of the budgets:

- Whether they should relate to CO_2 only, or to all greenhouse gas (GHG) emissions. This issue is discussed in Chapter 9: *Non-CO_2 greenhouse gases,* where we recommend that budgets should cover all Kyoto GHGs[3]. In this chapter we therefore set out the budgets as they would relate to CO_2 alone, and then illustrate the adjustment required to include non-CO_2 gases in Chapter 9.

- Whether they should include international aviation and shipping emissions. This issue is discussed in Chapter 8: *International Aviation and Shipping*, where we recommend that these should be included in the UK's climate change mitigation strategy but not explicitly in carbon budgets.

The analysis and results we present in this chapter are therefore for CO_2 only, measured in line with the UK National Atmospheric Emissions Inventory (NAEI). On this basis we recommend that:

- The UK should set an 'Intended' budget to apply once a global deal to reduce emissions has been agreed, and an 'Interim' that prepares for the Intended budget and applies for the period before there is a global agreement. The Intended budget should be based around a 40% CO_2 reduction in 2020 relative to 1990. The Interim budget should be based on a 29% target in 2020.

1 A carbon budget as defined in the Climate Change Act places a ceiling on the UK's carbon emissions for a five year period. It is envisaged that in due course the whole period to 2050 will be covered by carbon budgets, although initially only the first three carbon budgets will be laid in legislation. It is these three budgets which the Act requires the Committee to advise on by December 1st 2008.

2 We define 'effort' as the difference between the 2007 level of emissions and the emissions ceilings reflected in our carbon budgets and/or EU targets.

3 The terms 'GHG' and 'greenhouse gases' refer throughout this chapter to the Kyoto basket of greenhouse gases.

- Emissions reduction effort over the first three budget periods should be split approximately 70%/30% across the traded/non-traded sectors. Meeting our budgets is feasible based on energy efficiency improvement in buildings and industry and fuel efficiency improvement in road vehicles, combined with a significant shift towards renewables in electricity generation and heat. Some of the required emissions reduction can be achieved at negative cost and would therefore save money for individuals and businesses. Large parts of the required emissions reduction can be achieved at a cost below our forecast carbon price[4]. But some significant abatement options cost more than the carbon price, and would not be pursued if the objective were simply to minimise the cost of meeting a 2020 emissions reduction target. We believe, however, that it is important to pursue these options to foster technology innovation and to ensure that the UK is on the path to meeting the 2050 emissions reduction target.

- There should be no limit on the extent to which the UK could meet its budgets via the purchase of EUAs (European Union Allowances, the carbon emission permits within the EU ETS). But there should be no planned purchase of offset credits[5] to meet the non-traded part of the UK's Interim budget. Purchasing credits to meet the incremental non-traded sector effort associated with moving to the Intended budget would be acceptable, although further consideration is required of additional options for domestic action. In the traded sector, there should be no additional limitation on the use of credits to meet budgets relative to what is allowed under EU ETS.

- The cost of meeting budgets relative to a world without carbon constraints is less than 1% of GDP in 2020. The Committee believes that this should be regarded as affordable given the consequences and costs of not tackling climate change.

- The current policy framework will deliver some of the required emissions reduction. But strengthening of existing policies (e.g. the Supplier Obligation) will be required if they are to deliver the full abatement potential that we have identified. New policies will also be required to support deployment of renewable heat and to improve fuel efficiency of road vehicles. In addition, there are a range of other areas where new policies will have to be considered (e.g. to support widespread solid wall insulation, and the introduction of plug-in hybrid technologies in vans) with a view to managing risks around meeting budgets.

The analysis underpinning these conclusions comprises five main blocks (Box 3.1):

- **Definition of a set of reference emissions projections.** We present a number of scenarios, reflecting alternative assumptions on fossil fuel prices, GDP and population growth. Our scenarios only include emission reductions from policies in the Climate Change Programme 2006 and not those in the Energy White paper 2007. They represent a counterfactual against which we identify emissions reduction potential across the sectors of the economy.

- **Setting a 2020 target.** There are three factors that we take into account: the level of emissions reduction in 2020 commensurate with the UK being on the path to an 80% reduction in 2050; the contribution by the UK to required global emission reductions in 2020; and the UK's obligation under the recent EU climate framework, both for the traded and non-traded sectors. We set out two 2020 targets: an interim target, which builds in sufficient effort to be on track to an 80% reduction in 2050; an intended target, which includes additional emissions reduction that the UK should contribute to global effort following a post 2012 international agreement. For each of these, we conclude that the straight line trajectories to the 2020 target as proposed in the EU framework are an appropriate basis for setting the UK's carbon budgets; these underpin our ***Interim*** and ***Intended*** budgets.

4 See chapter 4: *Carbon markets and carbon prices.*
5 There are a range of offset credits available, discussed in Chapter 4. In this report, offset credits refer to credits generated under the Kyoto treaty's project based flexibility mechanisms: Joint Implementation (JI), Clean Development Mechanism (CDM) and any successors to these.

- **Investigation of feasible emissions reduction scenarios.** This involves a sector by sector analysis of the potential to achieve emission reductions, the cost of achieving them, and the policy levers which are already in place or could be put in place to deliver them. For each of the sectors we define three scenarios, which we aggregate to three economy-wide scenarios: ***Current Ambition***, ***Extended Ambition*** and ***Stretch Ambition***. We then consider how the overall emission reductions delivered by these scenarios compare with required reduction to meet budgets.

- **Analysis of the appropriate role of credit purchase in meeting budgets.** Here we note the potential benefits of credit purchase in reducing cost and in providing a potential flow of funds to developing countries, but also note the case for limiting their use to ensure adequate domestic progress towards the 2050 target. We set out current EU proposals to limit the use of offset credits purchased from outside the EU for both the traded (EU ETS) and non-traded sectors. We then propose specific limits on the use of credits to meet the UK budget commitments.

- **Analysis of how to transition from the Interim to the Intended budget**, if there is a successful negotiating outcome at Copenhagen. The choice here is whether larger total reductions in the non-traded sector should be met by intensifying domestic effort or by purchase of offset credits.

The final sectors of the chapter then present results from three models that we have used to estimate macroeconomic impacts from carbon budgets. The chapter finishes with a consideration of risks related to policy delivery and emissions growth.

Box 3.1 Deciding appropriate budgets: methodology and key definitions

1) Reference emissions projections

- Alternative assumptions for fossil fuel prices, GDP and population growth
- Including impact of policies announced in 2006 Climate Change Programme but not those in 2007 Energy White Paper.

2) Setting a 2020 target

- Required progress towards 2050 80% objective
- Reasonable UK contribution to required 2020 global action
- Existing/proposed EU commitments for both traded and non-traded sectors
  - 20% cut in GHG versus 1990 on unilateral basis
  - 30% cut within global deal at Copenhagen

Level of reduction required versus reference projections

- Intended budgets – compatible with EU 30% cut, for both traded and non-traded sectors
- Interim budgets – compatible with EU 20% cut, for both traded and non-traded sectors

Comparison of required reductions versus feasible reductions

5) Proposed budgets

- Interim budget including limits on use of offset credits
- Intended budget including limits on use of offset credits
- Transition from interim to intended

3) Feasible emissions reduction scenarios

- Sector by sector analysis of technical feasibility, costs and realistically achievable emissions reduction
- Definition for emissions reduction scenarios:
  - Current Ambition
  - Extended Ambition
  - Stretch Ambition

4) Appropriate role of credits

- Pros and cons of use of
  - EUAs
  - Offset credits (e.g. CDM)
- EU rules on use of offset credits
  - In non-traded sectors
  - Within EU ETS

Source: CCC

We now set out our analysis in eight sections:

1. Fossil fuel price scenarios and reference emission projections
2. 2020 targets required to meet 2050 objectives and EU commitments
3. The emissions reduction path to 2020
4. Feasibility of required targets given sectoral abatement opportunities
5. The role of purchased credits
6. Summary of recommendations
7. Macroeconomic costs
8. Risks and challenges in achieving the budgets.

1. FOSSIL FUEL PRICE SCENARIOS AND REFERENCE EMISSION PROJECTIONS

Our reference scenarios project what emissions would be in a world without new policies: they represent scenarios against which we would need to improve our emissions performance to meet carbon budgets. The difference between reference emissions and our proposed carbon budgets determines the scale of the challenge we face, the size of emissions reduction that we need to achieve.

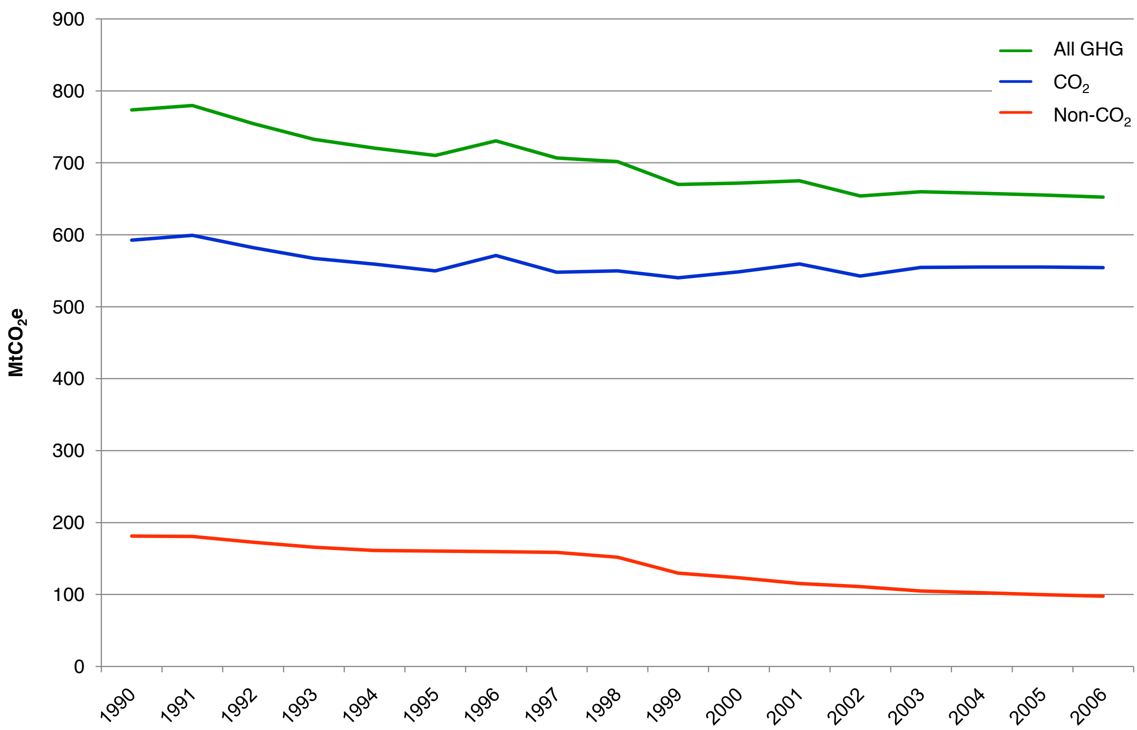
But reference emission projections are inherently uncertain. This section therefore sets out the factors which will influence reference emissions and a range of possible scenarios. It covers in turn:

(i) Historic emissions trends
(ii) Future scenarios for fossil fuel prices
(iii) Other important factors: population and GDP growth
(iv) Assumptions on policies already in place
(v) Resulting reference emission projections

(i) Historic emissions trends

Figure 3.1 sets out the historic trend of total UK GHG emissions over the period 1990 to 2006 (the latest year for which definitive data are available from the National Atmospheric Emission Inventory). Total GHG emissions on a CO_2 equivalent basis[6] have fallen by 16%; this is in excess of the 12.5% reduction to which the UK is committed (by 2008-12) under the Kyoto Protocol. Non-CO_2 emissions have fallen by 46% and CO_2 emissions by 6%. It is noticeable in both cases, however, that the rapid progress achieved in the 1990s has recently slowed.

Figure 3.1 UK greenhouse gas emissions 1990-2006



Source: National Atmospheric Emissions Inventory 2008

6 The CO_2 equivalence of non-CO_2 gases is discussed in Chapter 9: *Non-CO_2 greenhouse gases*.

(ii) Future scenarios for fossil fuel prices

Fossil fuel price scenarios create a particularly important context for climate change mitigation policy, because they influence both the likely future trend of emissions and the costs of mitigation options.

Higher fossil fuel prices will in general tend to decrease emissions, through their impact on demand for electricity, gas for heating, and transport fuels.

It is possible, however, that a particular variant of higher fossil fuel prices – one in which the coal price increases but the gas price increases even more – could induce an increase in emissions as electricity generators shift from burning gas to burning coal. This would be the case in the absence of any policy constraints. The existence of the EU ETS, however, means that total emissions in the traded sector are capped, so that a high gas/coal price differential will generate a higher price of carbon offsetting the incentive for fuel switching to coal generation. Thus whilst this effect has implications for reference emissions projections, it does not necessarily have an impact on the achievability of carbon budgets.

Higher fossil fuel prices also reduce the costs of deliberately chosen abatement options. For example, house insulation becomes more economic the higher the gas price; wind power becomes more economic the higher the coal or gas price. The macroeconomic cost of the budgets we propose (considered briefly in Section 7 below and in more detail in Chapter 11: *Economic costs and fiscal implications*) is therefore reduced the higher the future level of fossil fuel prices.

Projecting fossil fuel prices is inherently uncertain. In the first eight months of 2008, for example, oil prices rose by over two thirds, gas prices increased by around 140%, and coal prices doubled. More recently oil prices have fallen again, underlining the difficulty around making predictions. There have been more dramatic changes over longer periods, with oil and gas prices in 2008 more than three times what they were in 2001 (Figure 3.2).

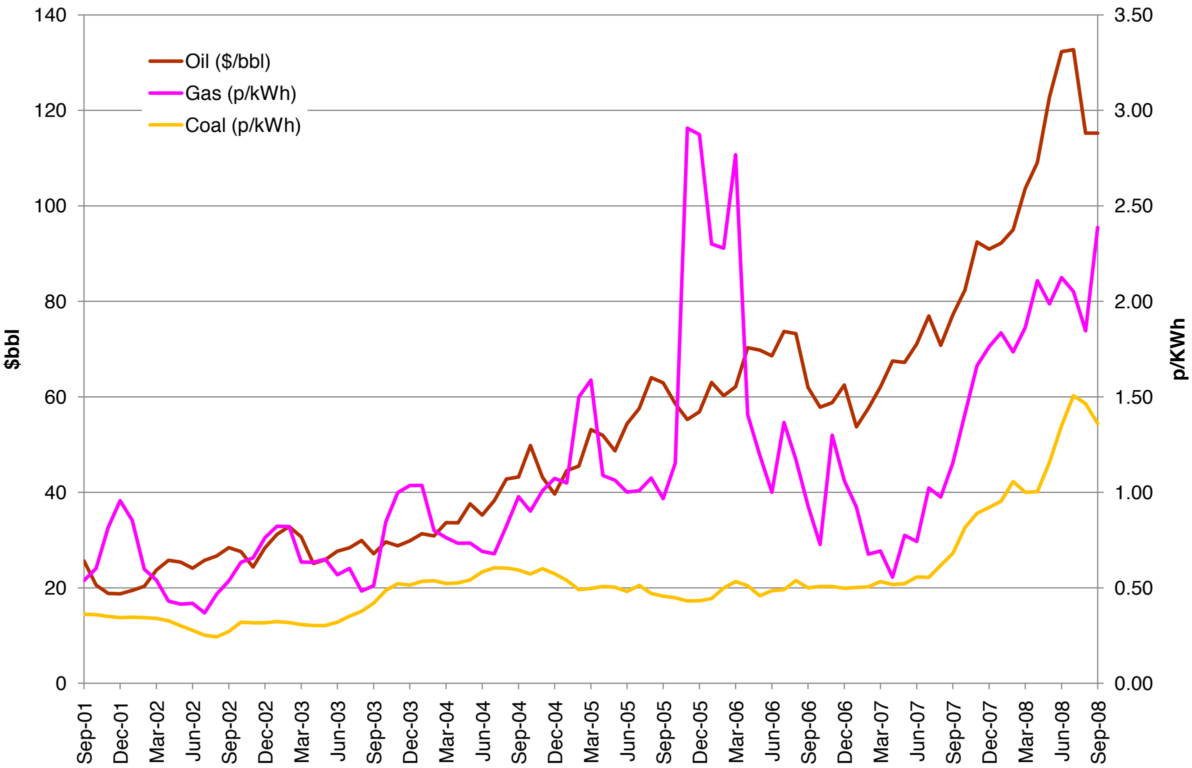
Official projections of future fossil fuel prices have also changed radically (Figure 3.3–Figure 3.5). The latest projections were published in 2008, but given significant price movements since that time, these differ from actual prices for 2008.

In developing our reference emissions projections and carbon budgets we have therefore considered the impact of a wide range of future potential prices covered by the latest Department of Energy and Climate Change (DECC) low, central, high and high-high scenarios. Based on these scenarios, delivery of carbon budgets has to be robust in the face of the possibility that in 2015:

- The oil price could be anywhere from $45 to $150 per barrel
- The UK wholesale gas price could lie between 30p and 92p per therm
- The UK delivered coal price could lie between $45 and $130 per tonne.

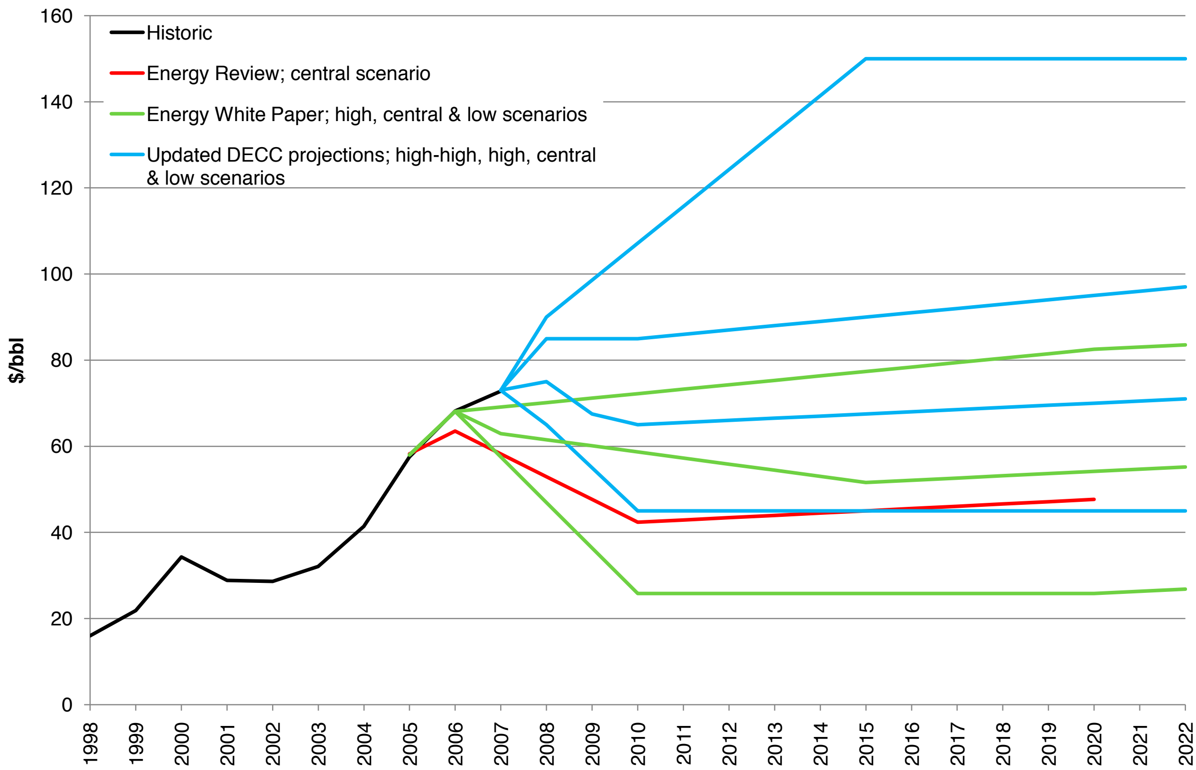
These uncertainties, and the danger that prices may vary dramatically over very short periods, as they have over the last two years, establishes a good case for pursuing energy efficiency and non-fossil fuel based energy developments as ends in themselves, quite apart from their beneficial climate strategy effect and potential cost savings; this argument is considered in Chapter 13: *Energy security of supply.*

Figure 3.2 Average monthly oil, gas and coal prices, September 2001 – September 2008



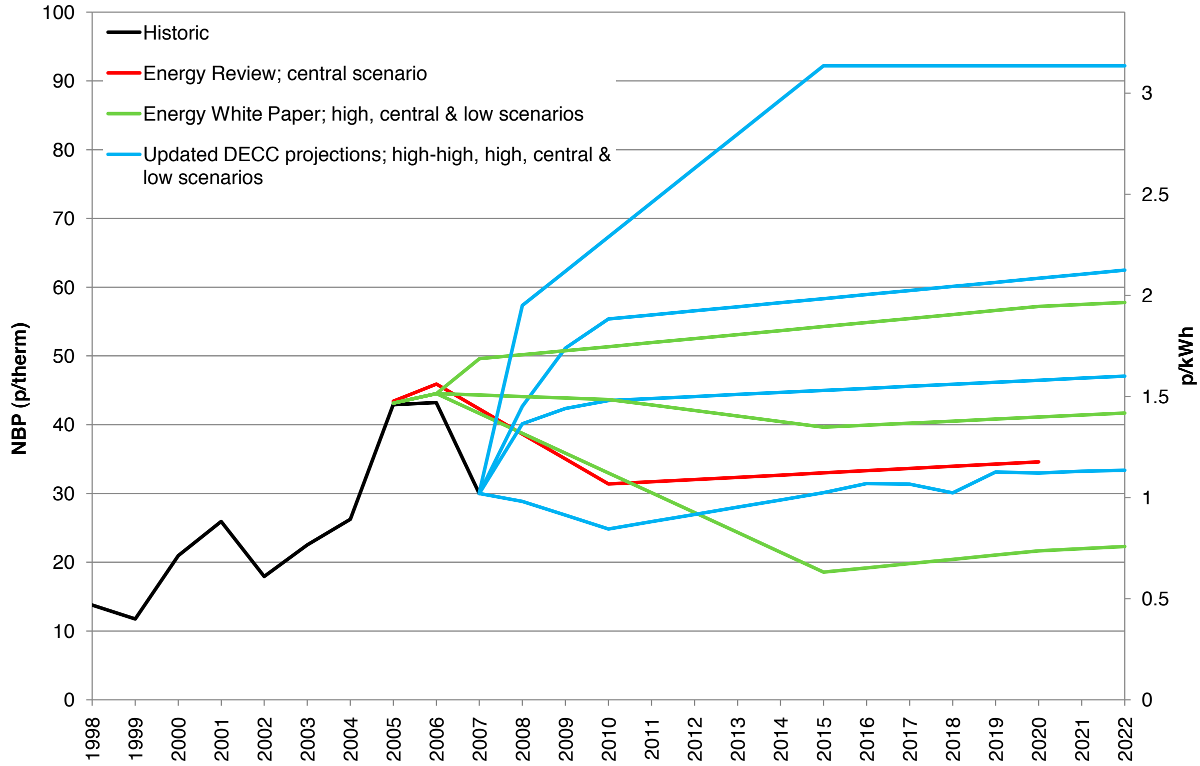
Source: Platts, US Government Energy Information Administration. Nominal prices (£). Oil – daily spot; Gas – day ahead NBP, Coal – 90-day CIF ARA.

Figure 3.3 Historic and projected oil prices, 1998-2022



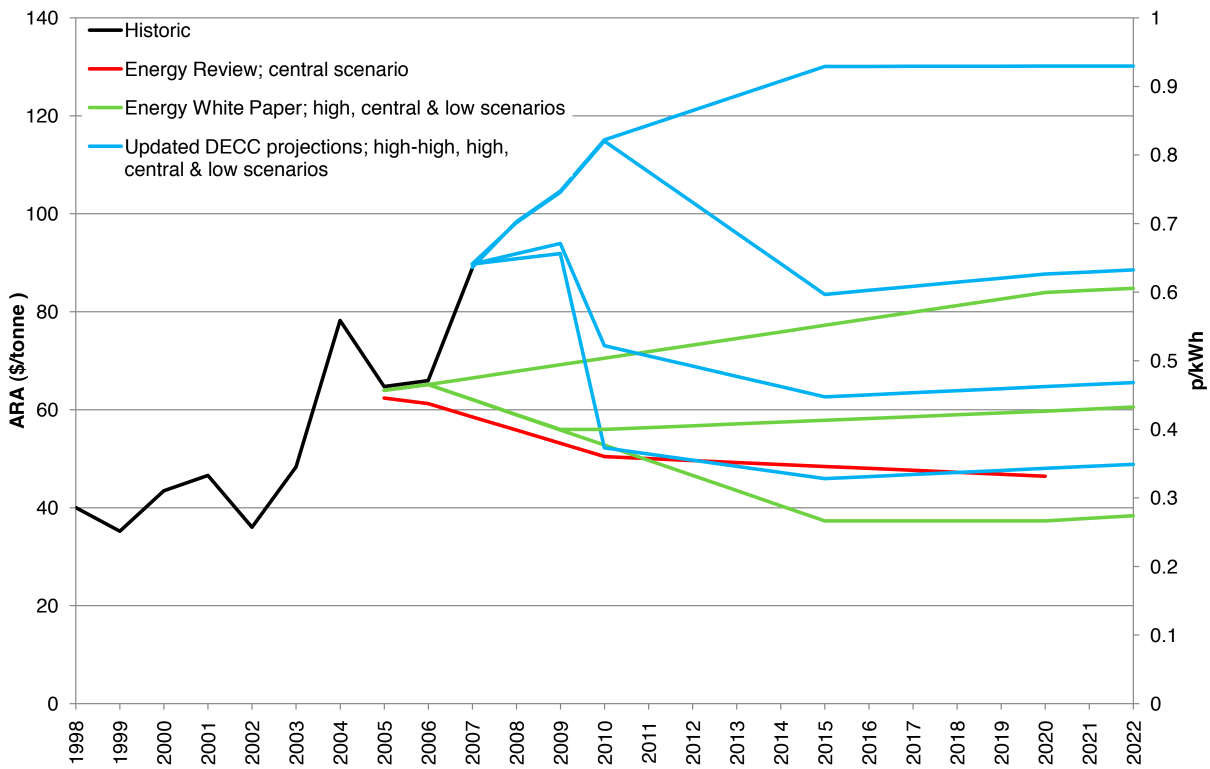
Source: Energy Information Admisnistration, DECC. $/bbl, 2007 prices. Energy Review projections published July 2006; Energy White Paper estimates published May 2007; updated DECC projections May 2008.

Figure 3.4 Historic and projected gas prices, 1998-2022



Source: Platts, DECC. 2007 prices. Energy Review projections published July 2006; Energy White Paper estimates published May 2007; updated DECC projections May 2008.

Figure 3.5 Historic and projected coal prices, 1998-2022



Source: Platts, DECC. 2007 prices. Energy Review projections published July 2006; Energy White Paper estimates published May 2007; updated DECC projections May 2008.

(iii) Other important factors: population and GDP growth

Emissions will tend to grow more rapidly the faster is population growth, and the faster is GDP growth.

- For population growth, our central case assumption is the Office for National Statistics (ONS) 2006-based Principal Projection, which shows the UK population growing from around 61 million today to 67 million in 2020.
- For GDP growth, we use a central forecast consistent with the March 2008 Budget under which real GDP growth is 2-2.5% annually in the period to 2020, such that the economy in 2022/23 will be around 35% larger than it is today (Figure 3.6).
- In addition to central cases, we have run a high-population/high-GDP growth scenario based on the ONS high variant where the population rises to around 69 million in 2020[7], and where annual GDP growth is increased by around ¼ percentage point relative to the central case.

(iv) Assumptions on policies already in place

In developing reference emissions projections, we have to decide which recently implemented or announced policies to include in the projections and what their impact will be.

Our approach here is to assume that the policies outlined in the Climate Change Programme 2006 are implemented and will produce the impact which was then anticipated. This impact was estimated as amounting to around 105 $MtCO_2$ per annum saved by 2010 increasing to around 122 $MtCO_2$ by 2020 (Table 3.1), as a result largely of energy efficiency and fuel efficiency improvements, together with increases in the level of renewable electricity and biofuels.

We do not include in our reference emissions projections, however, the more recent measures introduced or announced by the Energy White Paper 2007, nor those proposed in the draft Renewable Energy Strategy. Neither do we incorporate into the reference projections the impact of the proposals for Phase 3 of the EU ETS. Instead we estimate what emisisons would be before these initiatives, and then explicitly calculate the impact and the cost of the abatement measures which these initiatives might deliver.

(v) Resulting reference emission projections

To develop our reference emission projections we have taken the range of assumptions outlined above, and run these through two alternative models.

- The first is the DECC Energy Model (previously known as the BERR Energy Model), which comprises a set of energy demand equations based on econometric analysis of energy demand data. It also incorporates a linear programme which takes forecast electricity demand and minimises the cost of meeting this, given the existing generation stock and possible new investments. Box 3.2 outlines the main features of the DECC model and conclusions from a review of its effectiveness which we commissioned from *Oxford Economics*.
- The second is the Cambridge Econometrics Model, which is similar to the DECC Energy Model in that it projects energy demand on the basis of econometrically estimated relationships and estimates emissions from power generation using a linear programme. The difference between the DECC and Cambridge Econometrics models results chiefly from differences in the estimated demand equations upon which projections are based (e.g. the models contain differing demand elasticities and in some cases different demand drivers)[8].

7 This is a significant – around 15% – increase over a twelve year period. On the same trend, the UK population in 2050 would be around 90 million.
8 These issues are the subject of a technical paper, published alongside this report.

Table 3.1 List of Climate Change Programme measures and their estimated impact on CO_2 emissions in 2010

CCP2006 measures*	CO_2 savings in 2010 (Mt)**	CO_2 savings in 2020 (Mt)
Energy supply		
Renewable Obligation	9.2	12.8
Second phase of EU ETS	29.3	29.3
Subsidy for biomass heat	0.4	0.7
Business		0.0
*Climate change levy****	*13.6*	*13.6*
UK emissions trading scheme (effect on CO_2 only)	1.1	0.0
Carbon Trust	4.0	8.1
Building Regulations 2002 and 2005	2.2	7.0
Climate change agreements	10.6	1.1
Carbon Trust support for investment in energy efficiency in SMEs	0.4	0.4
Measures to encourage or assist SMEs to take up energy saving opportunities	0.4	0.4
Transport		
Voluntary Agreements package including reform of company car taxation and graduated VED	8.4	12.8
Wider transport measures	2.9	0.0
Sustainable distribution in Scotland and Wales	0.4	0.0
Fuel duty escalator	7.0	5.5
Renewable Transport Fuel Obligation (RTFO) (5%)	5.9	5.9
Domestic		0.0
Energy Efficiency Commitment (EEC) / CERT (2002-2011)	5.9	5.9
Increase activity in CERT (2008-2011)	1.8	1.8
Building Regulations 2002 and 2006 (including 2005 condensing boiler update)	5.5	16.5
Warm Front and fuel poverty programmes	1.5	1.1
Expansion of Warm Front	0.0	0.4
Market Transformation including appliance standards and labelling	0.7	3.7
Provision of advice to stimulate early replacement of inefficient boilers and implementation of the Energy Performance of Buildings Directive	0.7	0.7
Agriculture		
Woodlands Grants Scheme (England)	0.7	1.1
Woodlands planting since 1990 (Scotland)	1.8	2.6
Strategy for non-food crops	0.4	0.4
Public Sector		
Central Government, NHS, UK universities and English schools including Carbon Trust activities, plus regional Central Energy Efficiency Funds	0.7	0.7
Action by devolved administrations	1.1	0.0
Additional effort by local authorities	0.7	0.7
Revolving loan fund for the public sector	0.4	1.8
Waste		
Waste strategies saving CO_2	0.7	0.7
Other measures		
	0.4	0.4
TOTAL****	105.2	122.5

Source: UK Climate Change Programme 2006

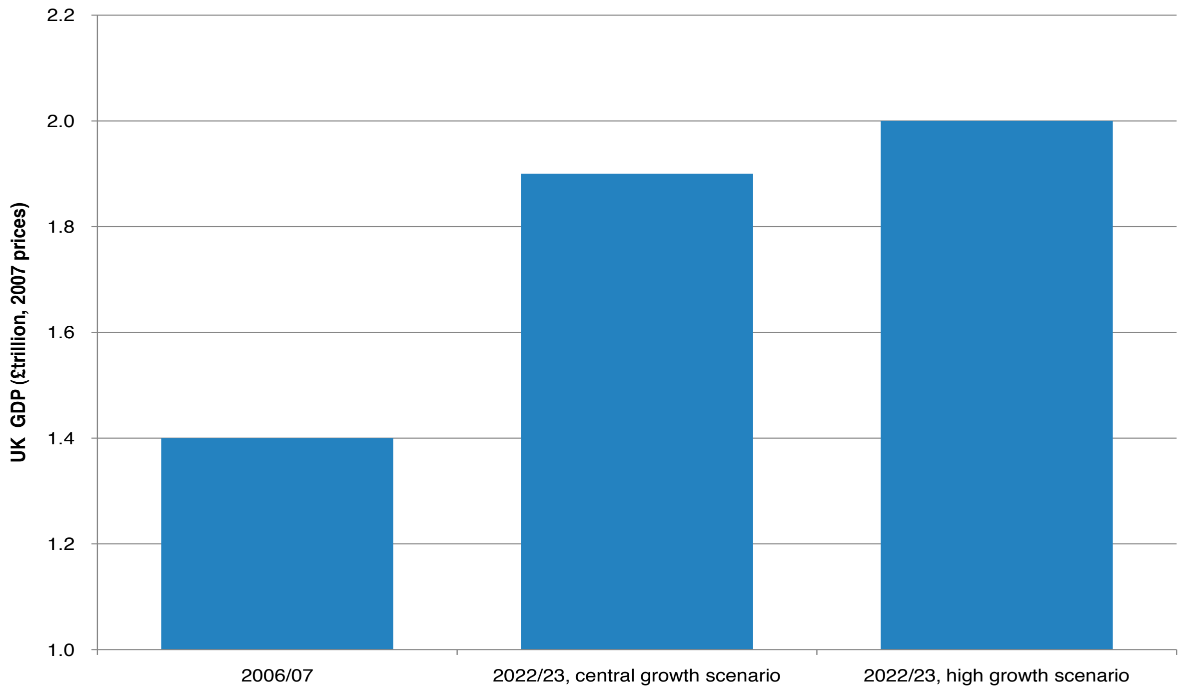
* The policies and reductions in emissions in this table only refer to CO_2. We have not included policies that were announced in the CCP 2006 but were subsequently firmed up and reappraised in the EWP 2007, namely: better billing and metering in the domestic sector, more energy efficient productss and the successor to the EU voluntary agreements on new car fuel efficiency.

** These are savings from reference emissions as they were estimates in CCP2006. Savings in CCC reference emissions may be different due to updated reference assumptions.

*** An independent evaluation by Cambridge Econometrics (CE) concluded that CCL would deliver annual carbon savings of 3.7MtC by 2010, from an announcement effect and price effect of the levy. This figure assumes CCL rates are increased in line with inflation from 2005 to 2010. The impact of CCL in the projections is incorporated through the price elasticity of demand for different fuels ('the price effect'), and there is no separately identified announcement effect within the UEP baseline.

**** Total does not include CO_2 savings from the climate change levy (The price effect of the levy is included in DECC Updated Energy Projections. The DECC energy projections do not include the announcement effect mentioned above).

Figure 3.6 Historic and projected UK Gross Domestic Product



Source: HMT and CCC calculations. £2007, rounded to the nearest £100 billion.

Box 3.2 Review of the DECC Energy Model by Oxford Economics

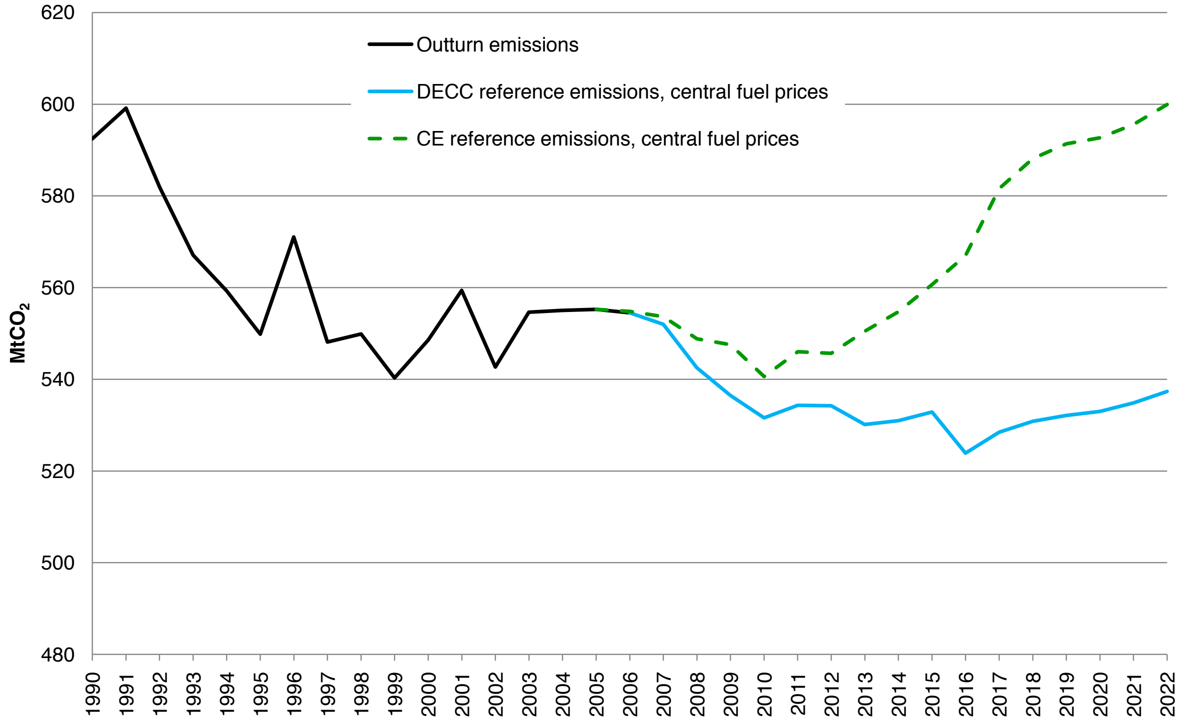
We asked Oxford Economics to conduct a review of the DECC Energy Model, the results of which are published alongside this report. Oxford Economics conclude that the model is broadly fit for purpose, with the forecast approach firmly based on observed past relationships between the drivers of energy demand and the resulting use of energy. They also highlight elements of the model that would benefit from further review – specifically, the equations for road transport energy demand. In response to this, we have compared transport emissions projections from the DECC model with those from DfT's National Transport Model (NTM). As the DECC projections are higher than those from the NTM, our analysis in this chapter, based on the DECC projections, requires more emissions reduction effort to meet budgets than would be necessary under projections taken from the NTM; in this respect, therefore, we have taken a conservative approach.

Source: CCC digest of the Oxford Economics report published alongside this report

The range of possible reference emission projections is shown in Figure 3.7 and Figure 3.8 below. In a high-high fossil fuel price economy, emissions could fall by up to 7% in the period to 2020. In a scenario with low fossil fuel prices, high GDP growth and high population growth, however, emissions in 2006 and 2020 could be broadly similar. And in the Cambridge Econometrics central scenario, emissions in 2020 are 12% higher than DECC projections, largely due to differences in the level of forecast emissions from the power and road transport sectors.

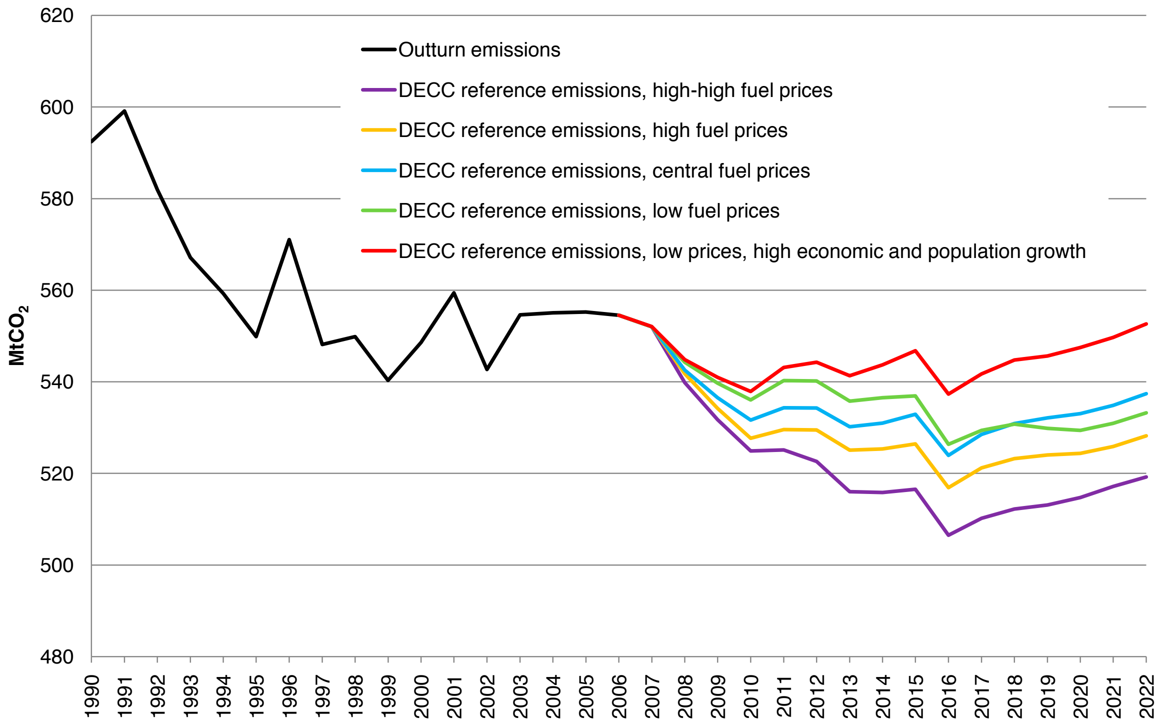
One of the key purposes of setting carbon budgets is to ensure that the UK makes steady progress towards a low-carbon economy whichever of the scenarios actually transpires (for fossil fuel prices, GDP growth, etc). In Section 4 of this chapter, we consider the emissions reduction effort which would be required against a single reference emissions projection, the DECC central scenario; as noted in Section 1(ii) above, this is larger than the effort which would be needed against scenarios based on higher fossil fuel prices, and smaller than the effort that would be required with low fossil fuel prices. We therefore consider the implications of alternative reference emissions projections too, in Section 8.

Figure 3.7 Projected UK CO_2 reference emissions from the DECC Energy Model and from Cambridge Econometrics



Source: DECC and Cambridge Econometrics, 2008

Figure 3.8 Projected UK CO_2 reference emissions under a range of fossil fuel price forecasts, DECC Energy Model



Source: DECC, 2008

2. 2020 TARGETS REQUIRED TO MEET 2050 OBJECTIVES AND EU COMMITMENTS

The UK's 2020 target needs to be consistent with making adequate progress towards the 80% reduction objective for 2050 outlined in Chapter 1: *Setting a 2050 target*. In addition, it should be consistent with the UK making an appropriate contribution to the global trajectories from which that 2050 target is derived. It is also constrained by the commitments which the UK has already made for the period to 2020 within the European Union ahead of the Copenhagen negotiations on a potential post-2012 international framework.

In this section we therefore:

(i) Identify the implications of our proposed 2050 target, and of the required global emissions reduction trajectory from now to 2050, for the UK's 2020 target.

(ii) Identify the implications of the UK's commitments within the European climate change strategy.

(iii) Define desirable 2020 targets upon which to base carbon budgets for two scenarios: one assuming an international deal at Copenhagen, the other assuming no deal.

In Section 3 of this chapter we consider the appropriate emissions trajectory to the 2020 target. In Section 4, we then consider whether and how these 2020 targets and trajectories can be met at acceptable cost, and consider the possible balance of action between different sectors of the economy.

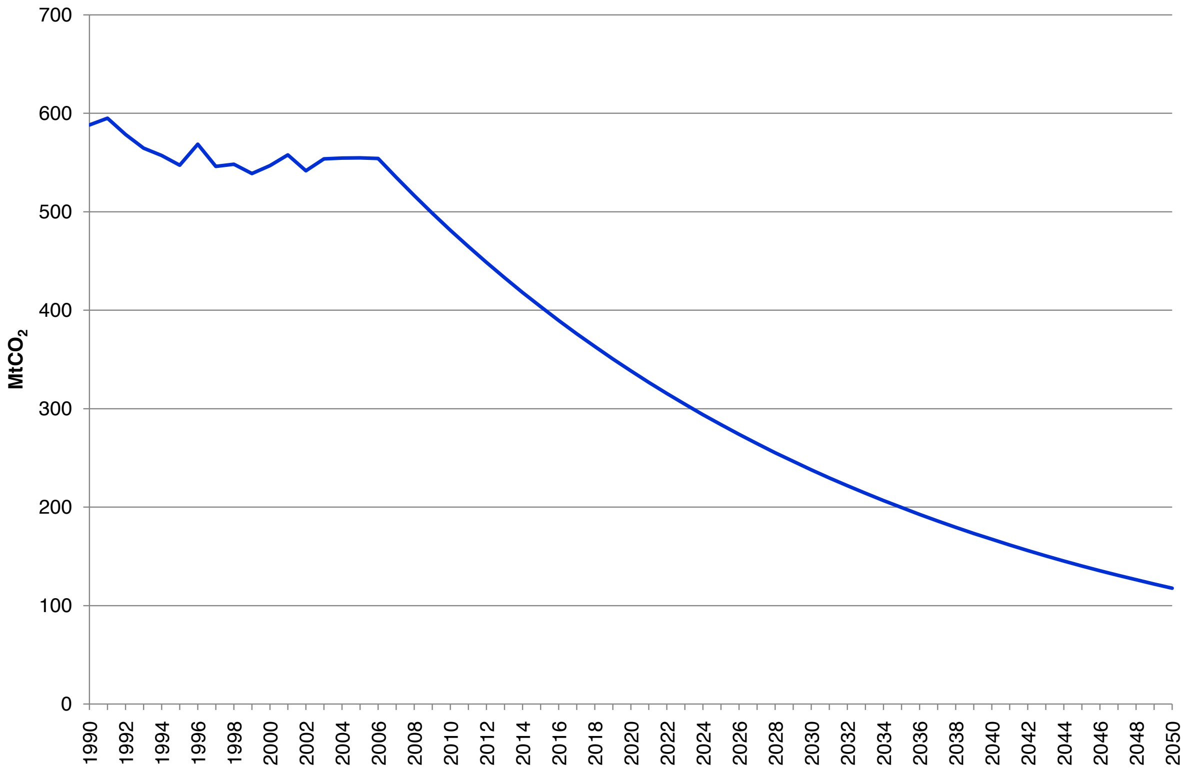
(i) The required path to 2050 global and UK objectives

The UK's 2020 emisisons reduction target should be set so as to ensure significant progress towards the desirable 2050 target of an 80% reduction in GHG emissions including international aviation and shipping. It should reflect the importance of ensuring that investment over the next 12 years does not lock us into high-carbon capital assets which make achieving the 2050 target more difficult. It should represent a reasonable UK contribution towards a global emissions trajectory which is consistent with the climate objectives outlined in Chapter 1. And it should reflect an assessment of the relative costs of reducing emissions more slowly than scientific analysis subsequently suggests is desirable (and having to then accelerate reductions) compared with reducing emissions faster than subsequently appears required (and being able then to decelerate).

We now consider these four criteria in turn:

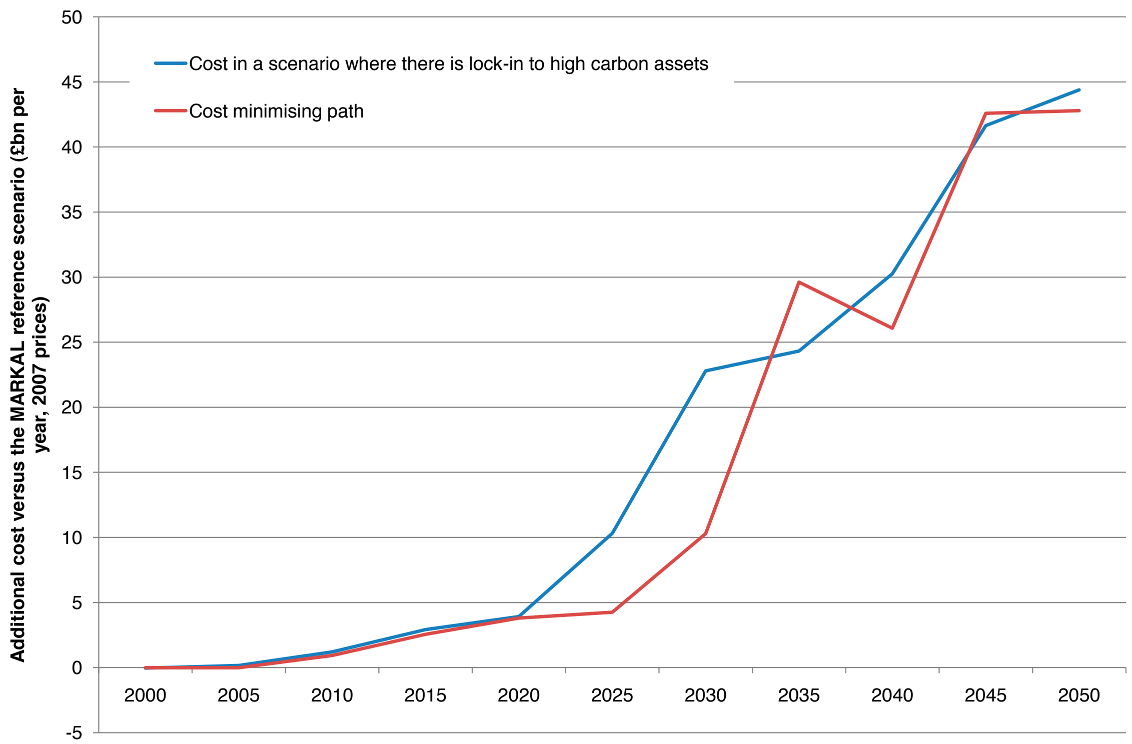
- **Steady progress to 2050: equal percentage reductions?** If we had no information about potential abatement costs and no climate-related preference for early or later action, it might be sensible to aim for equal annual percentage reductions towards the 2050 target. Slower progress in any one year or decade requires offsetting faster progress in later years or decades, and faster progress increases the challenge of renewing the capital stock to drive energy efficiency and new energy sources. Equal percentage reductions from 2006 to 2050 would require CO_2 emissions in 2020 to be 39% below the 2007 level and 43% below the 1990 level (Figure 3.9). This could be seen as an ideal benchmark: anything less in 2020 means that the challenge in subsequent years is increased.

Figure 3.9 Equal percentage reductions in UK CO_2 emissions from 2006 levels to 80% below 1990 levels by 2050



Source: CCC analysis

Figure 3.10 Illustrating the cost of incurring lock-in to high-carbon assets on the way an 80% reduction in CO_2 emissions by 2050



Source: MARKAL model, AEA 2008.

- **Avoiding lock-in to high-carbon investment:** The logic of the 'equal percentage reduction' approach can, however, be refined by looking in detail at the availability of abatement options over time and at capital replacement cycles. We have therefore used the MARKAL model – which captures both these factors, see Chapter 2: *Meeting a 2050 target* – to analyse the cost minimising path to an 80% reduction in 2050. This modelling highlights the costs of locking in to high-carbon power generation assets in the period to 2020 (Figure 3.10), and suggests that the cost minimising path to an 80% target involves a combination of energy efficiency improvement and power sector decarbonisation in 2020; we consider what this combination might involve in Section 4 below.

- **Consistency with required global trajectory to 2050:** Our recommendation of an 80% UK target for 2050 is based on the aim of keeping our central estimate of temperature change at or close to 2°C, and keeping the probability of exceeding 4°C at very low levels. As we showed in Chapter 1, this requires not only that the world achieves global emission cuts of at least 50% below current levels by 2050, but also that it begins to cut emissions from around 2015. The reason for this is that it is cumulative emissions to 2050 and beyond rather than emissions in 2050 alone that will determine the extent of climate change. An appropriate UK contribution to required global emissions reduction in 2020 is a reduction in CO_2 emissions of at least 35% and possibly as high as 45% (Box 3.3)

Box 3.3 UK contribution to an appropriate global emissions reduction target under alternative burden sharing methodologies

Analysis produced for Defra in 2007 considered UK contributions to alternative global emissions reduction trajectories. Amongst these trajectories is one which is designed to meet our climate objective in Chapter 1 to limit global temperature change at or close to 2°C. Specifically, this scenario assumes that global emissions in 2020 will be around 20% below current levels.

Various burden share methodologies (see Chapter 1) are used to define a range for UK contributions to this reduction trajectory. At the lower end of the range, the Triptych methodology suggests that a 35% GHG reduction in 2020 relative to 1990 would be appropriate. At the upper end of the range, methodologies where developing countries move more slowly towards long-term targets suggest a UK contribution of nearer 40%, rising to 45% for the 'Intensity' burden sharing rule, depending on baseline emissions.

We translate this range from GHG to CO_2 measured on the UK inventory basis (i.e. excluding international aviation) by assessing the level of emissions reduction which is likely to have been achieved by 2020 on 1990 levels for non-CO_2 and international aviation; the remaining reduction must fall on sectors emitting CO_2.

As non-CO_2 emissions are expected to fall by more than 35-45% by 2020 on 1990 levels, but with less than proportionate emissions reduction expected for international aviation, the net effect is that the UK must reduce its CO_2 emissions by around 35-45% from 1990 to 2020 to achieve its overall burden share.

Source: *Factors underpinning future action*, ECOFYS report for Defra, May 2007

- **Optimal early action in the face of uncertainties:** Our aim set out in Chapter 1 to keep our central estimate of temperature change at or close to 2°C requires GHG concentrations to remain below 500 ppm. As climate science progresses, however, it may become appropriate to aim for either a lower or a higher concentration limit. It is therefore useful to consider the relative costs involved in setting a target which subsequently looks too stretching or too weak. Our analysis suggests that a minimum emissions reduction consistent with keeping concentration below 500 ppm CO_2e (i.e. of the order 35% CO_2 or more below 1990 as the UK contribution to global effort) remains appropriate even in the face of uncertainty over whether a higher concentration may actually be acceptable (Box 3.4).

Box 3.4 Early action remains appropriate even in the face of uncertainty about the long-term climate objective

We have used the MARKAL model to consider two sets of scenarios:

In the first, the UK initially pursues an emission reduction path consistent with its contribution towards a 450-500 ppm concentration limit, but then reverts to a less stretching 550 ppm limit after 2020 as new science becomes available. In particular, it achieves 33% emission reductions by 2020 relative to 1990, which is of the order required for 2020 emissions reductions to limit concentration at 450-500 ppm; the 2050 target is set such that cumulative emissions are equal to those along a trajectory passing through 26% in 2020 and 60% in 2050. The additional costs incurred, relative to pursuing 60% from day one are small, reflecting the fact that marginal costs of abatement in 2020 and 2050 are a similar order of magnitude in present value terms.

In the second, the UK initially follows a stabilisation path consistent with its contribution towards a 550 ppm concentration limit, but then switches to a 450-500 ppm limit as new information becomes available. It achieves a lower 26% cut by 2020, but then accelerates effort to achieve over 80% reduction by 2050; the target in 2050 is set such that cumulative emissions are equal to what they would be along a trajectory passing through 33% in 2020 and 80% in 2050. The additional cost relative to pursuing 80% from day one is £25 billion in the period to 2050. This arises because the initial more limited ambition results in a lock-in to high-carbon investment and technology, and because more effort is required in 2050 when marginal costs are relatively high.

Source: MARKAL model, AEA 2008

Synthesis on paths to the 2050 target and global trajectories: The analysis presented in this subsection suggests that the UK should set a CO_2 reduction target for 2020 of the order 35% to 45% below 1990 levels: equal annual percentage reductions point to a cut of 43%; a reasonable UK contribution to an acceptable global trajectory, using standard burden sharing methodologies, would be at least 35% and possibly as high as 45%. This range of possible targets should be considered alongside the European Union agreed targets, to which we now turn.

(ii) Implications of the UK's European Union commitments

UK climate change policy needs to be designed within the context of European Union policy, to which the UK is politically committed and will shortly be legally committed. The European Union has agreed, or is in the process of agreeing, overall GHG reduction targets, and the UK's legally binding share of these. The EU framework therefore sets the minimum, but not the maximum, reductions which UK budgets will need to achieve.

This subsection describes the key features of the EU climate change programme and of the agreed EU stance in the international negotiations at Copenhagen in 2009.

- The overall approach, agreed in the Spring Council in 2007, is that the EU has adopted a unilateral commitment to cut its GHG emissions by 20% in 2020 relative to 1990, and will increase this commitment to 30% if there is an agreement to a global deal to reduce emissions.

- The 20-30% range straddles the sort of developed country reductions which Chapter 1 suggested are likely to be required in order to meet global climate stabilisation goals: 20% would be too low, but 30% would be clearly adequate if other countries were making commensurate commitments. The EU's approach therefore represents a responsible negotiation offer given the vital importance of arriving at a global agreement. And the arrangements relating to offset credits (discussed in Section 5 below) may create a significant incentive for developing countries to make an agreement.

- In January 2008 the European Commission proposed a package of legislation to support meeting these targets. It is expected that this package will enter legislation, with possible amendments, no later than the first quarter of 2009. The package splits the targets between those for emissions in traded sectors (i.e. in the EU ETS, see Chapter 4: *Carbon markets and carbon prices*) and non-traded sectors. We have worked out what the implications of the package are for the UK in terms of non-traded and traded targets for 2020, and added these together to give economy-wide targets. Against a 20% EU GHG target, we estimate that the UK will be required to reduce CO_2 emissions by 29% in 2020 relative to 1990. For a 30% EU GHG target, we estimate that the required UK CO_2 emissions reduction would be 40%. Box 3.5 provides a detailed mapping of how we move from the EU-wide GHG targets to the UK 29% and 40% targets for CO_2 measured on the UK inventory basis.

Box 3.5 Moving from the EU level GHG targets to UK level CO_2 targets measured on the UK inventory basis

Kyoto greenhouse gases

EU emissions

Estimated EU level GHG caps for 2020 under the EU package ($MtCO_2e$)

Percentage reduction 1990 -2020	Whole economy	20%	30%
	Whole economy excluding aviation	22%	32%
Percentage reduction 2005 -2020	ETS excluding aviation	22%	39%
	Non-traded sector	9%	16%
	Whole economy excluding aviation	15%	26%

Figures exclude LULUCF emissions and international marine in line with the EU package

CCC estimate of UK's likely share of EU-level GHG cap based on the January package

UK emissions

Estimated UK level GHG caps under the EU package ($MtCO_2e$)

1990 emissions	Whole economy excluding aviation	770	770
Percentage reduction 1990-2020	Whole economy excluding aviation	34%	42%
UK allocation/allowed emissions for 2020	ETS excluding aviation	199	157
	Non-traded sector	310	287
	Whole economy excluding aviation	509	443
Percentage reduction 2005-2020*	ETS excluding aviation	29%	44%
	Non-traded sector	16%	22%
	Whole economy excluding aviation	22%	32%

Figures exclude LULUCF and international marine in line with the EU package. Figures also exclude all aviation.

To arrive at a cap for CO_2 specifically we then estimated non-CO_2 emissions from the UK GHG total ($MtCO_2$)

Carbon dioxide

Estimated UK level CO_2 caps for 2020 under the EU package ($MtCO_2$)

1990 emissions	Whole economy excluding aviation	589	589
Percentage reduction 1990-2020	Whole economy excluding aviation	29%	40%
UK allocation/allowed emissions for 2020	ETS excluding aviation	199	157
	Non-traded sector	219	195
	Whole economy excluding aviation	418	352
Percentage reduction 2005-2020*	ETS excluding aviation	29%	44%
	Non-traded sector	19%	27%
	Whole economy excluding aviation	24%	36%

Figures exclude LULUCF and international marine in line with EU package. Figures also exclude all aviation and non-CO_2.

To arrive at UK carbon budget caps we add in our view on allowed emissions for LULUCF and domestic aviation

Estimated UK carbon budget caps for 2020 using the UK inventory coverage ($MtCO_2$)

1990 emissions	Whole economy	592	592
Percentage reduction 1990-2020	Whole economy	29%	40%
UK allocation/allowed emissions for 2020	ETS	202	160
	NTS	221	198
	Whole economy	423	358
Percentage reduction 2005-2020*	ETS	28%	43%
	NTS	19%	28%
	Whole economy	24%	36%

In line with the UK emissions inventory figures include LULUCF and domestic aviation but exclude international aviation and marine. Figures exclude non-CO_2. We include LULUCF and domestic aviation at business as usual rates out to 2022.

*The level of 2005 ETS emissions used in calculating this percentage has been adjusted to match the ETS coverage expected for 2020. This is to ensure the baseline measure of emissions is consistent with the emissions caps given in the January package apply.

Source: CCC analysis

(iii) Alternative budgets depending on global deal

The analysis in subsections (i) and (ii) above suggested a range of possible targets for CO_2 emissions reduction stretching from 29% to 45% (Figure 3.11). Deciding an appropriate budget for the UK therefore requires us to make a judgement on the relative weight to attach to the different aspects that we have considered. It also requires us to decide whether the UK should make its budgets contingent on the achievement of an international deal, as the EU targets are.

The judgements we have reached are that:

- The UK should make its budgets contingent on a global deal, setting a lower unilateral budget and a higher one to which it would move provided a global deal is achieved. This contingent approach mirrors that of the EU and represents a sensible strategy in light of the position which the EU has adopted in global negotiations.

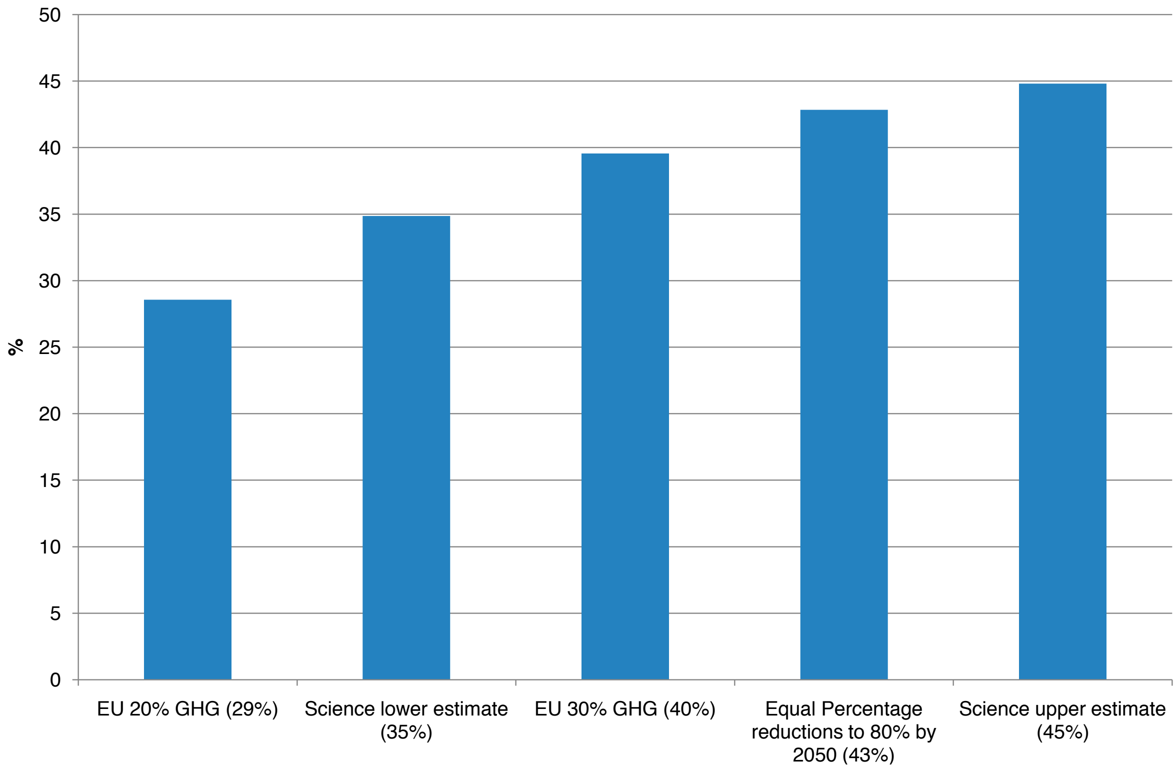
- The UK targets as defined under the European Union's 30% target are a sensible basis for setting the higher (global deal) UK budgets.

- The lower (unilateral) UK budget should be designed to prepare for meeting the higher budget. In particular, the lower budget should build in a level of domestic effort that will be required to meet the higher budget. This is because:
  - Preparing for a world where there is a global deal will avoid the need to change targets when a global deal is agreed and the uncertainty that this would cause.
  - Given long lead times, policies being designed now will come into force at the time when we hope and expect a global deal will be in place; policies should be designed to deliver in this world. The alternative would be to lock in to a set of policies that are not sufficiently ambitious for a world where there is a global deal. This would make the 40% target harder to meet or might entail additional cost, for example due to the stranding of assets.
  - Preparing for a global deal sends a positive signal in the context of forthcoming international negotiations.

- With this in mind, an appropriate approach for setting the lower budget is to base the UK reduction around its burden share of the European Union's 20% GHG target but to aim to ensure that all effort in the non-traded sector is achieved through domestic emissions reduction (i.e. without purchase of offset credits)[9]. This level of domestic effort is enough to prepare the UK for the move to a 30% world.

9 We discuss the use of credits in non-traded and traded sectors under the Interim and Intended budgets in Section 5 below. To the extent that the UK Government might wish to purchase credits (e.g. to help underpin its negotiating position for a global deal), this should be additional to domestic effort required to meet the Interim budget.

Figure 3.11 Various perspectives on what the UK's CO_2 emissions reduction target for 2020 should be (percentage reduction versus 1990 levels)



Source: CCC analysis

The proposed way forward would therefore entail:

- An initial budget – referred to hereinafter as our 'Interim' budget – to achieve at least 29% CO_2 reduction on 1990 levels by 2020[10]. This is below the lowest level likely to be appropriate as a UK contribution to a required global trajectory (in the order of 35%), but it would drive significant progress towards a low-carbon economy, given in particular the limitations that we are proposing on the use of offset credits to meet this target. And to aim significantly higher on a unilateral basis (ahead of other EU nations let alone the developing world) would incur increased costs without significant environmental benefit.

- A commitment that the UK will move to a budget to achieve at least 40% CO_2 reduction versus 1990 levels by 2020 in the event of a satisfactory global deal being agreed at Copenhagen or subsequent meetings; we call this our 'Intended' budget. This more ambitious budget would, as envisaged within the EU framework, involve a greater use of purchased credits with the possibility of increased domestic effort in some areas (see Section 5 below). A UK contribution of 40%, together with commensurate emission reductions from other Member States, would put the UK and EU on the path to a low-carbon economy and would represent appropriate UK and EU contributions to required global action towards meeting the climate change objective proposed in Chapter 1.

In recommending these budgets, the key issue then becomes whether the UK's targets within the EU framework and our proposed budgets are attainable at acceptable cost and with what policies in different sectors of the economy; Section 4 addresses these issues. Before moving to this, however, we first consider the appropriate trajectory to the 2020 targets.

10 As this number is derived from the EU package it could change before the package is finalised. Our budget proposals would then need to be revised too. Depending on when negotiations in Europe are concluded, revisions could be made prior to setting budgets in legislation. Alternatively, legislated budgets could be adjusted either at the time that the fourth budget is set in legislation (no later than June 2011 in line with the Climate Change Act), or when the lower budget is replaced with the higher budget following a global deal. Any revision would only have a material impact from the start of EU ETS Phase III in 2012.

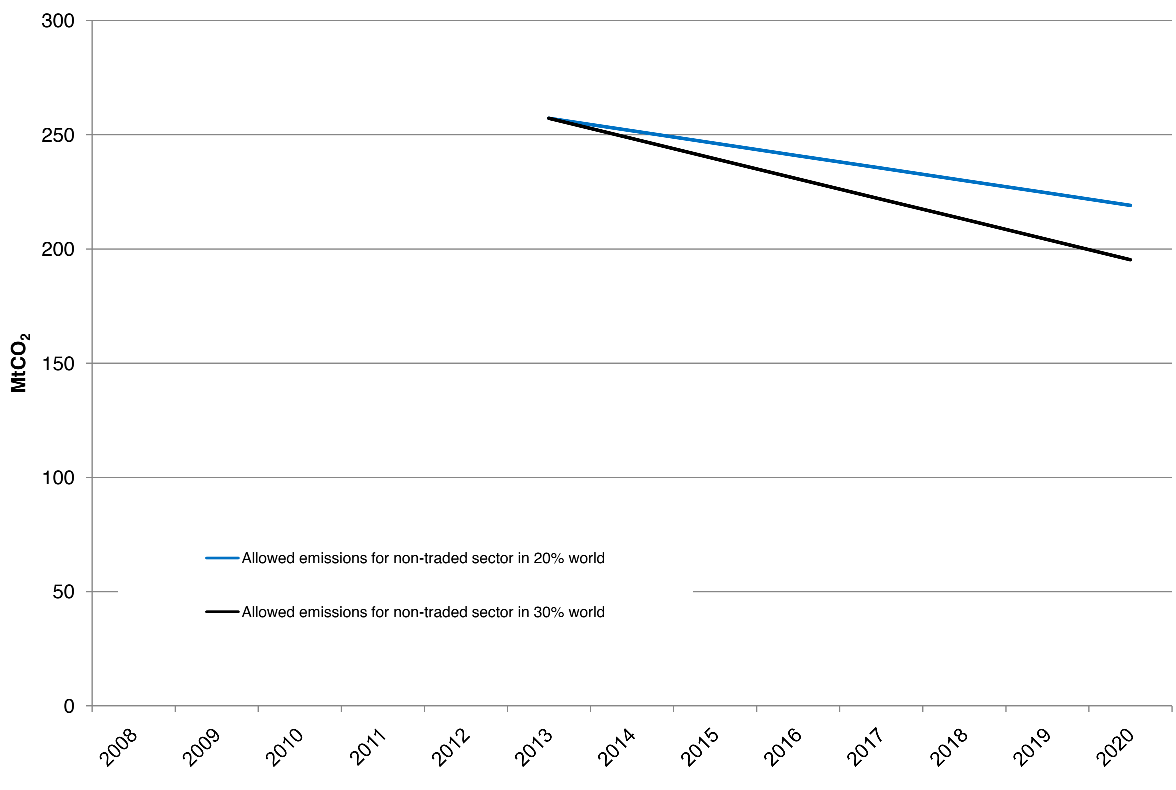
3. THE EMISSIONS REDUCTION PATH TO 2020

The EU framework also includes legally binding trajectories from 2013 towards the traded and non-traded targets for 2020. Specifically, Member States are required to approach traded and non-traded sector caps for 2020 along a straight line trajectory from 2013 (Figure 3.12 and Figure 3.13). In other words, there should be equal annual emission reductions in the years from 2013 to 2020; effort under this trajectory is slightly back-loaded compared with equal annual percentage reductions over the same period.

The EU framework sets a minimum level of effort over time for UK carbon budgets. We have considered whether there would be merit in going beyond this minimum. For example, it might be the case that aiming for equal annual *percentage* reductions would reduce the cost of moving to the 2020 target. We have concluded, however, that there is no evidence to suggest that more early action than is required under the EU framework would reduce costs. Moreover, the EU framework only slightly departs from equal annual percentage reductions, given the relatively short timeframe to 2020 and the level of emissions in this year. And it is not clear that we have scope to go far beyond what is required in the early years given inertia and lead times for policy development and innovation.

We do not therefore see an advantage in setting a legally binding trajectory that is more ambitious than the EU framework, and given that we are committed to the EU targets, we have decided to base our budgets on the trajectories in the EU framework[11]. This raises the question of how we will meet these trajectories, to which we now turn.

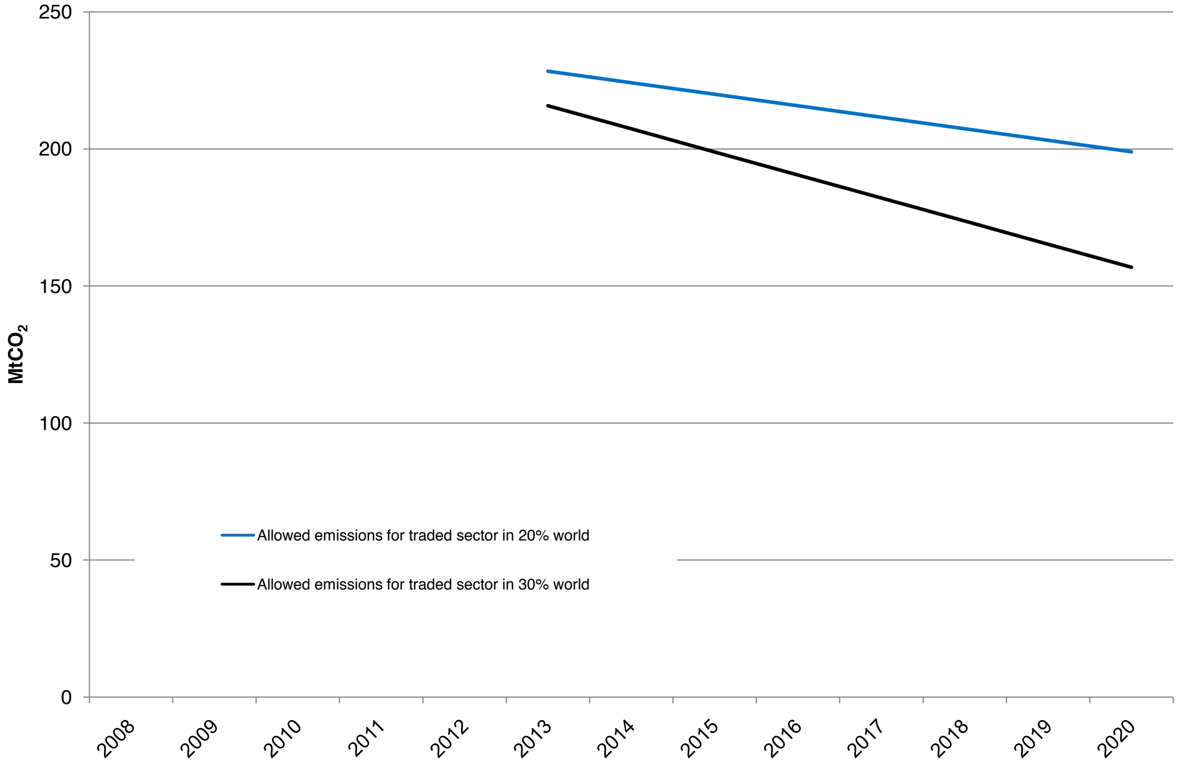
Figure 3.12 Allowed emissions for the UK non traded sector for 2013-2020 under the EU January package, 20% and 30% worlds



Source: DECC and CCC analysis based on the January package. Estimated figures.

11 The EU framework does not define a cap for the first budget period. We base our budget proposals on official central case emissions forecasts, see Section 6 below.

Figure 3.13 ETS cap for the UK traded sector for 2013-2020 under the EU January package, 20% and 30% worlds



Source: DECC and CCC analysis based on the January package. Estimated figures.

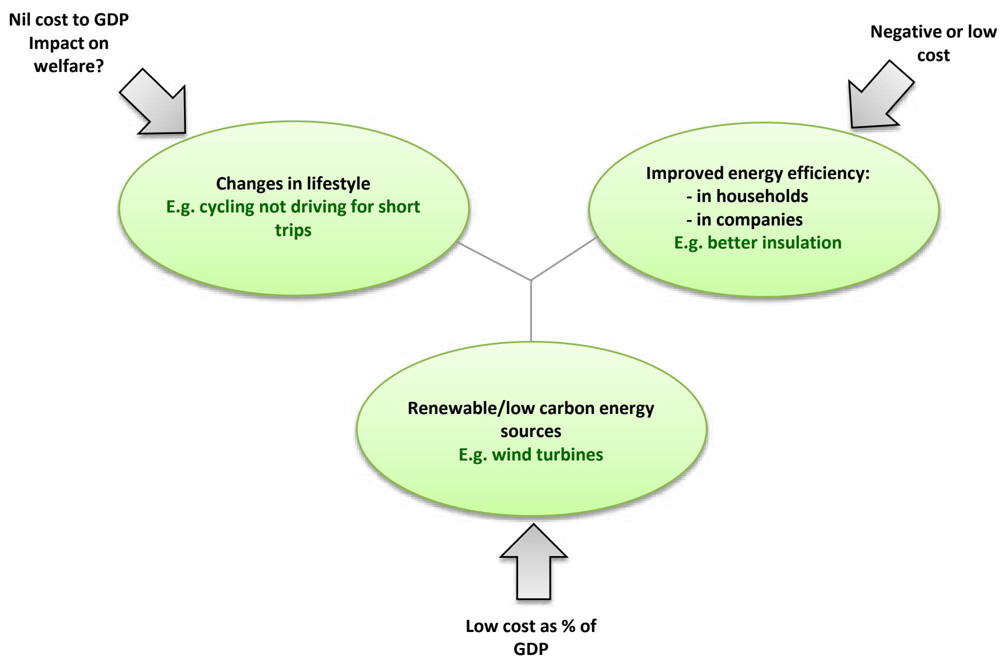
4. FEASIBILITY OF REQUIRED TARGETS GIVEN SECTORAL ABATEMENT OPPORTUNITIES

This section first sets out our approach to defining feasible emissions reduction. It then compares our estimates of feasible emissions reduction with those required under the EU framework.

(i) Our approach to defining feasible emissions reduction

This section sets out our analysis of feasible emissions reduction in the UK over the first three budget periods. It covers measures that fit into three emissions reduction categories: using lower carbon sources of energy, using energy more efficiently while leaving lifestyle unchanged, and changing our life-styles in ways which reduce energy usage (Figure 3.14).

Figure 3.14 Categories of abatement option



Source: CCC

Economy-wide scenarios: We have carried out a bottom-up assessment of each sector of the economy to identify abatement opportunities in each of these different categories. For each sector, we have developed three emissions reduction scenarios, which we then aggregate to three economy-wide scenarios, and which we label Current Ambition, Extended Ambition and Stretch Ambition.

- **The Current Ambition scenario** includes identified measures which would cost less per tonne than our forecast carbon price[12], and/or which are covered by policies already in place; the scenario includes cautious estimates of emission reductions from these measures. It also includes significant progress towards low-carbon electricity generation and some progress on improving fuel efficiency in new cars.

12 Our central case forecast is a carbon price of £40/tCO2 in 2020, see Chapter 4: *Carbon markets and carbon prices.*

- **The Extended Ambition scenario** incorporates more ambitious but still reasonable assumptions on the penetration of energy efficiency improvements and a number of measures which would cost appreciably more per tonne of carbon abated than our forecast carbon price, but which are important stepping stones on the path to 2050. It is broadly in line with policies to which the government is committed in principle, but where precise definition and implementation of policy is still required. It includes, for instance, a significant penetration of renewable heat, more ambitious energy efficiency improvement in cars, and some lifestyle changes in home and transport.

- **The Stretch Ambition scenario** adds further feasible abatement opportunities for which at the moment no policy commitment is in place, including more radical new technology deployment and more significant lifestyle adjustments.

Marginal Abatement Cost Curve (MACC) modelling: Our bottom-up assessment is based on MACC modelling (Box 3.6). Under this approach, we have considered the full range of abatement options and for each of these estimated emissions reduction potential and associated cost per tonne of CO_2. In moving from this assessment to defining scenarios, we have considered a range of factors:

- Cost minimisation for meeting a given target would be achieved by implementing all measures up to the carbon price, and purchasing any residual emissions reductions as required to meet the target in the international carbon markets. We have considered what level of abatement is available up to our central case forecast for the carbon price of £40/tCO_2.

- This is not the only criterion we have used, however, given a number of limitations to this approach which we discuss in detail in Chapter 4. The most compelling of these is that in setting the first three budgets, we are aiming to design a path towards meeting our 2050 goal to reduce emissions of GHGs by 80%. We argued in Chapter 2 that emissions reduction in 2050 will need to come largely from domestic effort, and that new technologies will be required, particularly for decarbonisation of heat and transport sectors. The implication of this is that we should seek to do more in the first three budget periods, both to support technology development and to reduce domestic emissions sufficiently to prepare for deep cuts that will be required later. We have therefore included some options that cost more than the carbon price in our scenarios, particularly in the Extended Ambition and Stretch Ambition scenarios.

- The principle of setting the marginal cost equal to the carbon price also fails to recognise that optimal abatement strategy also has to be shaped by the availability of practical policy levers. For a given domestic emissions reduction, some more expensive abatement options may appropriately be pursued simply because it is possible to design policy levers which will actually deliver them, while some theoretically cheap options may in practice be impossible to achieve due to behavioural barriers to implementation or the political unacceptability of required policy levers.

Box 3.6 Marginal Abatement Cost Curve (MACC) analysis

Economy-wide MACCs for the first three budget periods

- Marginal Abatement Cost Curves provide an assessment of emissions reduction potential across a range of measures at a point in time. They show the level of abatement potential for each measure, and the associated cost per tonne of CO_2.
- - We have developed an economy wide MACC for the UK which draws together sectoral MACCs for residential buildings, non-residential buildings, industry, transport and power generation.
- Our sectoral and economy-wide MACCs relate to 2020. We have made assumptions about the pace at which this potential can be unlocked to derive a series of annual MACCs over the period 2008-2022; we use these to derive emissions reduction trajectories in Section 4 below.

Economic versus financial analysis

- In developing MACCs, we need to compare costs and benefits that accrue at different points in time. In doing this, we have used a social rather than private discount rate. We have done this given our objective to identify the economically desirable set of measures that should be targeted under the UK's climate strategy.
- For those measures where there is a reasonable degree of certainty over returns, we have used the HMT Green Book discount rate (3.5% real). Where there is a high degree of uncertainty, we have used a risk adjusted social discount rate (e.g. for valuing the cost of investment in nuclear new build, where we have used a 10% real discount rate); this is in keeping with the methodology used by the Government in the 2007 Energy White Paper.
- Given our focus on economic rather than financial cash flows, we have adjusted cost savings from abatement measures by netting out taxes and fixed costs. Thus our valuation of energy savings is lower than would be suggested by financial analysis.
- We have also considered financial returns from measures by using a private discount rate and by valuing energy savings at retail prices. The implication is typically that measures become no less attractive (e.g. buildings measures), and in some cases become more attractive (e.g. cars). The exception is Combined Heat and Power (CHP), where emissions reduction costs are highly sensitive to the choice of discount rate.

Fossil fuel assumptions

- We present our MACC analysis based on central case fossil fuel price assumptions. We have considered, however, the implications of using alternative assumptions. Specifically, to the extent that fossil fuel prices are likely to be higher than the central case assumption, costs of abatement measures would fall.
- The implication is that those measures which we identify as being attractive based on economic analysis should typically be available in principle without the need for additional financial support.

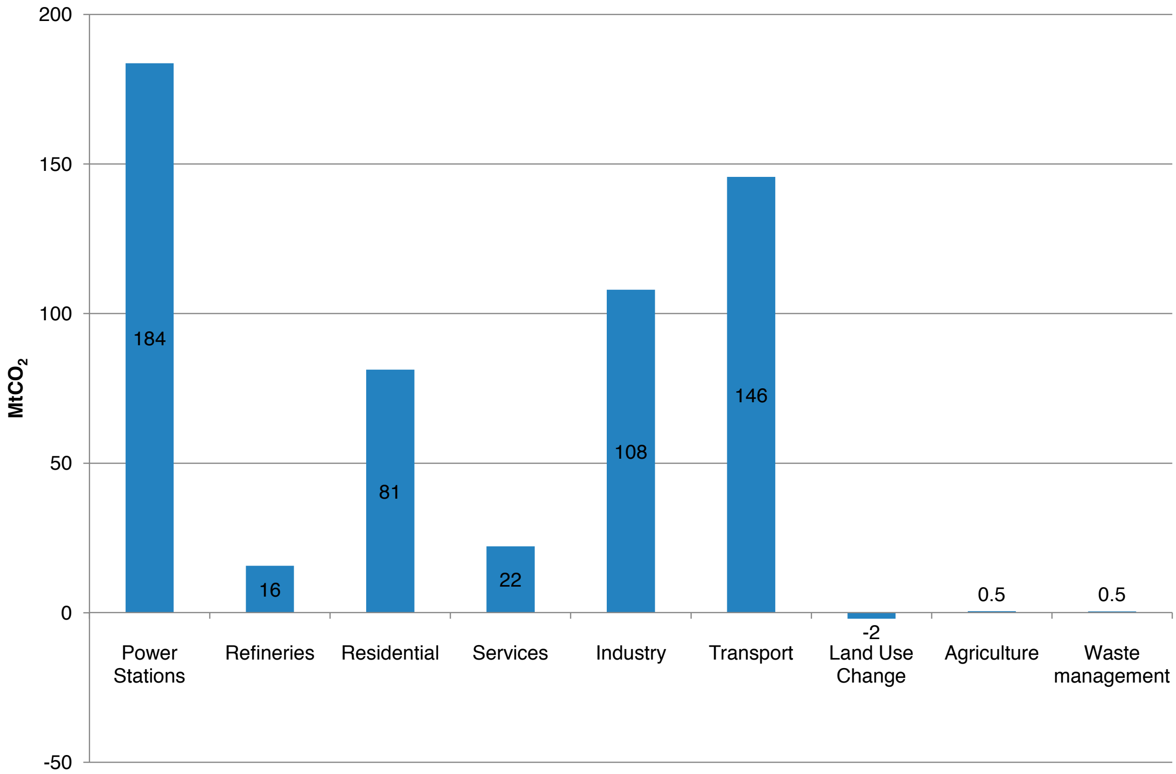
Technical versus realistically achievable potential

- The starting point for our MACC analysis is to identify technical potential that would be available if there were no emissions reduction constraints. We know in practice, however, that there are constraints associated with inertia, lack of information, hidden costs, etc. We have allowed for this by adjusting the abatement potential in our MACCs based on an assessment of the social research evidence base and the policy framework, both as it currently exists and as it might be extended.

Categorisation of sectoral emissions: We have developed sectoral MACCs for power generation, energy use in buildings and industry, and transport. There are however two different ways to categorize emissions by sector:

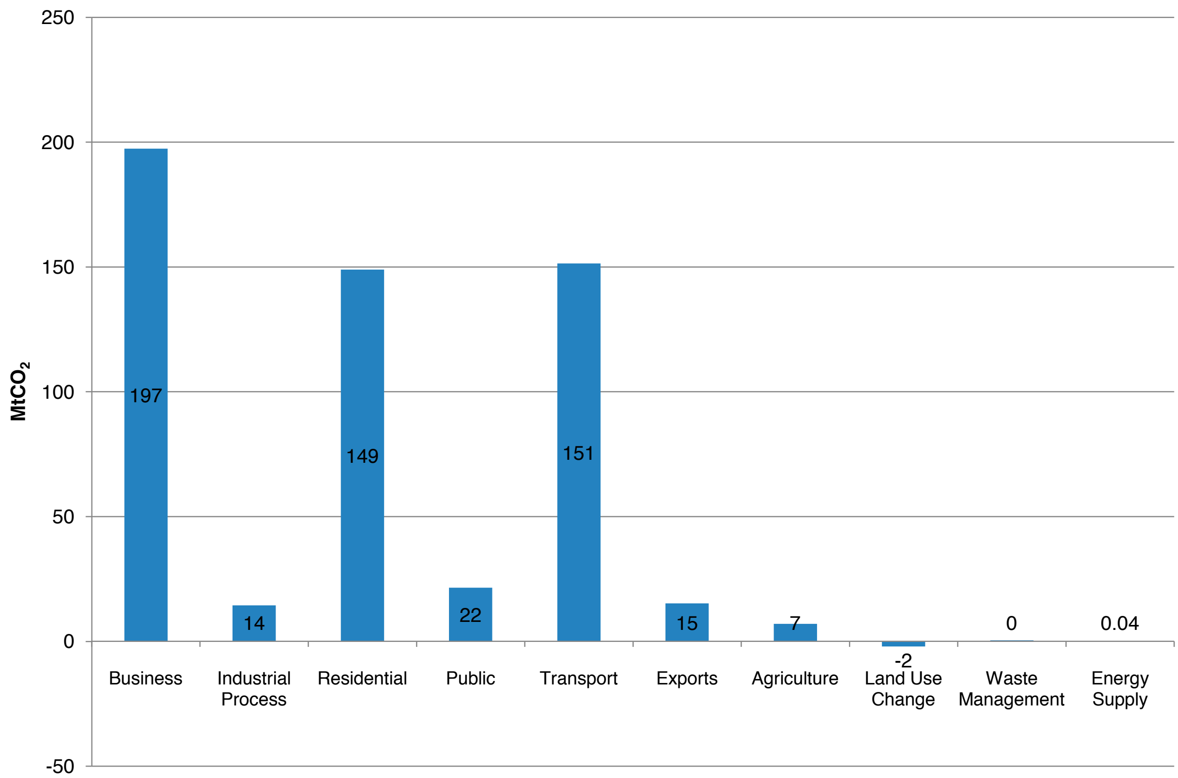
- In the first, emissions from all electricity generation are counted in a defined 'power' sector, while figures for the other sectors (e.g. residential buildings) show all emissions except those relating to electricity (Figure 3.15).
- In the second, end use sectors are shown with their allocated share of emissions from electricity generation, thus facilitating a focus on all forms of energy efficiency (Figure 3.16).

Figure 3.15 UK 2006 CO_2 emissions, presented by DECC source sector category



Source: National Atmospheric Emissions Inventory 2008

Figure 3.16 UK 2006 CO_2 emissions, presented by DECC end use sector category



Source: National Atmospheric Emissions Inventory 2008

In our sectoral analysis we use a hybrid approach. We first consider options to reduce emissions through using lower carbon energy sources in the centralised power sector; but when considering energy use in buildings, industry and transport we look at all emissions, including those from electricity consumption.

(ii) Feasible abatement opportunities: will they reach the EU's non-traded and traded sector targets?

We present our detailed assessment of sectoral abatement opportunities in Chapter 5: *Decarbonising power generation*, Chapter 6: *Energy use in buildings and industry*, and Chapter 7: *Reducing transport emissions*. In these chapters we present analysis of theoretical emissions reduction potential, and realistically achievable emissions reduction after allowing for barriers to uptake of measures and the way that these might be addressed through the policy framework. In each chapter, we explain exactly which measures are factored into the Current Ambition, Extended Ambition and Stretch Ambition scenarios.

In this chapter, we present the economy-wide levels of emissions reduction which result from summing the sectoral reductions that our detailed analysis suggests are feasible (Table 3.2). The range for economy-wide emissions reduction potential is therefore around 80 $MtCO_2$ in the Current Ambition scenario to around 130 $MtCO_2$ in the Stretch Ambition scenario. Furthermore:

- The Current Ambition scenario is dominated by energy efficiency improvement in buildings and decarbonisation of the power sector.

- The increased potential in moving from Current to Extended Ambition largely comprises lifestyle change, increased deployment of renewable heat and improved fuel efficiency in road vehicles.

- Increased potential in the Stretch scenario comes from solid wall insulation, introduction of new technology to vans and speed limiting.

Table 3.2 Summary of the total abatement potential identified in the CCC's three main abatement scenarios

	Savings in 2020 ($MtCO_2$)								
	Current Ambition			Extended Ambition			Stretch Ambition		
	Traded	Non-traded	Total	Traded	Non-traded	Total	Traded	Non-traded	Total
ETS price and 30% renewable electricity*	51	0.4	51	51	0.4	51	51	0.4	51
Residential	8	4	13	15	14	28	15	17	32
Commercial	2	2	4	3	5	8	3	5	8
Public sector	0.3	0.6	0.9	0.7	2	2	0.7	2	2
Industry	4	1	5	5	2	7	5	2	7
Transport	0.0	5	5	-1**	23	22	-1	31	30
TOTAL	66	14	79	74	47	121	73	58	131

Source: CCC analysis

* ETS price applied to power sector only.

** Due to electrification in transport.

To compare these reductions with required effort under the EU package, however, a distinction is needed between the UK traded and non-traded sectors, given that the EU framework splits the economy according to these categories:

- In the non-traded sector, there is 14 $MtCO_2$ emissions reduction in 2020 in our Current Ambition scenario. This increases to 47 $MtCO_2$ in our Extended Ambition scenario[13], and 59 $MtCO_2$ in our Stretch Ambition scenario.

- In the traded sector, our Current Ambition scenario includes emissions reduction of 66 $MtCO_2$ in 2020. This increases to 73 $MtCO_2$ in our Extended Ambition scenario, with no additional emissions reduction factored into our Stretch Ambition scenario.

These figures may be compared to emissions reduction effort required in 2020 to meet the EU's non-traded and traded sector targets[14]:

- Under an EU 20% GHG target, the required emissions reduction from our central case reference emissions projection in 2020 to meet the non-traded sector cap is 37 $MtCO_2$. This increases to 61 $MtCO_2$ for the non-traded sector under a 30% GHG target.

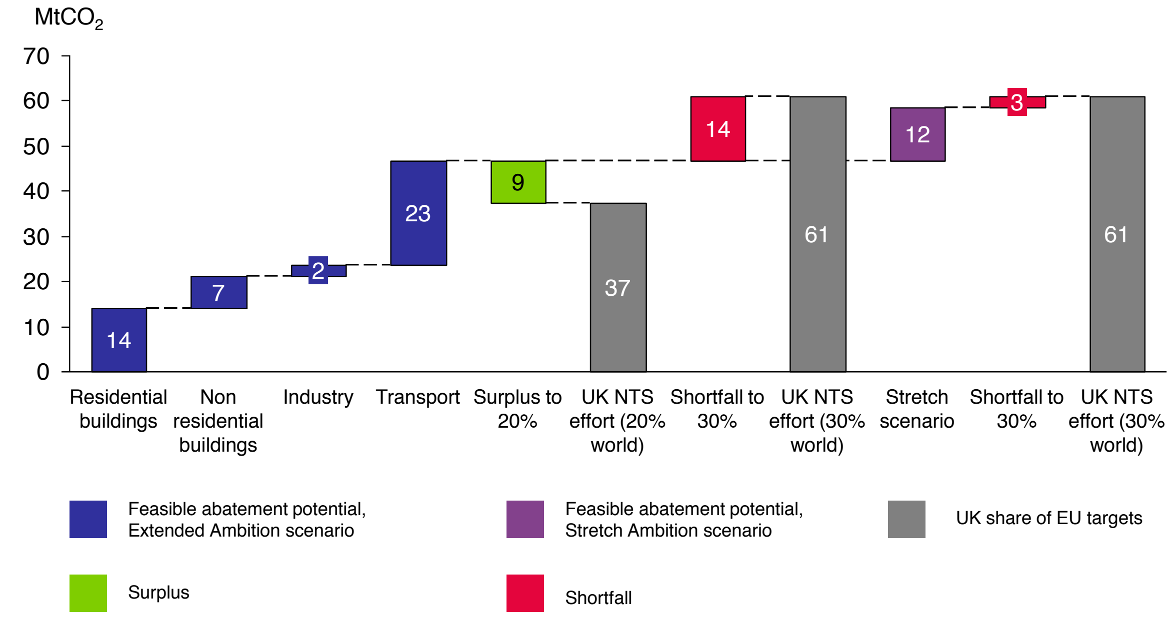
- The required emissions reduction in the traded sector in 2020 is 71 $MtCO_2$ for a 20% GHG target and 114 $MtCO_2$ for a 30% GHG target.

Therefore, if abatement opportunities in our Extended Ambition scenario were achieved, we would meet the non-traded cap for a 20% GHG target in 2020, but not the non-traded target for a 30% GHG target (Figure 3.17); our Stretch Ambition scenario would, however, come close to delivering the emissions reduction needed under a 30% GHG target. In the traded sector, we would just meet the traded sector target under a 20% GHG target through domestic effort alone and we would not meet the 30% GHG target through domestic effort alone (Figure 3.18).

13 This is a conservative estimate: we have not included significant emissions reduction potential in the draft RES from increased use of biogas. The reason we have not done this is because we have not been able to undertake detailed analysis in this area. We intend to explore scope for emissions reduction through increased use of biogas as part of our ongoing work programme.

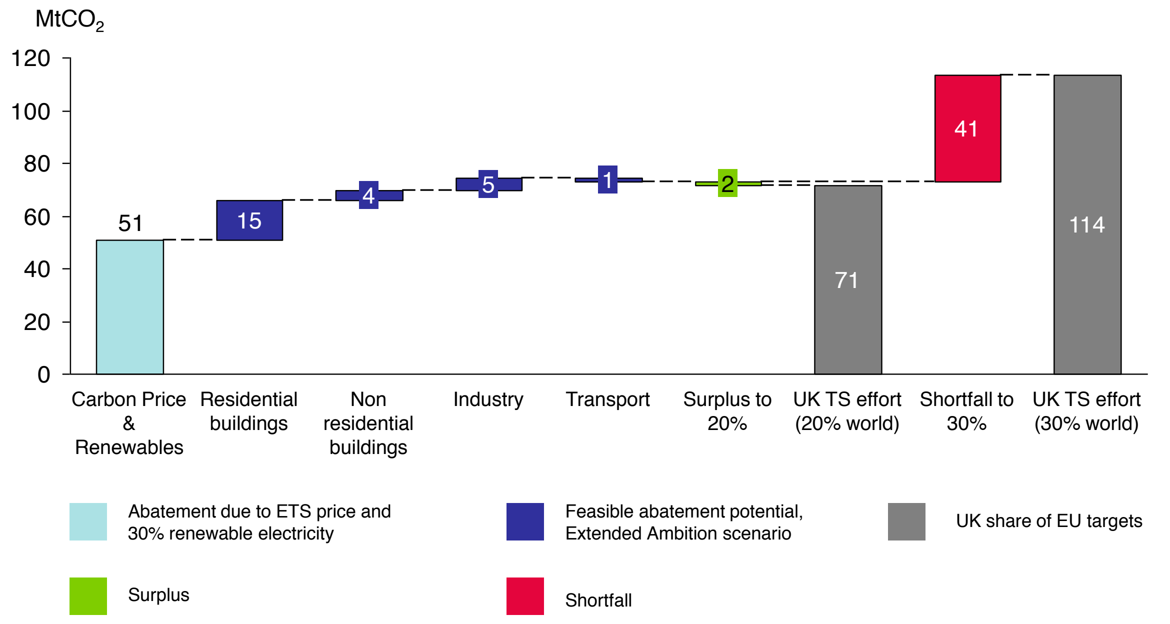
14 See Box 3.5 for details of these targets.

Figure 3.17 Total abatement potential available in the non-traded sector (NTS) versus the level of effort required under the EU January package, 2020



Source: CCC analysis

Figure 3.18 Total abatement potential available in the UK traded sector (TS) versus the level of effort required under the EU January package, 2020

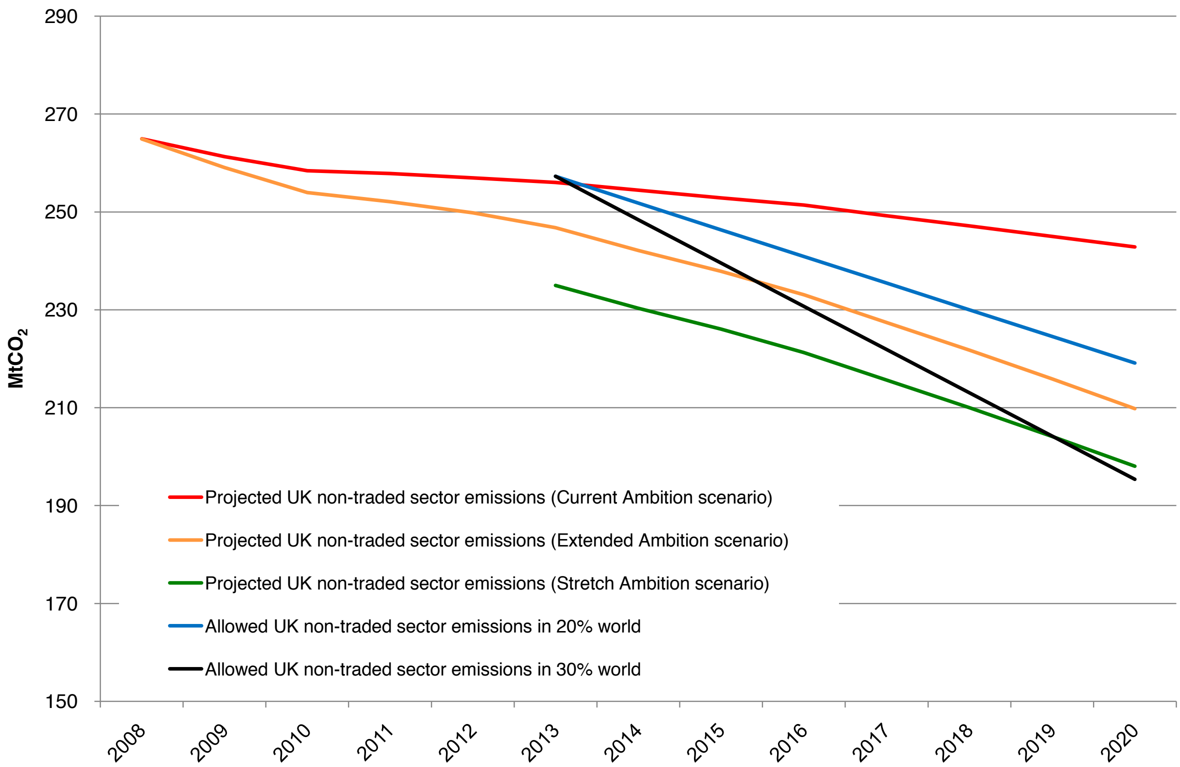


Source: CCC analysis

Note: Virtually all the downstream abatement potential illustrated in this chart stems from indirect demand reductions in the power sector with the exception of 0.1 $MtCO_2$ direct abatement potential in industry.

In the non-traded sector the pattern is similar for the period to 2020 (Figure 3.19): our Extended and Stretch Ambition scenarios would deliver the required EU trajectories in the non-traded sector for a 20% GHG target, with the Stretch Ambition scenario also delivering the required trajectory under a 30% GHG target. In the traded sector, however, neither scenario would be enough to ensure the UK meets its trajectories for the 20% or 30% worlds in the period to 2020 (Figure 3.20) through domestic effort alone.

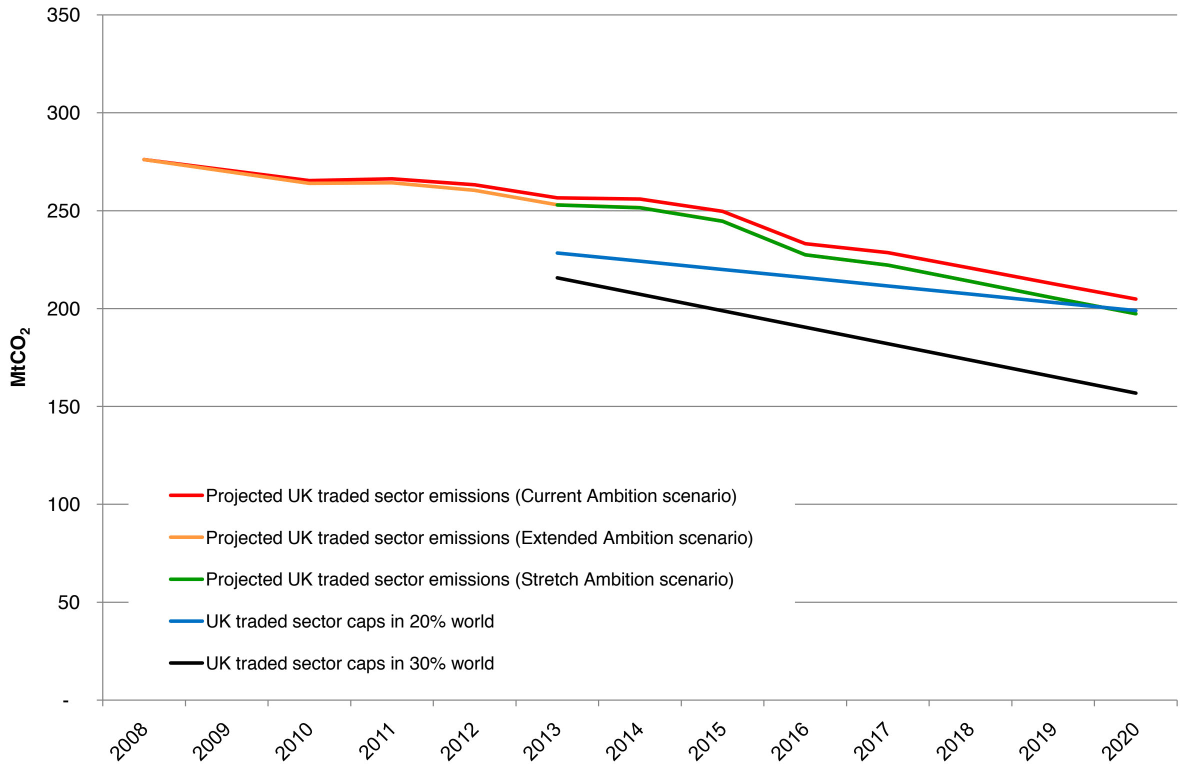
Figure 3.19 Comparing projected non-traded sector emissions net of abatement with allowed emissions under the January package for the 20% and 30% worlds



Source: CCC analysis.

Note: we do not define the stretch scenario before 2012, recognising the lead time for any new policies required to deliver it.

Figure 3.20 Comparing projected traded sector emissions with allowed emissions under the January package for the 20% and 30% worlds



Source: CCC analysis.

Given this analysis, we believe that the targets and trajectories proposed in sections 2 and 3 represent feasible objectives for the UK, and we accept the EU's proposed non-traded/traded targets as being an appropriate basis for the balance of effort required to meet our carbon budgets; this balance is approximately 30% in the non-traded sector and 70% in the traded sector under both the 20% and 30% GHG targets.

There is however a question of the extent to which the UK should aim to meet budgets through domestic action, and whether emissions reduction gaps should be closed through policy intensification (e.g. to move from the Extended Ambition to the Stretch Ambition scenario) or through purchase of credits. Alternatively, one option would be to relax domestic effort (e.g. aiming for the Current Ambition rather than the Extended Ambition scenario), thus creating a gap which could be filled through purchase of credits. We now turn to the role of domestic emissions reduction versus the purchase of credits in meeting budgets.

5. THE ROLE OF PURCHASED CREDITS

There are various pros and cons associated with the purchase of credits to meet carbon budgets. The benefits of credit purchase are that this can reduce the cost of meeting budgets, and it can help lay the foundations for decarbonisation that will be required in developing countries. The main problem with credit purchase, however, is that this does not prepare adequately for meeting longer-term emissions reduction targets. We consider these arguments in more detail in Chapter 4, where we distinguish between European Union Allowances (EUAs) and offset credits (Box 3.7) and where we conclude that:

- There should be no limit on the extent to which EUAs are allowed to count towards the UK budget.

- There should be a quantitative limit placed on offset credits which can count towards the UK budget, with this limit covering both offset credits purchased by the UK private sector within the EU ETS, and any purchases of offset credits to meet non-traded sector targets.

In the sections below we recommend what that limit should be, given the emissions reduction potential that we have identified, the desirable and required path to meeting a 2050 target, and restrictions on the use of offset credits in the EU framework. We conclude that:

- There should be no planned use of offset credits to meet the non-traded sector Interim budget. Use of credits to meet the incremental effort in moving to the Intended budget would be acceptable, although further consideration should first be given to domestic policy options in our Stretch Ambition scenario.

- Use of offset credits to meet the traded sector budget up to the limit allowed in the EU ETS is acceptable.

Box 3.7 European Union Allowances (EUAs) and offset credits

European Union Allowances (EUAs) are traded in the EU ETS, a cap and trade scheme which has covered the power sector and energy-intensive industry in the EU since 2005. Each EUA is equivalent to a tonne of CO_2. The EU ETS works by capping the CO_2 emissions of participating installations, who can then reduce emissions and sell EUAs, or emit beyond their cap and purchase EUAs in the market. Firms will abate and sell, or emit and purchase allowances, depending on the price of EUAs relative to the cost of abatement options available to them. Since the total amount of EUAs is strictly limited by the terms of the scheme, any purchases of EUAs by firms in the UK will result directly in emission reductions elsewhere in Europe.

Joint Implementation (JI) and Clean Development Mechanism (CDM) credits are produced by projects set up under the Kyoto Treaty's flexibility mechanisms. JI schemes can be set up in countries that have an emissions cap under the Kyoto agreement, whilst CDM schemes are allowed in countries without a cap (i.e. developing countries). Emissions from the projects covered by these schemes are not capped, rather projects must reduce emissions relative to a notional baseline. Any reductions relative to this baseline generate credits that can be sold in the carbon markets. Each credit is equivalent to a tonne of CO_2. Offset credits from JI and CDM projects are accepted in the EU ETS up to certain limits.

Source: CCC

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

(i) Use of credits to meet the non-traded sector budget

(ii) Use of credits to meet the traded sector budget

(iii) Offset credit purchase as a proportion of total effort

(i) Use of offset credits to meet the non-traded sector budget

In coming to our view on what level of offset credits the UK should purchase towards its non-traded sector budget, we have considered: what the UK would be allowed to purchase under the EU framework; and how much of this allowance the UK may want or need to use, given possible gaps between feasible emissions reduction and allowed emissions under the EU framework.

To do this, we distinguish between the level of domestic emissions allowed in the absence of the UK buying offset credits and the level allowed if the UK *does* buy offset credits. The latter is higher and could give the UK some headroom in meeting its EU obligations[15].

Allowed purchase of offset credits under EU rules: In the case of an EU 20% GHG target, the UK would be allowed to purchase a quantity of offset credits equal to up to 3% of its non-traded sector emissions for 2005. This would allow it to purchase up to 11 $MtCO_2$ of offset credits annually to 2020. For a 30% GHG target an additional allowance of credits would be available, equal to half the UK's incremental effort in the non-traded sector in moving to the 30% target; in 2020 the UK would therefore be able to purchase up to 23 $MtCO_2$ of offset credits in total to meet its non-traded sector cap. The implication is that allowed domestic emissions are higher by these quantities if the UK does purchase offset credits (e.g. as Figure 3.21 shows, in a 20% world allowed domestic emissions are 11 $MtCO_2$ higher if the UK does buy offsets than if it does not).

Appropriate use of offset credits under Interim and Intended budgets: Figure 3.22 compares allowed UK non-traded sector emissions for the EU 20% target (both with and without the possibility of buying offset credits) with our three scenarios for feasible domestic emissions. It shows that under the Extended Ambition scenario domestic emissions would be lower than even the tighter of the two 20% trajectories required under the EU target. In other words, if the Extended Ambition is achieved, the UK could meet its non-traded sector target (in the 20% EU case) without any purchase of offset credits. The issue is therefore whether the UK should commit to meeting this target through domestic emissions reduction alone, or plan instead on a less demanding domestic reduction path, purchasing credits to meet the target.

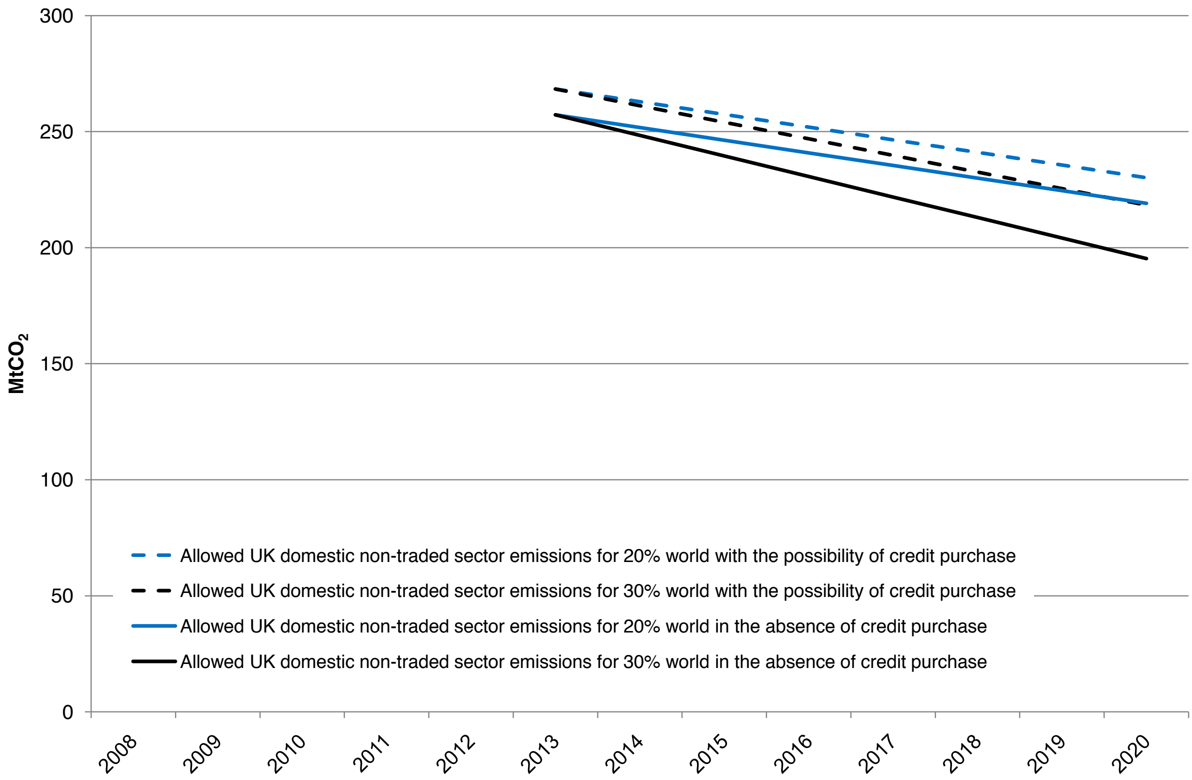
To make this decision we need to consider what the challenge will look like under the Intended budget consistent with an EU 30% GHG target. Figure 3.23 therefore shows how allowed domestic emissions in the 20% case, assuming no use of offset credits, stack up against allowed domestic emissions under the 30% EU target assuming full purchase of our allowance of offset credits. It shows that:

- The required domestic trajectory under the EU 30% target assuming full use of offset credits has an end point in 2020 very close to the required trajectory for the 20% case assuming no use of offset credits. For the years to 2020, the difference between the trajectories averages around 5 $MtCO_2$ annually.

- If the Extended Ambition scenario could be achieved, the UK would meet the reduction required for a 20% world without offset credits, but would still need to purchase credits to meet the 30% target shown in Figure 3.21.

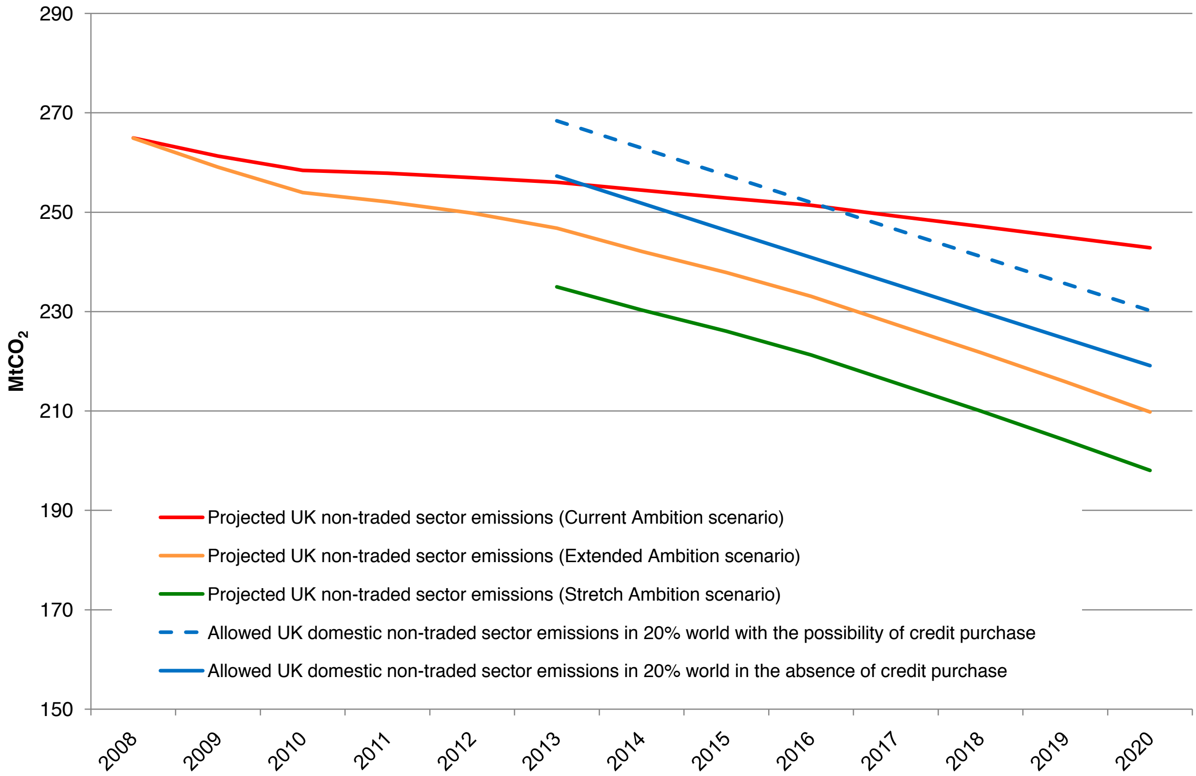
15 The caps and trajectories presented earlier in this chapter do not allow for the possibility of purchasing credits.

Figure 3.21 Allowed domestic emissions in the UK non-traded sector under the EU January package; 20% and 30% worlds, with and without possible offset credit purchase



Source: CCC analysis based on the January package.

Figure 3.22 Comparing projected non-traded sector emissions with allowed emissions under the January package in the 20% world



Source: CCC analysis, including based on the January package

Given, therefore, that the Interim Budget should be designed to make transition to the Intended budget feasible, the Committee recommends that:

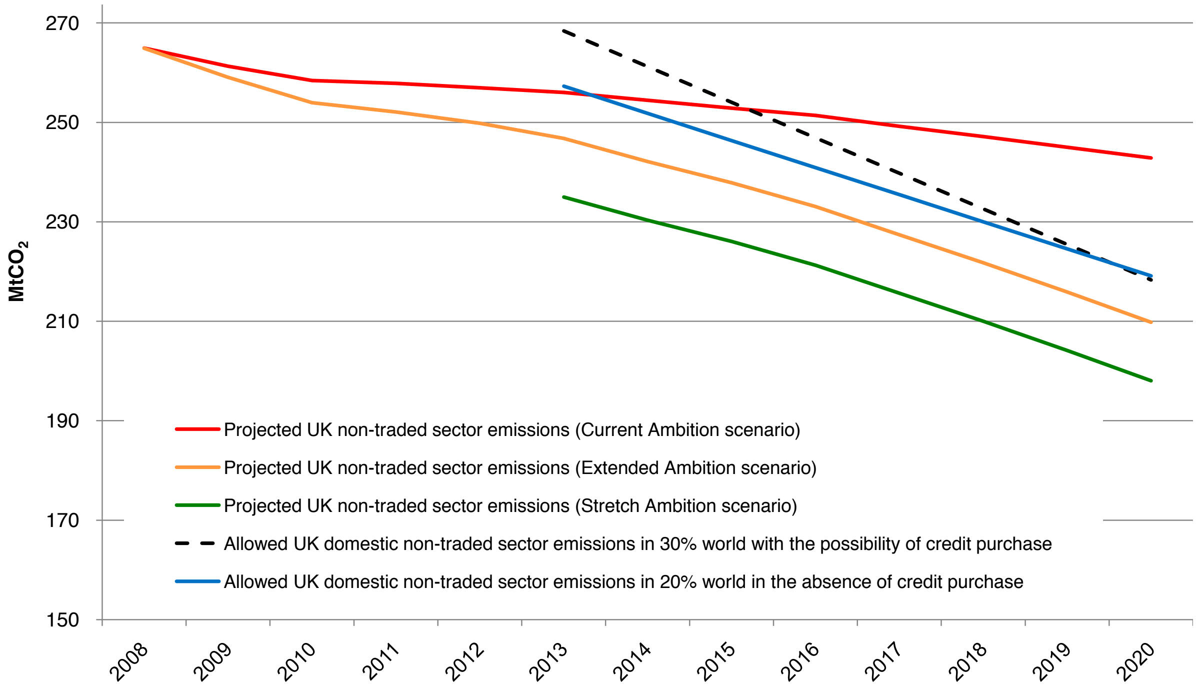
- The UK Interim Budget for the non-traded sector should be set in line the UK's obligations under the EU 20% GHG target.

- The UK should meet this budget in 2020 without any purchase of offset credits, with the result that domestic emissions should fall from around 255-260 $MtCO_2$ in 2013 to around 220 $MtCO_2$ in 2020.

There are two key points underpinning this recommendation:

- Meeting the Interim budget through domestic emissions reduction would deliver around the minimum level of domestic effort required to meet the Intended budget.
  - A possible alternative strategy would be to aim to meet the Interim Budget through domestic emissions reductions together with annual offset credit purchase of 5 $MtCO_2$. Given uncertainty however over what can be achieved in terms of domestic emissions reductions, there would be a risk of delivery shortfall. A more prudent strategy would be to aim to meet the Interim budget through domestic emissions reduction, reserving possible purchase of offset credits as an "insurance" option to be used in the event that domestic emissions reductions are not fully realised.
- Reducing the level of domestic ambition below that in the current policy framework (e.g. by cutting effort on more expensive options such as renewable heat and fuel efficiency improvement) would be inappropriate in the context of the 2050 target.
  - The Extended Ambition scenario embodies current policies and commitments which the government has made publicly.
  - It includes low cost measures (e.g. energy efficiency improvement) that cost less than offset credits, and that will be helpful in the context of the deep domestic emissions cuts required on the path to meeting the 2050 target.
  - It includes more expensive measures which are required to stimulate innovation of technologies that will be needed on the path to meeting the 2050 target.
  - It is the Committee's view therefore that aiming to deliver the Extended Ambition scenario/ deliver the Interim budget through domestic emissions reductions is appropriate on the path to meeting the 2050 target. Conversely, it is the Committee's view that a lower level of domestic effort would not be consistent with being on the appropriate path to meeting the 2050 target. In particular, this would leave too much to do after 2020 and would not bring forward the technologies that will be required in later years, raising the cost and jeopardising the feasibility of meeting the 2050 target.

Figure 3.23 Comparing projected non-traded sector emissions with allowed emissions in the 30% world (with offset credit purchase) and allowed emissions in the 20% (no offset credit purchase)



Source: CCC analysis, including based on the January package.

Meeting the Intended budget: This leaves the question of whether offset credits should be used to meet non-traded sector caps in moving from 20% to 30% GHG worlds, or whether policy effort should be intensified to deliver the Stretch Ambition scenario. We discuss this in Section 6(iii). Notwithstanding the outcome of this choice, however, the maximum use of credits in the non-traded sector should be no more than the incremental effort needed in moving from the Interim to the Intended budget in the non-traded sector.

(ii) Use of offset credits to meet the traded sector budget

Allowed offset credits purchase: There is some use of offset credits in EU ETS allowed in a 20% GHG world, with more use allowed in a 30% world (specifically, half of the incremental effort in moving from 20% to 30% can be met through purchase of offset credits, see Chapter 4). At the national level, we estimate that UK firms in EU ETS would be allowed to use around 8 $MtCO_2$ annually in a 20% world, rising to around 16 $MtCO_2$ annually in a 30% world[16].

Likely use of offset credits: Our assessment suggests that the UK will use its full quota of offset credits in the traded sector irrespective of the allocation methodology for EUAs (i.e. whether these are granted free or auctioned). The reason for this is that UK firms given free EUAs could sell these and purchase offset credits instead. As the level of free allowance allocation is reduced over time, firms will have the choice of whether to purchase EUAs or offset credits. In either case, the determining factor will be the relative price of EUAs and offset credits:

- Prices within the EU ETS could rise from about 28 Euro/tCO_2 today, to in the region of 50 Euro/tCO_2 by 2020.

16 These figures assume that UK ETS participants spread their total allowance of offsets for 2008-2020 evenly over that period.

- Offset credit prices are likely to be significantly lower, perhaps reaching 16 Euros per tonne in 2020[17].

It is therefore reasonable to assume that all permitted use of offset credits the in EU ETS will occur (firms will sell EUAs and buy offset credits, or buy offset credits rather than EUAs), and that the use of offset credits by the European and UK private sectors within the EU ETS will thus be policy constrained rather than price constrained.

Appropriate use of offset credits: The Committee believes that use of credits as would be allowed under current proposals for EU ETS is appropriate. We forecast that the resulting EU ETS carbon price under these proposals will be sufficiently high to encourage power sector decarbonisation and energy efficiency improvement in industry (see Chapters 4, 5 and 7). The implication of this is that further restricting the use of credits in EU ETS would unnecessarily raise the carbon price without necessarily changing behaviour of energy-intensive firms.

(iii) Offset credit purchase as a proportion of total effort

Subsections (i) and (ii) identified the amount of purchase that would be appropriate in meeting our Interim and Intended budgets. Another way of looking at credit purchase is to consider what this represents as a proportion of total emissions reduction effort.

We define effort for the purpose of budget setting as emissions reduction relative to a base year level of emissions, which is consistent with the UNFCCC methodology. The overall effort involved in the first three budget periods is therefore given by cumulative emissions reduction over the period 2008-2022 from the initial emissions level in 2007. Using this definition, the scenarios outlined above would imply that (Table 3.3):

- Under our Interim budget, no more than around 9% of whole economy effort over the first three budget periods should be achieved by purchasing offset credits.

- Under our Intended budget, this would rise to around 22% if none of the incremental effort in moving to this budget is undertaken domestically.

The Committee believes that reliance up to these levels on credits purchased from outside the EU is acceptable, given the balance of considerations set out in Chapter 4. In both scenarios there are major domestic reductions, driving progress towards a low-carbon economy. In the scenario for meeting the Intended budget, purchased credits account for a larger percentage of the total reduction, but the domestic reduction is in absolute terms higher than for the scenario to meet the Interim budget, with the UK and Europe in addition making a major commitment to the purchase of offset credits and thus to the resulting financial flow and technology transfer to developing countries.

Table 3.3 Recommended effort and maximum use of offset credits in the Interim and Intended budgets

	Interim budget		Intended budget	
	2008-2022	2020	2008-2022	2020
Traded sector CDM/effort	13%	9%	20%	13%
Non-traded sector CDM/effort	0%	0%	25%	32%
Whole economy CDM/effort	9%	6%	22%	20%

Source: CCC analysis
Note: Effort measured as reductions in emissions from 2007 levels.

17 The price may actually be higher than this in practice, reflecting transaction costs in bringing offset credits to market. It is unlikely, however, that transaction costs would result in offset credits being more expensive than EUAs, see Chapter 4:

6. SUMMARY OF RECOMMENDATIONS

This section presents our CO_2 budget proposals, based on the approach described in Sections 2, 3 and 5 above, and set out as follows:

(i) Interim budget proposals

(ii) Intended budget proposals

(iii) Transition from Interim to Intended budgets.

(i) Interim budget proposals

To recap, our Interim budget proposals are based on:

- Meeting the UK's non-traded sector target under the EU's 20% GHG ambition through domestic emissions reduction only.
- The UK's EU ETS caps. These are set for the period 2008-12 under EU ETS Phase II, and proposed for the period 2012-20 under EU ETS Phase III.

We also need, however, to make assumptions where there are gaps in the EU framework relative to what is required under the UK framework:

- The EU framework does not cover the non-traded sector for the first budget period. We have decided to base our non-traded sector cap for this period on what the Government is aiming to achieve through the range of policies that are already in place, recognising that there is limited scope to go further than this in the near term. We have therefore built the budget around the latest official central case emissions projection.
- The EU framework does not cover in detail emissions beyond 2020. In order to form our third budget, we have extrapolated straight-line trajectories under the EU framework for the years 2021 and 2022.

Budgets based on the EU framework adjusted in the ways set out above and in Box 3.5 are shown in Table 3.4, and characterised by:

- Total CO_2 emissions reduction of 29% in 2020 relative to 1990.
- Split of emissions reduction effort between traded and non-traded sectors approximately in the proportion 70% to 30%.
- All non-traded sector emissions reduction to be achieved through domestic effort rather than purchase of offset credits.

These are the budgets that, when restated in terms of GHGs rather than CO_2 (see Chapter 9: *Non-CO_2 greenhouse gases*), should form the basis of what enters the secondary legislation under the Climate Change Act.

Comparison of the first budget with the UK's 2010 target: We are required under the Climate Change Bill to comment on the consistency of our proposal for the first budget period with the UK's target to reduce CO_2 emissions by 20% in 2010 relative to 1990. Our budget proposal, based on our assessment of feasible emissions reduction, has emissions in 2010 at 14% below 1990. The Government could in principle purchase credits to close the gap between our proposed budget and the UK's 2010 target. However, the environmental benefit from such a purchase would be limited, and in our view the focus of Government would better be on designing policies to deliver the sustainable and deep emissions cuts required through the first three budget periods.

(ii) Intended budget proposals

In developing our Intended budget proposals, we have made the same adjustments to the EU framework as in Section 6(i) above. These budgets, set out in Table 3.5, are characterised as follows:

- Total CO_2 emissions reduction of 40% in 2020 relative to 1990.
- Split in emissions reduction effort between traded and non-traded sectors in the proportion 70% to 30%.
- Purchase of up to 140 $MtCO_2$ of offset credits over the period 2008-2022 to meet the required non-traded sector emissions reduction[18].

We envisage that these budgets will not enter legislation at the current stage, but that they will form the basis for the budgets to be legislated following a global deal to reduce emissions.

Table 3.4 Allowed CO_2 emissions under the Interim budget

	Interim CO_2 budget ($MtCO_2$)		
	Budget 1 (2008-2012)	Budget 2 (2013-2017)	Budget 3 (2018-2022)
Traded sector	1233	1114	1011
Non-traded sector	1304	1235	1103
Total	2537	2349	2114

Source: CCC analysis

Table 3.5 Allowed CO_2 emissions under the Intended budget

	Intended CO_2 budget ($MtCO_2$)		
	Budget 1 (2008-2012)	Budget 2 (2013-2017)	Budget 3 (2018-2022)
Traded sector	1233	1009	800
Non-traded sector	1304	1201	989
Total	2537	2210	1789

Source: CCC analysis

18 140 $MtCO_2$ is the additional effort incurred in the non-traded sector in moving to the Intended budget from the Interim budget met without purchase of offset credits. It is less than the total allowance of offsets available to the UK non-traded sector in the 30% world under the January package.

(iii) Transition from the Interim to Intended budgets

We have designed our budget proposals to facilitate the transition between Interim and Intended budgets. In particular, we have designed the Interim budget to include a sufficient level of domestic effort for meeting the Intended budget. One way to move between the two sets of budgets, therefore, would be simply to purchase EUAs and offset credits. An alternative would be to intensify domestic policy effort, for example, to deliver our Stretch Ambition scenario. We will advise on specific design of the Intended budget and measures to deliver this at the appropriate time and once a global deal has been agreed.

7. MACROECONOMIC COSTS

Under the Climate Change Act we are asked to account for "economic circumstances, and in particular the likely impact of [carbon budgets] on the economy". In this section we summarise the results of our macroeconomic analysis. A more detailed discussion, together with analysis of potential fiscal impacts, is presented in Chapter 11. Competitiveness, fuel poverty and security of supply implications of carbon budgets are covered in chapters 10, 12 and 13 respectively.

The impact of carbon budgets on the macro economy would depend upon the mix of the three different categories of measures taken to achieve abatement:

- Developing new low-carbon sources of energy will, if the costs are higher than fossil fuel based energy, require the dedication of additional real resources to energy production (e.g. wind farm construction) and will increase energy prices, reducing purchasing power and decreasing GDP.

- Energy efficiency improvements achieved at negative cost in the residential sector will increase disposable income. In the non-residential sector, negative cost energy efficiency improvement will result in reduced costs, particularly for energy-intensive products. Conversely, energy efficiency measures with positive cost (such as many of the road transport measures) will increase costs and reduce income. The overall GDP impact of energy efficiency improvement will depend on the balance between negative and positive cost measures.

- Lifestyle-change (e.g. substituting cycling for driving on short trips) will reduce energy consumption/production, with households reallocating expenditure towards less energy-intensive goods and services. This will have no significant impact on GDP; whether they have any impact on consumer welfare (positive or negative) is a debatable point considered briefly in Chapter 7.

In theory GDP could fall as a result of reduced competitiveness of energy-intensive/traded sectors if the UK or EU were to move more quickly in cutting emissions than other countries or regions. In Chapter 10: *Competitiveness challenges and opportunities*, however, we conclude that we would not expect any budget related competitiveness impacts on GDP.

We have used three alternative modelling approaches to estimate the potential impact on measured GDP: resource cost; macroeconometric and general equilibrium (Box 3.8). The estimated costs in 2020 from meeting our Intended budget are less than 1% of GDP. Higher fossil fuel prices lead to slightly lower GDP costs, reflecting lower carbon cost penalties relative to the reference case. The Committee believes that these costs are affordable in the context of an economy where medium term growth – notwithstanding any short-term macroeconomic considerations – is expected to be at least 2% per annum, with GDP in 2020 likely to be around 30% above current levels; the cost is equivalent to sacrificing around half of one from twelve years' growth. Moreover, it is low relative to the consequences and costs associated with not acting, and the Committee therefore recommends that it should be accepted.

Box 3.18 Three approaches to estimating the macroeconomic costs of carbon budgets

We have used three alternative modelling approaches to capture potential GDP impacts:

- Resource cost modelling which sums cost savings from (negative cost) energy efficiency improvements, and subtracts this from cost penalties (due to positive cost energy efficiency improvement, fuel efficiency improvement, renewable energy, low-carbon power generation, etc.). Essentially this methodology sums the areas under the Marginal Abatement Cost Curves (MACCs) set out in Chapters 5-7.
- Macroeconometric modelling which accounts for resource costs and second order effects of resource cost increases (e.g. higher energy costs driving a shift of resources from energy-intensive sector). This type of modelling is based on econometrically estimated historic relationships between prices and quantities. In order to estimate costs using this approach, we have used the Cambridge Econometrics model.
- General Equilibrium modelling which also accounts for resource costs and second order effects. In contrast to macroeconometric modelling, general equilibrium modelling assumes the economy adjusts to a new equilibrium in response to higher energy prices, based on theoretical supply and demand functions. We have used the HMRC model to estimate costs based on this approach.

These approaches are discussed in more detail in Chapter 11.

Source: CCC

8. RISKS AND CHALLENGES IN ACHIEVING THE BUDGETS

Our carbon budget proposals have been presented around our central reference emissions projection and associated emissions reduction potential. Moving to alternative reference projections would not be problematic from the perspective of meeting the traded sector budget given that this is capped under the EU ETS (e.g. so that higher emissions projections would result in more purchase of EUAs). There are, however, risks related to meeting non-traded sector budgets under alternative emissions projections, given that this sector is not capped. We now show that our budget proposals are robust under alternative assumptions, and that risks associated with meeting carbon budgets can be mitigated.

We consider:

(i) Policy risks

(ii) Fossil fuel price risk

(ii) Risks due to uncertainty over GDP and population growth

(iv) The risk of a macroeconomic rebound effect

(i) Policy risks

Our budget proposals are based on an assessment of feasible emissions reduction potential. In order that the budgets are delivered, policies must be in place to unlock this potential. The fact that policy has not always delivered raises the question of whether policy will deliver in future as emissions reduction targets become more challenging.

Historic performance: The UK has a mixed track record in terms of the ability of its climate change policies to deliver. As part of the analysis for the Climate Change Programme (CCP) 2006 an evaluation and reappraisal to 2010 of the policies included in CCP 2000 was carried out by Defra. The CCP 2000 was originally projected to save around 76 to 86 $MtCO_2$ per year by 2010. The revised estimates suggested that emissions reduction would be around 15 $MtCO_2$ lower. Failure to deliver a similar proportion of our high emissions reduction scenario would result in missing the non-traded sector budgets that we have proposed by around 10 $MtCO_2$ in the Extended Ambition scenario.

The current policy framework: We have compared emission reductions that the Government expects to get from its policy framework with those in our scenarios. The main policies are: the Supplier Obligation; the Carbon Reduction Commitment; EU ETS; standards for fuel efficiency of new cars; a range of measures aimed at influencing travel behaviour; new measures that the Government tends to introduce to support renewable energy and further fuel efficiency improvement.

- Aggregate emissions reduction from these policies is comparable with the reduction reflected in our Extended Ambition abatement scenario, although the composition of reductions differs somewhat (Box 3.9).

- However, large parts of the emissions reduction in our Extended Ambition scenario are covered by high-level commitments rather than firm and funded policies. Failure to make good on these commitments would result in forgoing up to 36 $MtCO_2$ of reductions in 2020 in the heat and transport sectors, undermining the UK's ability to meet its non-traded sector budgets.

- In addition, failure to significantly increase the level of renewable electricity generation by 2020 would have serious implications for the long-term objective of fully decarbonising the UK power sector, although it would not represent an immediate risk to the carbon budgets given the presence of the EU ETS cap.

Box 3.9 A comparison of emissions reduction in 2020 between the CCC Extended Ambition scenario and current government policy and aspiration

Emissions reduction in CCC extended ambition scenario		Emissions reduction in current government policies and aspirations			
Measure	**Expected savings by 2020 ($MtCO_2$)**	**Equivalent measure**	**Expected savings by 2020 ($MtCO_2$)**	**Firm and funded policies included in UEP?**	**Difference**
EEU domestic (incl. renewable heat)	28.7	Residential measures introduced by the EWP	22.6	Yes	
EEU commercial (incl. renewable heat)	12.7	Measures for commerce and public sector introduced by the EWP	8.9	Yes	
EEU industry (incl. renewable heat)	6	Measures for industry introduced by the EWP	2.7	Yes	
CHP	1.6	None	0		
		Renewable heat target - domestic*	16	No	
		Renewable heat target - commercial*	4	No	
		Renewable heat target - industry*	4	No	
Total EEU	**49**		**58.2**		**9.2**
Abatement measures for vans and HGVs	2	None	0		
8% penetration of biofuels by energy (additional to 4% in baseline)	5	10% penetration of biofuels by energy (additional to 5% in baseline)**	5.5	Yes	
Improvement in carbon efficiency of new cars consistent with achieving 95 gCO_2/km by 2020	11	Successor to EU voluntary agreement with car manufacturers, delivering 104 gCO_2/km by 2020	7.0	No	
Smarter choices	2.9	Smarter choices	2.9	No	
Eco-driving	1.3	Eco-driving***	2.2	No	
Rail measures	0.6	None	0.0	No	
Total Transport	**22.8**		**17.6**		**-5.2**
Total from scenario	**71.8**		**75.8**		
Total difference between full set of government policies and aspirations and CCC scenario					**4.0**
Total from government policies and aspirations that are not yet 'firm and funded'			**36.1**		
Total for UEP policy package only			**39.7**		
Total difference between UEP policy package and CCC scenario					**-32.1**

Notes:
* The CCC scenario does not include savings from biogas which account for about 5 $MtCO_2$ in the RES scenario
** Based on attribution of just 50% of tailpipe carbon saving
*** Provisional estimate by DfT

The table above compares end-user sector abatement by 2020 in the CCC high emission reduction scenario with emission abatement enshrined in government policies and aspirations. The latter have been taken to include:

- the Energy White Paper package (with estimated of levels of savings consistent with the latest UEP);
- 10% penetration of biofuels by energy by 2020 and meeting the EU car fuel efficiency target;
- estimated savings from meeting a 14% renewable heat target, based on analysis for the RES consultation;
- DfT estimates of savings from demand-side transport policies.

There are a number of key differences between our high emission reduction scenario and government policies and aspirations. Some of these differences relate to coverage, in particular:

- the government has not yet committed to pursuing abatement in certain areas such as supply-side measures for vans and HGVs or the rail;
- the CCC scenario does not include savings from biogas use which account for about 7 $MtCO_2$ based on RES consultation analysis;
- the CCC scenario does not include fuel switching from electric heating to gas in the domestic building sector.

There are also differences that relate to alternative modelling approaches, e.g.:

- differences in technical assumptions (e.g., on the effectiveness of insulation in the residential building sector) mean that CO_2 savings may differ slightly even for the same level of policy ambition;
- the CCC scenario on renewable heat is calibrated to meeting the 14% heat target in the RES, but for modelling reasons the CCC is assuming all the biomass is used in boilers as opposed to CHP, which will tend to understate the savings;
- government modelling of savings from biofuels scale down tailpipe savings over a litre of biofuels by 50%, while having constrained the uptake of biofuels in line with the Gallagher Review the CCC model focuses on tailpipe emissions (this is conventional accounting practice. Also any potential increases in emissions along the biofuels pipeline would either belong to other sectors of the economy or would not be captured by the UK inventory);
- the CCC estimates of savings from eco-driving explicitly accounts for overlap with improvement in fuel efficiency of vehicle and uptake of electric powered vehicles.

The key messages that can be drawn are the following:

- the level of emission reductions in the CCC scenario is comparable to the level of emission reductions implied by current government policies and aspirations, even if the composition of abatement sources differs slightly;
- however, the level of emission reductions in the CCC scenario is significantly more ambitious that the level of emission reductions from policies that are already in place. The latter may be taken to include 'firm and funded' measures, the latest UEP projections or the full EWP package (including the successor to the voluntary agreements with car manufacturers).

Sources: CCC analysis. Energy White Paper (EWP) 2007. Draft Renewable Energy Strategy and supporting analysis. Updated Energy Projections (UEP). DfT policy documents.

Strengthening Energy White Paper policies: Going forward, it will be important that past failure to deliver is avoided, and that Energy White Paper measures deliver the level of ambition that they are targeting. More detailed discussion of where the existing policy framework can be strengthened is included in Chapters 5-7. At a high level, we suggest that:

- A range of new measures around awareness raising and removing barriers will be required to deliver the Supplier Obligation.
- Further progress is required on EU mandatory standards for appliances and voluntary agreements at the UK level.
- Ambitious emissions reduction targets will be required for the Carbon Reduction Commitment and in the Climate Change Agreements.

Developing new policies to unlock potential and make good commitments: Areas where we believe it is a priority to develop new policies are:

- Introduction of a framework to provide incentives for firms not covered by existing cap and trade schemes to reduce emissions.
- Introduction of a framework to support wide-scale deployment of renewable heat.
- Adoption of a legally binding target at the EU level for average new car emissions to be below 100 gCO_2/km in 2020, and a set of implementing measures at the UK level.
- Adoption of a legally binding standard for new van fuel efficiency, with implementing measures at the UK level.
- Removal of barriers in planning and network access regimes to support increased deployment of renewable electricity.

Additional policy options that should be considered: Successful delivery of the Extended Ambition emissions reduction scenario would be sufficient to meet our non-traded sector targets under both the Interim and Intended budgets, allowing for some purchase of offset credits in the latter case. Given past experience, however, it would not be prudent to rely on full delivery. It is our view that appropriate risk management as regards meeting budgets will require developing policies in other areas. For this reason, we believe that the Government should give serious consideration to policies which would deliver emission reductions in areas covered by our Stretch Ambition scenario, including widespread solid wall insulation and lifestyle measures in transport.

In addition to options in our Stretch Ambition scenario, the Government should seriously consider developing a framework for reduction of non-CO_2 emissions from agriculture; these would provide a significant means for meeting budgets defined in terms of GHGs rather than carbon, and are considered in detail in Chapter 9, where we recommend that budgets should be set in terms of GHGs.

(ii) Fossil fuel price risk

We noted in Section 1 above that there is a great deal of uncertainty relating to future fossil fuel prices. Given the difference between the central case forecasts that we have used as the basis for the analysis in this chapter and current (higher) market prices, this raises the question of what would happen in other fossil fuel price worlds.

In fact, higher fossil fuel prices are good for meeting carbon budgets in that these depress energy demand in the (uncapped) non-traded sector. In moving from the central to the high-high fossil fuel price scenario, for example, reference emissions projections for the non-traded sector fall by 12 $MtCO_2$ in 2020.

In a low fossil fuel price scenario, however, reference emissions projections are relatively high. The difference, for example, between non-traded sector reference emissions projections in central and low fossil fuel price scenarios is around 5 $MtCO_2$ in 2020[19].

If the low fossil fuel price scenario were to ensue in practice, our Extended Ambition scenario would only just meet our proposed budgets. Recognising risks around delvering this scenario in full, it would again be prudent to develop policies targeted at measures in our Stretch Ambition emissions reduction scenario.

(iii) Risks due to uncertainty over GDP and population growth

Our high emissions growth projection scenario combines high GDP and population growth forecasts, together with low case fossil fuel price assumptions. The forecast for total emissions in 2020 is 3% above the central case, requiring an additional 15 $MtCO_2$ emissions reduction to meet the budget. Measures from our Stretch Ambition emissions scenario would then be required to meet budgets, and policies targeting these measures should be developed in order to allow for this contingency.

(iv) The risk of a macroeconomic rebound effect

The 'rebound effect' refers to the fact that energy and carbon savings from energy efficiency may not be as large as they first appear from bottom-up analysis of individual measures. Our emissions reduction scenarios account for 'direct' rebound effects (i.e. the increase in energy use in response to energy efficiency measures that make energy services cheaper and thus increase energy demand). Our scenarios do not account for 'indirect' or 'macroeconomic' rebound effects due to increased income that might follow energy efficiency improvement. Given however that we project a small decrease in GDP overall as a result of our carbon budgets, and an increase in energy costs, it is likely that any macroeconomic rebound effect will be insignificant or even reinforce abatement measures (Box 3.10).

19 Even at central fossil fuel prices, the Cambridge Econometrics model projects non-traded sector emissions 10 $MtCO_2$ higher than the DECC model. This difference is largely due to higher emissions from Road Transport (+15 $MtCO_2$) in the Cambridge Econometrics model. We believe that the DECC projections are more robust, given that these reflect more closely projections from DfT's National Transport Model. However, the difference between DECC and CE central projections is indicative of more general uncertainty around future emissions and the associated need to manage risk. Differences in the DECC and Cambridge projections are explored in more detail in a technical paper published alongside this Report.

Box 3.10 Direct and indirect rebound effects in the CCC analysis of carbon budgets

The ‘rebound effect’ refers to the fact that energy and carbon savings from energy efficiency may not be as large as they first appear from bottom-up analysis of individual measures.

A recent review by UK Energy Research Centre (UKERC)* classifies the economy-wide rebound effect into ‘direct’ and ‘indirect’ effects. Direct rebound effects refer to increased energy usage in response to energy efficiency measures, which effectively make energy services cheaper. Indirect rebound effects can occur where savings on energy expenditure might be spent on energy-intensive goods and services.

The Committee’s abatement scenarios explicitly take into account some of the direct rebound effect:

- We have accounted for ‘comfort taking’ in residential buildings, for example the tendency which households may have to turn their thermostats up if their accommodation is better insulated and therefore cheaper to heat. Equally we have accounted for the possibility that individuals will drive more often or further if they have a more fuel-efficient car. We assume that together these factors will reduce energy and carbon savings by around 15%;
- We have not explicitly accounted for such effects in non-residential buildings or industry, but our analysis suggests that there would be minimal rebound from the sectors, which historically have shown small demand responses to energy price changes. And for those firms covered by binding caps, this would prevent any rebound.

The main driver of indirect or macroeconomic rebound effects would be greater use of energy in response to increased GDP and/or a shift to energy-intensive industry. However, given that we project a small decrease in GDP as a result of our carbon budgets, and an increase in energy costs, there is likely to be a small reduction in demand for energy and energy-intensive goods, reinforcing abatement measures.

* UKERC (2007) *The Rebound Effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency*

Source: CCC

* * *

The discussion of risks around our proposed carbon budgets concludes this chapter. In the remaining chapters of Part II we examine in more detail the role of the carbon markets and the abatement potential from power generation, energy use in buildings and industry, and transport. In Part III we look at the implications of the recommended carbon budgets and we consider issues relating to the inclusion of non-CO_2 GHGs and international aviation and shipping.

CHAPTER 4:

CARBON MARKETS AND CARBON PRICES

Carbon markets could play an extensive role in meeting the UK's carbon budgets. They could be used to help ensure least-cost domestic abatement and to buy in credits from outside the UK to meet carbon budgets at lower cost than would be possible via domestic action alone. But there are limitations to carbon markets as tools to achieve abatement action. And the optimal use of credits purchased from overseas needs to reflect both the pros and cons of buying them in principle, and the likely carbon price which the UK might face in alternative potential markets. This chapter therefore covers both issues of principle (what role can and should carbon markets play) and empirical issues (i.e. best estimates of future carbon prices).

The key conclusions in the chapter are:

- Carbon markets provide incentives for investment in low-carbon technology in the UK. They are one of a number of instruments which will be important in delivering carbon budgets.

- There is a potentially important role for purchase of emission reductions in international markets to reduce the cost of meeting carbon budgets.

- We project a central case offset credit[1] price of 16 Euro/tCO_2 in 2020, with a range from 5–60 Euro/tCO_2.

- We project a central case European Union Emissions Trading Scheme (EU ETS) price of 51 Euro/tCO_2 in 2020 under a 30% greenhouse gas (GHG) emissions reduction target for the EU, with a range from 39-105 Euro/tCO_2.

The carbon price projections in this chapter feed into a number of other chapters in the report including:

- The discussion in Chapter 3 of the relative balance of domestic emissions reduction effort versus reliance on EU ETS and offset credit purchases.

- The more detailed discussion in Chapters 5-9 of abatement opportunities and appropriate policies in specific sectors.

- The discussion in Chapter 10 of the possible competitiveness impacts of carbon prices in internationally traded and energy-intensive sectors of the economy.

- The analysis in Chapter 11 of the macroeconomic and fiscal implications likely to arise from having a carbon price in the electricity price, from the auctioning of EU ETS allowances, and from the possible purchase of offset credits by the UK government.

- Chapter 12's discussion of the fuel poverty impact from the carbon price component of future electricity prices.

The chapter begins with a description of the types of carbon markets currently in place, and then addresses in turn the issues of principle and the empirical issue of possible future carbon prices. It is organised in six sections:

1 We use the the term 'offset credits' to refer to credits generated under the Kyoto treaty's project based flexibility mechanisms, Joint Implementation (JI) and Clean Development Mechanism (CDM) and any successors to these mechanisms which may be agreed under a future global deal.

1. Overview of carbon markets
2. The role of carbon markets and carbon prices: as policy levers and indicators of least-cost abatement opportunities
3. The pros and cons of relying on externally purchased carbon credits to meet carbon budgets
4. Offset credit price projections
5. EU ETS price projections
6. Price assumptions in other chapters

1. OVERVIEW OF CARBON MARKETS

In theory, carbon markets have three important advantages:

- They can be based on clearly defined limits to total CO_2 emissions, with caps reducing over time. This allows a tight link between mitigation policy instruments and climate change policy objectives: if these require an 80% cut by 2050, emissions trading system caps can be set so as to achieve that target.

- They provide a price incentive for firms to invest in low-carbon technologies. Since emitting each additional tonne of CO_2 incurs a cost, and saving each tonne reduces this cost, firms will seek to reduce emissions via abatement measures which cost less per tonne than the carbon price.

- They help minimise the cost of meeting any given emissions reduction target. Firms or countries which face a lower abatement cost per tonne will make more abatement effort than those which face higher costs, with higher cost firms and countries paying the lower cost ones to take action, via the purchase of carbon credits.

These potential advantages of carbon markets were recognised by the Kyoto Protocol, which established the range of allowed market instruments, sometimes referred to as its 'flexibility mechanisms'. The European Union in turn has established the EU ETS as a core element in its emissions reductions strategy. This allows large carbon emitting installations to trade carbon allowances with each other or to purchase reductions from outside Europe under the Kyoto mechanisms.

Table 4.1 describes the most important types of emissions trading and offset credit schemes. The Kyoto mechanisms and the EU ETS are considered in turn below.

(i) Flexibility mechanisms under the Kyoto protocol

The Kyoto Treaty recognised the potential benefits of carbon trading and established three flexibility mechanisms: Joint Implementation (JI), the Clean Development Mechanism (CDM), and Assigned Amount Units (AAUs). But it also recognised the need to place constraints on over-reliance on trading, introducing the principle of supplementarity.

- **JI and CDM:** JI covers all countries that have an emissions cap under the Kyoto agreement, whilst CDM covers those countries without a cap (i.e. developing countries). In both cases, projects that reduce emissions relative to a notional baseline are granted credits that can be sold in the carbon markets. On the demand side of the market are governments (e.g. Japan and the Netherlands have purchased significant amounts of JI and CDM credits) and private sector participants in trading schemes such as the EU ETS.

- **AAUs:** Each country with a cap under the Kyoto Treaty was given an 'assigned amount' of tradable units, equivalent to the country's annual allowed emissions. Japan, Italy and Spain are among those expected to purchase AAUs from the Central and Eastern European countries who have large surpluses that resulted from industry restructuring as part of economic transition. To alleviate concerns over the additionality of the savings represented by AAUs, many countries are selling these accompanied by Green Investment Schemes (Table 4.1).

- **Supplementarity:** The Kyoto agreement recognised that in order to effectively tackle climate change, it is essential that developed countries (i.e. the Annex I countries covered by explicit caps within the Protocol) start making significant domestic emissions reductions, both to prepare for the deep emissions cuts that will be required by 2050, and to drive development of low-carbon technologies. It therefore established the principle that the purchase of credits from other countries should only be 'supplemental' to domestic action. It did not however specify a precise quantitative balance between domestic effort and emissions reductions purchased from abroad.

The market for CDM credits was established in 2000 and has since grown significantly. Around 200 million CDM credits have been issued to date, with an additional 1.3 billion credits forecast by the UNEP to be issued by 2012. In terms of finance, issued credits and those in the pipeline would be worth 23–30 billion Euro at the current CDM price of 15–20 Euro/tCO_2. The market for JI credits was established in 2008 and is currently small.

Going forward, there would be scope for rapid expansion of the market for offset credits following a successor agreement to Kyoto on a global emissions reduction. This would result in increased demand for offset credits, in particular from developed countries seeking to meet commitments to significant cuts in the period to 2020 and beyond.

Table 4.1 Emissions trading and offset credit schemes

Scheme	Description
EU Emissions Trading Scheme	Cap and trade scheme covering the power sector and energy intensive industry in the EU.
Clean Development Mechanism	Scheme which allows credits to be issued from projects reducing GHG gases in Kyoto non-Annex 1 countries (developing countries). Regulated by the UN. Credits are valid in the EU ETS and to meet EU targets in the non-traded sector, up to certain limits.
Joint Implementation	Scheme which allows credits to be issued from projects that reduce emissions of GHGs in Kyoto Annex 1 countries. Regulated by the UN. Credits are valid in the EU ETS up to certain limits. The scheme will not continue after the end of the current Kyoto compliance period unless new quantified emissions targets are in place for host countries.
Kyoto assigned amounts	Scheme which allows the trading of assigned amount units (AAUs) between countries. AAUs can be used for compliance with the Kyoto treaty. There are some concerns about the additionality of savings associated with AAUs, since economic restructuring in Eastern Europe has resulted in a long market. Not valid for use in the EU ETS or to meet EU targets in the non-traded sector.
Green Investment Schemes	Some countries are attaching Green Investment Schemes (GIS) to AAUs in order to overcome buyers' concerns about additionality. Examples of GIS include direct investment in projects or policies to encourage non-fossil energy use, improvements in energy efficiency; or projects to slow the rate of deforestation.
Voluntary credits	Credits generated by a wide variety of projects and sold to companies or individuals wishing to offset their emissions. No mandatory regulation. Currently, no credits from these schemes can be used in the EU ETS or to meet EU targets.
Credits from other trading schemes	A range of voluntary and mandatory trading schemes exist around the world- e.g. NSW/ACT in Australia, RGGI in US, Japanese VETS. Currently, no credits from these schemes can be used in the EU ETS or to meet EU targets.

(ii) The EU ETS

The EU ETS is the European Union's carbon trading scheme for power generators and other energy-intensive firms and covers close to half of European CO_2 emissions. In the UK, the EU ETS covers around 50% of UK CO_2 emissions, including all power stations and refineries, around 76% of industrial emissions and around 9% of emissions from services (Figure 4.1). It was established in 2005, with a Phase I which covered the period 2005-07, a Phase II covering 2008-12, and a Phase III that will cover 2013-20. It works by capping the carbon emissions of energy-intensive firms, who can then reduce emissions and sell allowances (known as European Union Allowances, or EUAs), or emit beyond their cap and purchase allowances in the market. Firms will abate and sell or emit and purchase allowances depending on the price of EUAs relative to the cost of potential abatement options.

In Phase I emission caps were not tight enough to drive a significant reduction in emissions. Phase II has seen some tightening and, going forward, Phase III is likely to be based on significantly tighter caps generating higher carbon prices and more abatement action.

Phase I and II: In both phases I and II, EU ETS caps were proposed by Member States and approved by the EC. Caps were set to deliver Kyoto commitments taking account of emissions reductions expected to be achieved in sectors outside the EU ETS (e.g. in transport or residential housing). Typically allowances have been given free to firms, resulting in windfall profits for firms able to reflect carbon prices in their output prices. In the UK, for example, it is estimated that free allowances for the power sector could result in windfall profits of up to £1.6 billion annually during Phase II.

Member States setting of emissions caps resulted initially in too generous an overall allocation of emission permits.

- In Phase I, the total EUAs issued were 152 $MtCO_2$ in excess of actual annual emissions. This oversupply drove the carbon price down to zero in 2007 (Figure 4.2).

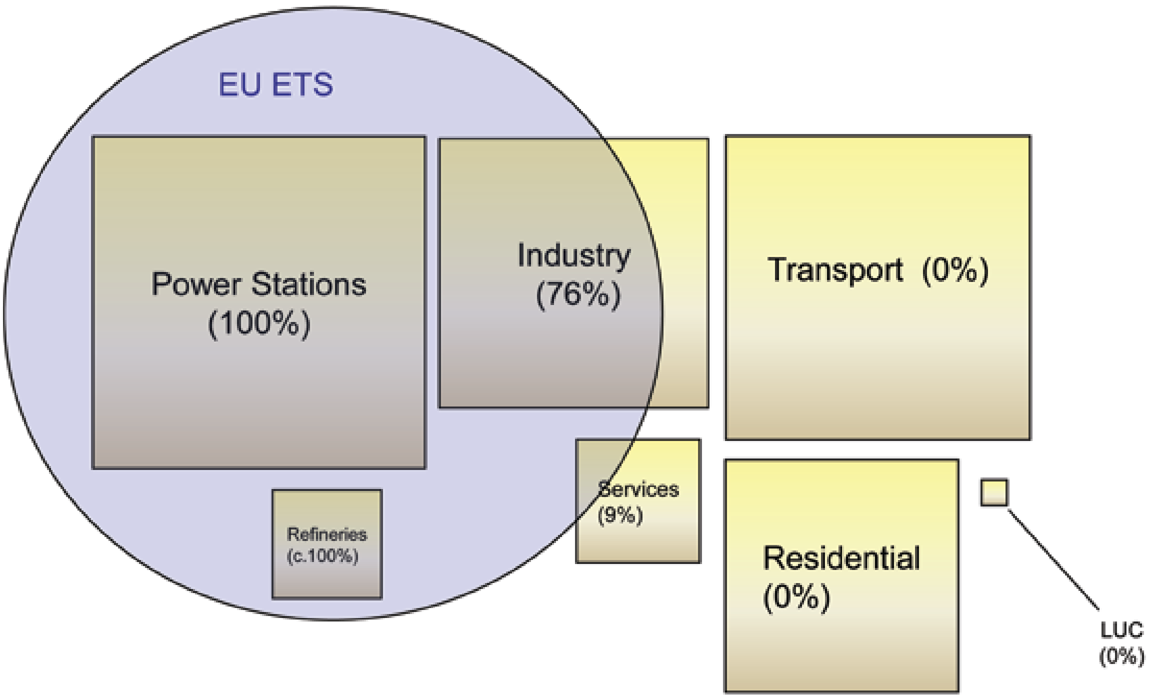
- Phase II saw some tightening of national allocations, but in addition in this phase some purchase of offset credits was allowed (i.e. a firm wishing to go beyond its capped level can do so by purchasing offset credits rather than EUAs, which it will choose to do if the offset credit price is below the EUA price). Member States were allowed to choose the maximum level of offset credits to be purchased by their firms. The UK chose to cap the use of offset credits at 8% of total emissions, which was around two thirds of the required emissions reduction. At the EU level, however, the allowed use of offset credits is sufficiently generous that there will need to be no emissions reductions within the EU to meet the Phase II cap (i.e. all required emissions reductions can be purchased through offset credits, see Figure 4.3).

Despite this, however, the carbon price within Phase II increased to over 20 Euro/tCO_2 in the first half of 2008 (though it has recently fallen back somewhat). This reflected expectations of the banking arrangements between Phases II and III which are explained below.

Proposed framework for Phase III: In January 2008, the EC issued a set of proposals designed to strengthen the EU ETS and to deliver a robust carbon price. The crucial change is that the overall EU cap is no longer the aggregation of independent Member State caps, but is set by the EU, and then allocated to Member State level[2]. In addition, there are tighter limits on the use of offset credits, unlimited banking between Phases II and III, and a move from free allowances to auctioning.

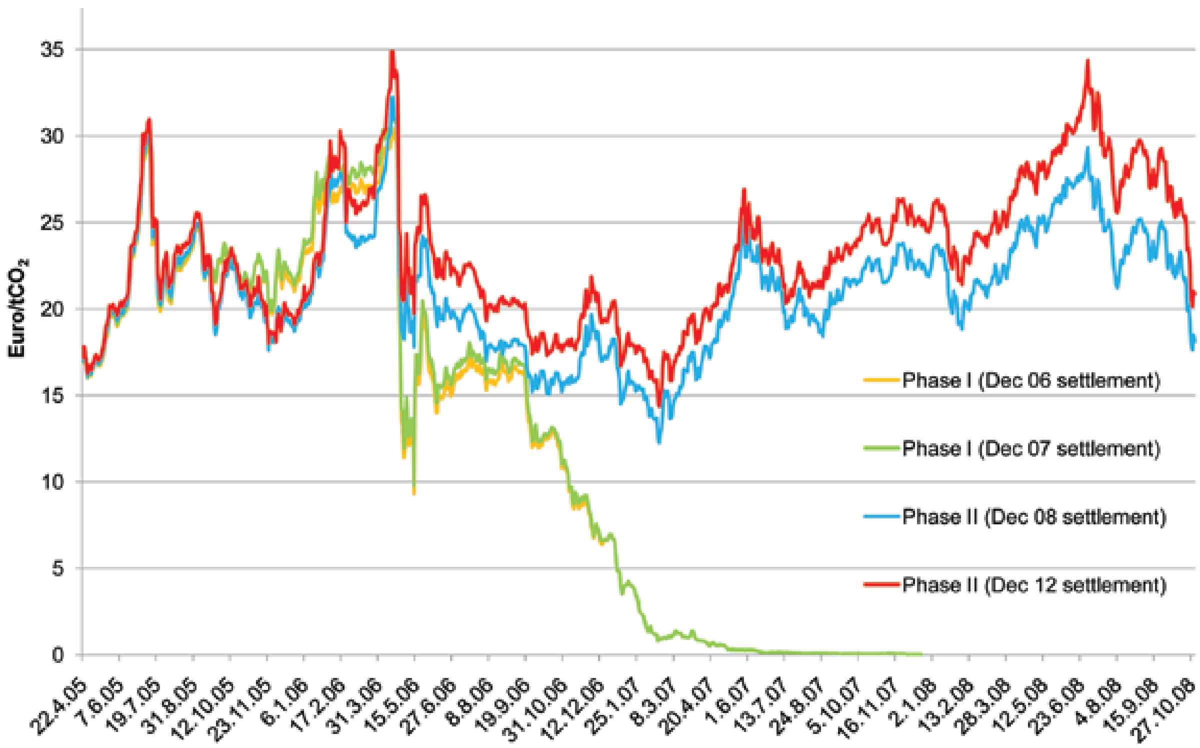
2 This allocation is via issuing of free allowances to firms that can be aggregated at the Member State level or auction rights that are granted to Member States.

Figure 4. 1 Coverage of the EU ETS by UK sector



Source: Based on DECC data on verified emissions, adjusted to take account of changes in scope in Phase II

Figure 4.2 Allowance price evolution in the EU ETS 2005–2008



Source: European Climate Exchange

In a world where there is an economy wide 20% GHG emissions reduction target for the EU in 2020 relative to 1990:[3]

- The overall cap for EU ETS will achieve a reduction in total emissions from an annual average of 2083 million tonnes per annum in Phase II to 1720 million tonnes in 2020, with the total falling by around 36 million tonnes per annum (equal to 1.74% of the Phase II annual average cap, Figure 4.4).

- Beyond 2020, it is planned that further reductions will continue with an initial guideline of annual reductions at the same pace. This would imply an increasing rate of percentage reduction per annum: in 2020, for instance, a 36 million tonnes per annum reduction will equal 2% of the total.

- The proposed policy on offset credits would allow no additional use of offset credits beyond the 1400 million tonnes allowed in Phase II, which would thus become the total allowable purchase of offset credits across Phases II and III combined. As a result, maximum allowed use of offset credits will still result in a 22% reduction in total domestic EU emissions relative to 2005 levels (Figure 4.5).

- Banking of surplus allowances from Phase II will be allowed into Phase III. While this has the adverse consequence of allowing the slacker allocations of Phase II to impact the Phase III price, it has the clear advantage of pulling back into the Phase II price the impact of the tighter Phase III targets.

- The system is likely to move towards an auctioned rather than free allowance system, but with the possibility that energy-intensive firms operating in globally competitive markets will continue to receive some free allowances. For those industries that are not globally competitive, auctioning will reduce windfall profits and provide appropriate carbon price signals in the output price. The pros and cons of this as a means of addressing competitiveness concerns are considered in Chapter 10: *Competitiveness challenges and opportunities*.

In a world where there is an economy wide 30% GHG emissions reduction target for the EU:

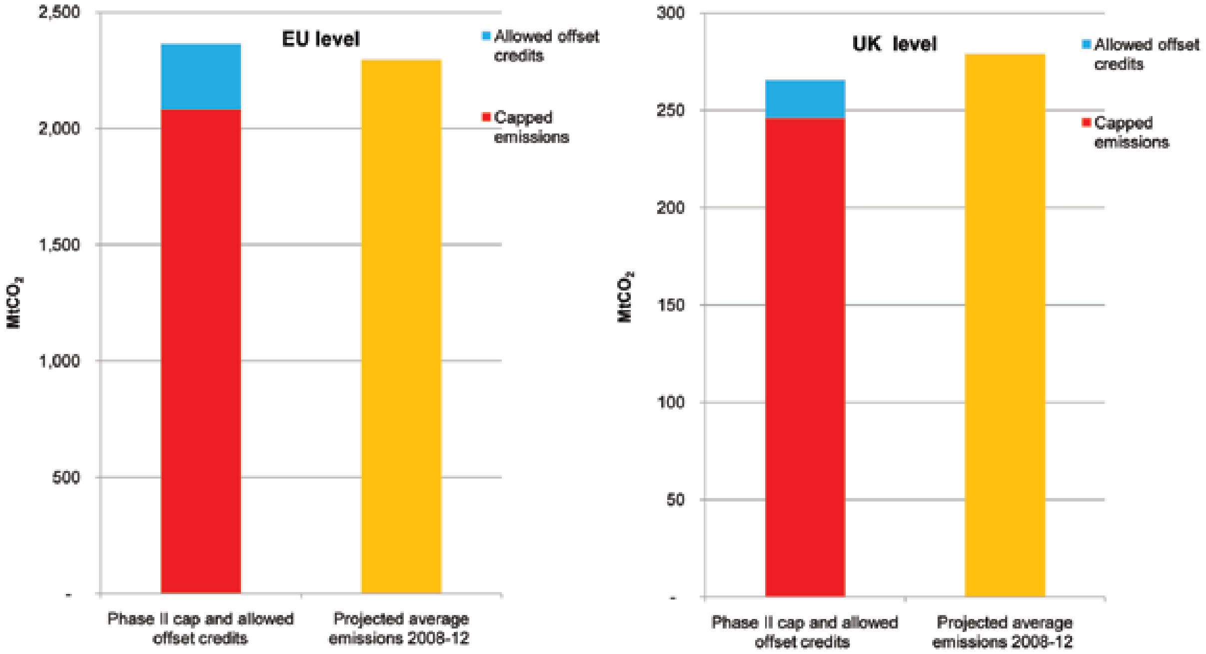
- Based on the EC's proposed Directive, we estimate the cap would be around 1360 million tonnes in 2020.

- Half the additional abatement needed to move to this tighter cap may be covered by offset credits. We estimate that this will allow an additional 950 Mt of offset credits into the EU ETS between 2013 and 2020.

These proposals are currently being negotiated by the European Council and the European Parliament. Whilst there are some issues that still need to be resolved, it is expected that a package including the elements described above will be approved by the European Parliament in late 2008 or in the first quarter of 2009.

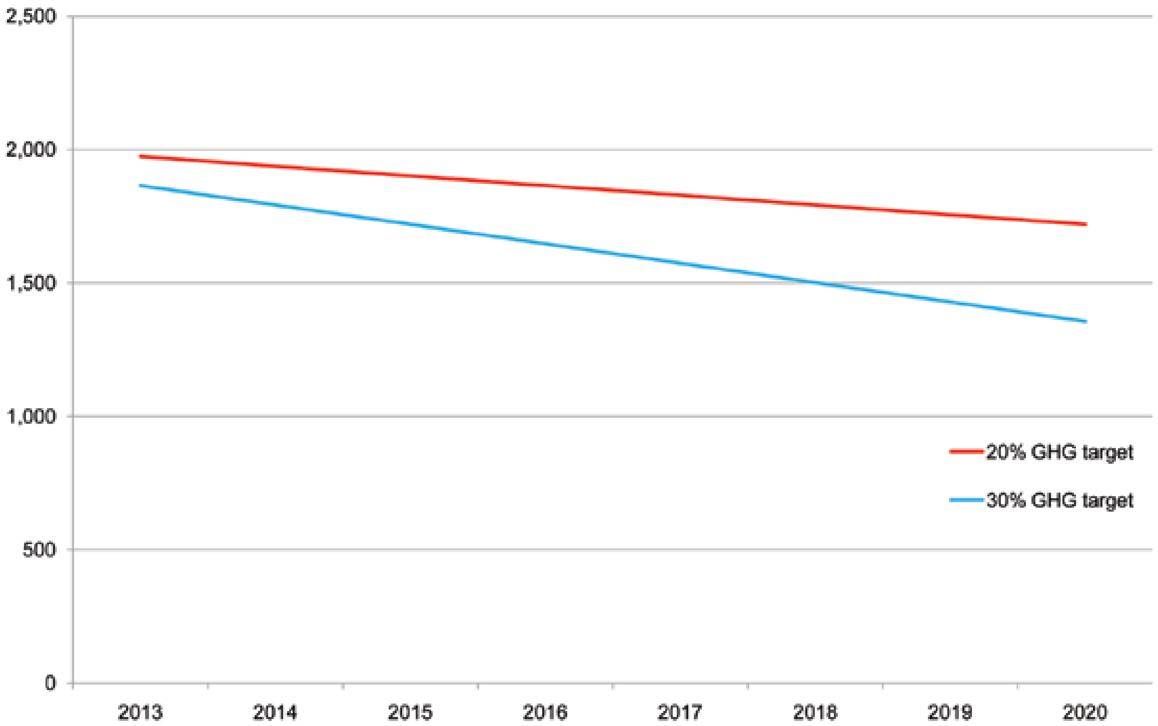
3 See Chapter 3: *The first three budgets* for an overview of the EU GHG target.

Figure 4.3 EU ETS Phase II caps plus allowed offset credits versus emissions projections at EU and UK levels



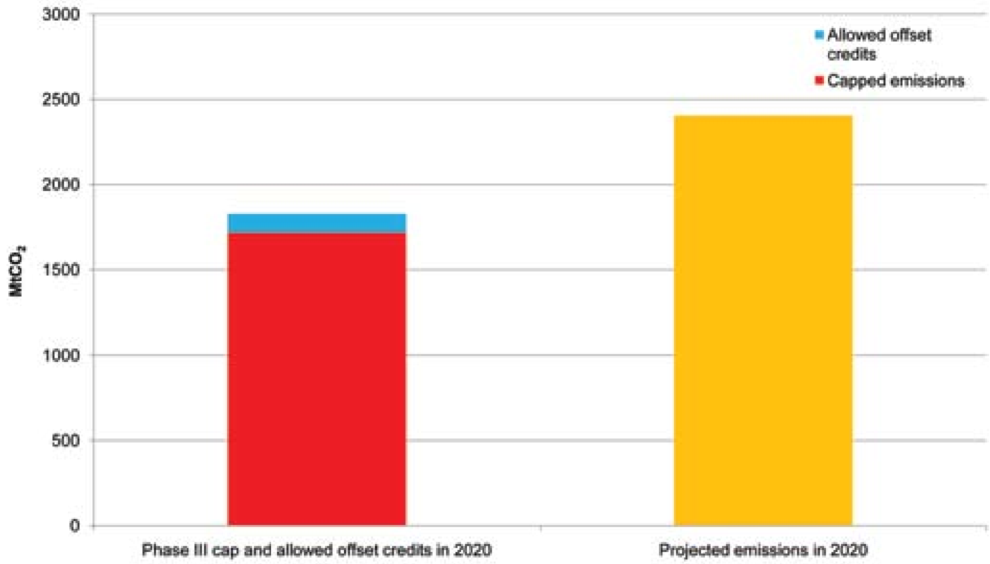
Source: Estimates based on the EC's proposal to revise the EU Emissions Trading Scheme, CCC estimates of projected emissions based on PRIMES, DECC calculations

Figure 4.4 Proposed EU ETS cap in Phase III



Source: Estimates based on the EC's proposal to revise the EU Emissions Trading Scheme

Figure 4.5 Cap plus allowed offset credits versus emissions projections in 2020, 20% GHG target



Source: Estimates based on the EC's proposal to revise the EU Emissions Trading System, CCC estimates of projected emissions based on PRIMES.
Note: Allowed offset credits in 2020 are assumed to be equivalent to the annual average of the total number of offset credits allowed over Phases II and III. These figures exclude aviation

2. THE ROLE OF CARBON MARKETS AND CARBON PRICES: AS POLICY LEVERS AND INDICATORS OF LEAST-COST ABATEMENT OPPORTUNITIES

Carbon markets, and the prices they give rise to, can be used as policy levers to incentivise abatement activity in specific domestic sectors. Carbon prices can also in theory be used to indicate which abatement opportunities ought to be pursued, even if other policy instruments are used to achieve them. This section considers both roles of carbon prices, and sets out the Committee's point of view on how far we can rely on carbon markets as the primary tool of policy. We consider therefore:

- Carbon markets as policy levers
- Carbon prices as indicators of least-cost opportunity.

(i) Carbon markets as policy levers

Carbon prices are one of three mechanisms set out in the Stern Review for delivering emissions reductions (Box 4.1). Carbon price signals can delivered through carbon markets or taxes. There are pros and cons to each type of price instrument, which vary according to the sectors where they are being applied. The UK has accepted that carbon markets have a major role to play in achieving abatement in those sectors of the economy covered by the EU ETS and in stimulation of the development of renewable energy through the Renewable Obligation Certificate (ROC) regime (see Chapter 5: *Decarbonising electricity generation*). In addition the UK will introduce from 2010 a carbon market in non-energy-intensive business sectors, the Carbon Reduction Commitment (see Chapter 6: *Energy use in building and industry*). Carbon price signals are also being created by taxes and regulation in the UK, for example through Climate Change Agreements (CCAs, see Chapter 6), and in the development of transport bio fuels (the Renewable Transport Fuel Obligation regime, see Chapter 7: *Reducing domestic transport emissions*).

This extensive and growing reliance on the carbon market mechanism reflects the significant potential advantages of the carbon market approach set out in Section 1 above. Carbon markets are in particular likely to be effective in incentivising abatement in sectors where energy cost is a significant element in the total cost base, where energy cost is explicitly and professionally managed, and where the transaction costs of trading are low. The limitations of a sole reliance on carbon markets need, however, to be recognised. Even in energy-intensive sectors, their effectiveness can be imperfect; and in other sectors alternative instruments may be more effective (Box 4.1).

Energy-intensive sectors: Energy-intensive sectors comprise power generation together with those industrial sectors where energy input accounts for a significant proportion of total cost. In these sectors any price signal is bound to have a significant effect, on both operational and investment decisions. For example the price signal provided by the EU ETS in the power sector should help determine both the market's choice of fuel to use in generation on an hourly basis, and its choice of investment in new capacity.

There is, however, an issue over whether carbon markets in reality provide the clear and widely understood pricing signals which are needed to encourage investment in abatement technologies, given price volatility. The potential variability of carbon prices is discussed in Sections 4 and 5 below; volatile expectations, and therefore, prices, can arise either from inherent uncertainties in the relative price of coal and gas (a key determinant of the carbon price), from uncertainties in the policy environment (the future tightness of the emissions cap), or from changing assessments of abatement opportunities.

Box 4.1 Carbon pricing and the Stern Review's three essential elements of climate change mitigation policy

The Stern Review argued that establishing a global carbon price is essential to ensure that the full social costs imposed on the world and on future generations by GHG emissions are reflected in the prices of goods and services. As such, **carbon pricing** is the first essential element of climate change mitigation policy.

In principle a global carbon price could be imposed by either a carbon tax or a global cap and trade scheme. Both have theoretical advantages and disadvantages. A global carbon tax could provide a less volatile carbon price (which helps investment decisions) and more certainty on abatement costs. On the other hand a global cap and trade scheme may be preferable if exceeding the absolute emission reduction target implies major risks.
In practice a global carbon market is more likely to emerge as the way forward because of the difficulties associated with coordinating taxation across national borders and because the expected evolution of the climate change policy framework towards absolute emission targets lends itself to emission trading. Nonetheless taxes have a role to play in pricing carbon at a national level. In sectors where there are large numbers of small emitters the transactions costs associated with emission trading may be undesirably high and a tax may be preferable.

In addition to a carbon price, **technology policy** is needed to ensure that the potential market failures associated with delivering low-carbon technology are overcome. These include knowledge spillovers from innovation, the need to provide new infrastructure to support roll-out of new technologies and risk aversion in market participants. Technology policy can range from supporting research and development, to demonstration and early stage deployment. Stern recommended that support given to low-carbon technology should at least double globally to ensure that low-carbon investment is delivered at the pace required.

Finally, Stern argued that **policies to remove barriers to behaviour change** are also needed to ensure that opportunities for cost-effective mitigation options are not missed because of other market failures, such as the lack of information, the complexity of the choices available or the high upfront cost and long payback period. Regulation, provision of information, financial incentives and loans are among the policies that can be employed to overcome these market failures.

Source: Stern (2007) *The Economics of Climate Change.*

If carbon prices are too volatile, abatement opportunities which require significant long-term investment may not be pursued, with firms choosing instead to invest in carbon intensive technologies and to offset emissions through the purchase of allowances, even though investment in low-carbon technology may be desirable from an economic perspective. Carbon market interventions or alternatives to carbon markets may therefore be required in order to provide appropriate investment incentives. The appropriate nature of these interventions depends on the maturity of the technology:

- In the case of mature technologies, the argument for reliance on a price mechanism is strongest. But there can be a case for introducing a carbon price floor (a minimum level below which the price of carbon is not allowed to fall) in order to provide a sufficient degree of certainty to support investment decisions. Such a floor might be particularly valuable in relation to mature low-carbon electricity generation technologies (e.g. nuclear), but also in driving energy efficiency improvements in industry, where the myriad nature of the technologies and techniques by which industrial energy efficiency is pursued makes direct regulatory intervention inappropriate or ineffective, but where greater certainty of future carbon price might intensify abatement efforts.

- For technologies at an earlier stage of development, it may be the case that these are not competitive at the carbon price, but would be competitive following deployment and resulting cost reduction. In these cases, financial support above and beyond that provided by the carbon price, such as that given to renewable energy via the ROC system, can be appropriate.

- For technologies further away from deployment (e.g. carbon capture and storage in power generation), meanwhile, direct financial support for research, development and demonstration may be the most effective lever.

The potential role of these alternative policy levers in the electricity generation sector is discussed in Chapter 5.

Consumer/household sectors: In sectors where decisions are made by consumers rather than business managers (e.g. residential housing and non business transport), it is highly likely that carbon prices alone will not be the most effective policy levers, and that other measures such as information or regulation may be more appropriate. This is because:

- Energy costs are in some cases only a small element in total consumer expenditure. Thus while in poorer families household energy costs for heating and appliances are a significant element in total household budgets, among many middle and higher income families they are relatively small and therefore not subject to detailed scrutiny except during periods of rapid price rise. As a result price levers alone (e.g a carbon price on domestic gas) might not drive adequate change, and the scale of price increase needed to encourage the uptake of all theoretically cost-effective energy efficiency improvements might be so great that it would have major adverse fuel poverty consequences among lower income households.

- Households face significant information and hassle factor barriers to pursuing theoretically cost-effective abatement opportunities. Home insulation projects would often be cost effective at a relatively low (or indeed no) carbon price, but many will not be pursued even at a high carbon price, because of the hassle involved in deciding which particular solution to pursue, in appointing suppliers and supervising work. As a result non-price policy interventions can in many instances be more effective than carbon prices. This may include:

– Measures to raise awareness and reduce transaction costs to drive home insulation improvements and lifestyle change.
– Energy efficiency standards for appliances to drive efficiency improvements more effectively than price incentives alone.
– Regulatory measures to reduce transaction costs, for example, through requiring that all new boilers are energy efficient.

This does not mean that the use of carbon markets at the household level should be ruled out. The price of domestic electricity indeed is already being increased as a consequence of the EU ETS coverage of the electricity generating sector, and price elasticity is high enough for this to produce some useful reduction of demand. A carbon price on domestic gas (which would be achieved if gas supply were brought into the EU ETS) would intensify pressure to achieve heating efficiency, though the consequences for fuel poverty would need careful consideration. And the comprehensive application of carbon markets to the household level through personal carbon trading would be technically feasible, could have some advantages in terms of public engagement and could in principle be used to translate the scientific objective of a certain emissions reduction into a hard emission cap, thereby achieving the first major advantage of carbon market mechanisms described in Section 1 above.

A recent pre-feasibility study on personal carbon trading commissioned by Defra has, however, highlighted concerns about high implementation costs, distributional impacts on some low-income households and rural populations, and public acceptability and willingness to trade.[4] And even if further carbon market mechanisms were applied to the residential sector, other non price mechanisms would remain essential to ensure that abatement measures really were achieved.

Smaller and non energy-intensive businesses: In sectors where decisions are made by business managers but where firms are not energy intensive, it is likely that carbon pricing together with non-price levers will be effective in reducing emissions.

- In any firm, there are commercial incentives for energy efficiency improvement where this results in energy bill reductions in excess of any up-front costs. We have shown in Chapter 6 that such opportunities do exist, and we would therefore expect to see firms exploiting opportunities for energy efficiency improvement. In practice, however, the fact that many of these opportunities remain unexploited suggests that financial incentives may be weak, due in part to the fact that energy costs are a relatively small proportion of total costs. Introduction of a carbon price would strengthen incentives for energy efficiency improvement.

- There are also however a number of non-price constraints (e.g. hidden costs, market failures, split incentives within organisations, see Chapter 6) that stop small and non-energy-intensive firms undertaking measures which in principle appear to be commercially attractive. Introduction of a carbon price alone is unlikely to address these barriers. Introduction of a carbon price together with complementary actions, however, would strengthen incentives for firms to undertake actions to reduce energy consumption and reduce emissions. This is the rationale underpinning of the Carbon Reduction Committment which is aimed at addressing both of these impacts (see Chapter 6). This point applies to larger non-energy-intensive firms, and may apply also to smaller firms, although further consideration of appropriate policy instruments is required here given the possibility of high transaction costs relative to potential emissions reduction for firms below a certain size.

4 Defra (2008) *Synthesis report of the findings from Defra's pre-feasibility study into personal carbon trading*.

Overall therefore carbon prices produced by carbon markets are a crucial lever to drive emissions reduction but optimal policy will require the use of a range of other levers, including taxes, regulation, direct technology support, and measures to raise awareness and provide information.

(ii) Carbon prices as indicators of least-cost opportunity

Even for those sectors of the economy not covered by carbon markets, reference to a carbon price can play an important role in designing a least-cost emissions reductions program by facilitating the comparison of opportunities across different segments. Thus:

- In Chapters 5, 6 and 7 we present marginal abatement cost curves (MACCs) for the power generation, buildings, industry, and transport sectors, ranking theoretically available abatement opportunities by cost per tonne of carbon saved. In theory, the lowest cost programme to achieve any specific reduction target, would be one where the marginal project pursued in each sector had the same cost per tonne of carbon saved.

- In some sectors, however (for instance energy-intensive industry), the primary policy lever is the carbon price set via the EU ETS and the selection of abatement actions is therefore directly driven by the carbon price.

- One possible approach to the selection of abatement opportunities in sectors not covered by the EU ETS would be to take the price of carbon predicted within the EU ETS and to pursue all projects with a cost per tonne abated less than this carbon price (Figure 4.6). If any project with a higher cost were selected, theory would tell us that it would be better to purchase an additional EU ETS allowance, and that a fully equivalent but lower cost abatement would result.

- And the approach could be extended to consider the additional option of buying offset credits if these were cheaper than EU ETS allowances. Thus if we are indifferent as to whether UK budget reductions are achieved domestically or via overseas credits, we would design a least-cost reduction strategy by selecting only those projects in non-traded sectors with an estimated cost per tonne less than or equal to whichever of the EU ETS or offset credit price was predicted to be lower.

In the analysis presented in Chapters 5, 6 and 7, we therefore illustrate for each sector what abatement would result if all projects up to the projected carbon price were pursued. But while this is a useful technique, the Committee does not believe that it is appropriate to apply it in a mechanistic fashion, excluding all projects with a higher calculated cost than the projected carbon price. This is because:

- Our estimates of the carbon price within the EU ETS and of abatement costs are inherently uncertain.

- Abatement opportunities that appear to have a high cost when compared with the carbon price in the period 2020 might actually be cost-effective in the longer term given rising carbon prices over time. This consideration is particularly relevant where there are opportunities for investment in long-lived asset and where, if these are not taken up the result could be lock-in to high-carbon technologies. Therefore abatement opportunities should not be ruled out on the basis that they are more expensive than the current carbon price.

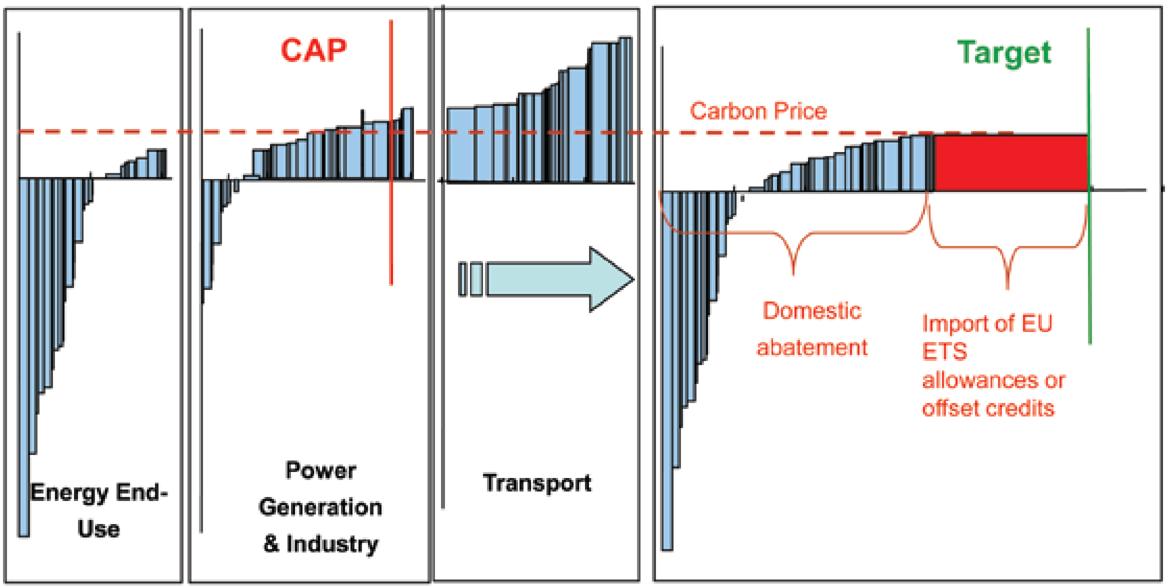
- As noted in the discussion of carbon markets above, there are technologies which are not mature and which may appear to be expensive when compared with the carbon price, but which are nevertheless desirable with a view to driving costs down for future deployment. Where there is the expectation that deployment will drive costs down, opportunities should not be ruled out on the basis that they are not economically viable according to the carbon price.

- A related point is that the UK has EU commitments to significantly increase levels of renewable energy and improve fuel efficiency in cars. To the extent that delivery measures here might not fall below the carbon price, they should not be ruled out, because:
  - They will be required for the UK to fulfill its commitments.
  - The delivery measures are aimed at stimulating technology innovation and driving costs down in the future.
  - Early adoption of new technologies in the UK may offer subsequent export opportunities.

- Many theoretically available opportunities for low cost abatement may in practice be difficult to achieve given behavioural barriers and /or political opposition to required policies. Conversely, theoretically higher cost opportunities may be appropriately selected to meet a given domestic emissions reduction simply because there exist clearly implementable and politically acceptable policy levers. In Chapters 5, 6, and 7 we therefore combine analysis of the theoretical MACCs with consideration of the feasibility and certainty of achieving abatement via the use of available policy levers.

- The extent to which the UK should be willing to rely on the purchase of credits from overseas, is a complex and contentious issue and one on which the Committee has been explicitly asked to make a recommendation. The next section addresses that issue.

Figure 4.6 Theoretical use of the carbon price as a cost-effectiveness threshold



3. THE PROS AND CONS OF RELYING ON EXTERNALLY PURCHASED CARBON CREDITS TO MEET CARBON BUDGETS

We have already set out the pros of carbon markets in Section 1 above: where the cost of abatement opportunities differs between different firms and different countries, free trading of credits can ensure that mitigation occurs at least-cost. The ideal long-term strategy for the whole world, indeed, would be one in which all countries were covered by agreed and binding targets, but with free trade in credits between them.

Arguments in favour of carbon markets and buying in offset credits, however, are matched by three arguments against too great a reliance on them:

- The first is that rich developed economies need to start demonstrating that a low-carbon economy is possible and compatible with economic prosperity, in order to gain developing country commitment to long-term emissions reductions, and need to start driving the technologies and energy efficiency improvements which will make a low-carbon economy possible. They can only do this by employing measures which drive down emissions in rich developed economies rather than relying solely on purchased credits.

- The second, closely related, is that in the long-term (e.g. 2050) the scope to achieve radical reductions via purchased credits is likely to be very limited. As Chapter 2: *Meeting a 2050 target* argued, by 2050 climate change mitigation will require all countries to be limiting their emissions to well below current developed country levels, and the potential for developed countries to buy cheap abatement in other countries will be severely limited. The vast majority of our recommended 80% reduction in the UK emissions by 2050 will be most effectively achieved by domestic action, with the cost of purchased credits likely to be extremely high. A stretching 2050 domestic target in turn requires significant domestic progress by 2020 and 2030, given the limit to the feasible pace of new technology deployment and capital stock replacement. A policy of relying too much on purchased credits in the initial years could make a stretching 2050 domestic target unachievable and could cost the UK dearly by mid century given the likely high and rising cost of purchased credits.

- Finally, there remain concerns as to whether offset credits can ever be as certain a form of emission reduction as domestic reductions. While the procedures for the approval and monitoring of CDM projects are being continually improved, any system of credits for reduction against a hypothetical business-as-usual scenario, is inherently less robust than a cap and trade system where reductions are required in the certifiable total of all emissions.

It should be noted, however, that these arguments against reliance on purchased credits relate primarily or entirely to offset credits, and not to the purchase of EUAs and thus to reliance on reductions elsewhere within the EU. As long as the EU ETS total emissions target is adequately tight (and with appropriate limits on offset credit purchase into the EU ETS) emission reductions will be achieved within Europe, and new technologies for energy efficiency and renewable energy will be developed. And concerns about the certainty of emissions reductions associated with offset credits such as CDM do not apply, to anything like the same extent, in relation to the EU ETS.

Given these considerations, we recommend that in defining an appropriate limit to the use of purchased credits, for the purposes of the UK budgets, a clear distinction should be drawn between allowances purchased from the rest of Europe and offset credits purchased from outside Europe. In particular:

- We recommend that there should be no limit to the extent to which allowances purchased by the private sector from within the EU ETS should count towards the UK budget (i.e. if the UK private sector is a net buyer of EU ETS allowances they should count towards the UK budget, however large this net purchase).

- We similarly recommend that any UK government purchases of EUAs should count towards the budget, and that no quantitative limit should be placed on such purchases for UK carbon budget purposes[5]. These purchases will ensure reductions elsewhere in Europe, and since they would be a fiscal burden on the UK government, this will place a clear incentive on government to achieve domestic reductions rather than to face this cost.

- But we recommend that there should be a quantitative limit placed on offset credits which can count towards the UK budget, with this limit covering both offset credits purchased by the UK private sector within the EU ETS, and any purchases of offset credits by the UK government.

We consider what this limit should be in the context of the UK's carbon budgets in Chapter 3: *The first three budgets*, given an assessment of the emissions reduction that the budgets require. This assessment covers: the domestic emissions reduction potential that we have identified; the domestic emissions reduction that will be required in the context of meeting our 2050 target; and the amount of offset credits that the UK is allowed to purchase under the European framework. Part of understanding what the appropriate level of offset credit purchase would be, however, is their likely price, to which we now turn.

5 We note, however, that such purchases would not count towards non-traded sector targets in the EU context under current proposals.

4. OFFSET CREDIT PRICE PROJECTIONS

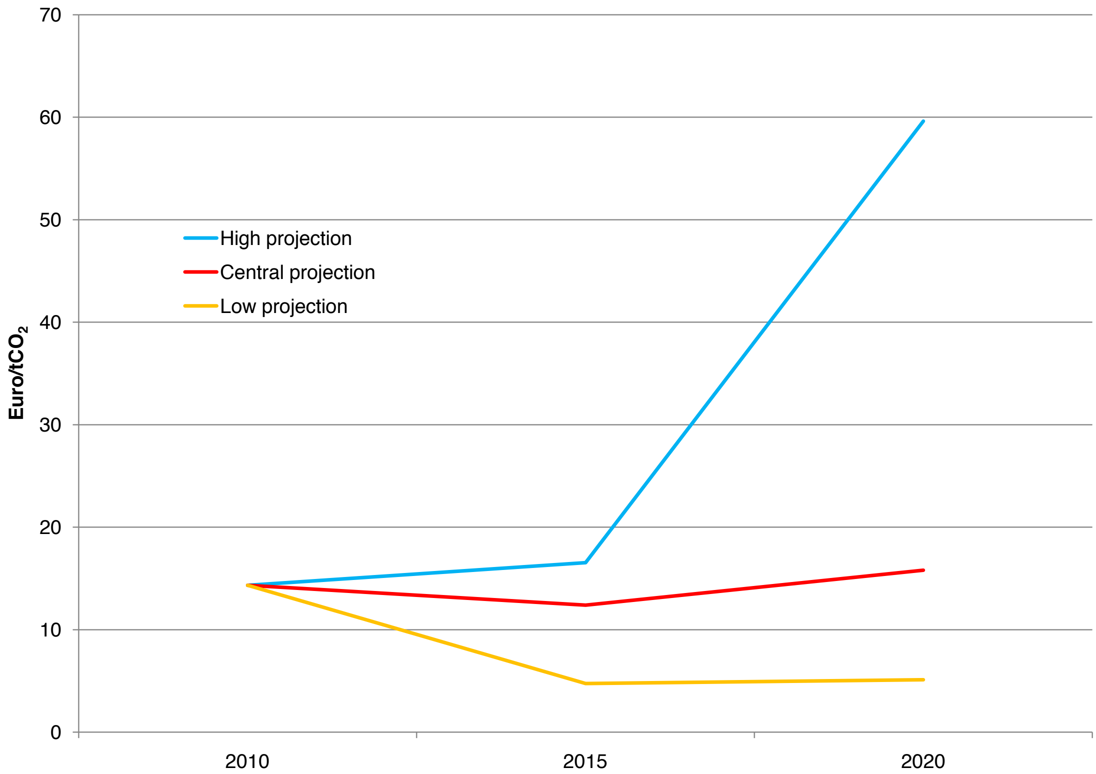
In order to project the price of offset credits, we use the GLOCAF model of the Government's Office of Climate Change[6]. This model can analyse scenarios around a global deal to reduce emissions, using reference case emissions projections and a series of disaggregated MACCs taken from a range of sources. Running a set of assumptions on reference case emissions, scenarios for a global deal and constraints on trading through GLOCAF (see Box 4.2), we developed three scenarios for the price of offset credits:

- **Low case offset credit price projections:** This case is highly pessimistic, with no global agreement on emissions reduction before 2020. The offset credit price in 2020 in this scenario is 5 Euro/tCO_2.
- **Central case offset credit price projections**: This case is more ambitious, and is based around a global agreement that aims to limit concentration of CO_2e at 500 ppm. Restrictions on the purchase of offset credits in developed countries are assumed to be either broadly consistent with recent proposals relevant to each country, or with the usual interpretation of supplementarity under the Kyoto agreement. The offset credit price projection in this scenario is 16 Euro/tCO_2 in 2020.
- **High case offset credit price projections**: In this case it is assumed that there is a highly ambitious global agreement resulting in a concentration limit of 450 ppm of CO_2e in the atmosphere (though before falling to this level, concentration peaks at 500ppm). Relatively relaxed supplementarity restrictions are assumed to apply. This results in a projected offset credit price of 60 Euro/tCO_2 in 2020.

Low, central and high price projections for offset credits for the period to 2030 are illustrated in Figure 4.7. The projections reflect emissions reduction costs adjusted for inefficiencies and some transaction costs. However, there may be additional costs associated with bringing the credits to market which are not reflected in these projections. Based on the difference between the offset credit price in the primary and secondary markets, these additional costs may currently be of the order 10 Euro/tCO_2.

6 GLOCAF was presented at the Bali UN COP/MOP in December 2007. Though this is a UK Government model, the scenarios presented in this chapter were designed by the CCC. Resulting price projections are not Government forecasts.

Figure 4.7 Offset credit price projections for the period to 2020



Source: GLOCAF modelling for the CCC.

Box 4.2 Scenarios for the price of offset credits

Given estimates of emissions reduction effort and abatement potential that may be available for purchase in the global carbon market, we have projected the offset credit price by using GLOCAF to rank abatement opportunities on the basis of cost, and to choose the set of abatement opportunities that minimises the cost of delivering the required emissions reduction, subject to supplementarity constraints; the offset credit price is then the most expensive abatement opportunity within this set.

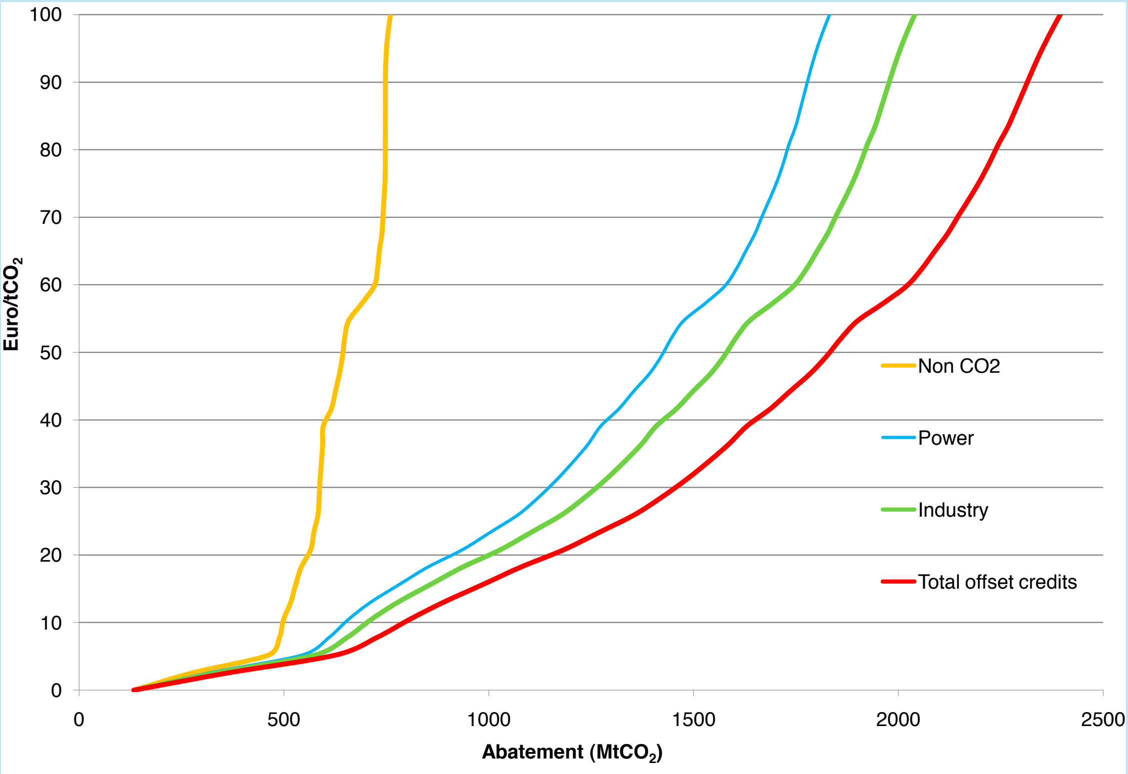
Our estimates for emissions reduction effort are based on the following assumptions:

- **Reference case emissions**: GLOCAF includes a number of alternative reference case emissions scenarios. For all of our offset price scenarios, we chose a reference case characterised by the following:
  - Emissions grow at an annual average of 1.4% in the period to 2020.
  - Drivers of growth are GDP, population, technological progress and relative price changes.
  - The reference case includes emissions reductions related to policies in place in 2005, but not beyond.

- **Scenarios for a global deal**: A wide range of scenarios for a global deal can be run through GLOCAF. We defined our scenarios according to the following assumptions:
  - The concentration of carbon in the atmosphere is limited in a range from 450ppm CO_2e in our high scenario, 500ppm CO_2e in our central scenario and 550 ppm CO_2e in our low scenario.
  - At the country level, Kyoto Annex I countries (most developed countries) are capped in the period to 2020 but developing country caps do not apply until beyond this period, except in our high scenario, where some developing countries take on caps before 2020.
  - Developed country caps are in the range 20%-30% below 1990 in 2020 in our central and high scenarios and between 5-20% below 1990 in our low scenario.
- **Constraints on trading:** In modelling constraints on purchase of credits by developed countries, we chose to apply actual constraints proposed in the EU framework, and a range of assumed constraints for other developed countries.

In order to estimate the level of abatement potential available through offset credits, the GLOCAF model draws on a library of marginal abatement cost curves produced from a number of different models. The cost curves used in our scenarios include a full range of abatement options in energy end use, transport, power, forestry and non-CO_2 gases, and identify 2.2 $GtCO_2$ potential emissions reduction that could be available for purchase in the offset credit market in 2020 at a price up to 100 Euros/tCO_2 (see Figure).

Figure GLOCAF marginal abatement costs and quantities in 2020



Source: GLOCAF modelling for the CCC, based on ENERDATA'S POLES MODEL, Dutch PBL's IMAGE Model and II ASA's DIMA Model
Note: Sectoral curves show cumulative abatement

5. EU ETS PRICE PROJECTIONS

We follow a similar methodology as above to develop EU ETS price projections (Box 4.3). Specifically, we start with a reference case which we derive from the outputs of the emission projections model used by the EC. We define emissions reduction effort as the difference between the reference case and the EU ETS cap as proposed by the EC, less any emissions reduction in the sectors covered by EU ETS that we regard as exogenous to the carbon price (such as savings from meeting the European targets for renewable energy and energy efficiency)[7]. We overlay resulting scenarios across the DECC model of marginal abatement costs in EU ETS[8]. By varying assumptions on fossil fuel prices, EU ETS caps, exogenous emissions reductions and reference case emissions we can therefore project a range for the EU ETS price, the main driver of which is the assumption on fossil fuel prices.

Under an assumption that EU economy wide target is to reduce GHG emissions by 30% in 2020 relative to 1990 our analysis shows that:

- With central fossil fuel price assumptions the carbon price is estimated to be 51 Euro/tCO_2 in 2020. This rises to 66 Euro/tCO_2 in a high fossil fuel price scenario, and 105 Euro/tCO_2 in a high-high fuel price scenario .

- In a world where only 12.5% of energy comes from renewable sources in 2020, the carbon price rises to 60 Euro/tCO_2. Where the Energy Efficiency Action Plan delivers 15% rather than 40% of total ambition, the carbon price rises to 55 Euro/tCO_2.

- For a lower reference case emissions forecast, the carbon price falls to 39 Euro/tCO_2 in 2020.

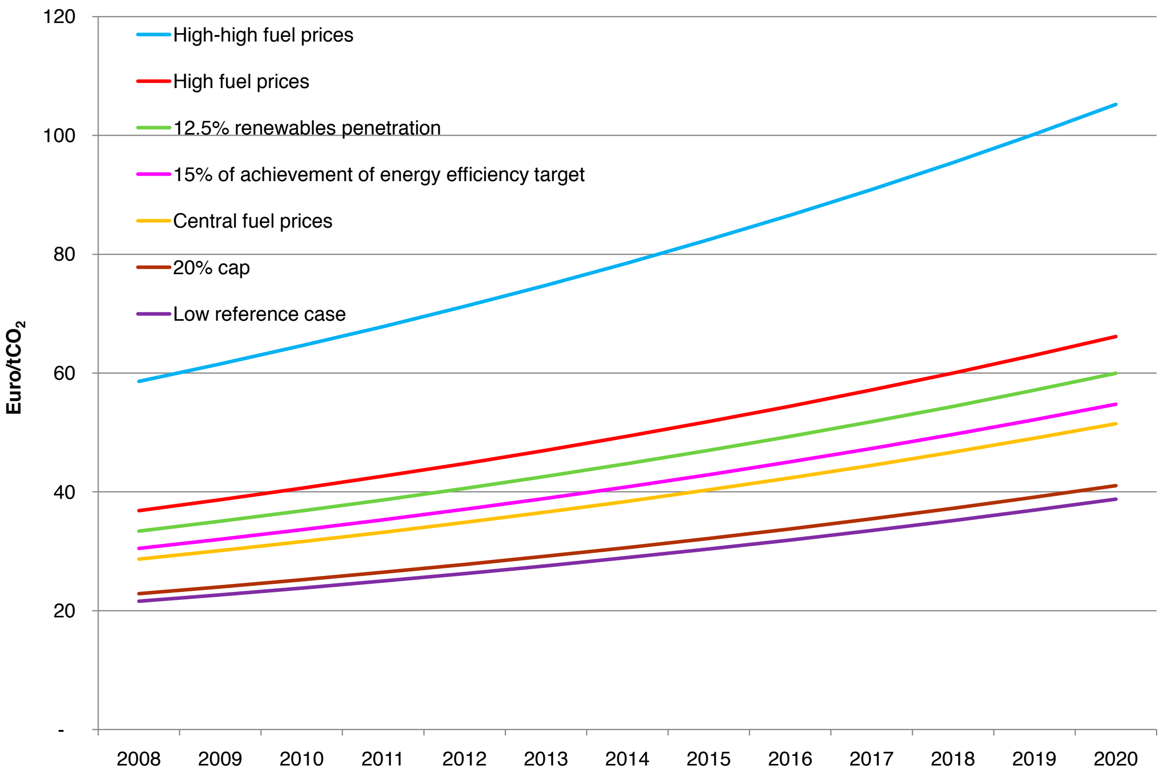
The carbon price projection falls to 41 Euro/tCO_2 for a less ambitious EU ETS cap related to a 20% GHG reduction target in a world where there is no new agreement on a global emissions reduction.

In all cases, it is the cost of fuel switching between coal and gas-fired generation that determines the estimated carbon price, with variations in estimated prices reflecting underlying assumptions about variation in thermal efficiency of coal and gas-fired generation plants across the EU. Price projections are shown in Figure 4.8.

7 Estimates of savings from meeting the renewables target are based on Poyry (2008) *Compliance costs for meeting the 20% Renewables Energy Target in 2020.*

8 Though the DECC model of marginal abatement costs in the EU ETS is a Government model, the scenarios presented in this chapter were designed by the CCC. Resulting price projections are not Government forecasts.

Figure 4.8 EU ETS allowance price projections 2008–2020



Source: Outputs from DECC EU ETS marginal abatement cost model, based on CCC scenarios
Note: All price projections are based on central fossil fuel price projections except where stated

Box 4.3 Scenarios for the price of EU ETS allowances

We project the EU ETS price based on the set of abatement opportunities that minimises the cost of delivering the required effort; the price is then the cost of the most expensive opportunity within this set. The set will comprise some abatement that occurs outside the EU ETS, and that can be purchased by EU ETS participants in the form of offset credits. We allow a level of offset credit purchase consistent with the limits proposed by the EC (Section 1 above).

The emissions reference case together with the EU ETS cap and exogenous emissions reductions define the level of emissions reduction effort required from EU ETS (i.e. the reference case minus the cap minus the exogenous emissions reductions):

- **Reference case emissions**: Our reference case emissions for sectors covered by EU ETS are derived from the outputs of DG TREN's PRIMES/GAINS models, which project energy demand across Europe in the period to 2030. The model assumes a carbon price of 20 Euros/tCO_2 but we have adjusted the projection upwards to model a scenario where there is no carbon price. Reference case emissions increase by 5% from 2005-2020 under these assumptions. In addition to our central forecast, we use a lower forecast based on the unadjusted PRIMES/GAINS projection as a sensitivity.

- **The EU ETS cap**: we derive EU ETS caps from EC proposals (see Section 1), and assume that departing aviation is included in EU ETS.

- **Exogenous emissions reductions:** part of the emissions reduction required to move from the reference case to the EU ETS cap will be delivered by measures that are exogenous to EU ETS. In particular, it is reasonable to assume that cost-effective energy efficiency improvement would occur even without a carbon price and increased levels of renewable electricity will result from mechanisms required to deliver the EU's 20% renewable energy target (e.g. Renewable Obligation Certificates or feed-in-tariffs, see Chapter 7).
  - We assume that two thirds of the measures set out in the EU's Energy Efficiency Action Plan[9] fall into the traded sector. Based on the figures in the Action Plan, we estimate these measures would result in around 335 $MtCO_2$ savings in 2020 if fully achieved.
  - Noting that the targets are non-binding, our central scenario assumes that 40% of the target is delivered. We run a sensitivity under which 15% of the action plan is delivered.
  - We estimate that meeting the EU's renewable energy target will save around 250 $MtCO_2$ in the traded sector in 2020, based on an assumption that all renewable electricity and half of renewable heat is in the traded sector
  - Our central scenario assumes that the target is met in full, with a sensitivity that places a lower bound on the level of renewables in 2020 at 12.5% of final energy demand.

In order to understand where and at what cost this effort will ensue, we use the DECC model of marginal abatement costs in the EU ETS sectors across Europe. This model is dominated by abatement potential in the power sector due to fuel switching from coal to gas, with a smaller order of magnitude of emissions reductions available from measures in other energy-intensive industries. The quantity and cost of abatement potential depends on a range of factors, but most importantly fossil fuel prices:

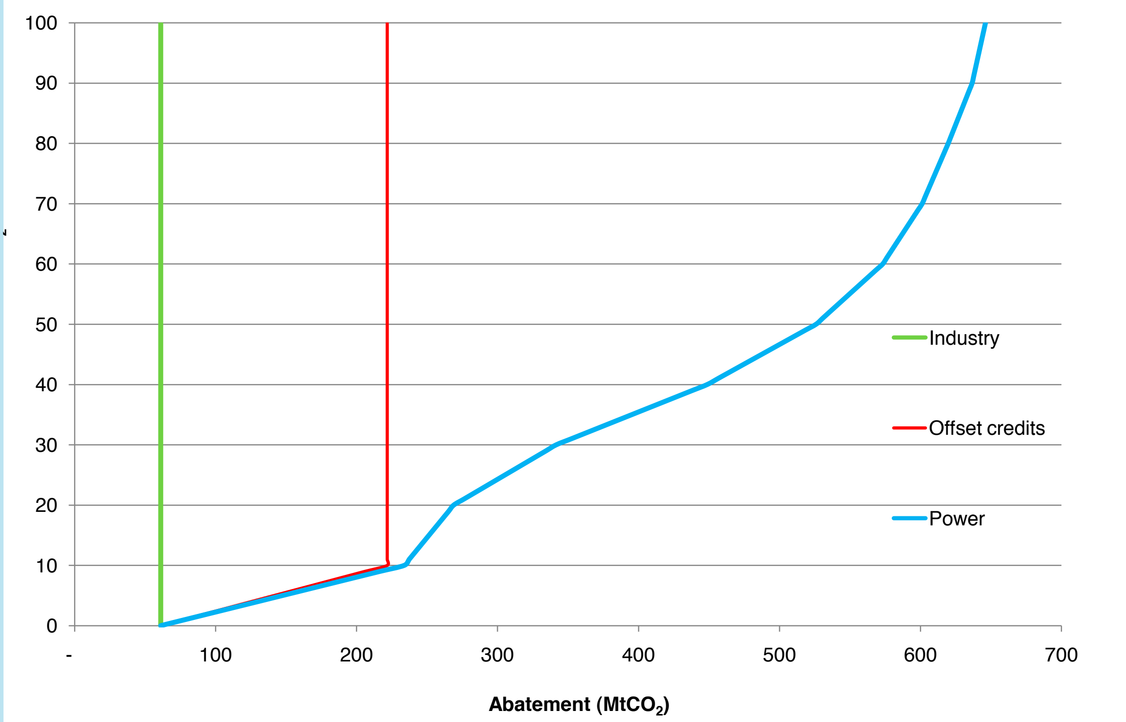
- The power generation part of the model assumes a pattern of investment in new capacity to retiring plants and to meet demand growth. The majority of new build is assumed to be gas-fired or renewable. There is some coal and nuclear new build, but overall, a net fall in capacity from these technologies.

- Given existing stock and investment, there is fuel switching potential of around 450 $MtCO_2$ up to a price of 100 Euros/tCO_2, with spare gas capacity in the UK, Eastern and South Eastern Europe, and export of gas-fired generation from Italy to Germany. Much of the fuel switching (enough to deliver around 200 $MtCO_2$) is available at 40–50 Euro/tCO_2 in the central case, and 90-100 Euro/tCO_2 in the high-high fuel price case.

Abatement from industry results from long-term investments rather than short-run measures such as fuel switching in the power sector. It is thus assumed that industrial abatement reacts to an expectation of the carbon price rather than the carbon price itself, and that this (conservative) expectation is of a carbon price around 20 Euro/tCO_2 in the period to 2020. This results in approximately 70 $MtCO_2$ abatement in 2020. Marginal abatement quantities and costs for the EU ETS sectors in the central fossil fuel price case are illustrated in the below figure.

9 EC (2006) *Action Plan for Energy Efficiency.*

Figure Marginal abatement quantities and costs in the EU ETS sectors in 2020



Source: Outputs from DECC EU ETS marginal abatement cost model, based on CCC scenarios
Note: Sectoral curves show cumulative abatement. The industrial abatement potential show here is broadly consistent with that presented in the Chapter 6 at UK level. However, we recognise that our modelling may not fully capture the range of responses industry can make to the carbon price and that there may be additional abatement potential in industrial sectors. This is unlikely to substantially change the resulting price though, as even with a large amount of additional abatement, fuel switching in the power sector would still be the marginal abatement option in the EU ETS. The cost of offset credits shown here is less than the 16 Euro/tCO_2 in 2020 quoted earlier as our modelling suggests that participants in the EU ETS will purchase offset credits in earlier years when they are cheaper.

6. PRICE ASSUMPTIONS IN OTHER CHAPTERS

As noted in the introduction to this chapter, we use carbon prices in various parts of the analysis in this report, both as a means for identifying abatement potential that should be targeted under the UK's climate strategy, and for understanding implications of this strategy for the macroeconomy, budget and fuel poverty. This raises the question of which carbon price from our range of forecasts we use in this analysis.

We have chosen to use the EU ETS price forecast of 51 Euro/tCO_2 under the assumption of an EU 30% GHG target and central fossil fuel prices. We believe that it is appropriate to use this forecast rather than the forecast under a 20% GHG target because it corresponds to the post global deal world that we are expecting and planning for. We believe that it is appropriate to use the EU ETS rather than the offset credit price projection given that the level of offset credits should and will be constrained.

Given that the rest of our analysis is in £ rather than Euro, we refer in other chapters to a carbon price of £40/tCO_2. To the extent that prices might be higher, we show sensitivities as appropriate.

CHAPTER 5:

DECARBONISING ELECTRICITY GENERATION

Electricity generation accounts for about 37% of all UK CO_2 emissions. Reductions in these emissions are possible at relatively low cost when compared with other sectors; and radical reductions in emissions in this sector are essential if overall greenhouse gas targets are to be achieved. Our analysis in Chapter 2: *Meeting the 2050 target* illustrated that any path to an 80% reduction by 2050 requires that electricity generation is almost entirely decarbonised by 2030; but it also illustrated that as electricity is decarbonised it is highly likely that the relative importance of electricity within overall energy end use should grow, with increasing substitution of low-carbon electricity for fossil fuels in surface transport and heating. Achieving a decarbonised electricity generation system is therefore even more important than its current share of CO_2 emissions suggests.

This chapter focuses on the prospects for reducing emissions from electricity generation in the first three budget periods. While emissions from the power sector are capped under the EU ETS, it is important that the foundations for radical decarbonisation in the 2020s are laid during this period. The fact that much of the UK's existing electricity generation capacity will need to be replaced in the next ten to fifteen years creates a major opportunity to invest in low-carbon technology. There is also a danger that failure to grasp this opportunity will result in lock-in to high carbon generation, increasing the cost of subsequently meeting long-term targets.

The overall conclusions of this chapter are that:

- There exist a set of technological options which will make it possible to reduce CO_2 emissions from the electricity generation sector by around 40% on 1990 levels by 2020.[1] The carbon intensity of generation could fall from around 560 gCO_2/kWh to around 310 gCO_2/kWh by 2020.

- While this report does not propose any one specific portfolio of generation capacity, it is likely that in the period to 2022, decarbonisation will be primarily achieved through deployment of renewable energy as part of the UK's contribution to the EU renewable energy target. There may also be an important role for new nuclear in the period to 2022, depending on the realistic potential for renewables deployment. Renewables, new nuclear and carbon capture and storage (CCS) will all have a potentially important role in the 2020s.

- The creation of a clear carbon price signal within the EU ETS is a vital tool in driving electricity sector emission reductions, but additional policy levers will be required:
  - The financial support and non-financial policy measures of the draft Renewable Energy Strategy are vital
  - The extension of the EU ETS beyond 2020 is essential
  - Expenditure on CCS demonstration projects is a priority
  - New conventional coal-fired power stations should only be built on the clear expectation that they will be retrofitted with CCS capability by the early 2020s.

- The cost of reducing CO_2 emissions from electricity generation by 40% within the next 15 years is about 0.2% of GDP in 2020. Achieving this reduction will add significantly to electricity bills, with resulting fuel poverty implications; we address issues relating to fuel poverty impact and mitigation in Chapter 12: *Fuel poverty implications*.

1 In the DECC Energy Model, this rises to up to 55% taking into account the electricity demand savings in end-use sectors in the Extended Ambition scenario, which we look at in Chapter 6: *Energy use in buildings and industry.* See Figure 5.22.

The analysis which underpins these conclusions is set out in six sections:

1. The starting point and reference emissions projections

2. Economics of low-carbon generation technologies

3. Policy issues in driving low-carbon investment: is a carbon price sufficient?

4. Scenarios for generation mix and implications for emissions

5. Aggregate costs to GDP and to the consumer

6. Power generation scenarios in the economy-wide abatement scenarios.

The analysis in this chapter covers centralised generation from major power producers and renewable generators[2] – micro-generation and CHP are covered in Chapter 6: *Energy use in buildings and industry*.

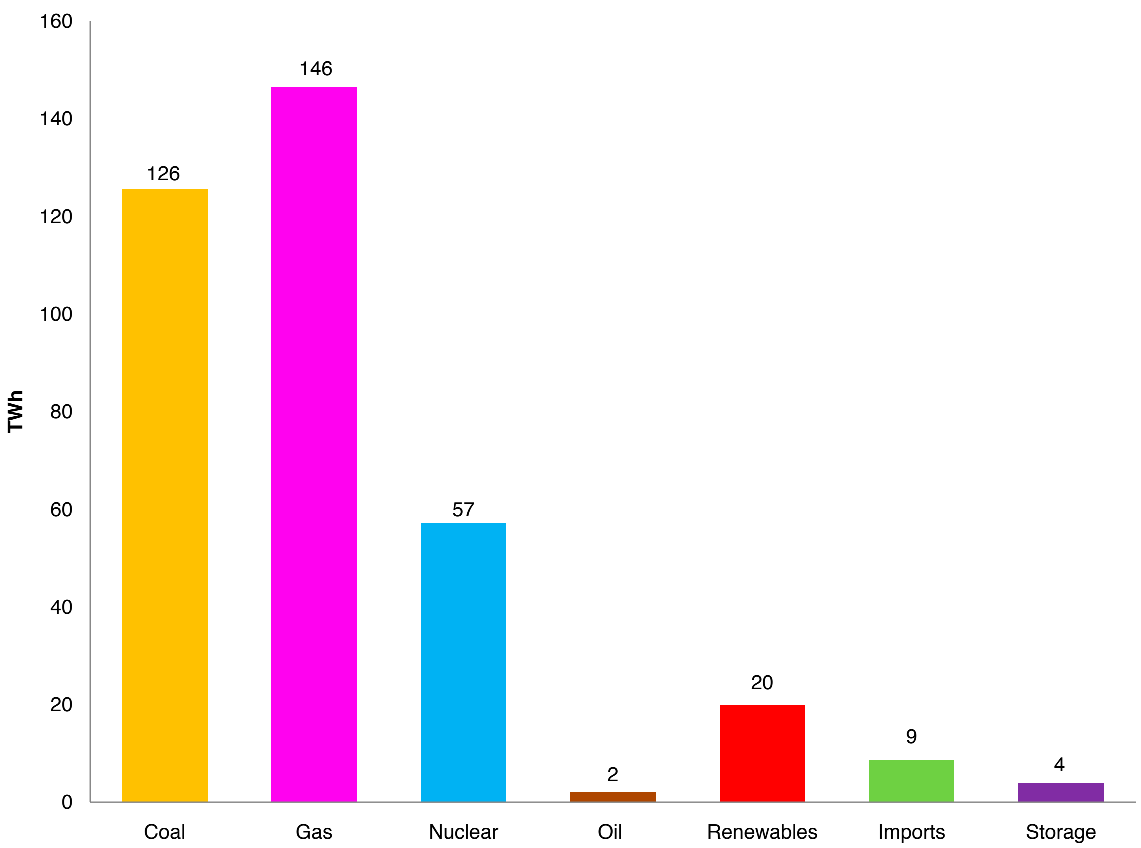
2 Major power producers are separated from 'other generators' and are defined in DUKES as companies whose sole purpose is the generation of electricity. However, most renewable generators are defined as 'other generators' due to their comparatively small size. We also include other renewable generators in our analysis.

1. THE STARTING POINT AND REFERENCE EMISSIONS PROJECTIONS

Emissions from UK electricity generation are to a significant extent driven by the relative importance of coal within the fuel mix. Looking forward, most existing coal generation capacity will cease operation over the next 15 years, but without a carbon price it is likely that some new coal investment would replace it. Given the EU ETS and carbon prices in line with the estimates in Chapter 4: *Carbon markets and carbon prices*, investment in new gas-fired generation would be likely to dominate, but with the possibility of portfolio investment in coal:

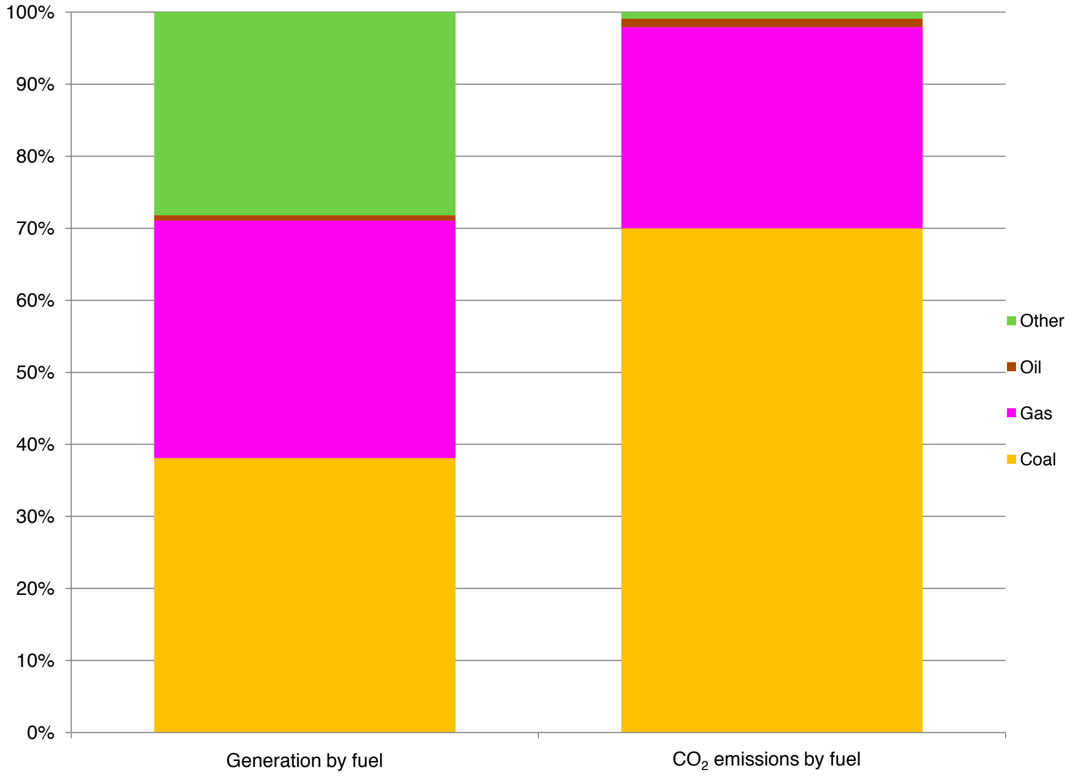
- The UK's current (2007) electricity generation mix is shown in Figure 5.1, with fossil fuels (gas and coal) accounting for over 75% of the electricity supplied, nuclear 16%, and renewables (including long-established hydropower) about 5%.
- The emissions produced are dominated by coal generation, reflecting the high-carbon intensity of coal generation per kWh generated (Figures 5.2 and 5.3).
- Electricity demand increased at about 1.6% per annum over the period 1990 to 2005, but since then demand has declined, and in 2007, demand was 1.3% lower than in 2005 (Figure 5.4).
- Meanwhile, emissions have fallen as a result of the shift during the 1990s from coal to gas generation. Since around 2000, however, this reduction has halted and indeed slightly reversed, as high gas prices have induced a shift back to coal generation (Figure 5.5).

Figure 5.1 Electricity generation by fuel, 2007



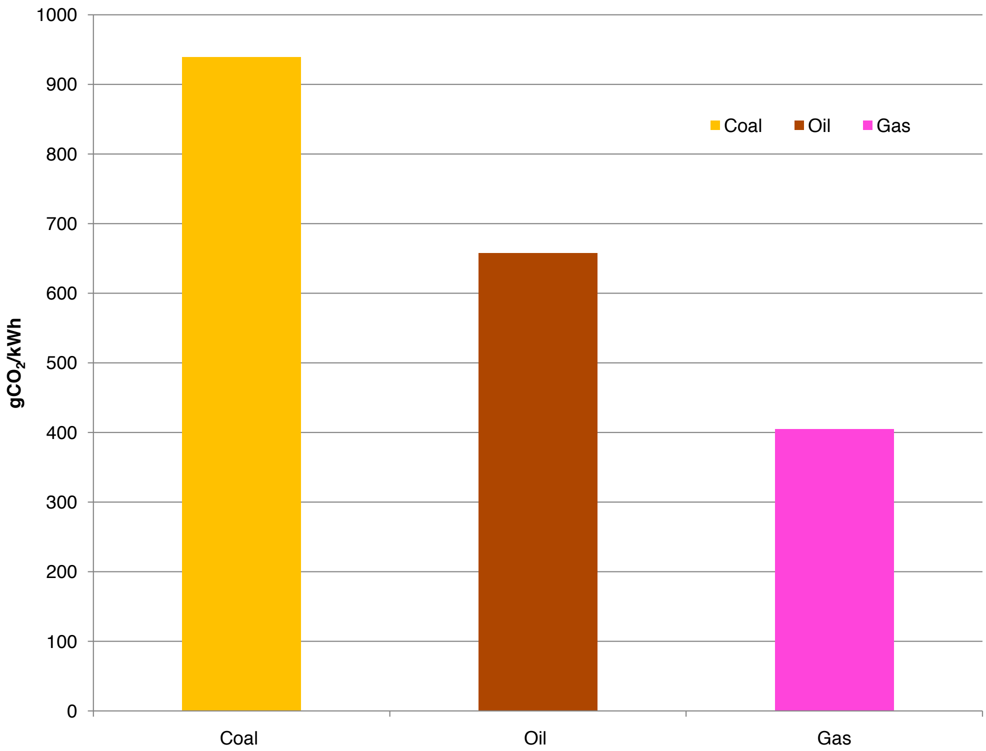
Source: DUKES (2008), Table 5.6.
Note: Covers electricity generated from all major power producers (MPPs) only; and renewable generation. Excludes electricity used in generation process ('own use').

Figure 5.2 Share of generation and CO_2 emissions by fuel for power stations, 2006



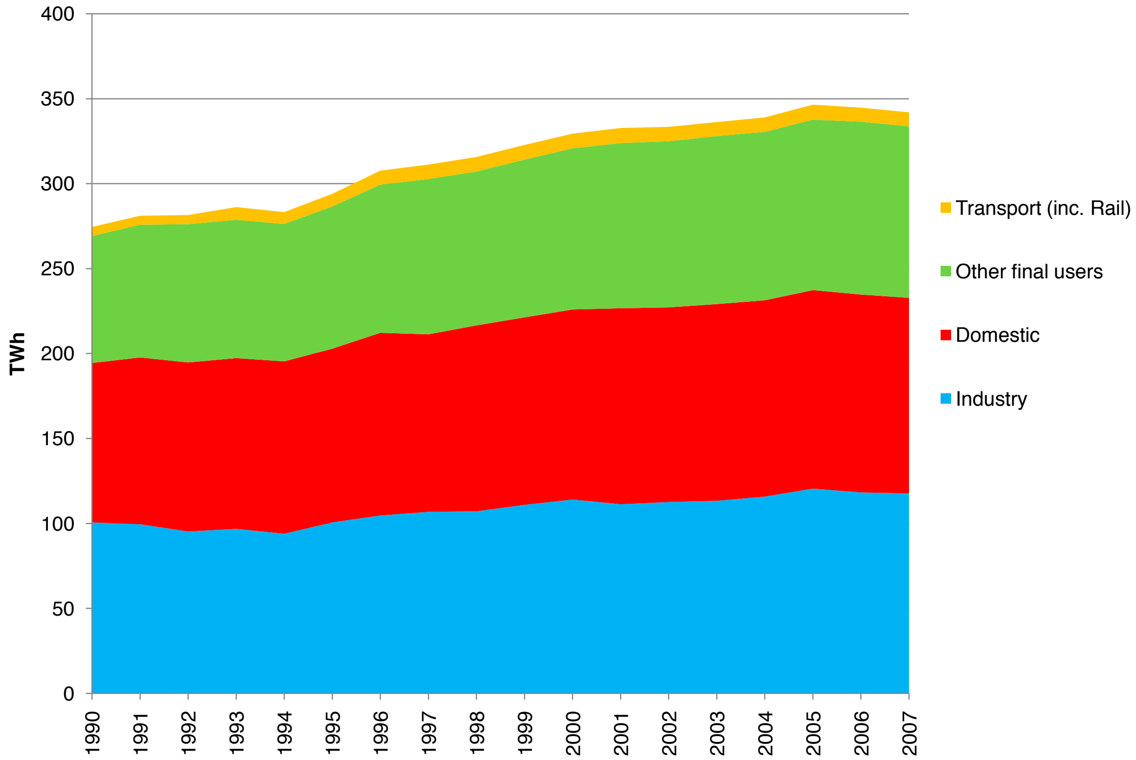
Source: DUKES (2008), NAEI (2008)
Note: Generation from MPPs only and renewable non-MPP and excluding 'own use'. CO_2 emissions from NAEI (2008) (including own use generation).

Figure 5.3 Estimated CO_2 content of electricity by fuel, 2007 (gCO_2/kWh of electricity supplied)



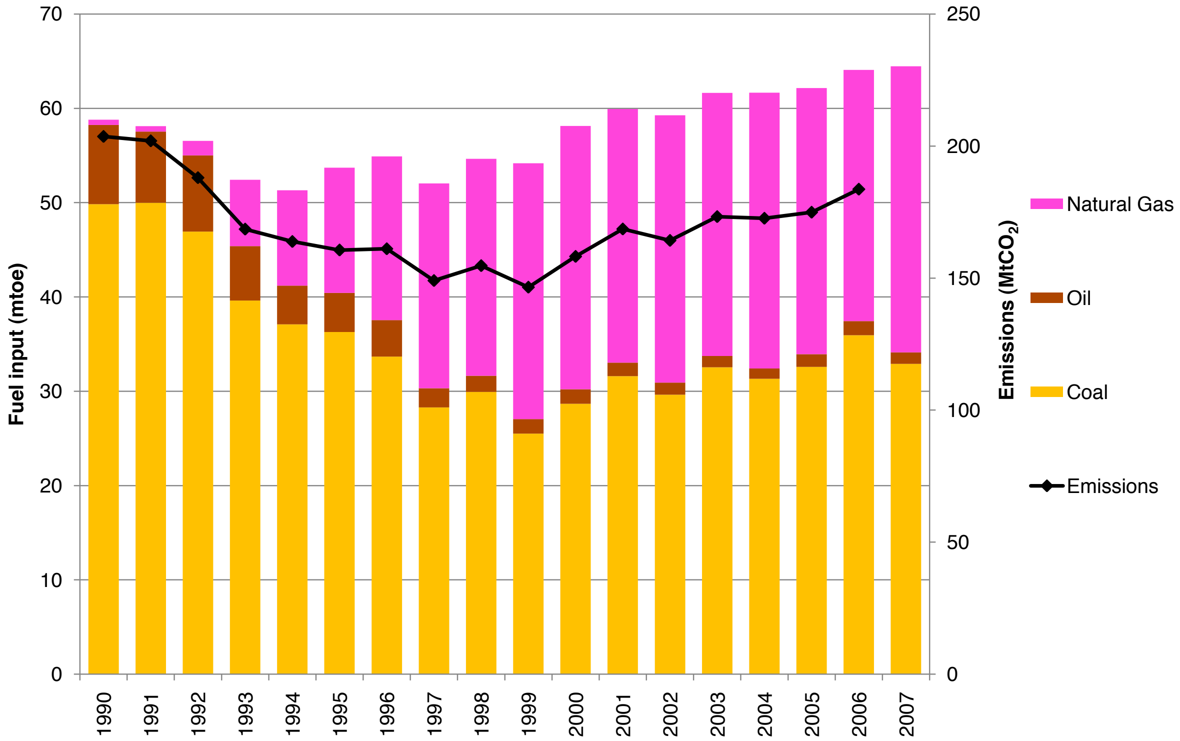
Source: DUKES (2008), Table 5C.
Note: Not adjusted for losses in transmission and distribution. Includes MPPs and all other generators.

Figure 5.4 Electricity demand since 1990, final users



Source: DUKES (2008) *Long Term Trends*, Table 1.1.5.
Note: Final users excludes fuel industries. Other final users: agriculture, commercial and public sectors.

Figure 5.5 Fuel input for electricity generation and CO_2 emissions since 1990



Source: DUKES (2008) *Long Term Trends*, NAEI (2008).

- A significant amount of existing generation capacity is scheduled to retire within the next 15 years, as shown in Figure 5.6. This is due to the closures of coal plants which cannot meet the requirements of the Large Combustion Plant Directive and from nuclear plants reaching the end of their scheduled lives. Electricity demand should ideally fall slightly over this period, given the potential and the need to achieve the energy efficiency improvements discussed in Chapter 6: *Energy use in buildings and industry*, but a major gap will still emerge between capacity and demand, as shown in Figure 5.6.

- As a result major new investments in generation capacity will be required. This creates an opportunity for the UK to start building a decarbonised electricity generation system. Seizing this opportunity is vital, especially given the likelihood (discussed in Chapter 2: *Meeting a 2050 target)* that electricity will play an increasing role in energy use beyond 2020, particularly in surface transport and heating, as Figure 5.7 illustrates.

- Forecasts for new generation investment, however, suggest that a mix of new coal and gas plant capacity would dominate if additional climate change policies were not in place.[3] Without the carbon price established by the EU ETS, the run off of existing coal capacity would probably be largely matched by new coal investments, and emissions would be unlikely to fall (Figure 5.8).

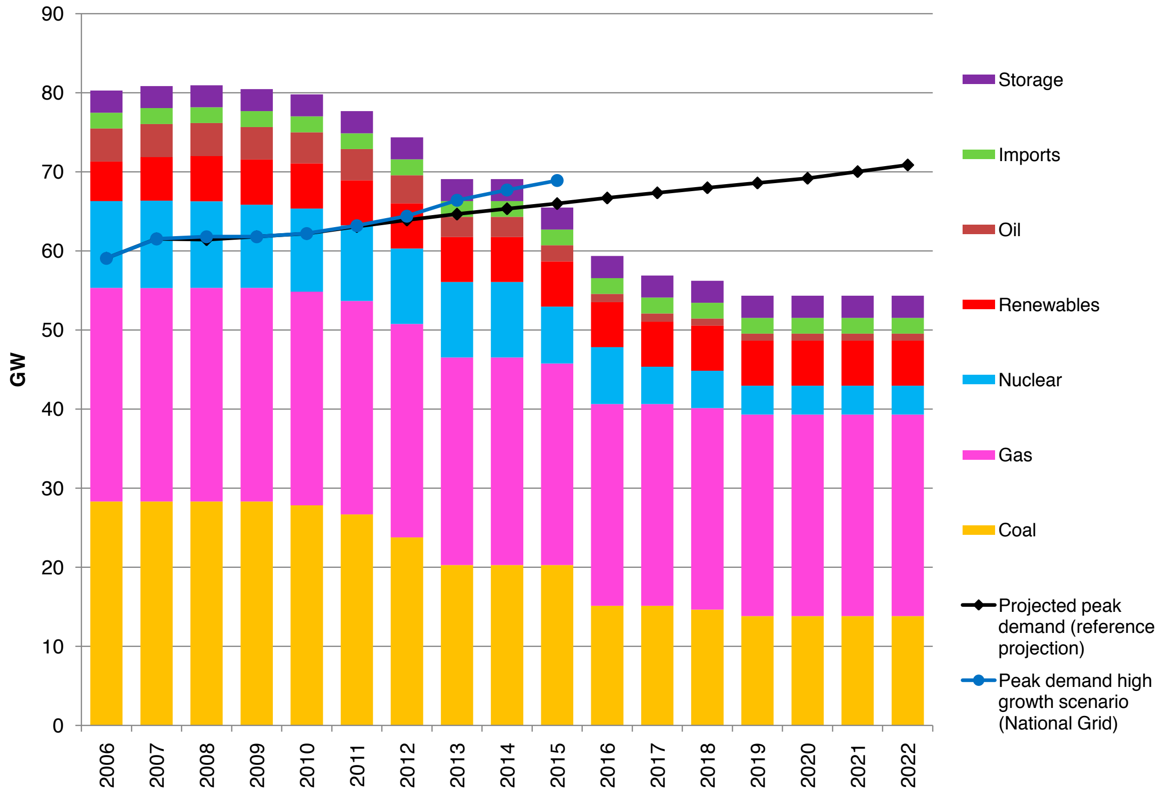
- With a carbon price in line with our estimates in Chapter 4, and with fossil fuel prices in line with the central projection, as shown in Figure 5.9, investment in new gas generation would be likely to dominate.[4]

- Expectations of future gas and coal prices and of carbon prices will play a crucial role in determining the precise mix of coal and gas new investment, while current coal, gas and carbon prices will determine which capacity (coal or gas) is most intensively used. For example Figure 5.10 shows generation under alternative coal and gas price assumptions.

This generation mix will in turn be a crucial driver of year by year emissions (Figure 5.11). These scenarios do not, however, reflect full potential for decarbonisation through aggressive deployment of renewable electricity, nuclear new build and CCS; we now consider these technologies.

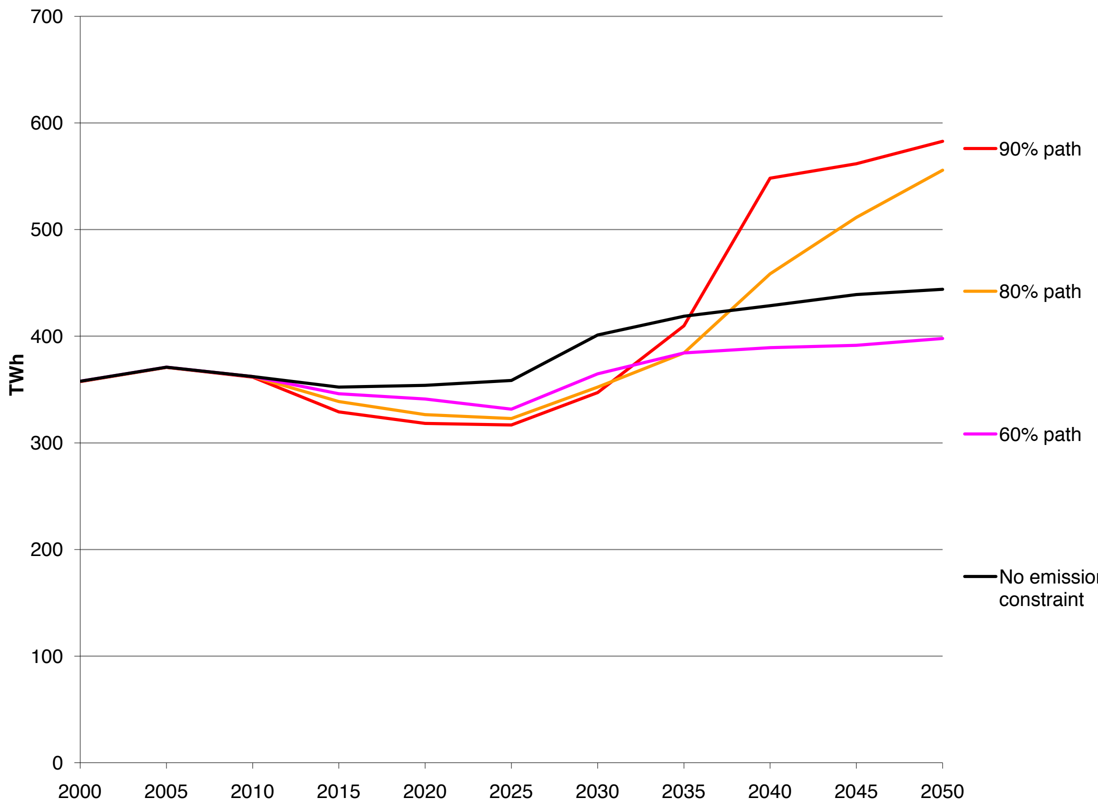
3 The reference projections include the impact of the non-banded Renewables Obligation, but not the EU ETS.
4 The DECC Energy Model is a least-cost optimisation model, therefore does not formally capture investment that might occur on a portfolio basis, such as new coal build.

Figure 5.6 Capacity of existing generation and projected peak demand, 2006-2022



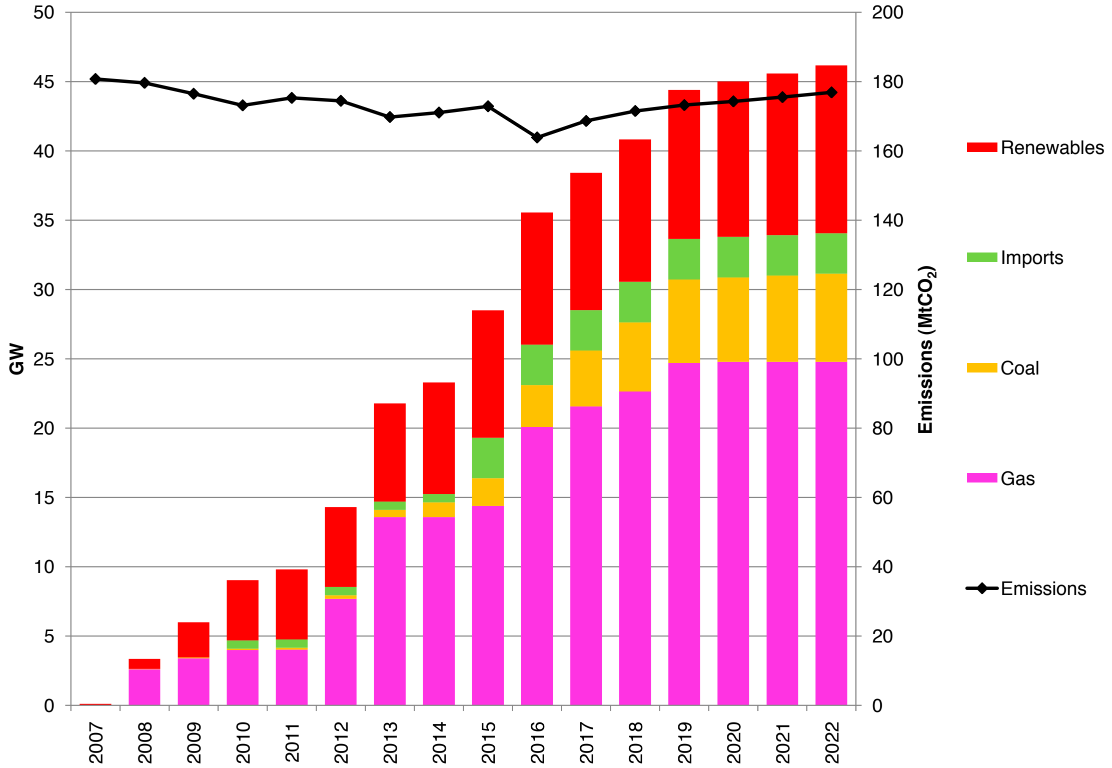
Source: DECC Energy Model, National Grid (2008) *Seven Year Statement*.
Note: Assumes peak demand grows in line with demand in our central case reference emission projection.

Figure 5.7 Long-term electricity generation, 2000–2050



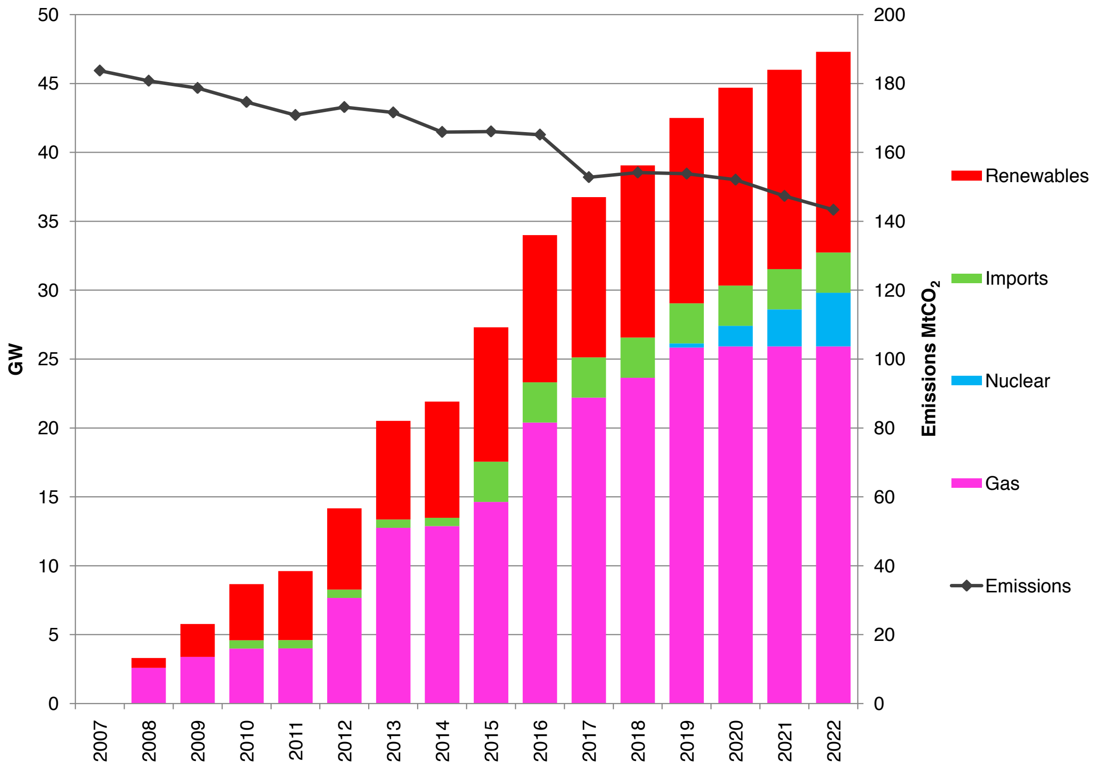
Source: MARKAL model based on CCC assumptions.

Figure 5.8 Projected cumulative new build and CO_2 emissions in the reference emissions projection without a carbon price (central fossil fuel prices)



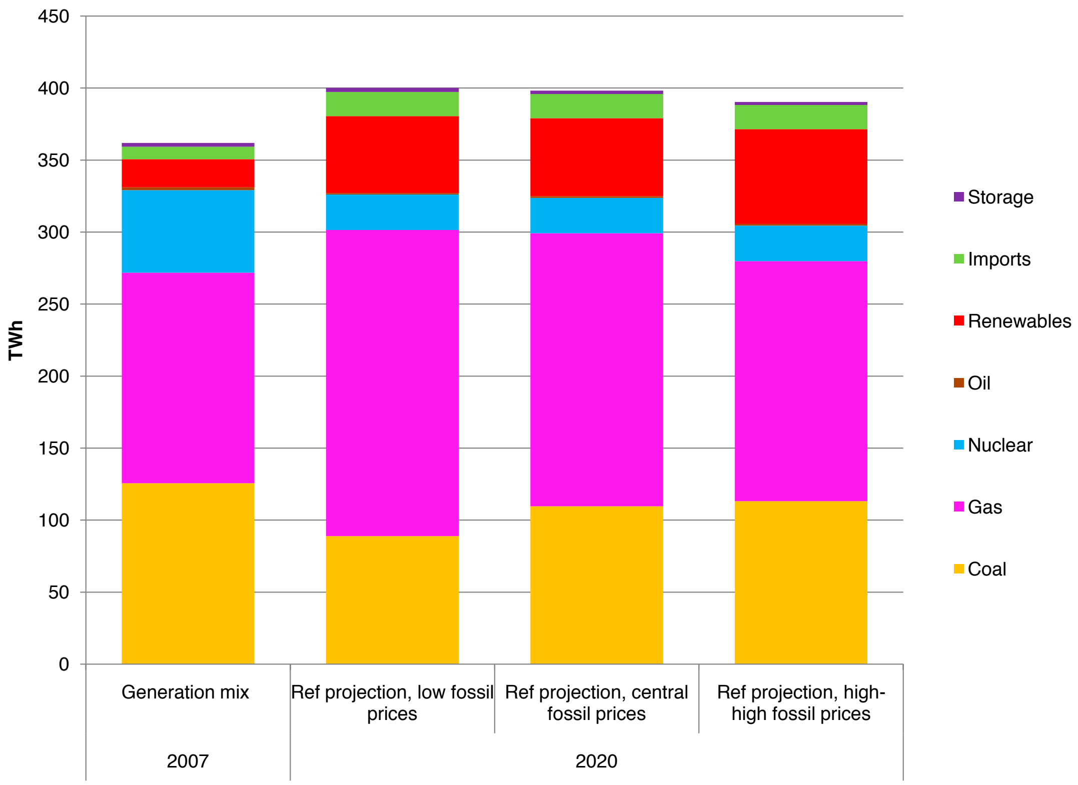
Source: DECC Energy Model based on CCC assumptions.

Figure 5.9 Projected cumulative new build and CO_2 emissions in the reference emissions projection with a carbon price (central fossil fuel prices)



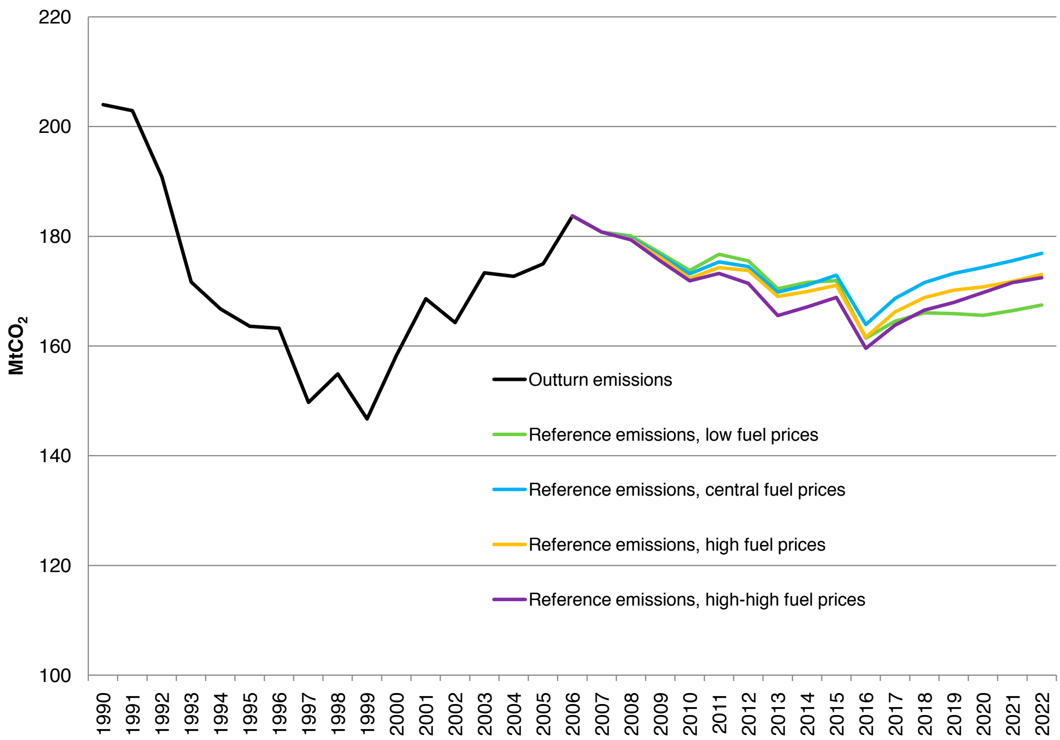
Source: DECC Energy Model based on CCC assumptions.

Figure 5.10 Historic and projected generation mix in the reference emissions projection under a range of fossil fuel prices, 2007 and 2020



Source: DECC Energy Model based on CCC assumptions.

Figure 5.11 Historic and projected CO_2 emissions from the power sector under range of fossil fuel prices (reference emissions projection), 1990 to 2022



Source: DECC Energy Model based on CCC assumptions.

2. ECONOMICS OF LOW-CARBON GENERATION TECHNOLOGIES

The economic cost of decarbonising electricity generation depends on the cost of low-carbon electricity relative to that of coal or gas based electricity generated without CCS. Making this comparison is complex for four reasons:

- **Fossil fuel price volatility and uncertainty:** Wholesale electricity prices are determined by the price of fossil fuels (i.e. gas and coal). When the current set of regulatory arrangements were introduced (see Box 5.1), the costs of coal or gas based generation in the UK were typically estimated at about 1.5-2p/kWh, and wholesale electricity prices reflected these costs. But in recent years, fuel prices and particularly gas prices have increased markedly. The average wholesale electricity price in the year to October 2008 was around 6-7p/kWh, compared with 2-3p/kWh in the same period a year earlier (Figure 5.12). When fossil fuel prices are low, all low-carbon alternatives face a significant cost penalty; but at recent prices, some are cost-effective without any policy intervention. Looking forward, fossil fuel price uncertainty is at least as great as the variation over the last three years.[5]

- **Different stages of technological development:** Some low-carbon technologies (e.g. wind and nuclear) are proven and are already installed on a significant scale and in normal commercial generation across the world. Some (e.g. wave power and CCS) have yet to be deployed on a significant scale. Relative cost figures therefore often depend on comparisons between the actual costs of one technology and the estimated future costs of another.

- **Long-term cost trends:** The cost of deploying new technologies typically falls significantly as volumes of production increase, cumulative research and development commitments rise, and manufacturing scale is achieved. Estimates of the future cost of renewables, of new generation nuclear plants, and of CCS, therefore depend crucially on assumptions about the potential for future cost reduction: apparently minor changes in assumptions can dramatically shift the relative cost of different technologies.

- **Short-term cost trends and supply bottlenecks:** Over the last few years, however, the investment costs of all electricity generation options have increased as a result of rising energy and steel prices and of supply bottlenecks which have driven up the price of wind turbines and solar photovoltaic panels, but also the costs of nuclear new build and of conventional power station construction. Some of these supply bottlenecks may diminish in a few years, some may last many years. Estimates of the relative cost of different technologies in the future are therefore highly sensitive to the date at which each individual cost was calculated, and to the extent to which future supply bottlenecks (or their disappearance) have been anticipated. In particular there is a danger that the relative cost of the already deployed technologies (e.g. wind or nuclear) can be overstated relative to speculative technologies (e.g. CCS) simply because the impact of supply bottlenecks on the former is already apparent, while desktop calculations of the latter's cost do not allow for the bottlenecks which might emerge if CCS were deployed on large scale.

The impact of these factors on the economics of alternative technologies is considered in detail in a separate technical paper.[6] This section summarises our key conclusions in respect to renewables, nuclear, and CCS, and identifies the implications for the relative cost likely to pertain over the first three budget periods.

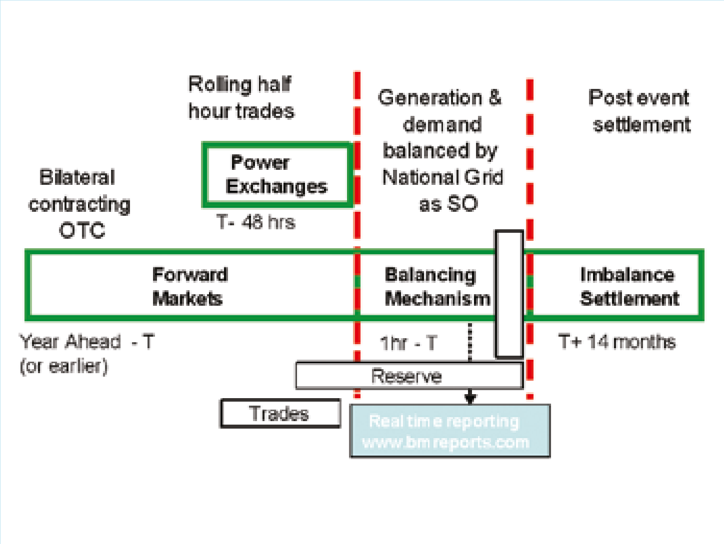
5 The projections of fossil fuel prices used in our analysis is presented and disscussed in Chapter 3, Section 1.
6 Forthcoming on the CCC website.

Box 5.1 The UK market for electricity

The market for electricity is governed by a complex set of regulatory arrangements known as BETTA (British Electricity Trading and Transmission Arrangements). Within BETTA, electricity is bought and sold on a bilateral basis between generators and suppliers.

Forward markets allow contracts for electricity to be struck up to years in advance. Closer to real time (i.e. within an hour of delivery) power is exchanged within the 'balancing mechanism' (see Figure, below). Within this mechanism, the System Operator (i.e. National Grid) is able to fine tune contract positions to ensure that supply and demand for electricity is matched in real time and that the system remains within safe technical limits.

Figure: Key features of BETTA

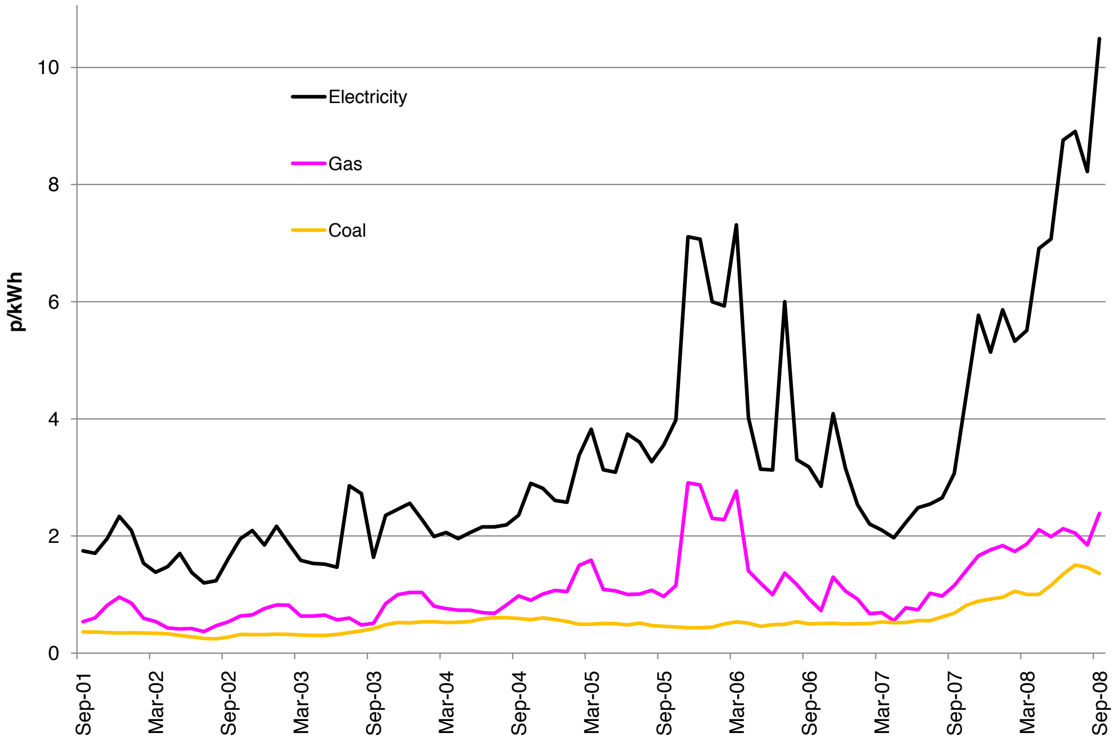


Source: National Grid

Price formation for electricity occurs in a similar way to other commodity markets. Within the balancing mechanism generators offer to dispatch electricity and the spot price is set by the market's view of the short-run marginal cost of the last plant dispatched to meet demand. Forward prices for electricity are typically much less volatile than the spot price, which will oscillate widely depending on the time of day (i.e. very high during peak periods when more expensive plants are dispatched in order to meet high levels of demand). Conversely, during periods of low demand (i.e. in the middle of the night) prices are low.

Very few consumers are exposed to the spot price and the majority of electricity is exchanged on forward contracts that have been struck on a quarterly or annual basis. In the short to medium-term the wholesale electricity price in the UK remains closely linked to the price of gas (as the marginal source of generation) as Figure 5.12 illustrates.

Figure 5.12 Average monthly wholesale electricity, gas and coal prices, September 2001 – September 2008



Source: Platts.
Note: Electricity – Day-ahead baseload; Gas – Day-ahead NBP; Coal – 90 day forward CIF ARA. Nominal prices .

Renewables

Chapter 2: *Meeting a 2050 target* considered a range of renewable technologies which could play a role in decarbonising electricity generation. Of these, two groups of technology are unlikely to play a significant role in the UK within the first three budget periods. These are:

- **Wave and tidal stream power:** which are currently at a much earlier stage of technological development than wind, and which if deployed commercially today would face a very significant cost penalty. Given the UK's inherent natural resource, these technologies may become important in the long-term, but over the first three budget periods, their contribution to UK emission reductions is likely to be marginal.

- **Solar photovoltaic (PV):** At present solar PV electricity generation costs are much higher than those for wind, and indeed have increased in the last few years as a result of bottlenecks in supply in the face of unanticipated and rapid increases in demand. Over the medium to long-term, it is quite possible that solar PV costs will fall dramatically due to learning curve effects, manufacturing scale and research breakthroughs, and that solar PV will play a major role in electricity generation in many naturally sunny countries. But the more limited sunshine resource of the UK makes large-scale deployment in the UK less likely even in the longer-term, and within the first three budget periods the emissions reduction potential of solar PV deployment is very small.

Conversely there are three renewable technologies which could play a significant role in emission reduction in the next three budget periods. The most important of these is wind; but the role of biomass merits careful consideration; and tidal range could play a significant role by the end of the third budget.

Wind power: Various estimates of the cost of wind generated electricity in 2010 are shown in Figure 5.13[7]. These range widely, from as low as 3p/kWh for the lowest estimates for onshore wind, to as high as 10p/kWh or higher for offshore. Three key points should be noted in assessing the implications of these estimates.

- **Long-term versus short-term cost trends**
  - The long-term cost trend has been downwards, with the cost of wind generation falling by over 75% in the last 20 years (see Chapter 2: *Meeting a 2050 target*). But over the last two years costs of turbines and switchgear have increased significantly, due to steel price increases and supply bottlenecks. Typical estimated costs for onshore generation in the UK have therefore increased to about 7p/kWh.
  - In the medium term, however, supply bottlenecks may well ease (given few inherent barriers to entry for new production capacity) and the long-term trend decline may be resumed. There is therefore a danger that current estimates are overstating the long-term cost of wind power deployment. The fact that German onshore feed-in-tariffs (a market measure of the price at which operators are willing to invest) are significantly below typical UK cost estimates provides some support for this hypothesis[8].
  - Conversely it is possible that the UK may face a significant cost penalty as it drives wind deployment over the next several years with wind deployment more expensive than in, for instance, Germany or Spain, which have achieved rapid progress over the last ten years when costs have been lower. This may be particularly the case in offshore deployment given supply chain bottlenecks (e.g. there are only a limited number of appropriately equipped supply vessels currently available to support offshore construction activity).

- **Costs of intermittency, back-up, connection and transmission.**[9] Since wind power is inherently intermittent, it is important that estimates of the cost of wind generated electricity allows for the back-up generation capacity (usually gas based) needed to meet demand when the wind is not blowing.[10] These estimates are considered in more detail in a separate technical paper but essential points to note are:[11]
  - As discussed in Chapter 13: *Energy security of supply*, there is no inherent 'security of supply' problem created by intermittency, but simply one of cost: how much back-up capacity is required and how much does it cost to keep it available. Estimates by Redpoint for the draft Renewable Energy Strategy consultation published in June this year suggest that around 1.3p/kWh should be added to the cost of renewable electricity if intermittent renewables, primarily wind, reach around 25% of UK electricity supply. Estimates by SKM for the draft Renewable Energy Strategy consultation put these costs at around 1.7p/kWh of intermittent renewable electricity, while recent estimates from the Carbon Trust put them at around 1.2p/kWh (Figure 5.14). While there is much uncertainty around these cost estimates, it is likely that they are within the range of 1–2p/kWh of intermittent electricity, at the levels of wind penetration likely to be required to meet the renewables target[12].

---

7 Except where stated to the contrary, levelised cost estimates in this document come from the following sources: Carbon Trust (2008), *Offshore wind power: big challenge, big opportunity;* Ernst & Young (2007) *Impact of Banding the Renewables Obligation – Costs of electricity production*; IPPC (2005) *Special report on carbon dioxide capture and storage*; Pöyry (2008) *Compliance costs for meeting the 20% renewable energy target in 2020*; Redpoint et al (2008) *Implementation of the EU 2020 renewable target in the UK electricity sector: Renewable support schemes*; SKM(2008), *Growth scenarios for UK renewables generation and implications for future developments and operation of electricity networks*, UKERC (2006), *An assessment of the evidence on the costs and impacts of intermittent generation on the British electricity network.*

8 Although part of the difference is likely to be explained by the fact that unlike the levelised cost estimates, the German feed-in-tariffs do not cover grid connection and extension costs. Pöyry (2008) estimate that grid related costs make up around 14% of the capital cost of onshore wind.

9 System balancing and back-up costs are not included in the levelised cost estimates presented in Figure 5.13, but are included in our assessment of total costs in Section 5 below, and in Figure 5.17.

10 The back-up generation capacity referred to here is the capacity needed to cover the difference between the proportion of wind generation which will be reliably available to meet demand any time it is needed (the capacity credit, assumed to be around 20%) and the average annual availability of wind plant (between 21% and 39%, depending on the site),

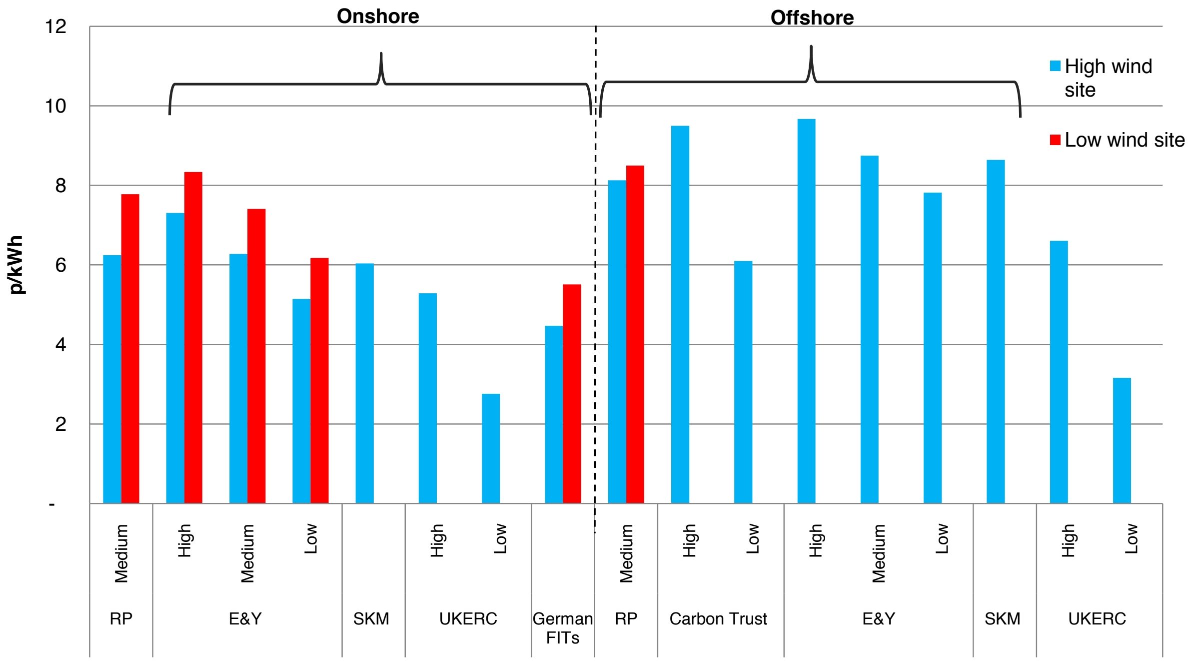
11 Forthcoming on the CCC website.

12 Other studies have come up with lower estimates, for example, a systematic review by UKERC (2006) estimated that the costs would be 0.8p/kWh at 20% penetration of intermittent renewables.

- Over the long-term, and in the context of the technological vision presented in Chapter 2, the cost penalty incurred as a result of intermittency can be reduced if more electricity is stored in car and other batteries, and if smart metering allows non time-critical demand for electricity to be switched off in the face of supply shortage. Costs can also be reduced by increasing the degree of interconnect with other national grids.

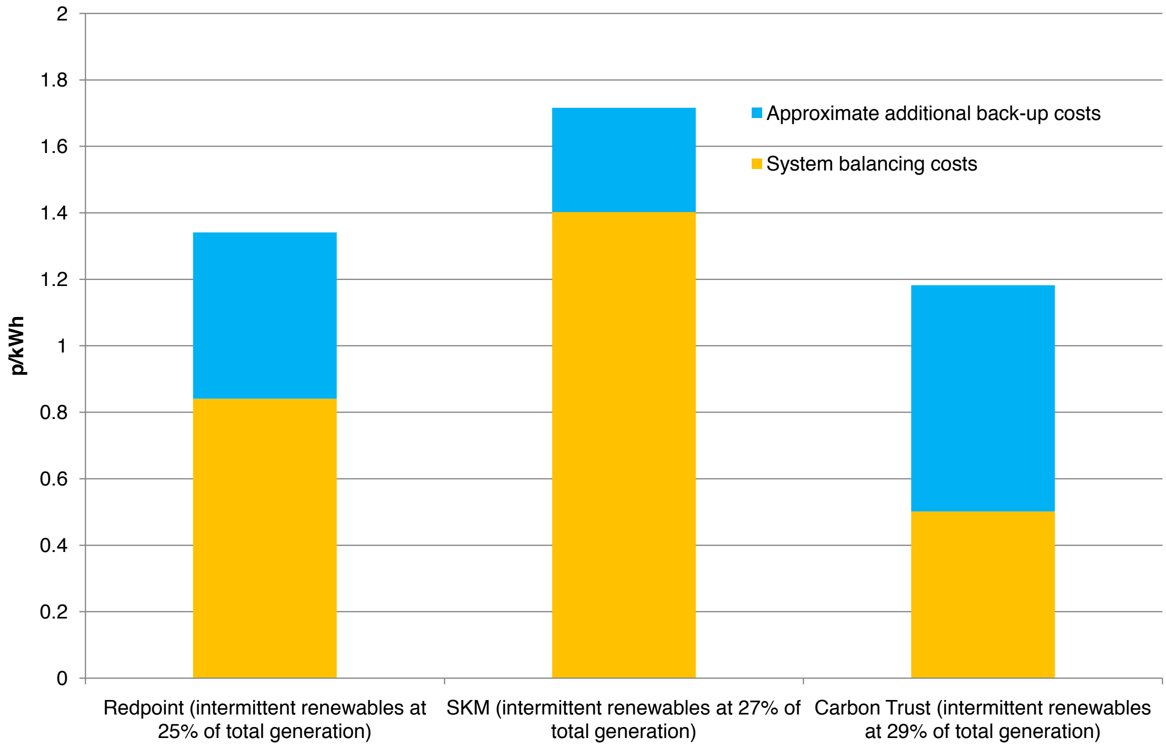
- **Offshore wind is significantly more expensive than onshore:** Whatever the uncertainties about the absolute cost of wind power, or of wind power relative to fossil fuel power, it is clear that offshore wind will be significantly more expensive than onshore, with typical estimates placing the additional cost penalty at 2p/kWh. In addition it appears likely that supply bottlenecks may be more severe and longer lasting in offshore deployment than in onshore. High reliance on offshore wind would therefore increase the danger that renewables targets cannot be met as a result of supply bottlenecks and will result in significant additional costs over and above those strictly necessary to achieve emissions reduction targets.

Figure 5.13 Estimates of levelised costs for wind



Source: SKM (2008), Ernst & Young (2006), UKERC (2006), Redpoint et al (2008), Carbon Trust (2008). Calculations of German feed-in-tariffs (FITs) based on www.wind-energie.de.and www.windworks.org
Note: £2008. All costs relate to 2020 except for UKERC costs which are based on a systematic review of costs from a range of years, and German FITs which are based on current levels. Top of Carbon Trust range relates to best site. Bottom of range relates to worst site.

Figure 5.14 Additional costs at different penetrations of intermittent renewable generation (e.g. wind generation)



Source: CCC Calculations based on SKM (2008), Redpoint et al (2008) and Carbon Trust (2008).

Biomass: The UK currently generates around 2 TWh annually from biomass which is co-fired with coal. The cost per tonne of emissions saved from co-firing is comparable with other forms of renewable electricity generation, and so there may be a role for co-firing alonside onshore and offshore wind.

This may be true for the first three budget periods. Further into the future, however, it is our view that there is no role for conventional coal-fired generation without CCS; we discuss this in Section 3 below. Any role for co-firing would then have to be in the context of CCS technology; this could potentially be an attractive means for reducing residual CCS emissions as the carbon price increases through the 2020s and beyond.

One alternative to co-firing is dedicated biomass generation (i.e. where biomass is the only fuel used). This may be regarded as a low-carbon source of electricity, and could in principle be an attractive option for power sector decarbonisation. In practice, however, Defra's Biomass Strategy (2007) and the draft Renewable Energy Strategy concluded that dedicated biomass generation is relatively expensive, both in comparison with other forms of renewable electricity generation, and in comparison with alternative uses for biomass. In particular, Defra's Biomass Strategy suggested that biomass should be used for generation of renewable heat rather than renewable electricity.

In addition, there may be questions over the sustainability of biomass production and the associated life-cycle emissions. These are discussed in the Gallagher Review.[13]

Tidal range: This is a potentially large source of renewable energy generation that could make a significant contribution to power sector decarbonisation. The proposed Severn Barrage project, for example, could contribute up to 4% of total UK power generation.[14] It may be attractive for this

13 RFA (2008) *The Gallagher review of the indirect effects of biofuel production.*
14 Sustainable Development Commission (2007), *Turning the Tide: Tidal power in the UK.*

reason, and because it would generate on a predictable basis, in contrast to the unpredictably variable nature of wind generation.

Questions remain, however, over the economics of this technology. Cost estimates provided by the Sustainable Development Commission (SDC) for the Severn Barrage range from 4p/kWh to 12p/kWh and are highly sensitive to assumptions on construction and financing costs (with the higher end of this range corresponding to the risk adjusted discount rates assumed elsewhere in this chapter).[15] Clearly at the lower end of the range, the economics of the Severn Barrage are favourable, whereas at the higher end of the range it is relatively expensive in comparison even with offshore wind. Going beyond narrow economic considerations, there are a number of possible impacts of the project which would have to be considered as part of any investment decision. These could include flood protection benefits, changes in water quality, and impacts on biodiversity.

Our view is that the Severn Barrage and other potential tidal range projects certainly warrant further assessment and could be an important contributor to power sector decarbonisation. For the purposes of this chapter, however, which focuses on the first three carbon budgets, we recognise that tidal range is likely to have very limited impact during this period, given long lead times for project development and implementation.

Nuclear

Current estimates of the likely cost of generating electricity from new nuclear are in the range 4-5p/kWh (Figure 5.15). These cost estimates are higher than typically produced two to three years ago, as a result of the significant increases in steel and other component prices, and of significant supply bottlenecks which have emerged as demand for new nuclear power station construction has come up against a limited capacity supply industry.

But fossil fuel price increases over that period have produced an even greater increase in the cost of fossil fuel based electricity, and the relative cost position of nuclear has therefore improved (Figure 5.16).

The future path of fossil fuel prices is inherently uncertain, but under the central, high and high-high fuel price projection, it is likely that nuclear power could be fully economic compared to coal and gas generation even before the impact of a significant carbon price, and even more so given the possible range of future carbon prices discussed in Chapter 4: *Carbon markets and carbon prices* (Figure 5.15)[16].

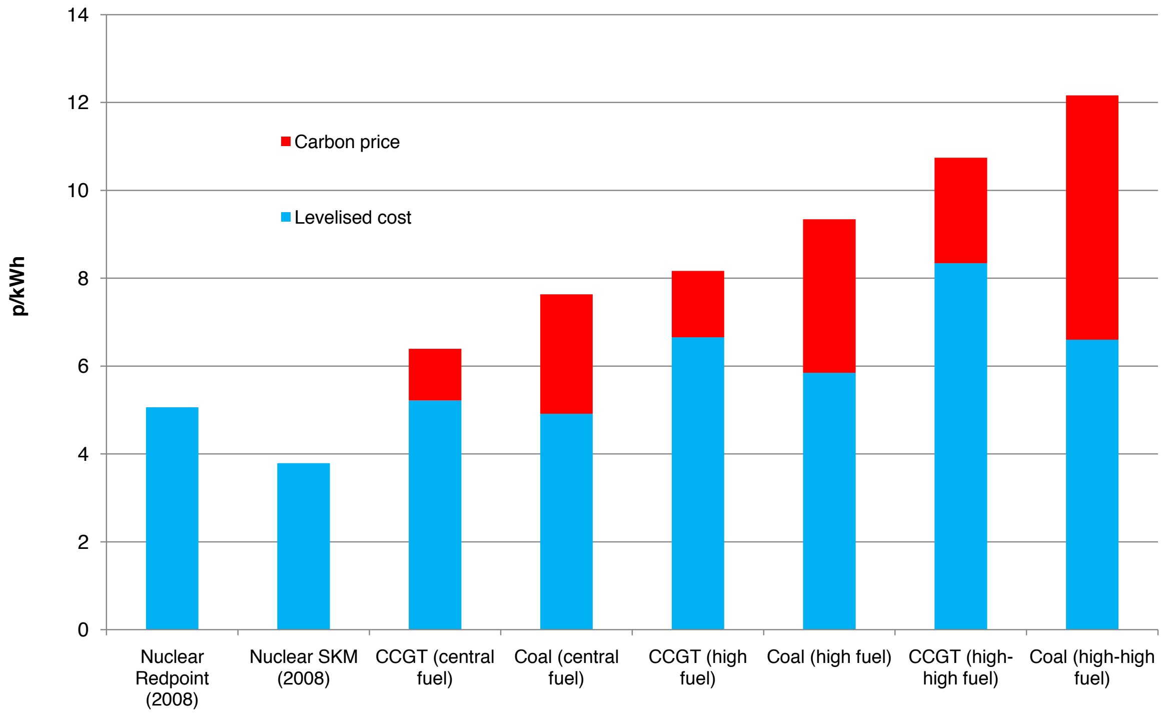
There is therefore a strong economic case for nuclear power to play a role in the future UK electricity generation mix. And our analysis suggests that some of the standard arguments made against the costs of nuclear power are not valid.

- The £80 billion of decommissioning and waste disposal costs which the UK may face from previous nuclear deployment are often cited. But the vast majority of these relate to military-linked research programmes in the 1940s to 1960s and to the Magnox reactors, and are not relevant to the estimation of future costs. The £3.4 billion of decommissioning costs estimated for the ten advanced gas-cooled reactors built in the 1970s are more relevant and costs for latest generation stations may be lower still. Estimates for both decommissioning and waste handling costs are included in the total cost figures presented in Figures 5.15 and 5.16.

- Potential limits to the availability of uranium fuel supplies are also sometimes cited, but the 2006 SDC report on nuclear power (despite concluding on balance against its deployment), argued that concerns about the availability and cost of uranium supplies were not a valid basis for rejecting the nuclear option.[17]

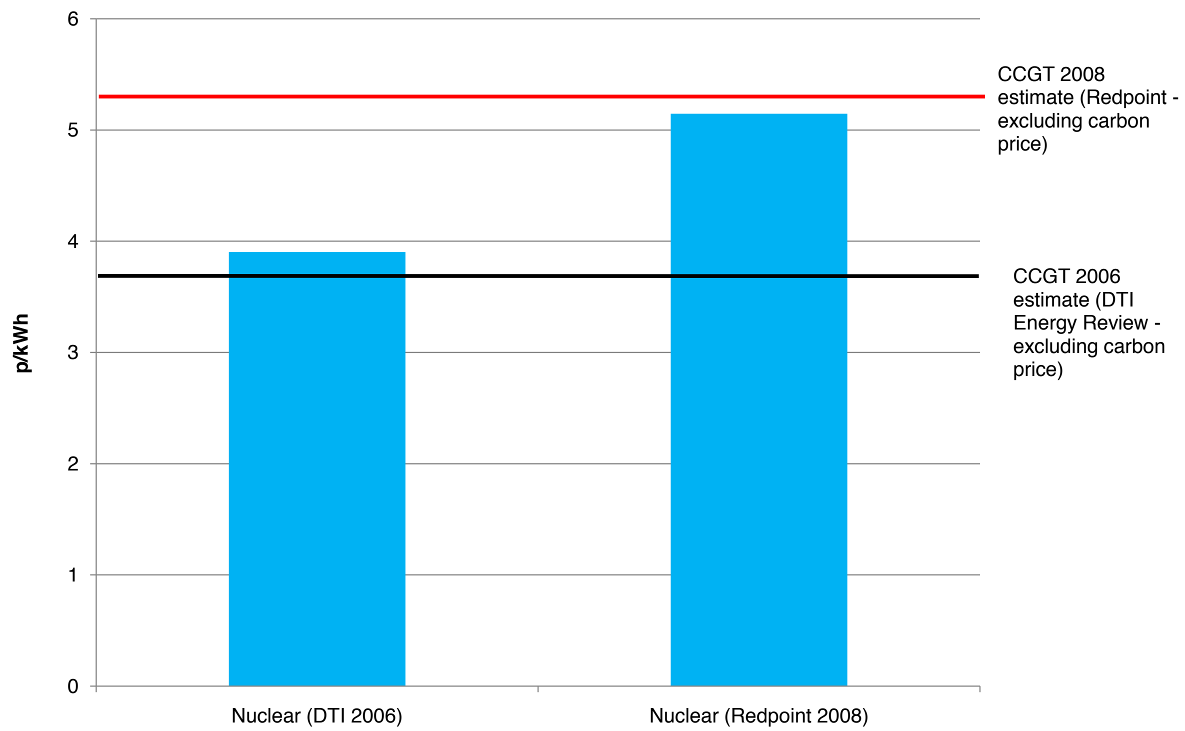
15 Costs cited are for discount rates ranging from 3.5-10%, SDC (2007)
16 As noted in UKERC (2006), *A Review of Electricity Unit Cost Estimates*, low levelised costs do not necessarily lead to investment. Other considerations will affect take up, for example, the correlation of gas prices to electricity prices can make investment in CCGT more attractive than its levelised costs would suggest due to a lower risk return.
17 SDC (2006) *The role of nuclear in a low-carbon economy.*

Figure 5.15 Current estimates of the levelised costs of nuclear plant relative to CCGT and coal under central, high, and high-high fossil fuel prices



Source: Redpoint et al (2008) SKM (2008) and CCC estimates of the carbon price.
Note: £2008. The carbon price rises with higher fossil fuel prices as the coal to gas price differential increases. SKM cost estimate is for 2020. All other estimates are current.

Figure 5.16 Levelised cost of nuclear relative to CCGT, 2006 and 2008 estimates



Source: Redpoint et al (2008) and DTI (2006) *Energy Review*.
Note: £2008.

The only valid basis for excluding nuclear power from the future generation mix therefore relate not to cost, but to concerns about the long-term sustainability of nuclear waste storage and about the possible implications of an extensive global nuclear power industry for nuclear military proliferation. The Committee recognises that these debates raise issues which go beyond cost economics alone.

If, however, nuclear power is in principle acceptable, it is likely that cost economics will argue for a significant nuclear role within the generation mix, particularly if and when greater use of battery electrical storage (for instance for electric cars) increases the demand for predictable off peak (e.g. overnight) capacity.

Within the first three budget periods, however, there are limits to the feasible pace of nuclear deployment, with the timetable for planning consent, licensing and construction, making it difficult to envisage that a new nuclear power plant could come on stream before 2017. And it is worth noting that if many countries in the world simultaneously opted for a significant expansion of nuclear power, significant supply bottlenecks could emerge. In our discussion of scenarios in Section 4 below, we therefore assume that up to three new stations represents a realistic range of possible new nuclear deployment by the middle of the third budget (i.e. by 2020). Beyond then, however, it is possible that new nuclear investment could and should at least replace, and possibly exceed, existing nuclear capacity.

Carbon capture and storage (CCS)

Chapter 2 described the elements of CCS technology and suggested that it is highly likely to be economically feasible within the next 20 years, and almost certainly essential if the world is to meet appropriate CO_2 reduction targets, given the pace at which coal-fired generating plant is now being built, for instance in China and India. Estimates of the cost of CCS, meanwhile, built up from engineering analysis of the separate system elements, suggests that it may add about 2-3p/kWh to the cost of coal or gas based electricity,[18] resulting in total costs under the central fossil fuel price scenario close to those for onshore wind, and higher than those for nuclear power. Under the high and high-high fuel price scenarios, the cost would be slightly higher than that of onshore wind.

It is important to note, however, as we did in Chapter 2: *Meeting a 2050 target*, that CCS is not yet a proven technology at full commercial scale, and cost estimates must therefore be considered more uncertain than those for wind or nuclear power. It should also be noted that if many countries were simultaneously to attempt the large-scale and rapid deployment of CCS, supply chain bottlenecks might well produce cost increases of the sort currently being experienced in wind and nuclear deployment. And the deployment of CCS will not be uncontroversial or straightforward: it will for instance require the building of pipelines which may well be opposed on local environmental grounds, delaying considerably the feasible pace of deployment.

It is not therefore prudent to assume that CCS is likely to make a major contribution to the achievement of emission reductions in the first three budget periods. Instead the key issue is how policy during those periods can best be designed to facilitate a major take-off of CCS in the 2020s. That issue is considered in Section 3 below.

18 Based on IPCC (2005) *Special report on carbon dioxide capture and storage*. This cost estimate relates to post demonstration. Inevitably, demonstration CCS projects in the 2010s will have significantly higher costs than those of plants built in the 2020s, which will benefit from the learning that takes place within earlier projects,

Relative costs: summary and implications

The technologies discussed above will make it possible to almost entirely decarbonise electricity generation over the next 20 years. The implication of the analysis above is that the cost of decarbonisation will depend crucially on the level of fossil fuel prices, and that this cost is likely to be manageable across the range of fossil fuel prices. Key summary points are illustrated in Figure 5.17 and discussed below:

- If onshore wind costs are towards the lower end of estimates, onshore wind will be competitive with coal and gas-fired generation in the central fossil fuel and carbon price scenarios. Under the high and high-high scenarios, onshore wind is almost certain to be fully competitive.

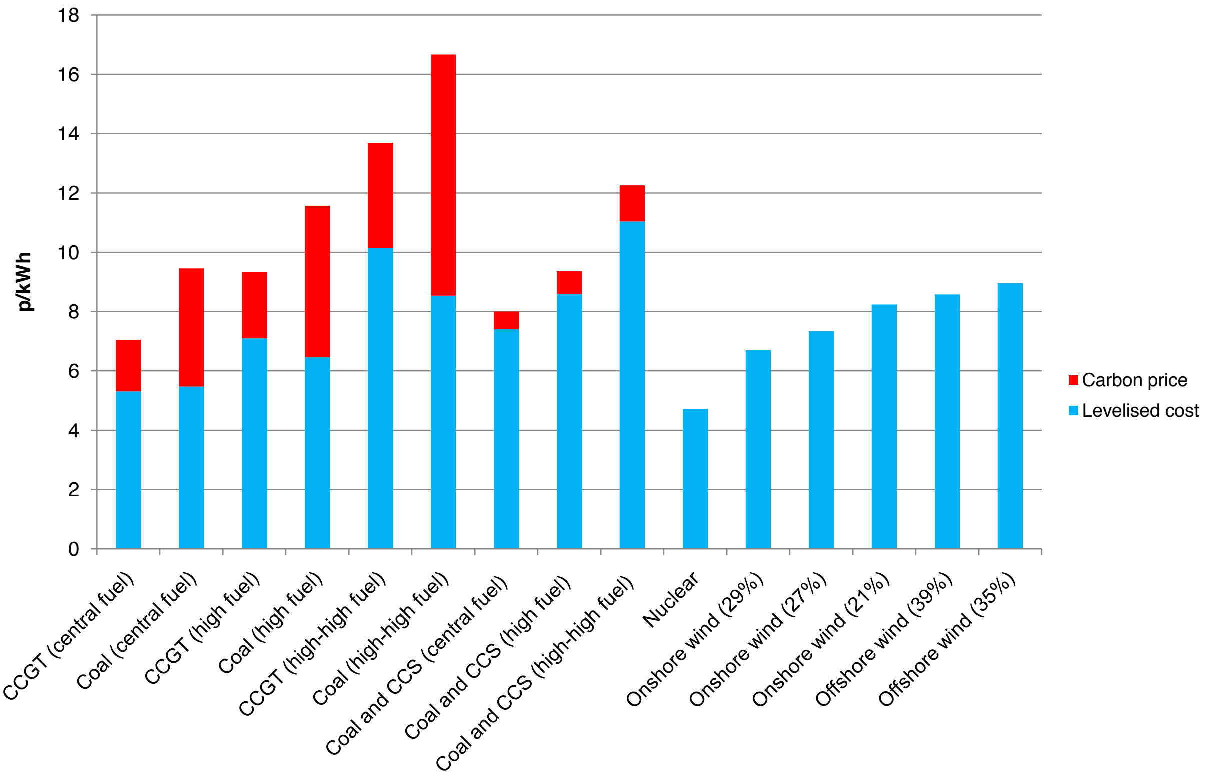
- Nuclear power is competitive with both coal and gas-fired generation in the central fossil fuel price scenario even without a carbon price. Under the high and high-high fuel price scenarios, nuclear is a clearly lower cost solution.

- Offshore wind is competitive with fossil fuel price generation under the high fossil fuel price scenario, with a carbon price.

- Given central carbon price forecasts, coal with CCS might be competitive with conventional fossil fuel price generation, but this relies on cost estimates which are inherently uncertain until large-scale deployment has been achieved. CCS options are similar to onshore wind under the central fossil fuel price scenario, and similar to offshore wind under high fossil fuel prices. CCS is unlikely to be cheaper than nuclear unless fossil fuel prices are significantly below the central scenario.

The cost of decarbonising electricity generation will therefore depend crucially on fossil fuel price assumptions. And the optimal mix of different low-carbon technologies will depend on the evolution of cost trends which cannot be predicted in advance. But the range of technologies available suggests that electricity generation can be significantly decarbonised without an unduly high cost penalty over the next 20 years, and that major emission reductions can be achieved over the first three budgets. Section 4 outlines alternative decarbonisation scenarios for those first three periods, and Section 5 analyses the aggregate costs involved. First, however, Section 3 addresses policy issues relevant to the definition of appropriate and credible scenarios.

Figure 5.17 Summary of levelised costs in 2020 under central, high and high-high fossil fuel prices[19]



Source: IPCC (2005) Redpoint et al (2008), CCC estimates of the carbon price.
Note: £2008. Percentages next to wind relate to average annual availability at the site. Intermittency costs are included in cost estimates.

19 Here we are presenting unit costs used in the 2008 analysis carried out by Redpoint for the draft Renewable Energy Strategy published by BERR in June 2008. These costs underpin the cost estimates presented elsewhere in this chapter.

3. POLICY ISSUES IN DRIVING LOW-CARBON INVESTMENT: IS A CARBON PRICE SUFFICIENT?

All emissions from major electricity generating plants are included within the EU ETS. In theory therefore, adequately tight emission reduction targets within the EU ETS should produce a carbon price which will automatically drive market behaviour compatible with those targets. A key policy issue is therefore whether this theory can be assumed to hold, or whether other policies, in addition to a carbon price, are required to ensure adequate progress towards electricity decarbonisation.[20] This section addresses this issue, considering in turn:

- The rationale for providing financial support to renewables in addition to a carbon price
- Whether nuclear energy deployment should receive support beyond that implicit in a carbon price, and whether a carbon price floor is desirable
- The appropriate policy stance towards any proposed investment in conventional coal-fired power generation

Renewable energy strategy: quantitative targets and non carbon price support

The UK is now politically committed to the EU's goal of sourcing 20% of all energy from renewable sources by 2020. The likely UK 'burden share' within this objective will require the UK to meet 15% of its demand for energy from renewable sources (see Box 5.2). Given limitations on the potential pace of renewables deployment in transport and heating, this is likely to imply that over 30% of UK electricity will need to come from renewable sources by 2020.

Box 5.2 EU renewables target and the UK draft Renewable Energy Strategy

At the Spring Council in 2007 the EU adopted a commitment to ensure that at least 20% of its final energy consumption comes from renewable sources by 2020. In January of this year the Commission published an energy and climate package which included details how this target would be met: the UK for its part must deliver 15% renewable energy by 2020, up from a baseline level of 1.5% in 2006. Recently BERR (DECC) published a draft strategy setting out how the UK might split effort between its power, heat and transport sectors and how policy can be developed to facilitate delivery. Investment in renewables will be particularly important in the power sector: BERR's analysis suggests that at least 30% of electricity generation must be delivered from renewable sources by 2020 in order for the target to be met.

This penetration of renewable electricity is very unlikely to be achieved by relying solely on the carbon price. Given the range of possible carbon prices suggested in Chapter 4, and under the central fossil fuel price scenario, wind deployment would not be economic if the only subsidy were via the carbon price. Only if the market confidently expected high or high-high fossil fuel prices would there be any possibility that carbon prices alone would drive wind deployment consistent with the required quantitative targets (see Figure 5.17 above).

The Government already has in place additional financial support through the Renewable Obligation Certificate (ROC) regime, with more support given to offshore wind than onshore (see Box 5.3). And in the draft Renewable Energy Strategy, the Government has laid out further non-financial measures likely to be required to drive renewables deployment.

20 The issue of whether a carbon price is a sufficient policy instrument alone also arises in relation to potential energy efficiency improvements and changes in consumer behaviour (see Chapter 4: *Carbon markets and carbon prices*)

Box 5.3 Financial mechanisms for encouraging renewables deployment

There are a range of support mechanisms for renewable electricity. In the UK the Renewable Obligation (RO) places a requirement on suppliers to source an increasing proportion of electricity from renewable sources. In other countries, such as in Germany and Spain, renewable generators are offered a guaranteed price for the output according to a fixed tariff (so called 'feed-in-tariff' or FIT mechanism). Here we describe the UK arrangement and a FIT mechanism (as in Germany) in more detail:

UK: Eligible generators are issued with Renewable Obligation Certificates (ROCs) for each unit (MWh) of electricity generated. Provisions to 'band' the RO were made in the 2008 Energy Act, so that the number of ROCs awarded to generators will vary according to generation types. Mature technologies (such as landfill gas) are eligible for fewer ROCs per MWh of electricity than less mature technologies such as wave or tidal. Generators, who also get a wholesale price for their electricity, can then sell their ROCs to electricity suppliers who can either present them, or pay a buy-out price to meet their obligation. At the end of each obligation period the buy-out 'fund' is recycled back to suppliers who have bought ROCs.*

Germany: The German system is similar to the banded RO insofar as it differentiates between technologies. However, grid operators are required to pay a fixed tariff for electricity from a range of technologies including landfill gas, geothermal, wind and solar. Tariffs are negotiated and guaranteed for a number of years (up to 20), but may be adjusted for new projects, and in the case of wind are related to the output of a reference plant.

Renewable generators in Germany do not necessarily receive higher subsidies than UK ones – indeed, in the UK market, (see Box 5.1, above) renewable generators potentially receive very high levels of subsidy under high fossil fuel prices. With no variable fuel costs, incumbent renewable generators benefit not only from selling ROCs but also high electricity prices. On the other hand, German renewable generators benefit from lower risk and uncertainty with a guaranteed income, therefore lowering the cost of capital for new and existing investors. It is consumers who are exposed to the risk and it is up to the government to set appropriate tariffs that set the right balance between supporting development without encouraging rent-seeking.

*In 2008/09 suppliers are required to present ROCs equivalent to 9.1% of total electricity sold, rising to 15.4% by 2015/16. The buy-out price is set for each Obligation period and is currently set at £34.30/MWh for 07/08, rising in line with RPI.

The UK's existing and evolving policy for renewable energy, and in particular for renewable electricity, already therefore represents a major departure from the pure market principle of relying on a carbon price instrument alone. The Committee believes that this departure is justified for the following reasons:

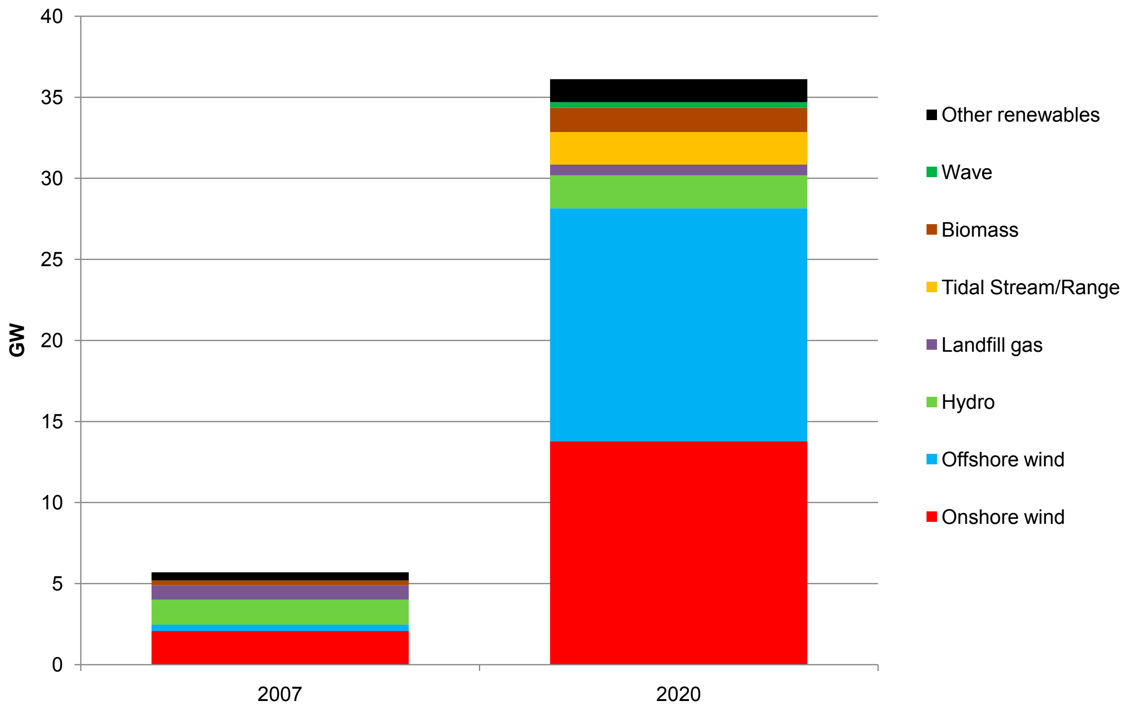
- Renewable technologies are still at an early stage of development with significant further cost reductions possible if scale is driven by initial government support. This may be particularly true for offshore wind, which is a relatively immature technology and where there may be significant opportunities for cost reduction going forward.

- Relying on other technologies to drive emission reductions would entail significant risks. Considerable progress in emission reductions in the first three budget periods could be achieved simply by replacing coal generation with gas, but further progress in subsequent budget periods would not be possible unless still lower carbon technologies were then available. Nuclear deployment is justified on cost grounds, but there are limits to the pace at which it can be deployed, and its deployment remains controversial for reasons unrelated to cost. And while CCS may be available to drive down emissions in the 2020s, the costs are uncertain and the pipeline construction required may be controversial, delaying deployment.

- Given this context, the deployment of renewable energy, in particular wind-based, makes sense even with a cost penalty. It is a proven technology, deployable in small capacity increments. And while its costs on central estimates are likely to be higher than those of fossil fuel based generation, they are within the range of possible fossil fuel generation costs given uncertainty over future fossil fuel prices.

The Committee therefore endorses the decision to set a quantitative target for renewable energy and renewable electricity.

Figure 5.18 Historic and projected renewable generation capacity, 2007 and 2020



Source: DUKES (2008); BERR Renewable Energy Strategy Consultation (2008).
Note: Other renewables includes solar PV, municipal solid waste (MSW) and sewage sludge.

The draft Renewable Energy Strategy has set out a scenario of how the UK's EU target could be met, with onshore wind power growing from 2 GW to 14 GW of capacity and offshore growing dramatically from 1 GW to 14 GW (see Figure 5.18). To achieve these targets, two sets of policies are required and are now either in place or envisaged:

- Financial support above the carbon price needs to be provided. Support mechanisms for renewable technologies are described in more detail in Box 5.3. In the UK support is provided via the Renewables Obligation, with the subsidy varying by renewable technology, and according to the balance of supply and demand in the market for renewable certificates (ROCs). There is some evidence to suggest that this regime may be less effective than a feed-in-tariff (i.e. more expensive per volume of renewable electricity supply stimulated)[21]. However there is considerable merit in continuity in the financial subsidy regime, and it seems likely that the key driver of the UK's lower rate of wind deployment compared with for instance Germany or Spain, has not been the different financial subsidy regime, but the existence of non-financial barriers such as those relating to planning consent and grid connection.

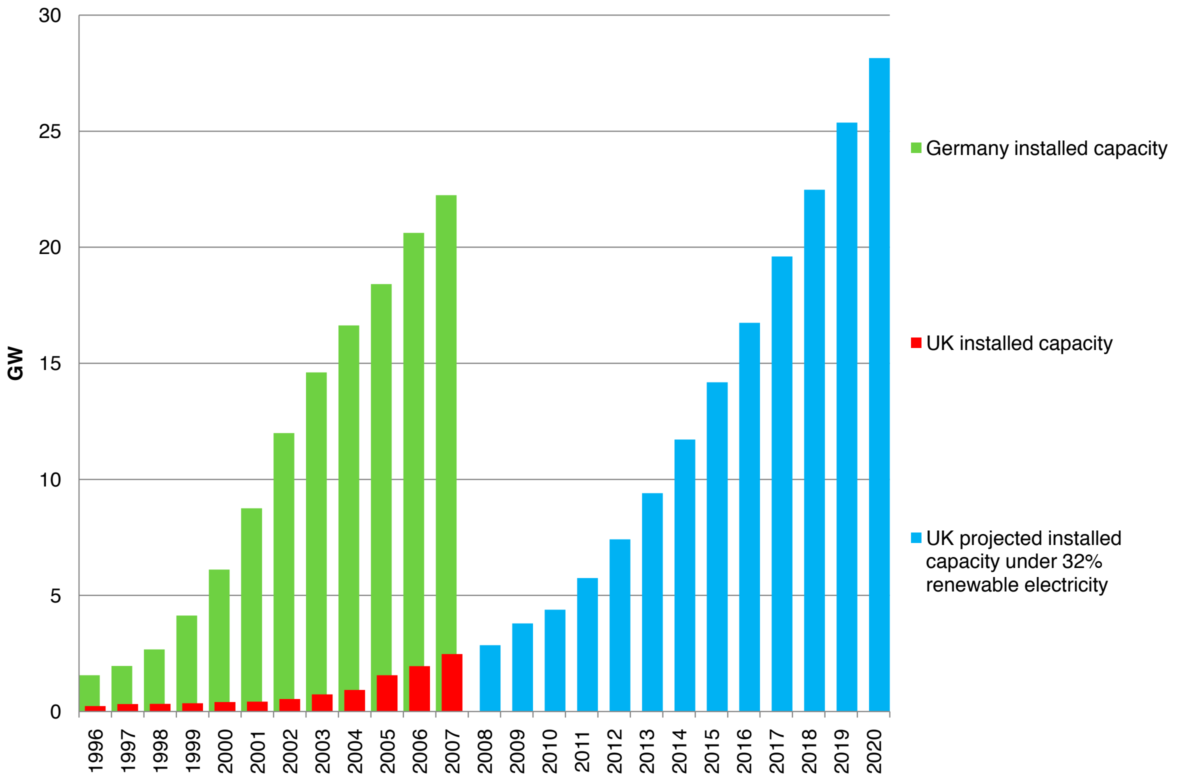
- Actions to remove non-financial barriers to deployment are therefore essential and are envisaged in the draft Renewable Energy Strategy. They include reforms to the planning system, changes to the Ofgem rules which determine the ease with which new wind operators

21 Redpoint et al (2008).

can connect to the grid, and additional investments within the high voltage transmission system. Rapid progress on all these dimensions is essential if the quantitative objectives of the draft Renewable Energy Strategy are to be met. More generally, Government will have to signal a very strong commitment in order to elicit the necessary supply chain response.

Provided these measures are taken, the objectives of the draft Renewable Energy Strategy should, in theory, be attainable. The increase in wind power deployment proposed in the UK for the next 12 years is no more rapid than that which has been achieved over the last 12 in Germany (Figure 5.19).

Figure 5.19 Cumulative installed wind capacity in UK and Germany 1996-2007 and projected UK 2008-2020 in the draft Renewable Energy Strategy



Source: European Wind Energy Association, DUKES (2008), BERR Renewable Energy Strategy Consultation (2008).
Note: Growth in wind capacity in the draft Renewable Energy Strategy, Redpoint et al (2008) achieving 32% electricity by 2020.

We therefore use the targets in the draft Renewable Energy Strategy as one key element in defining the scenarios for generation mix set out in Section 4 below, rather than presenting scenarios constructed on the basis of theoretical least-cost modelling.

But it also has to be recognised that the pace of deployment envisaged is very challenging, particularly in the face of the supply bottlenecks facing offshore wind deployment. Section 4 therefore also presents a scenario in which we fall somewhat short of the 30%+ target, but with more nuclear deployment offsetting that shortfall. Section 5 provides a cost estimate for this scenario, with cost savings resulting as nuclear is substituted for offshore wind, and which would also be attractive from a fuel poverty perspective.

These two scenarios are feasible alternatives today. If however the renewables option were to be chosen but then not achieved, the nuclear option could not be implemented rapidly, with increased investment in gas-fired generation the likely result.

- It is very unlikely that current electricity market arrangements would result in planned investment both in renewables at the levels envisaged in the draft Renewable Energy Strategy and in new nuclear before 2020. This is because if the market assumes that a high proportion of capacity will be intermittent, it will favour investment in low capital cost and flexible plant (e.g. gas) as the most economic complement. This is borne out in modelling commissioned in support of the draft Renewable Energy Strategy, which suggested that with high levels of intermittent renewables, investment in nuclear generation would be pushed back into the 2020s[22].

- If, however, it becomes apparent in future that renewables investment in line with the draft Renewable Energy Strategy is not feasible, it will not be possible to substitute nuclear for renewables at short notice, given long project lead times.

- The result would be more investment in gas-fired plant, which can be added relatively quickly to the system. This would not be desirable in terms of the radical decarbonisation of electricity generation that will be required through the 2020s.

This suggests that it is important to set a realistically achievable renewables target if emission reduction potential from the power sector is to be fully realised. It also raises questions about the functioning of the power market which are discussed in Chapter 13: *Energy security of supply*.

Nuclear energy: long-term expectations key

Putting aside the tension with renewables, nuclear energy is a long-established technology which has received very large public research and development support over the last 60 years. In contrast with renewables there is not therefore an ‘emerging technology’ argument for public support beyond that implicit in the carbon price. But there is a good argument that the costs of nuclear deployment would likely be reduced if multiple new nuclear stations were built rather than one or two: and the very long time scales of new nuclear deployment (both in the construction phase and in operation) mean that expectations of fossil fuel and carbon prices reaching far into the future are crucial to the investment case.

The key public policy priorities to facilitate new nuclear investment are therefore:

- A clear commitment to the principle of nuclear power deployment if and when cost justified, with supporting licensing and planning policies.

- Clear and radical long-term emission reduction objectives, such as the Committee’s proposed 80% by 2050 target, which will only be achievable if electricity generation is almost completely decarbonised by 2030.

- A clear commitment to keep tightening EU ETS caps and to appropriately limit the use of offset credit purchased within the EU ETS, to the extent required to meet long-term emission reduction targets. Given that the technology vision set out in Chapter 2 achieving a 80% cut by 2050 implies the almost total decarbonisation of electricity by 2030, and given that electricity generation accounted for around 70% of EU ETS emissions in the UK in 2007, the EU ETS emissions cap will need to fall particularly quickly in the 2020s.

22 As discussed in Chapter 2, the prospects for nuclear investment alongside intermittent renewables improve in the 2020s as off-peak electricity demand increases with the roll-out of electric cars and increased use of electric heating.

The planned evolution of EU ETS emission caps in the 2020s and 2030s is therefore crucial to the successful decarbonisation of electricity, and in particular to the prospects for both nuclear and CCS deployment, if these are not covered by quantitative targets of the sort applied to renewables. But it may be difficult to get political agreement on an appropriately tight cap regime sufficiently far ahead and with sufficient certainty to establish the carbon price expectations which will support the investment required to achieve radical decarbonisation. There is therefore a danger that fluctuating expectations and periodic low forward prices may deter required investment. Given this uncertainty there may be merit in considering whether policy for the development of the EU ETS should include not only setting emission caps as far in advance as possible, but also setting a floor price for carbon (i.e. a minimum price at which allowances will be auctioned) rising gradually over time. More clarity on the need for such a floor will be given following finalisation of the new EU ETS Directive (by early 2009) and the market and investor response to this.

CCS and conventional coal investment

The technology vision presented in Chapter 2 illustrated that any feasible path to a 80% reduction by 2050 will require the almost total decarbonisation of electricity generation by 2030, with further final steps in that process by 2050. This implies that any coal-fired generation plant operating in 2030 must only do so with CCS, and that CCS will need to be applied also to gas generating plant in the subsequent two decades. But the chapter also described the reality that CCS is not yet a proven technology at full commercial scale, that its costs are uncertain, and that the deployment of CCS will involve significant physical construction (e.g. of pipelines) which will in some cases be controversial and which therefore may produce significant delays. In a market context, any coal-fired power stations built over the next ten years are therefore almost certain to be built without CCS, notwithstanding the existence of a significant carbon price.

The reference emissions projections presented in Section 1 illustrated the retirement of existing coal generation capacity (see Figure 5.6). The mix of replacement capacity built will depend on expectations of both fossil fuel prices and carbon prices. Under some price expectations, it would theoretically make sense in least-cost terms only to build new gas plants (alongside renewables and some nuclear).

But it is also possible that proposals for coal-fired power stations will be brought forward, particularly if electricity generators have a preference in principle for a portfolio of different technologies in order to diversify risks of supply interruption and price volatility.

An important issue is therefore whether the only policy instrument influencing decisions on new conventional coal investments should be the carbon price, or whether other policies are required.

Provided that expectations of carbon prices in the 2020s and 2030s are consistent with the vision of radical decarbonisation, those expectations should themselves ensure that conventional coal stations are only built with the expectation and intention of retrofitting CCS, since conventional coal-fired generation will be in danger of becoming uneconomic in the face of those carbon prices.

But given the uncertainties of the political processes which determine EU ETS caps, and given uncertain and fluctuating carbon price expectations beyond the next few years, conventional coal investments could possibly go ahead without a clear acceptance of the need for future CCS installation.

There is therefore a strong case for buttressing the carbon price lever by establishing a clear and publicly stated expectation that coal-fired power stations will not be able to generate unabated through the 2020s and beyond the early 2020s.

One way to achieve this would be to establish a requirement that coal-fired power stations cannot be built beyond a certain date without CCS (say 2020), that those built before that date will be given a deadline for retrofitting CCS (say in the period 2020-2025), or that plants which choose not to retrofit should be allowed to generate for a very limited number of hours. Alternatives could be (i) to set emissions standards (i.e. company specific ceilings on the g/kWh emissions from power generation) implying the need for CCS retrofit in the 2020s to any conventional plant added over the next ten years, and ensuring that overall progress towards decarbonisation of electricity was in line with the required path to 2030 and beyond, and (ii) to establish a floor price within the EU ETS, as already discussed in the subsection on nuclear power above. These and other possible policy options warrant further consideration.

Alongside these possible policy measures, however, it is vital that planned demonstration projects of CCS technology go ahead as rapidly as possible, ideally on a larger scale and covering more variants of the technology than currently planned, whether in the UK or wider EU contexts.

4. SCENARIOS FOR GENERATION MIX AND IMPLICATIONS FOR EMISSIONS

The technology mix of UK electricity generation by the end of the third budget period will reflect both the new capacity investment decisions made over the next ten to fifteen years, and the operating decisions then being made on the capacity utilisation of the existing fossil fuel plants (coal or gas). The latter decision will be determined by the future relative balance of coal, gas, and carbon prices. The former decisions will be determined by expectations of fossil fuel and carbon prices, by the capital costs of alternative new capacity investments, and by the policy framework that the Government puts in place. Each of these is uncertain and will evolve over time. It is not therefore possible to define what the generation mix should or will be, rather decisions will be made by private companies within the framework of public policy.

All emissions from major power generators, moreover, are covered by EU ETS allowances. If therefore the Government accepts the Committee's recommendation that the UK's carbon budget should make no distinction between domestic UK emission reductions and those reductions achieved by allowance purchase within the EU ETS, different generation mix results will not change the UK's performance relative to the budget, but simply the degree to which the UK is a net buyer or seller of allowances within the EU ETS.

It is nevertheless useful to illustrate scenarios for the generation mix which might result from current policies for three purposes: (i) to gauge whether the UK is likely to be a net seller or buyer of allowances; (ii) to identify whether the UK is likely to be making adequate domestic progress towards a decarbonised electricity system; and (iii) as a basis for estimating possible cost implications.

The key variables which will affect generation mix and resulting domestic emissions will be the degree of success in achieving the renewable target, the extent of new nuclear deployment, and the balance between coal and gas plants in new fossil fuel investment. We have therefore modelled the impact of three scenarios with different assumptions along these dimensions, which illustrate the likely range of resulting possible generation mixes.[23]

- In Scenario 1 we assume the full success of the draft Renewable Energy Strategy, achieving in excess of 30% electricity from renewables by 2020,[24] with one CCS demonstration coal plant (0.3GW) by 2014. In addition we impose a CO_2 price as set out in Chapter 4 which stimulates all other new fossil fuel plants to be gas, and therefore no new conventional coal build. The capacity and generation mix in this scenario are shown in Figures 5.20 and 5.21. This would result in domestic electricity emissions falling by around 30% relative to what they otherwise would have been (i.e. the reference projection), or 40% on 1990 levels (Figure 5.22).

- To consider implications for progress against our EU ETS cap, we have combined the savings from supply side measures in Scenario 1 with the electricity demand reductions identified in Chapter 6: *Energy use in buildings and industry*, which together result in an emissions reduction from the power sector of 55% relative to 1990. Under our Interim budget (see Chapter 3: *The first three budgets*), this would make the UK a net seller of around 2 million tonnes of allowances in 2020, but in our Intended budget the UK would be a net purchaser of around 41 million tonnes of allowances in 2020.[25]

23 In these scenarios, we do not include abatement through merit order fuel switching, as the DECC model runs found that this did not occur under our central carbon price estimates, due to the relatively low amount coal burn in the reference case. However, other models (e.g. Pöyry's EurECa model) suggest that under a £40/tCO_2 carbon price, fuel switching would occur in the UK.

24 In line with the scenario presented in the draft Renewable Energy Strategy this is around 120TWh of renewable generation by 2020.

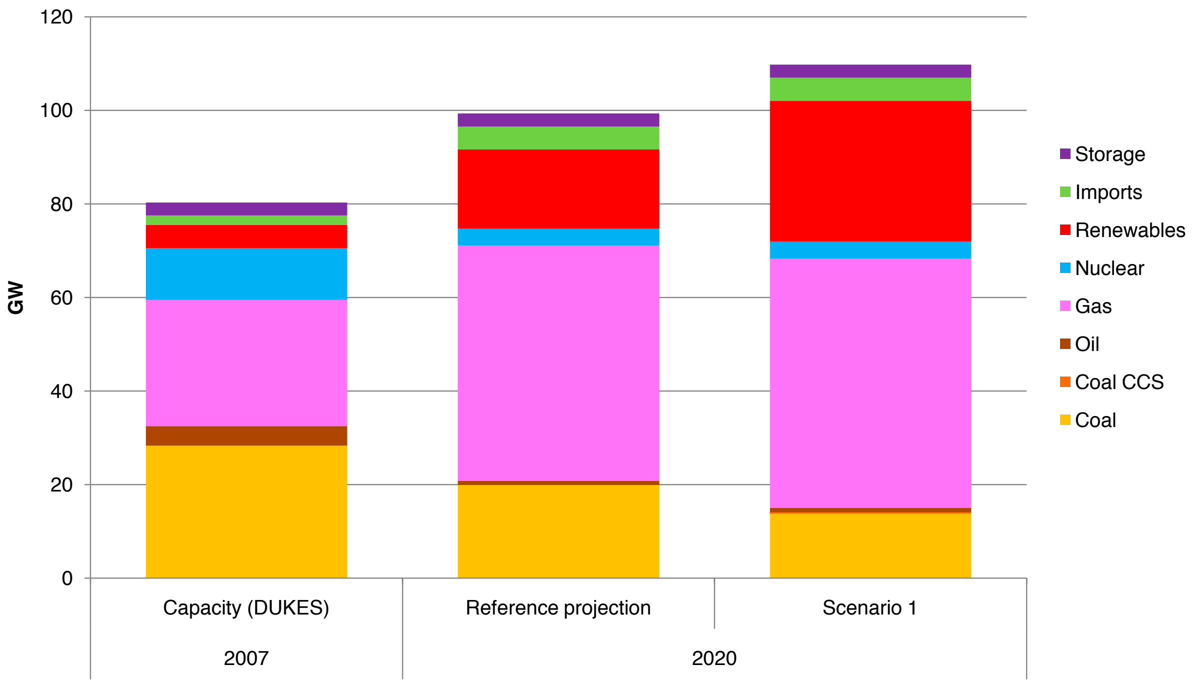
25 Under our intended budget the carbon price will be higher as the cap on the EU ETS sector will be tighter in line with the 30% GHG target (see Chapter 4). However, our modelling suggests that that UK power sector abatement would be similar under both carbon prices and the tighter cap would be mainly reached through additional purchases.

- In Scenario 2 we assume that the draft Renewable Energy Strategy is only around 75% successful, resulting in a capacity and generation mix shown in Figures 5.23 and 5.24[26]. Emissions here are the same as in Scenario 1 as the shortfall of the renewables is simply met by three new nuclear plants by 2020.[27]

- In Scenario 3, again we assume that the draft Renewable Energy Strategy is only 75% successful, but, that there is only one new nuclear power plant, and one-third of retiring coal capacity is replaced by new coal rather than new gas (Figure 5.23, Figure 5.24). Under this scenario the UK would be a net buyer of around 67 million tonnes of allowances against the Intended budget, and as a result could face an increasing economic burden with rising carbon prices in the 2020s and 2030s.

The emissions intensity in 2020 for all Scenarios is shown in Figure 5.25. In Scenarios 1 and 2 emissions intensity falls to around 310 gCO_2/kWh, compared with around 560g today. In Scenario 3, due to higher coal burn intensity falls to 375 gCO_2/kWh.

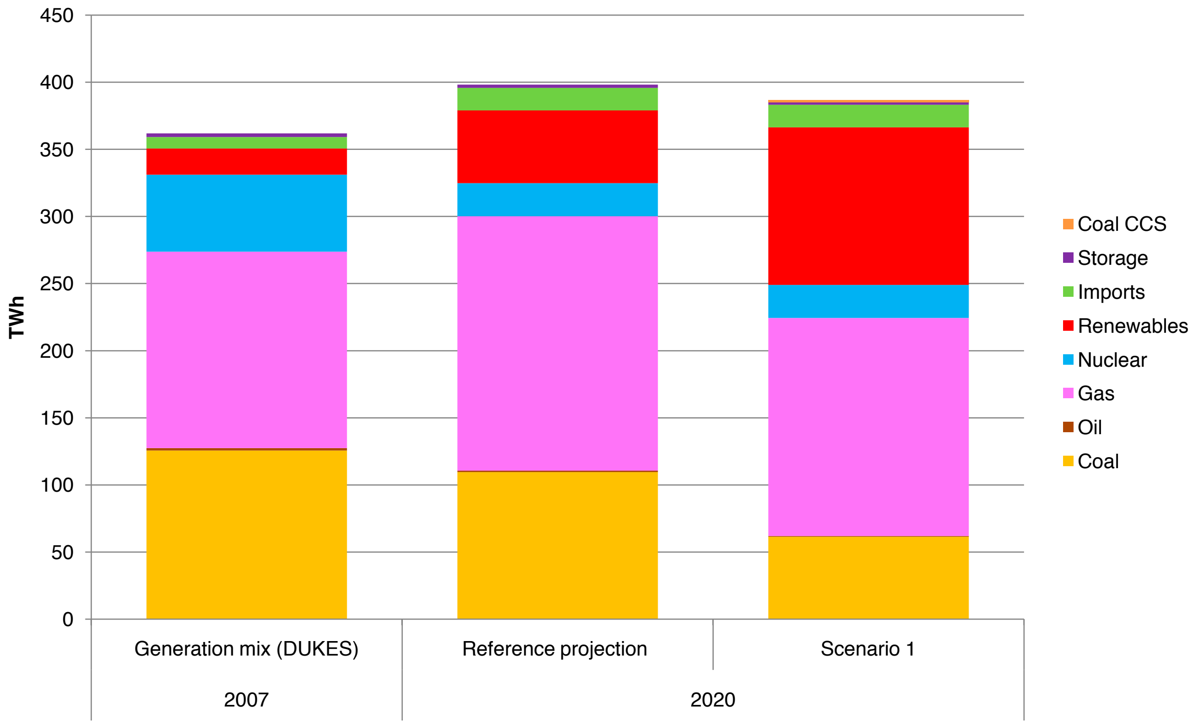
Figure 5.20 UK generation capacity in 2007 and projected in 2020, reference projection and Scenario 1 (central fossil fuel prices)



Source: DECC Energy Model based on CCC assumptions, DUKES (2008).

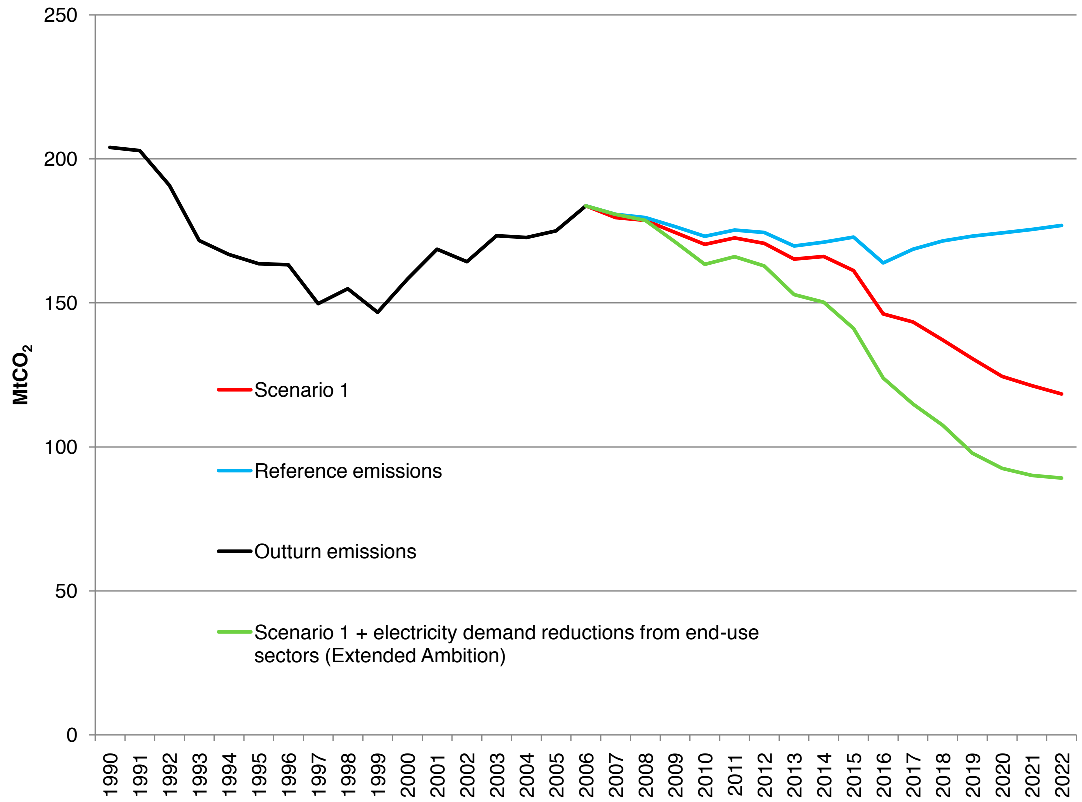
26 In Scenarios 2 and 3 renewable generation rises to around 90TWh in 2020, instead of around 120TWh in Scenario 1.
27 Emissions could be lower than Scenario 1 if, because of less wind capacity, there is also less need to hold gas plant as spinning reserve.

Figure 5.21 UK generation in 2007 and projected in 2020, reference projection and Scenario 1 (central fossil fuel prices)



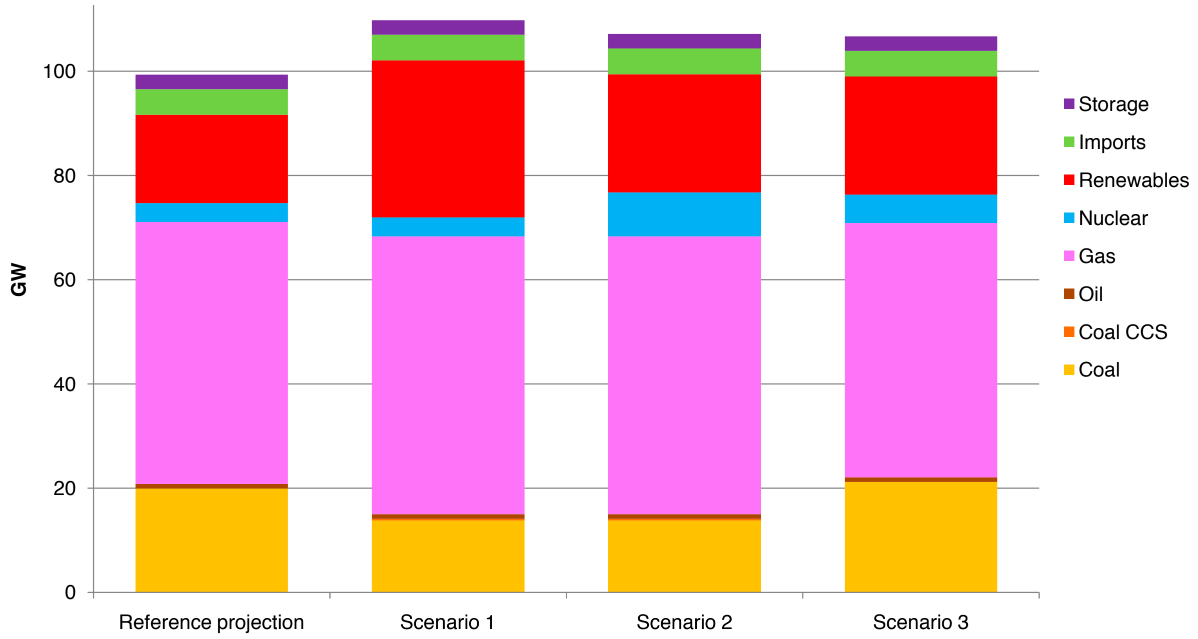
Source: DECC Energy Model based on CCC assumptions, DUKES (2008).

Figure 5.22 Historic and projected emissions in the power sector, reference projection and Scenario 1 (central fossil fuel prices) 1990–2022



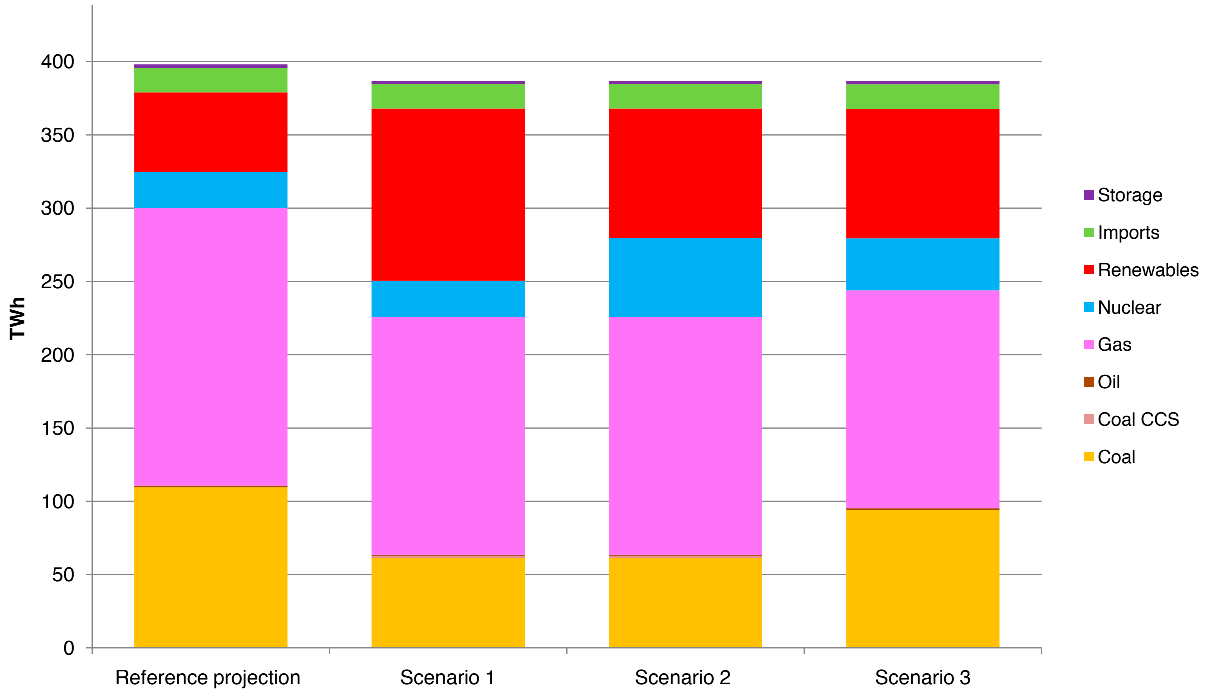
Source: DECC Energy Model based on CCC assumptions.

Figure 5.23 Projected UK generation capacity, reference projection and Scenarios 1, 2 and 3, 2020



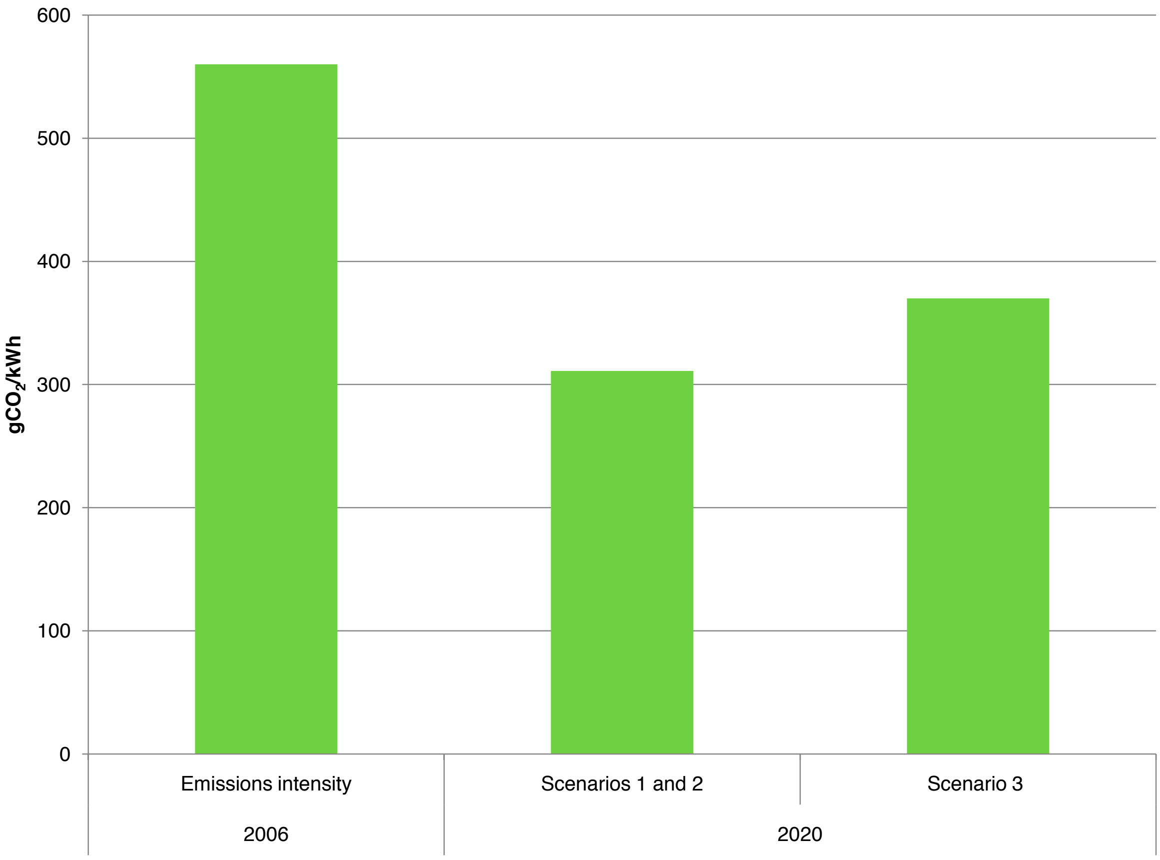
Source: DECC Energy Demand model (Scenario 1), CCC modelling (Scenarios 2 and 3)

Figure 5.24 Projected UK generation, reference projection and Scenarios 1, 2 and 3, 2020



Source: DECC Energy Model (Scenario 1), CCC modelling (Scenarios 2 and 3)

Figure 5.25 Emissions intensity per kWh of generation in 2020, Scenario 1, 2 and 3



Source: DUKES (2008); DECC Energy Model (Scenario 1, 2); CCC modelling (Scenario 3).

5. AGGREGATE COSTS TO GDP AND TO THE CONSUMER

The cost of decarbonising electricity generation is given by the costs of producing electricity in the emission reduction scenarios, minus the cost which would be incurred under the reference projection. The size of this additional cost burden is determined not only by the costs of deploying low-carbon technologies but also crucially by the level of fossil fuel prices and the carbon price. Given these multiple uncertainties, a wide range of estimates can be produced. But three key messages are clear from our cost modelling:

- In 2020 the total cost of the more aggressive Scenario 1 might lie around 0.2% of GDP (in a central fossil fuel price world) or 0.1% of GDP (if fossil fuel prices were as in the high-high scenario).[28] The fact that the costs fall as fossil fuel prices rise illustrates that decarbonising electricity provides a hedge against fossil fuel price uncertainty: the value of this hedge is considered in Chapter 13: *Energy security of supply.*

- In terms of the impact on electricity prices, however, costs are obviously much more significant. Under Scenario 1, relative to the reference projection, the residential retail electricity price could be around 15p/kWh (ie. 25% higher in 2020), if the central fossil fuel price scenario held. If the high-high fuel prices held, prices would be even higher at 20p/kWh (or around 25% higher than the high-high reference projection of 16pkWh,[29] see Figure 5.29). This raises important issues about the potential impact of decarbonising electricity on fuel poverty: these are discussed in Chapter 12: *Fuel poverty implications.*

- Resource costs could be significantly reduced if new nuclear build were to replace offshore wind investment. The cost of Scenario 2 as a proportion of GDP in 2020 would be 0.1%, which is £2 billion lower than the cost in 2020 in Scenario 1.

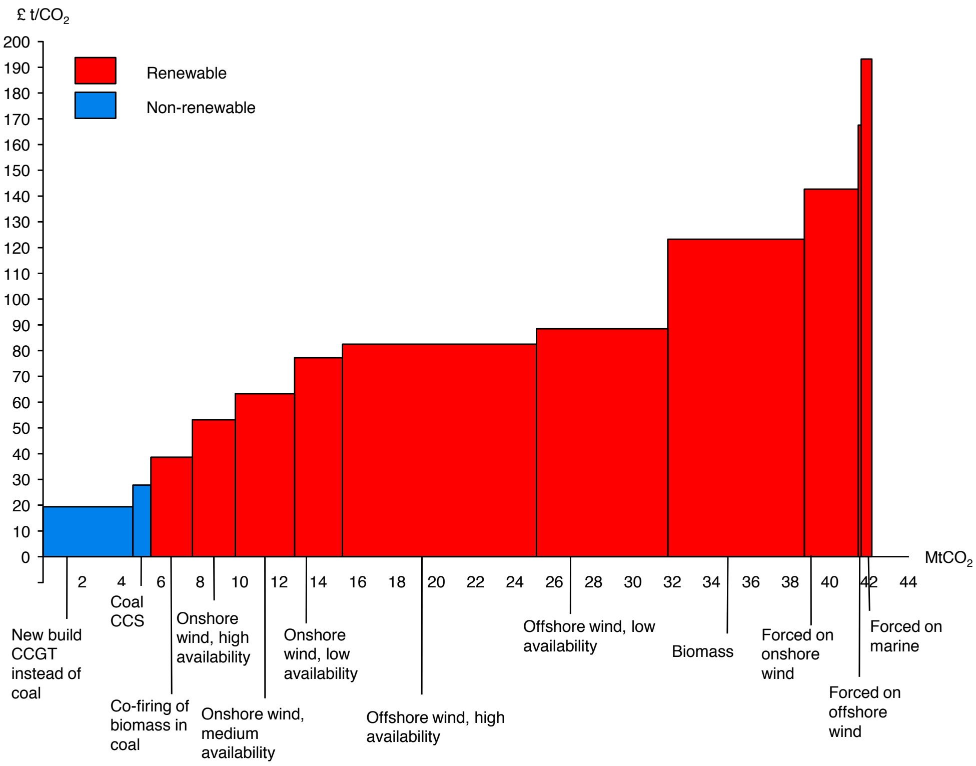
Marginal abatement cost curves (MACCs, see Chapter 3) showing quantities of emissions reductions and associated costs for each scenario are shown in Figures 5.26–5.28[30].

28 This is close to estimates made in work carried out for the draft Renewable Energy Strategy. Estimates in Redpoint (2008) suggest that these costs would be closer to 0.3% of GDP in 2020 under the central fuel price scenario.

29 Electricity prices are higher in the high-high fuel price scenario because of the higher gas and carbon prices. Even in a world with 30% or more renewables, gas could continue to set the electricity price as the marginal plant. Under high-high fuel prices, the carbon price is higher as the absolute difference between the coal and gas price is higher (see Chapter 4).

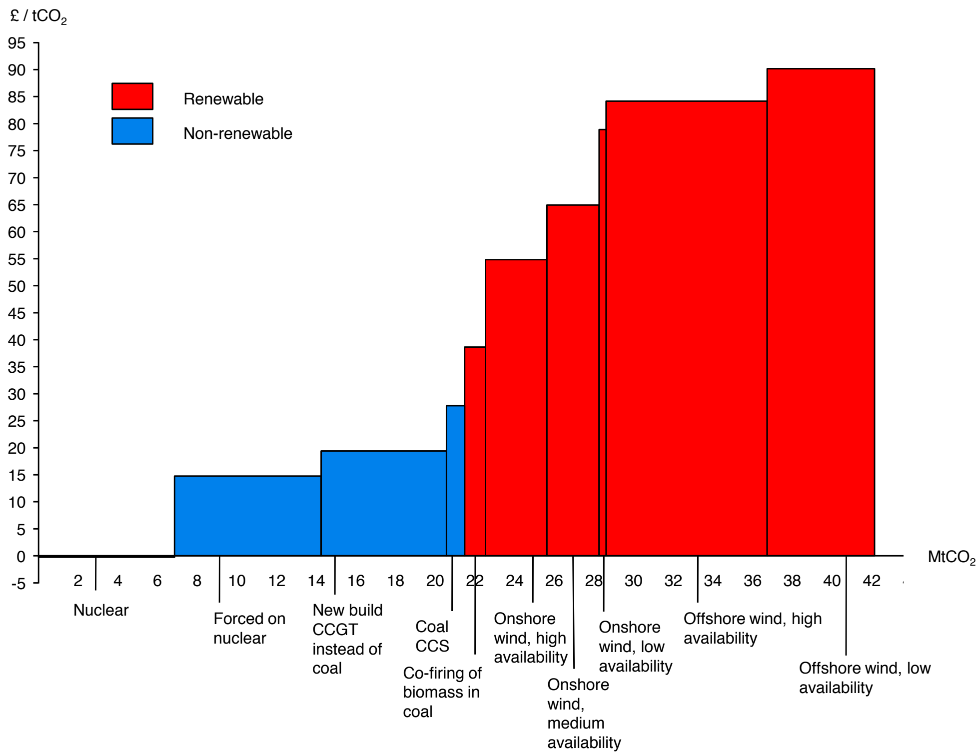
30 The MACCs are generated from a model originally built for us by McKinsey. We have subsequently developed this model substantially, and run our own scenarios across it.

Figure 5.26 Power sector MACC, Scenario 1



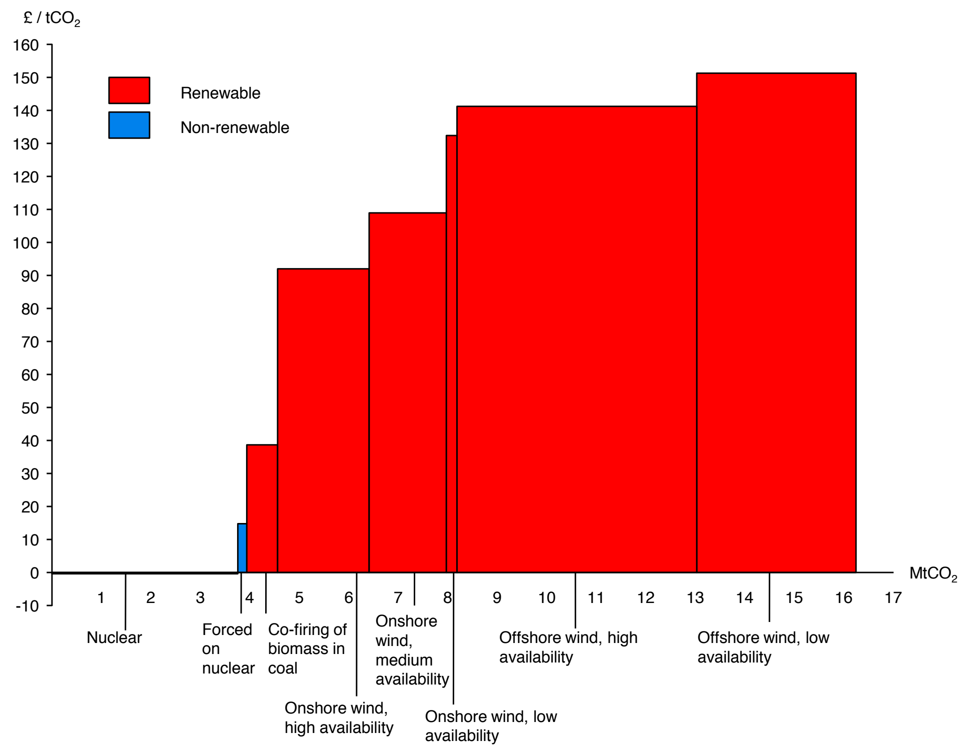
Source: CCC Modelling.
Note: 'Forced on' plant refers to plant which is built despite the existence of enough generation capacity on the system (e.g. to meet a target). It therefore displaces existing plant rather than new plant.

Figure 5.27 Power sector MACC, Scenario 2



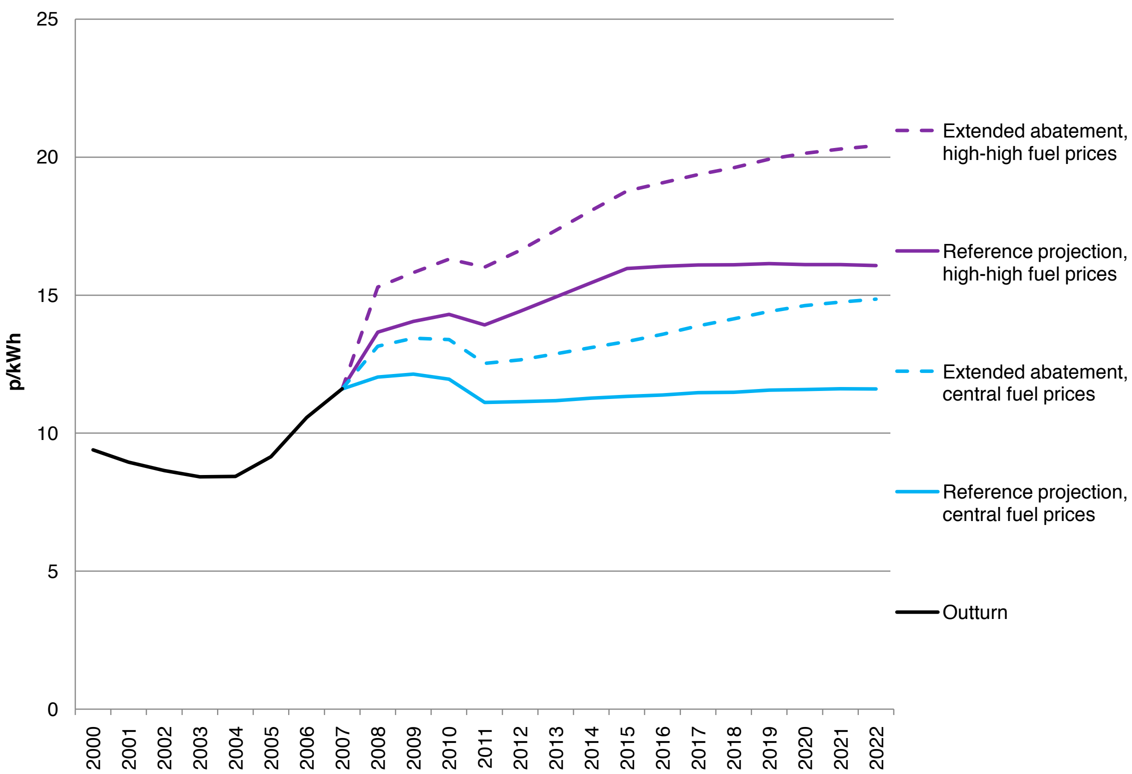
Source: CCC Modelling.
Note: 'Forced on' plant refers to plant which is built despite the existence of enough generation capacity on the system (e.g. to meet a target). It therefore displaces existing plant rather than new plant.

Figure 5.28 Power sector MACC, Scenario 3



Source: CCC Modelling.
Note: 'Forced on' plant refers to plant which is built despite the existence of enough generation capacity on the system (e.g. to meet a target). It therefore displaces existing plant rather than new build plant.

Figure 5.29 Retail electricity prices in the residential sector in reference projection and Extended Ambition scenario, central and high-high fuel prices



Source: DECC Energy Model and CCC calculations.
Note: 'Extended Ambition' models Scenario I.

6. POWER GENERATION SCENARIOS IN THE ECONOMY-WIDE ABATEMENT SCENARIOS

We have used Scenarios 1 and 2 in the economy-wide scenarios presented in Chapter 3: *The first three budgets*, to define the emission reductions that could occur in the first three budget periods. Specifically, we have used the trajectory in Scenarios 1 and 2 across the *Current, Extended* and *Stretch Ambition* scenarios for economy-wide emissions reduction. The reason we have done this is because we think that these reductions are achievable, desirable and necessary, given the path to complete decarbonisation of electricity generation by 2050.

CHAPTER 6:

ENERGY USE IN BUILDINGS AND INDUSTRY

This chapter covers emissions from energy consumption in buildings and industry. In 2006 these energy end use emissions were just under 400 $MtCO_2$, and accounted for 70% of the UK total. The chapter covers both residential and commercial/industrial sectors; and it covers *direct* emissions, due to the burning of fossil fuels in homes and businesses, and *indirect* emissions due to electricity consumption.

The indirect emissions of these sectors will be reduced via the decarbonisation of centrally generated electricity, which we consider in Chapter 5: *Decarbonising electricity generation*. In this chapter, we focus on four categories of potential abatement action:

1. Actions which reduce electricity demand, whether via energy efficiency improvements or lifestyle change.

2. Actions which reduce direct fossil fuel use, whether via energy efficiency improvements or lifestyle change.

3. Actions to produce heat more carbon efficiently, whether via the development of renewable heat sources, or the use of electricity to generate low carbon heat.

4. The microgeneration of electricity at locally distributed level.

One key feature of the sectors covered, in particular of the residential sector, is that there appears to be scope for significant energy efficiency improvement at a cost to the economy and to individuals which is low, nil, or indeed negative (i.e. where upfront investment would be quickly repaid and give a good return). In practice however, there are numerous barriers which prevent theoretically attractive opportunities from being implemented. Conversely there is a wide range of possible options for the microgeneration of electricity which are technically possible but high cost. A crucial distinction in this chapter is therefore between theoretical technical potential, cost-effective potential, and realistic potential.

Our key conclusions are that:

- In the residential sector there is technical potential to reduce emissions by almost 40 $MtCO_2$, over half of which is through negative cost energy efficiency improvements and lifestyle changes, and with much of the remainder costing less than our forecast carbon price of £40/tCO_2. Our assessment of realistic potential suggests that a reduction of 9-18 $MtCO_2$ could be achieved from existing buildings, with an additional 4 $MtCO_2$ from new buildings.

- In addition the development of renewable heat sources (mainly biomass) and of microgeneration (solar photovoltaic) could save up to 65 $MtCO_2$ but at a much higher cost per tonne saved. Our assessment of realistic potential suggests a much lower reduction of up to 10 $MtCO_2$.

- In non-domestic buildings there is technical potential to reduce emissions by 11 $MtCO_2$ through zero or negative cost energy efficiency improvements, of which we believe 5-9 $MtCO_2$ can realistically be saved. In addition, we estimate a realistic potential to save up to 2 $MtCO_2$ via higher cost abatement actions involving renewable heat and micro-generation.

- In industry, there is only limited technical potential (7 $MtCO_2$) to save CO_2 at zero or negative cost, but the majority of this (4-6 $MtCO_2$) should be realistically achievable given the application of strong binding policy levers covering over 95% of industry's emissions.

These ranges for realistic emissions reduction are incorporated in our economy wide Current Ambition, Extended Ambition and Stretch Ambition scenarios which are described in Chapter 3: *The first three budgets*. We set out the analysis that underpins the ranges in four sections:

1. Overview of energy end use emissions: trends and projections
2. Emissions reduction in residential buildings
3. Emissions reduction in non-residential buildings and industry
4. Overall conclusions: scenarios for emissions reduction from energy use in buildings and industry

1. OVERVIEW OF ENERGY END USE EMISSIONS: TRENDS AND PROJECTIONS

Emissions in buildings and industry were just under 400 $MtCO_2$ in 2006, accounting for 70% of total UK CO_2 emissions. Within this, emissions from residential buildings were around 149 $MtCO_2$, with emissions from public sector and commercial buildings accounting for 78 $MtCO_2$ and the rest of industry accounting for the remaining 155 $MtCO_2$ (Figure 6.1).

Overall just over half of these emissions come directly from the combustion of fossil fuels, particularly for the generation of heat in the residential and industrial sectors, with the remainder coming indirectly through electricity consumption based on fossil fuel-fired generation. There is, however, significant variation across type of user, with the service sector (commercial buildings) having a much higher proportion of indirect emissions than other sectors.

Emissions trends: Overall emissions from buildings and industry have fallen by 12% over the period 1990 to 2006 (Figure 6.2).

- Residential emissions have fallen by around 4%, with growth in the number of households and demand for heat and electrical appliances being more than offset by improved energy efficiency and fuel switching in power generation.

- Non-residential emissions have fallen by 15% over the same period. Breaking this down:
  - Industrial emissions fell by 18% due to falling output in some sectors and changing industrial composition leading to lower energy consumption.
  - Public sector emissions declined by 26% between 1990 and 2006 due to more use of lower carbon fuels, and with overall energy consumption remaining largely flat.
  - Commercial emissions rose by 4%, with growing output driving higher demand for energy despite efficiency improvements.

Emissions projections: Looking forward, the DECC Energy Model projects that total emissions in these sectors will fall by almost 20% over the period to 2020 (Figure 6.3).

This trend can be decomposed into:

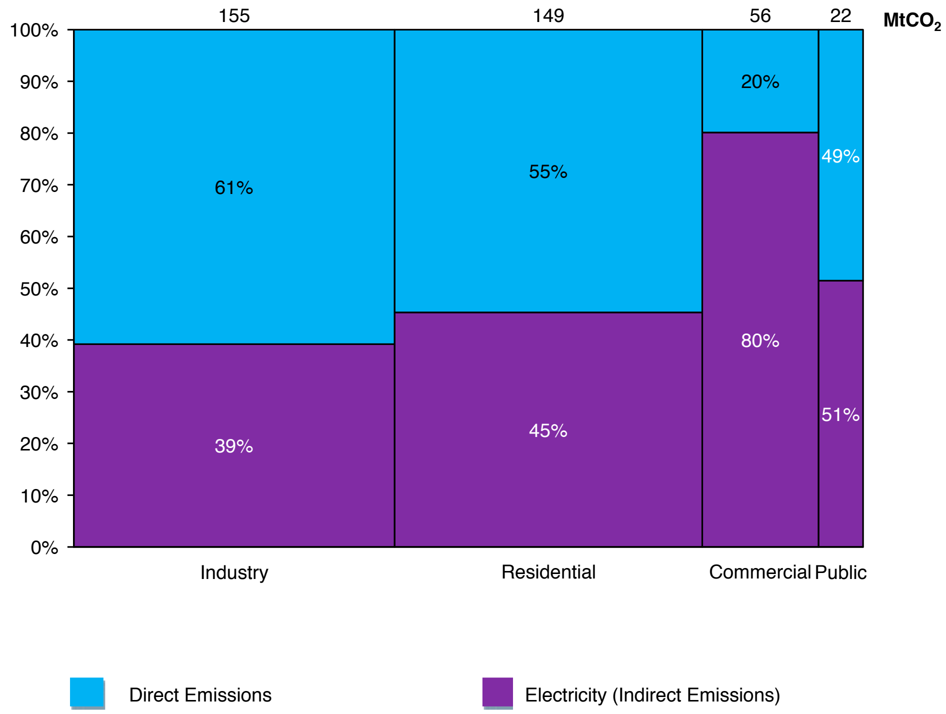
- The decarbonisation of electricity discussed in Chapter 5: *Decarbonising electricity generation*, with average grams per kWh of electricity expected to fall from 560 today to 350 in 2020[1]. This drives falling emissions across all sectors.

- Residential emissions are forecast to decline by 25%, driven by both direct and indirect emissions reduction.

- Emissions in public and commercial buildings are forecast to fall by almost 25%, and industrial emissions are forecast to fall by 10%. These falls are driven entirely by the lower carbon intensity of electricity, with electricity demand in kWh forecast to rise, and with a slight rise in direct (non-electricity-related) emissions.

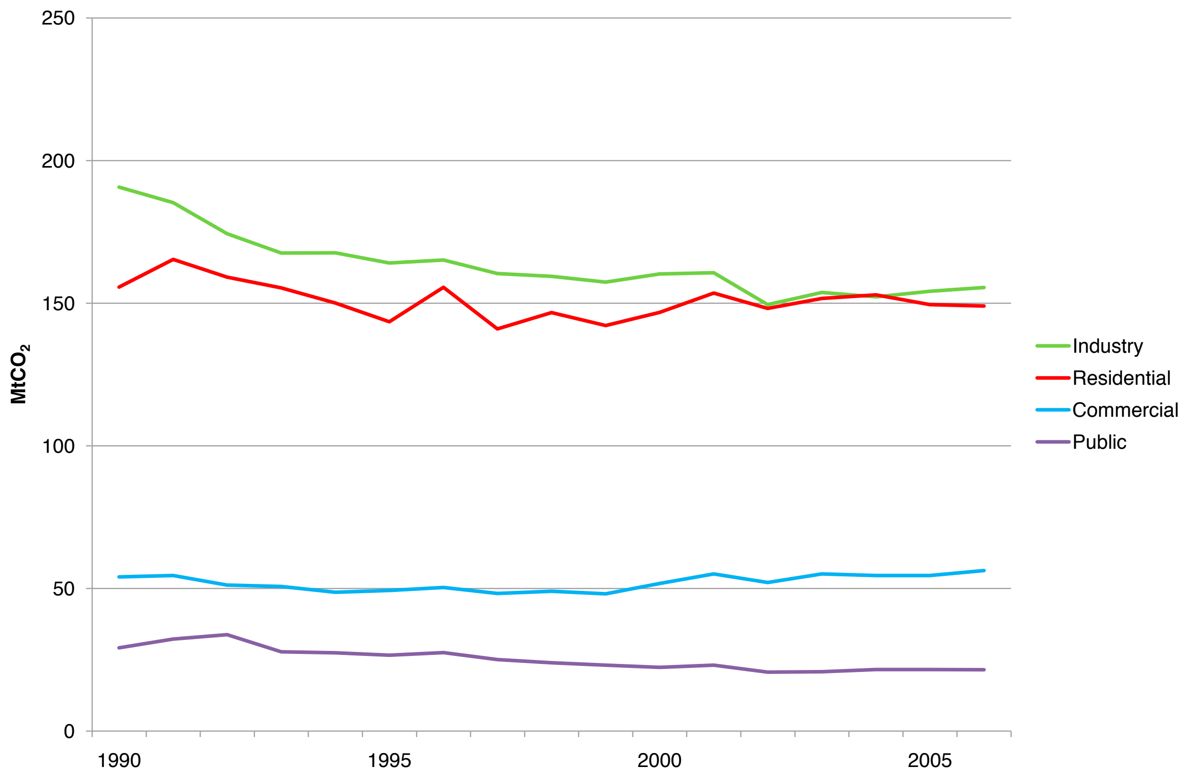
1 These figures differ very slightly from those in Chapter 5 which includes the impact of emissions reductions identified later in this chapter.

Figure 6.1 Direct and indirect emissions from energy use in buildings and industry in 2006



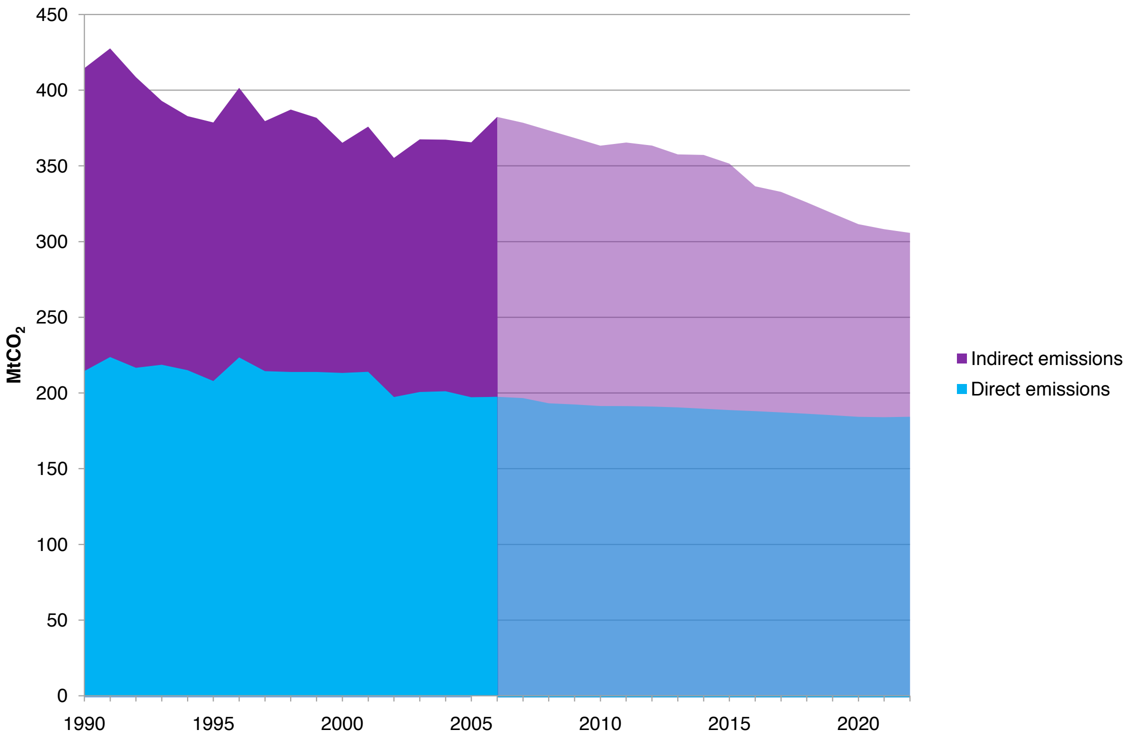
Source: NAEI (2008)

Figure 6.2 Emissions from energy use in buildings and industry by sector 1990 – 2006



Source: NAEI (2008)

Figure 6.3 Emissions projections for energy use in buildings and industry



Source: DECC modelling on behalf of CCC

2. EMISSIONS REDUCTION IN RESIDENTIAL BUILDINGS

In developing our assessment of the potential for energy end use emissions reduction in the residential sector, we have considered:

(i) Residential emissions trends and projections

(ii) Overview of technical emissions reduction potential

(iii) Potential for residential energy efficiency improvement

(iv) Potential for lifestyle change

(v) Barriers to action in the residential sector

(vi) Policies to support residential energy efficiency improvement and lifestyle change

(vii) Realistic potential for residential emissions reduction from energy efficiency improvement and lifestyle change

(viii) Microgeneration and renewable heat in residential buildings.

(i) Residential emissions trends and projections

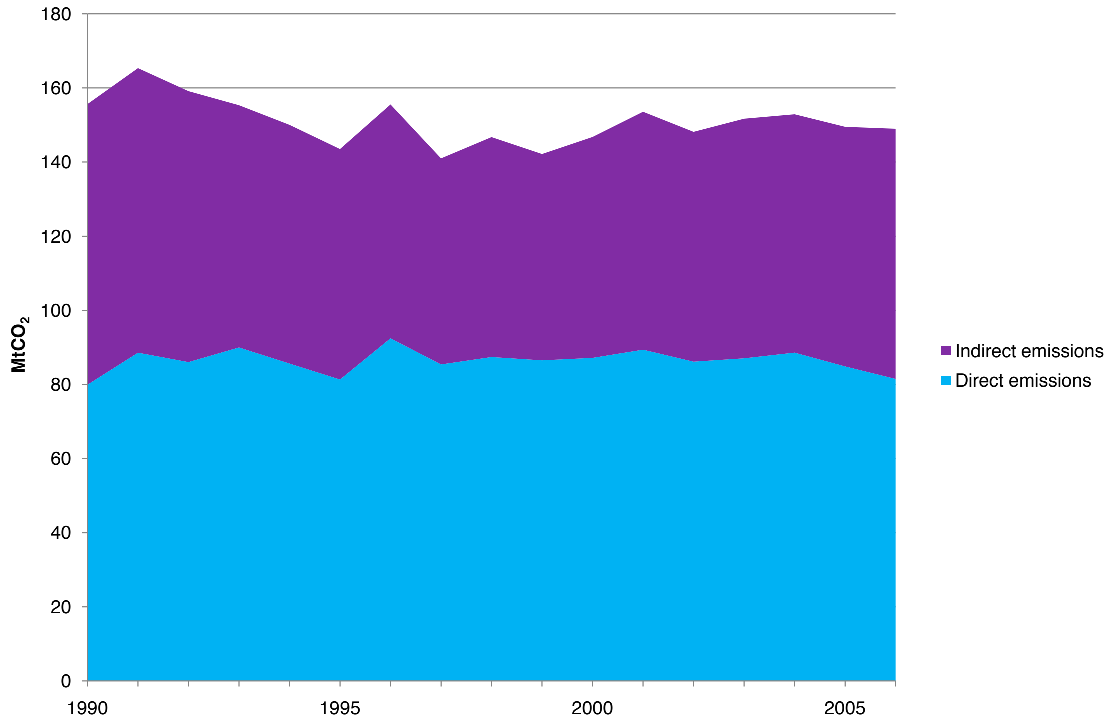
Residential emissions have fallen by 4% over the period 1990-2006. Underpinning this trend is a decline in indirect emissions, whilst direct emissions have been broadly level over this period (Figure 6.4):

- The flat trend in direct emissions has resulted from a complex combination of factors. End user demand has increased as average internal home temperatures have increased (Figure 6.5); but insulation efficiency has improved, and heating efficiency has improved with the development and installation of more fuel efficient gas boilers (Figure 6.6).

- Electricity consumption per household has increased by almost 9% since 1990. This increase has been driven by significant growth in demand for consumer electronics and information and communications technology. Demand growth has more than offset the slight fall in electricity consumption for cold, wet and cooking appliances which resulted from energy efficiency improvements (Figure 6.7).

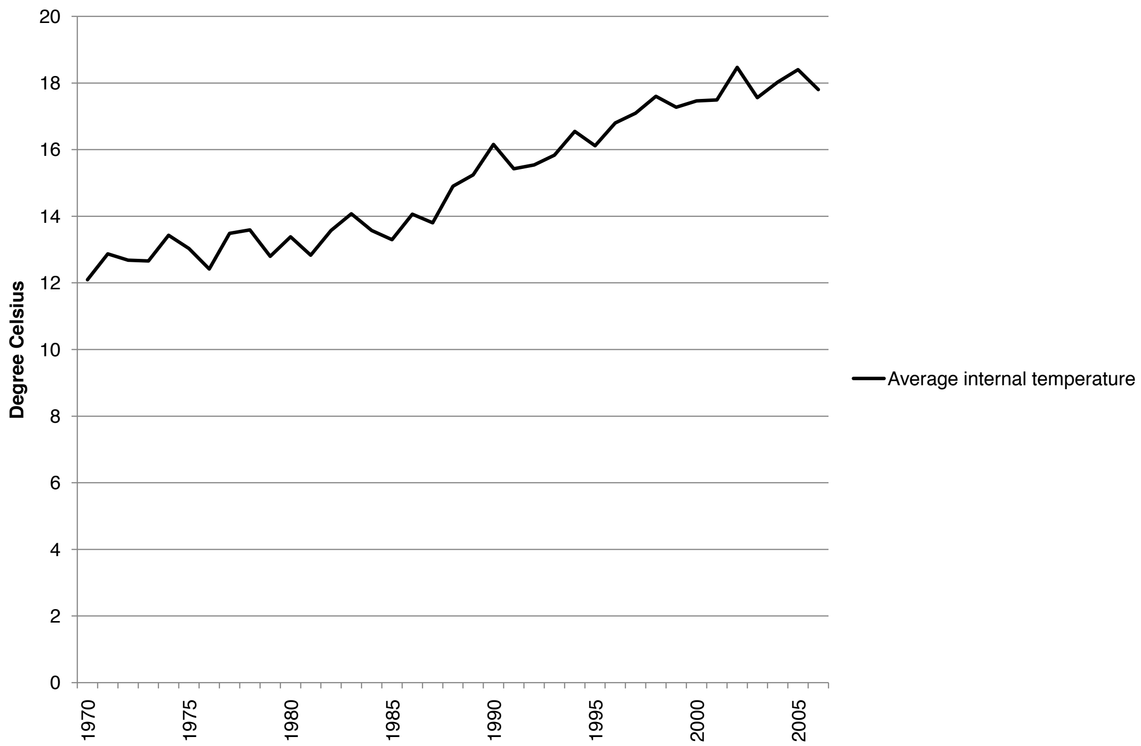
- This increase in consumption per household, combined with an 14% increase in the number of households, has resulted in a rise of total electricity consumption of 24% (Figure 6.8). But this increase has been offset by the 27% fall in the average carbon intensity of electricity, producing the 11% fall in indirect emissions shown in Figure 6.4.

Figure 6.4 Emissions from energy use in residential buildings by source



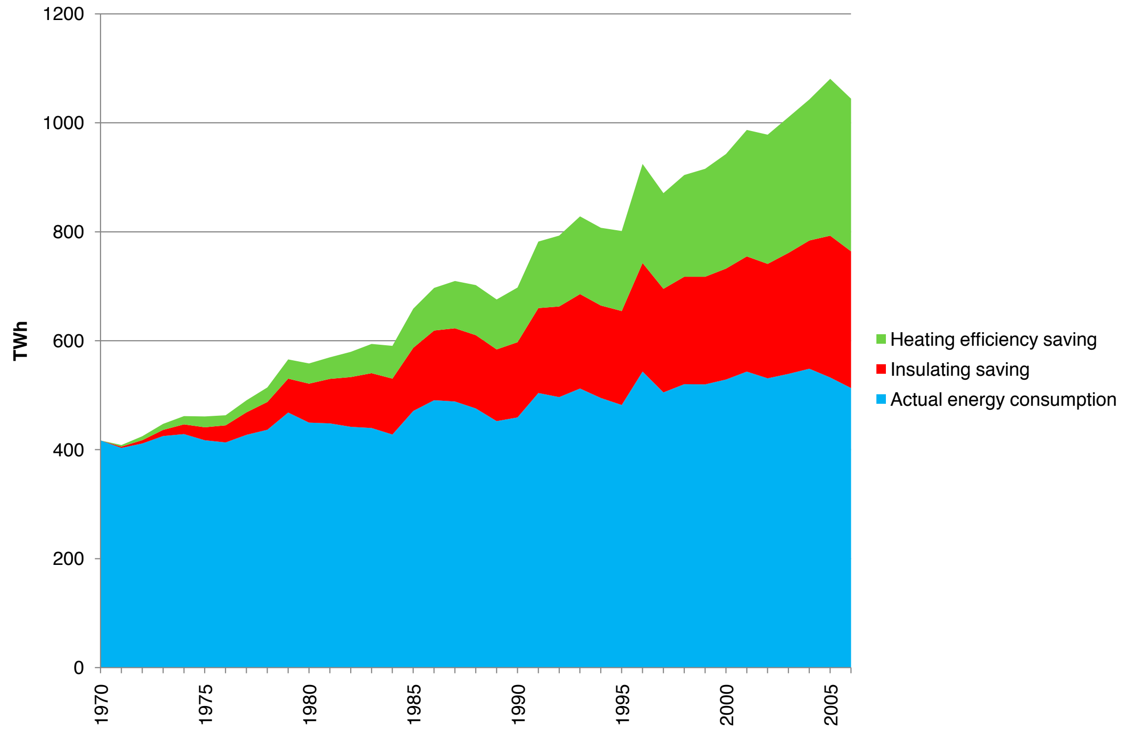
Source: NAEI (2008)

Figure 6.5 Average internal temperature in residential buildings 1970 to 2006



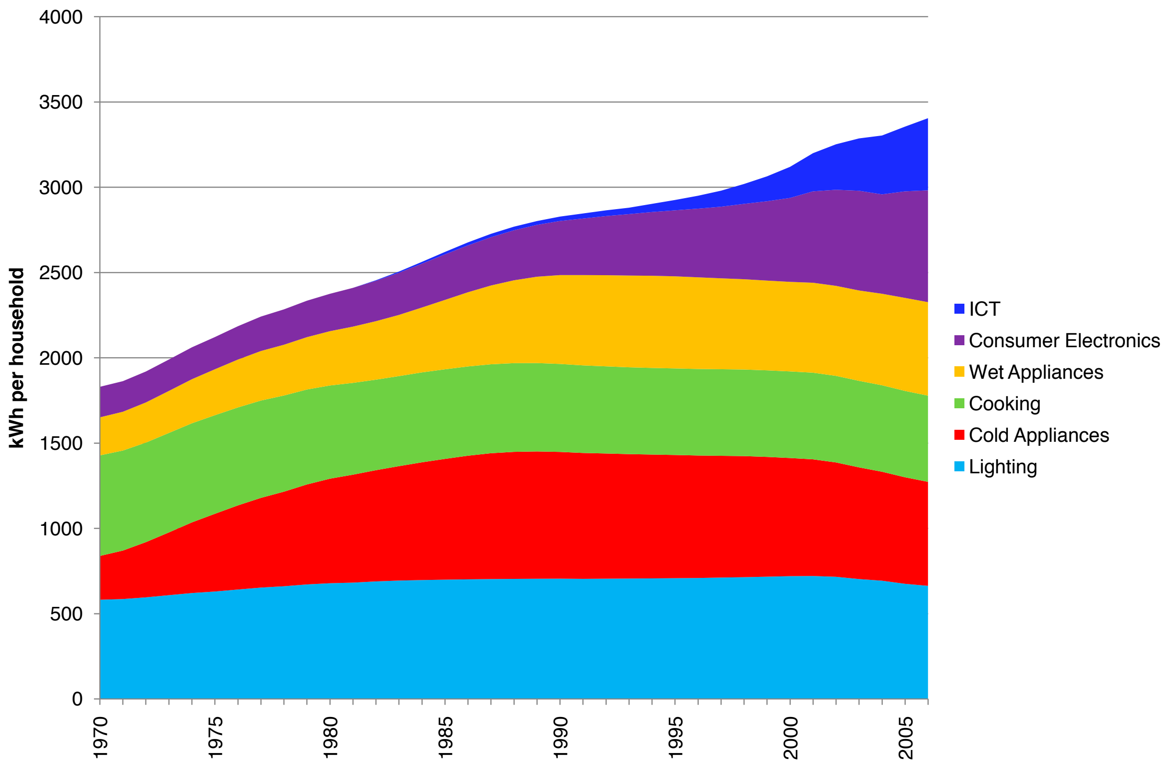
Source: BERR (2008) *Energy Consumption in the UK*

Figure 6.6 Energy savings due to insulation and heating efficiency improvements in Great Britain 1970 to 2006



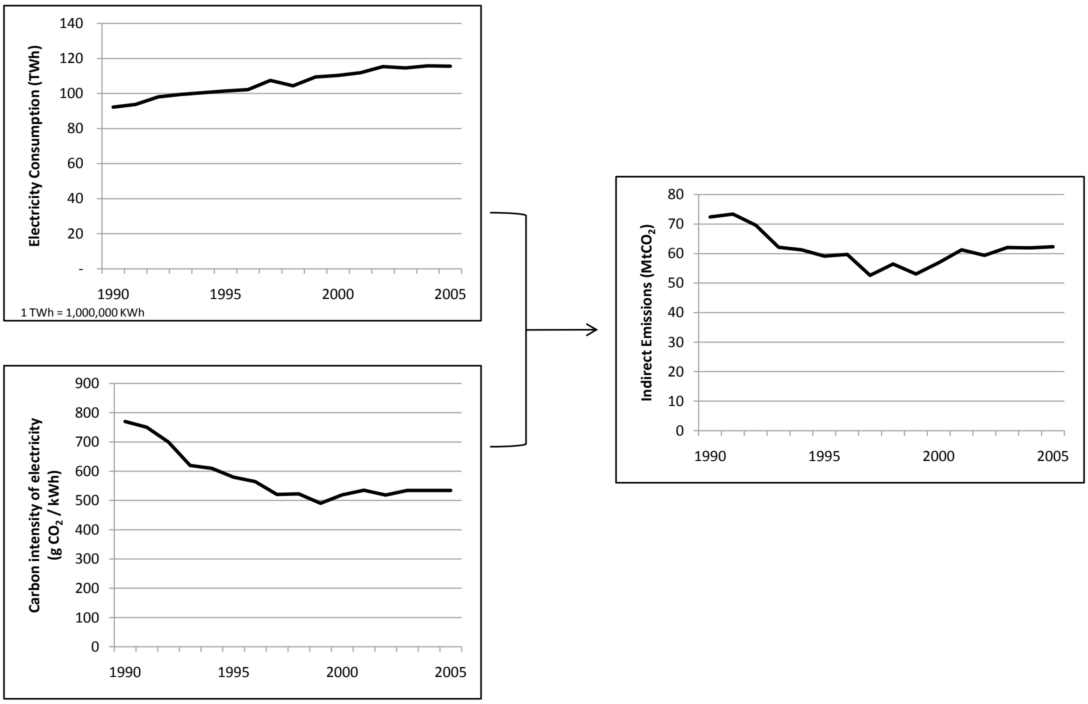
Source: BERR (2008) *Energy Consumption in the UK*

Figure 6.7 Electricity consumption per household by domestic appliances 1970 to 2006



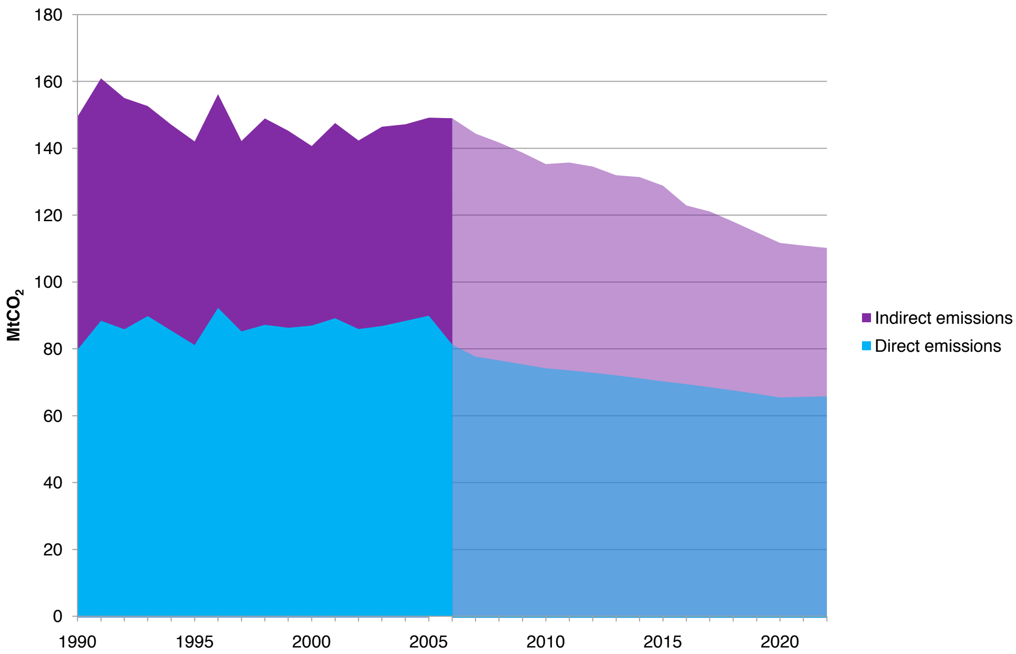
Source: BERR (2008) *Energy Consumption in the UK*

Figure 6.8 Electricity consumption, carbon intensity and indirect emissions from residential buildings



Source: BERR (2008) *Energy Consumption in the UK*; Defra (2007) *Guidelines to Defra's GHG conversion factors for company reporting*; and NAEI (2008)

Figure 6.9 Projections of emissions from energy use in residential buildings



Source: DECC modelling on behalf of CCC

Going forward, our projections suggest that residential direct emissions will fall by almost 20% over the period to 2020, and that indirect emissions will fall by over 30% (Figure 6.9):

- Direct emissions are projected to fall due to uptake of energy efficiency improvement measures (e.g. insulation, replacement of old boilers).

- Indirect emissions are projected to fall due to the impact of electricity sector decarbonisation as coal-fired plants are retired and replaced with lower carbon forms of generation. Grams per kWh of electricity consumed are projected to fall by almost 40%, but electricity consumed increases by over 10%. If the carbon intensity of electricity were not to be reduced, residential indirect emissions would grow by more than 10%.

(ii) Overview of technical emissions reduction potential

There is a range of measures for reducing emissions below the levels in these projections, including:

- Measures to reduce the energy needed to heat homes through improved insulation and more efficient and lower carbon ways to generate heat.
- Measures to improve boiler efficiency and reduce gas demand.
- The use of more efficient appliances, resulting in electricity demand reductions.
- Investment in microgeneration technologies, reducing demand for electricity, gas or other fossil fuels.
- Lifestyle measures (e.g. turning down heating thermostats, using economy washing programmes), resulting in electricity and gas demand reductions.

To analyse emissions reduction potential from these and other actions, we commissioned the Buildings Research Establishment (BRE) and AEA to develop a set of Marginal Abatement Cost Curves (MACCs). These show the quantity of emissions reduction together with the associated cost per tonne of CO_2 saved under assumptions about the housing stock, up-front costs of energy saving measures, and resulting cost savings.

The summary residential buildings MACC suggests that there is a technical potential to achieve 70-105 $MtCO_2$ emissions reduction from existing buildings in 2020 (Figure 6.10). It also however illustrates the variation in cost-effectiveness of different categories of action. The MACC suggests:

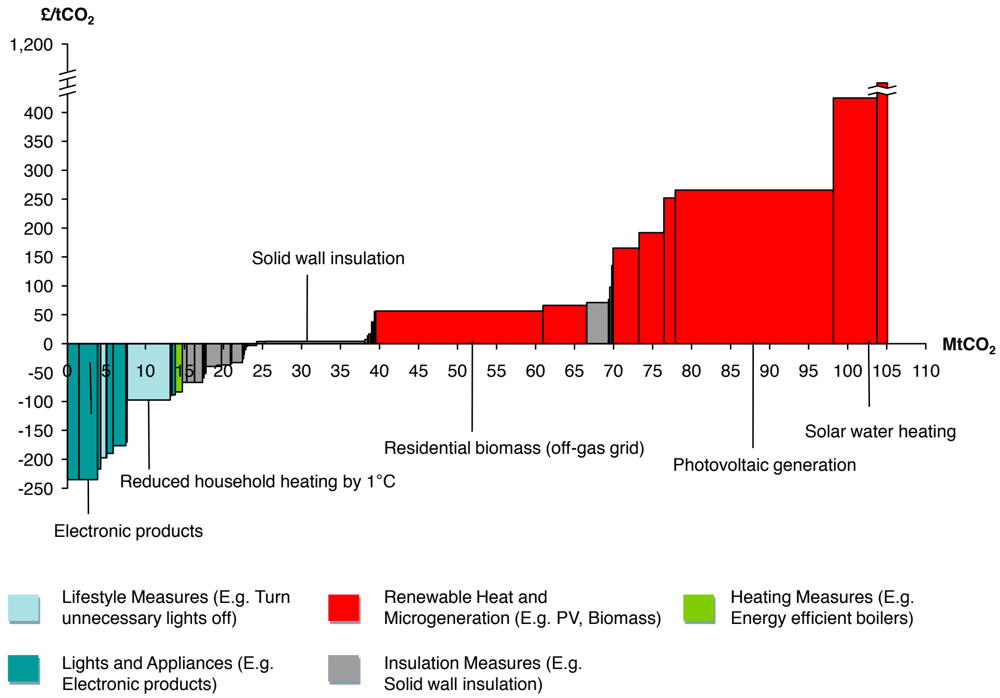
- There is almost 40 $MtCO_2$ of abatement opportunity available at a cost below our forecast carbon price of £40/tCO_2[2]. The vast majority of these reductions (33 $MtCO_2$) derive from energy efficiency improvements achieved through better insulation, more efficient lighting and appliances, and more efficient gas boilers.

- Lifestyle measures could also deliver an estimated 6 $MtCO_2$ reduction and save consumers up to £690m annually. These actions are negative cost if we do not factor in any discomfort cost that may or may not ensue from adopting these behaviours.

- In contrast, the measures which rely on the use of new low-carbon energy sources, whether to provide renewable heat or electricity, tend to be more expensive. Renewable heat from biomass has an estimated technical potential to save over 20 $MtCO_2$ at a cost of almost £60/tCO_2; this is above our estimated carbon price. Solar PV microgeneration of electricity could save another 20 $MtCO_2$, but at a cost of several hundred £s per tonne saved.

2 See Chapter 4: *Carbon markets and carbon prices*

Figure 6.10 Residential sector MACC – technical potential in 2020



Source: CCC

Given the very different economics of the options we therefore:

- Consider first, in subsections (iii) to (vii) the realistic potential to achieve the apparently low cost opportunity in energy efficiency and lifestyle change.

- Consider in subsection (viii) the opportunities in renewable heat and microgeneration, which are to a significant degree determined by policies on the appropriate level of financial subsides.

(iii) Potential for residential energy efficiency improvement

Within the broad categories above (improved insulation, more efficient boilers etc.) the MACC models include around 50 detailed measures. We have considered these first in the context of new buildings, and then in the context of existing buildings.

New buildings: There are two key points to recognise in understanding potential for emissions reduction in new buildings:

- New homes are already 70% more energy efficient than homes built before 1990[3], with scope for even more efficiency improvements going forward. These improvements, moreover, can be achieved at much lower cost than incurred when retrofitting existing buildings, given the potential to incorporate energy efficiency improvements within overall design and build.

- These opportunities are, however, limited by the fact that there will be relatively few new buildings added during the first three carbon budgets, as new houses built in any one year will make up less than 1% of the stock, and demolition rates are less than 0.1% per year. We estimate that 99% of existing homes will still exist in 2020, and that these will then form 88% of the housing stock.

3 Communities and Local Government, 2007, *Building a Greener Future: Towards Zero Carbon Development*

- The Government's intention is that new homes in England and Wales will become increasingly carbon efficient in the next 8 years, and that from 2016 all new homes will be zero carbon, to be mandated through buildings regulations. Though there is not yet any formal definition of what zero carbon means, this is likely to require that net emissions of new homes from heating, lighting, hot water, and appliances are zero, to be achieved through better energy management in the home together with energy supply from renewable sources.

Our MACC model focuses on individual measures that can be applied to existing buildings rather than combinations of measures that might be applied to new buildings. We do not therefore use our model to estimate the emissions reduction potential of the zero carbon homes policy. Communities and Local Government (CLG), however, estimate that zero carbon homes have the potential to abate 4 $MtCO_2$ by 2020. This is based on a range of scenarios that include both on-site and off-site energy generation using technologies including wind, biomass Combined Heat and Power (CHP) and solar PV, and for which cost estimates range from £23 – £115/tCO_2. The Committee believes that the zero carbon homes policy is appropriate. It will make a small but useful contribution to emissions reduction in the early years, but with gradually growing impact over time, and it will stimulate technology innovation applicable both in new homes and existing buildings.

Existing buildings: The two key points to recognise in understanding potential for emissions reduction in existing buildings are the converse of those for new buildings above:

- Implementation of emissions reduction measures may be more expensive than for new buildings, given the higher costs of retrofitting rather than building these into design.

- But, aggregate emissions reduction potential from existing buildings is likely to far exceed that for new buildings given that the former will continue to dominate the building stock in the period to 2020 and beyond.

More specifically, we estimate that there is scope to:

- Add and upgrade loft insulation to 13 million houses in the UK, resulting in emissions reduction of 1 $MtCO_2$ in 2020. In many cases this will give a saving of over £30 per tonne of CO_2, but 'topping up' existing insulation to the recommended thickness will yield a lower saving.

- Insulate cavity walls in 4 million houses, reducing emissions by 2 $MtCO_2$ and saving consumers around £35 per tonne of CO_2 saved.

- Insulate solid walls in 7 million houses, resulting in emissions reduction of 13 $MtCO_2$ at a cost of around £5 per tonne of CO_2 saved.

- Accelerate replacement of existing boilers with condensing boilers. This would result in emissions reduction of 2 $MtCO_2$ in 2020 and save consumers around £45 per tonne of CO_2.

- Increase the percentage of customers buying A+ rated wet appliances and A++ rated cold appliances, with potential for delivering over 2 $MtCO_2$ overall and saving £190 and £175 per tonne of CO_2 respectively.

- Replace conventional light bulbs with energy efficiency bulbs, reducing emissions by 0.5 $MtCO_2$ and saving around £90 per tonne of CO_2.

We have taken a conservative approach in estimating these numbers. This entails:

- Allowing for potential double counting across different initiatives. For example, since improving insulation reduces the amount of heat required from a boiler, installing a more efficient boiler after improving insulation will have less impact. We therefore assume that all other measures are simultaneously pursued when estimating the impact of any one specific measure. One implication of this is that if some specific measures were not implemented, the potential benefit of each remaining measure would be slightly higher than suggested above.

- Savings for insulation measures are reduced to reflect evidence that the actual savings are typically lower than what appears theoretically possible. This partly reflects 'comfort taking' where consumers increase temperatures in their homes to warmer levels as a result of lower fuel bills.

- We incorporate the 'heat replacement effect'. Making electrical appliances more efficient reduces the heat they generate and in cold months, but not in summer; this has to be offset by higher energy consumption in central heating if house temperatures are to be maintained at desired levels.

The list of measures is not exhaustive, but focuses on those measures where more significant emissions reduction is available. It is important to note that for most of these measures, associated costs is negative, suggesting that implementing households would benefit financially, with any up-front costs offset by energy bill reductions. This raises the question why households have not already implemented these measures, which we consider in Section 2(v) below.

(iv) Potential for lifestyle change

The measures above are based on using energy more efficiently while leaving lifestyle unchanged. It is also possible to achieve reduced energy use through modest lifestyle changes:

- Turning thermostats down by 1°C would reduce emissions by 5.5 $MtCO_2$. Where houses are already heated to a high standard, this is a way to save carbon and money with only a modest impact on quality of life.

- Washing clothes at low temperatures would reduce emissions by 0.7 $MtCO_2$. This saves money and carbon, and since many modern detergents provide similar performance at both low and high temperatures there is little impact on the quality of the wash.

- Switching lights off when leaving the room, which would reduce emissions by 0.1 $MtCO_2$ and would not have any impact on quality of life.

In total, our analysis suggests that just over 6 $MtCO_2$ emissions reduction could be achieved in 2020 through lifestyle measures of the type described above. Further reduction would obviously be possible given potential for more significant behaviour change. What reduction can be achieved in practice will depend on social attitudes and behaviour and on the effectiveness of the policy levers used to encourage change.

(v) Barriers to action in the residential sector

We have shown that there is significant technical potential for residential emissions reduction through energy efficiency improvement and lifestyle change. Where this potential is available at negative cost (i.e. the reduction in energy bills over time more than off-sets the initial outlay, sometimes many times over) we would expect rational consumers to exploit this. But much of the available potential has continued to remain unexploited. To assess the realistic potential for abatement we therefore have to:

- Understand the barriers to action and how these may vary by segment of the population.

- Assess the potential effectiveness of available policy levers in overcoming these barriers.

This subsection covers the barriers; subsection (vi) looks at policies.

A widely cited study by NERA identified seven constraints which help to explain the failure of households to seize negative cost energy efficiency improvements (Box 6.1).

Box 6.1 NERA's classification of barriers to energy efficiency

- **Basic financial barriers:** These include the potentially higher upfront costs of energy efficiency products, e.g. cavity wall insulation, and the interest rates available to households.
- **Hidden costs:** These include 'transaction costs' associated with finding reputable providers, time costs of disruption, and the costs of differences in quality of product or service. Many of these hidden costs are related to the cost of acquiring information about, for example, suppliers.
- **Lack of information:** From a rational choice model of human behaviour if households do not know their level of energy expenditure, how energy can be reduced, by how much, or at what cost, they are unlikely to consider investment in energy efficiency. However although information provision is often necessary it is rarely sufficient in itself to encourage behaviour change.
- **Risks and uncertainty:** Uncertainty about future energy prices can deter households from investing since they cannot be assured of further savings. Households may also be wary of the risk associated with unfamiliar products.
- **Poorly aligned incentives:** The most commonly cited barrier of this kind is the 'landlord-tenant' split whereby landlords may under invest in energy efficiency measures because their tenants pay the energy bills or conversely tenants have no incentive to reduce their energy use as their landlord foots the bill.
- **Psychological/sociological barriers:** These include a range of less tangible barriers that do not conform to a 'rational consumer' model of human behaviour. This may include inertia in decision making or basing decisions on habit or a wish not to be perceived as the only one adopting a new technology - 'I will if you will' mentality.
- **Regulatory barriers:** There are also regulatory barriers that have been identified which relate specifically to the regulatory framework within the UK which can make it more difficult for certain households to benefit from or consider energy efficient measures.

Source: NERA Economic Consulting (2007) *Evaluation of Supplier Obligation Policy Options: Report for DTI and Defra*

The first two constraints identified by NERA (basic financial barriers and hidden costs) suggest that the rational economics of action to the individual households are less favourable than first appears, and it is possible to adjust MACC model assumptions to allow for these constraints by:

- Increasing the discount rate at which energy efficiency improvements are valued, to reflect the fact that households may not be able to borrow at the 3.5% real discount rate assumed in Figure 6.10 and that households may apply implicit discount rates far above this level.

- Estimating hidden costs associated with investigating a measure and organising installation, as well as allowing for perceived risks in the performance of the measure (Box 6.2).

Box 6.2 Hidden and missing costs in MACCs

Many economists have suggested that the presence of negative cost measures in MACCs is not evidence that there is significant potential to be exploited, but that it is evidence the models incorrectly estimate costs. They argue that 'rational' consumers would exploit these opportunities if they existed and that the models ignore many costs – particularly those that are either non-financial or those not directly related to installing a given measure.

Enviros (2006) attempted to build in several of these 'hidden and missing' costs, and this work has been updated by AEA Technology. Enviros identify 7 types of hidden and missing cost:

- **Project Identification** – These include the cost of identifying opportunities and gathering sufficient information to take a decision. It represents a key barrier since many consumers and businesses may be unaware of the opportunities available to them.
- **Project appraisal** – Once an opportunity has been identified it needs to be appraised to assess whether it is worthwhile pursuing, and if so who should install the measure.
- **Project Commissioning** – Once the decision has been taken to go ahead, there will generally be time to commission and manage a project. It often corresponds to a 'hassle factor', having to arrange and attend meetings with engineers (or be at home so engineers can see the work involved).
- **Production disruption** – The disruption to the production chain can be important for firms, but also for consumers who might have to take time off work to provide access for an engineer to their house.
- **Additional Engineering** – These are costs borne by the customer in preparation for installing a measure (which are not typically included in quotes by the vendor). These might include adjustments to existing equipment or additional land.
- **Perceived Risks** – Whilst many technologies are tried and tested there is often the perception by the customer that a product will not perform as stated by the supplier. This may range from a belief that savings are over stated or may not be maintained, to a lack of understanding about the technology itself.
- **Ongoing management and supervision time** – This is unlikely to be captured in the installation cost of a measure. However these costs may be important, particularly for lifestyle measures where ongoing effort is required to maintain the savings.

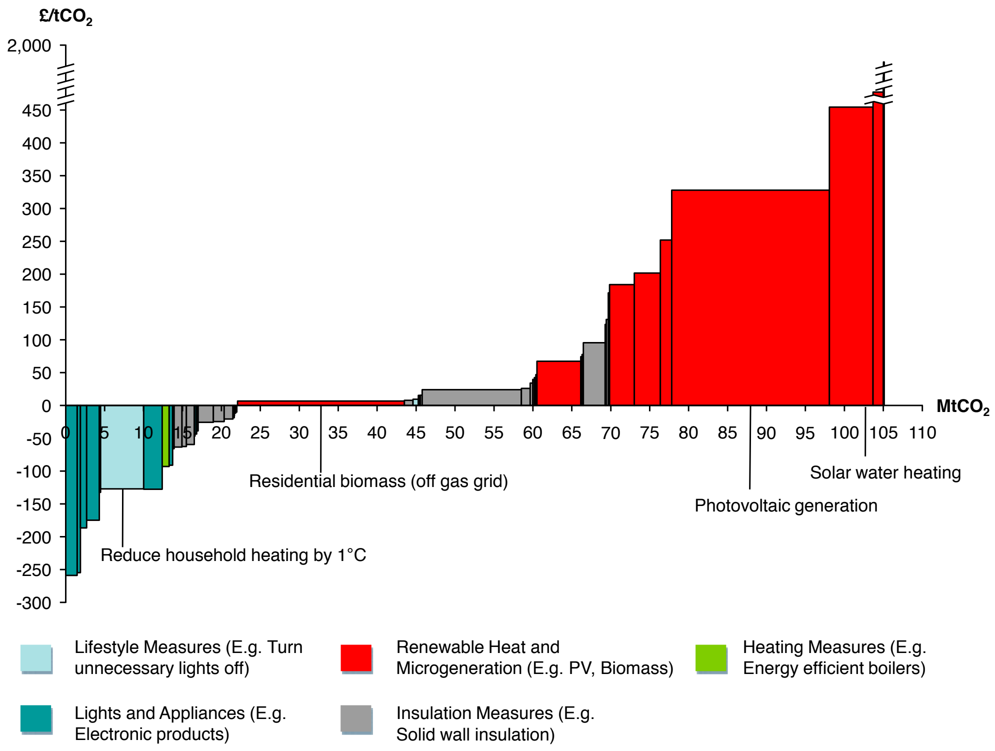
The CCC's models are capable of including these hidden and missing costs and this, along with evidence from social research has been used in developing our view of how much emissions reduction can realistically be delivered.

Source: Enviros (2006) *Review and development of carbon dioxide abatement curves for available technologies as part of the Energy Efficiency Innovation Review*

The impact of these factors can be modelled and is not dramatic. Assuming a 10% real discount rate and incorporating reasonable estimates of hidden costs suggest that the level of emissions reduction available at negative cost falls only from 22 to 20 $MtCO_2$ in 2022 (Figure 6.11). Even after allowing for high discount rates and hidden costs, therefore, significant potential remains to cut emissions at negative cost to the householder.

This implies that some of the less quantifiable barriers to action may be more important. These include problems of poorly aligned incentives, in particular those arising in the rented accommodation sector, where it is difficult to design contract terms which encourage landlords to invest in energy efficiency improvements from which tenants will derive cost savings. They also include subtle but extremely important barriers relating to information availability, awareness of energy costs and climate change concerns. To assess these we have looked at the emerging social research evidence base developed by Defra, the Energy Saving Trust and others.

Figure 6.11 Residential sector MACC – technical potential in 2020 including hidden and missing costs and private discount rates and fuel prices



Source: CCC

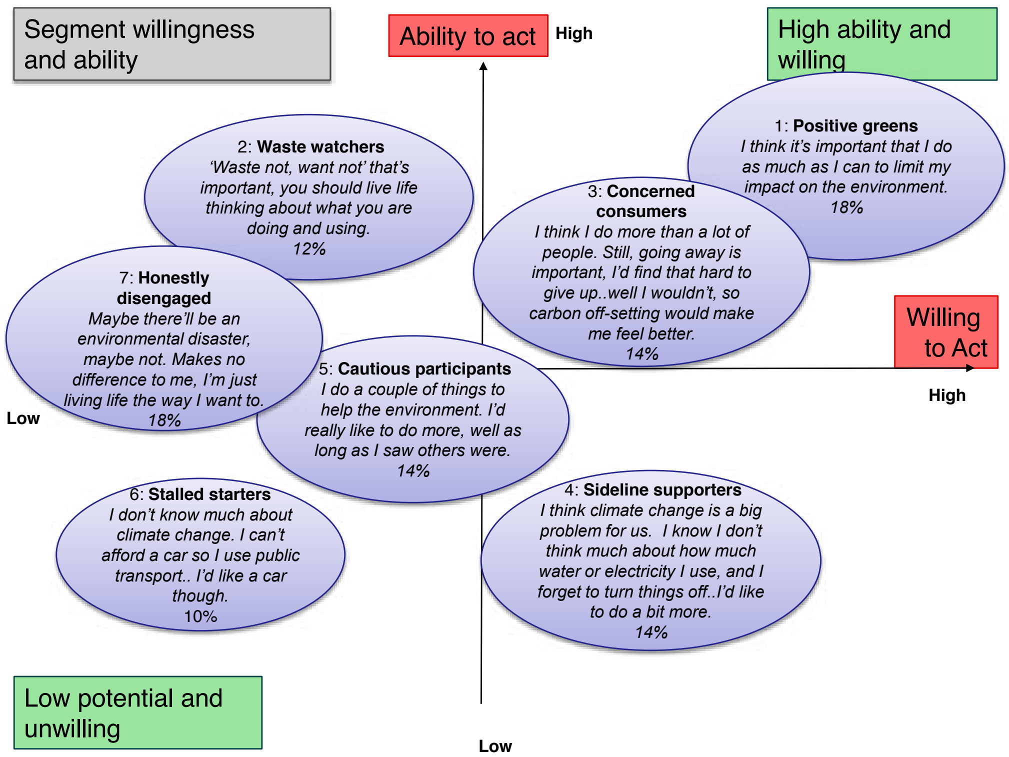
The social research evidence base: Our review of this evidence suggests that:

- The vast majority of people have some awareness of and concern about climate change.
- There is often a disconnect, however, between this and any behaviour to mitigate climate change, referred to as the attitude-behaviour gap.
- Few people are prepared to voluntarily make *radical* lifestyle change to reduce their carbon footprint.
- But many would be prepared to change in a way that does not unduly disrupt current lifestyle.

Building on this evidence Defra have developed a segmentation model that divides the population into seven segments each sharing a distinct set of attitudes and beliefs towards the environment[4]. They have distinguished between the willingness and ability to act on climate change for each of the seven segments (Figure 6.12). Aggregating across the segments this analysis suggests that a significant proportion of the population (almost half) are relatively willing and able to do more, with the remainder of the population either less able or less willing to act. Defra has also considered the potential for increasing the scope for action through a range of levers based around principles of enabling, engaging, encouraging and exemplifying (Figure 6.13). The analysis concluded that provided a package of mutually supporting levers is in place (including fiscal and regulatory levers) there is further scope for action, both from those who are currently willing and able to act, and from those who have the potential to become willing and able (Figure 6.14).

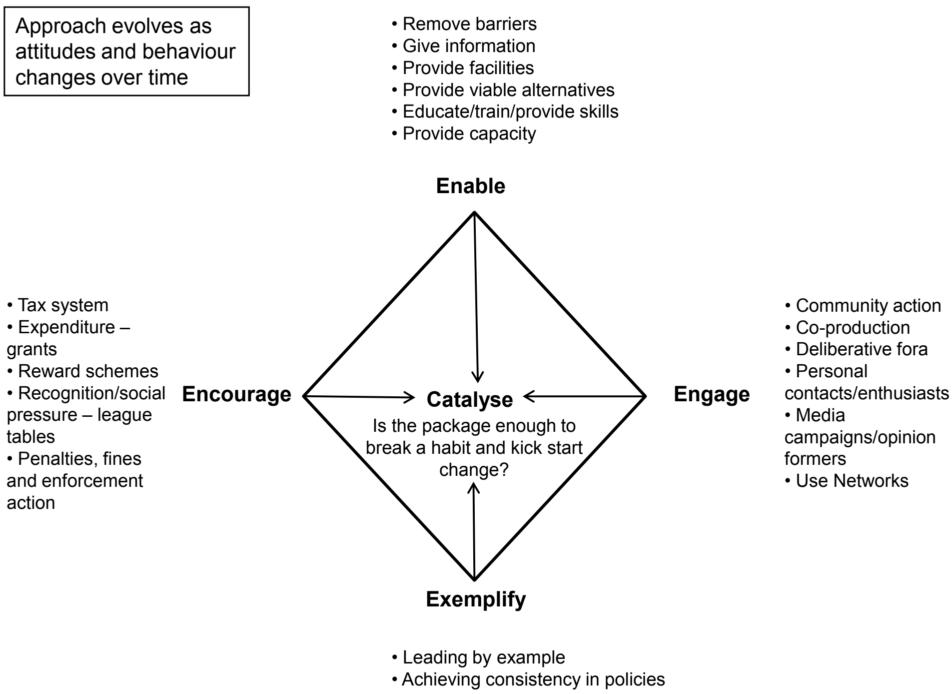
4 Defra (2008) *A Framework for Pro-Environmental Behaviours*

Figure 6.12 The seven population segments and relative willingness and ability to act[5]



Source: Defra (2008) *A Framework for Pro-Environmental Behaviours*
Note: The estimated population sizes are based on the size of the population in England, aged 16 and over (41.1 million)

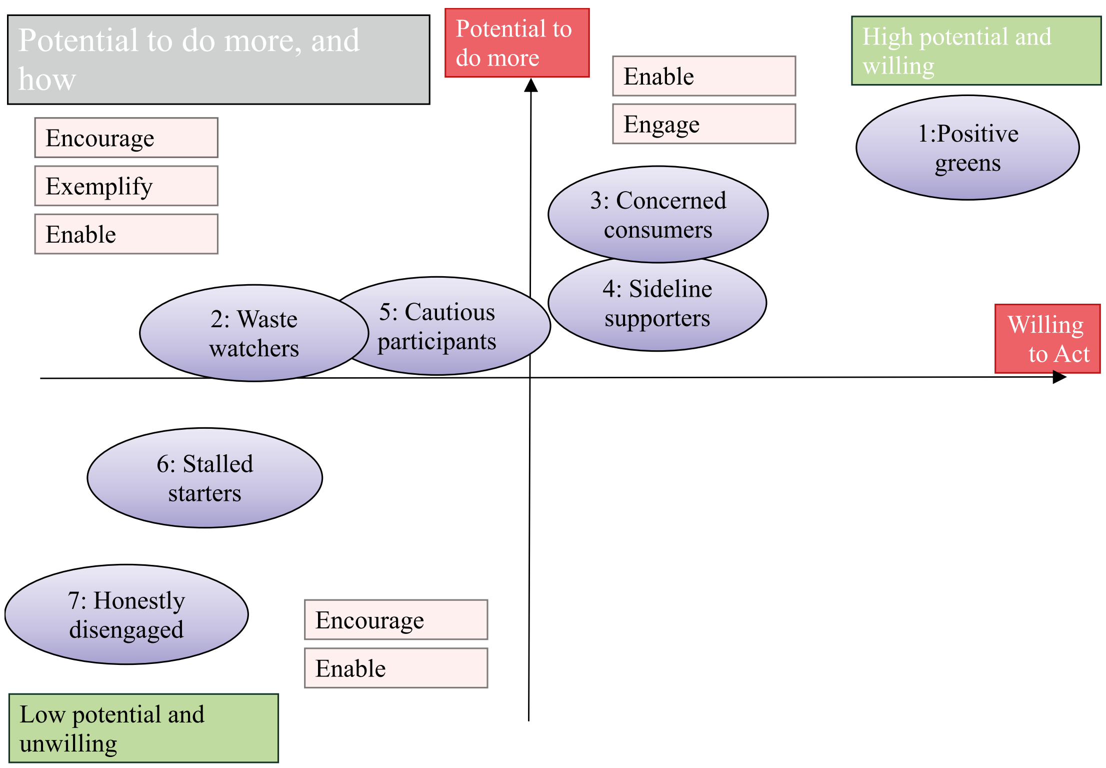
Figure 6.13 Diagrammatic representation of the 4E's model



Source: HM Government (March 2005) *Securing the Future: delivering UK Sustainable Development Strategy*

5 'Ability to act' depends on mainly external constraints which enable or limit ability to act such as income level and access to finance. 'Willingness to act' is more complex and takes account of internal barriers and motivators such as whether a behaviour fits with ones self-identity.

Figure 6.14 Segmented strategy for encouraging pro-environmental behaviours



At the strategic level, and for the purpose of designing policy, Defra suggest the segments fall into three broad groups:

- People who are keen to act and have relatively high potential to do more, where *enabling* different choices by providing tailored information and direct *engagement* such as community action are important to promote change (segments 1, 3 and 4 who make up 46% of the population);
- People who are willing to act and have the potential to do so, for whom it is important not only to *enable* new choices, but also for Government to *encourage* change, for example through fiscal incentives, and to *exemplify* through its own actions (segments 2 and 5 who make up 26% of the population); and
- People who are less likely to act and the emphasis is likely to be on interventions that *enable* and *encourage* such as regulation and choice editing of products (segments 6 and 7 who make up 28% of the population).

Source: Defra (2008) *A Framework for Pro-Environmental Behaviours*

Our interpretation of the social research evidence base: It is clear that emissions reduction constraints represent a considerable challenge. However the analysis above suggests that these constraints should not be regarded as binding. With appropriately designed policies, the majority of households could be willing and able to undertake at least some of the measures that we have identified and in particular those where disruption and lifestyle change are least (e.g. cavity wall insulation, loft insulation, purchase of more efficient appliances). Persuading them to implement the more disruptive measures (e.g. solid wall insulation) is likely to require a greater degree of subsidy, encouragement or compulsion. The forcefulness and effectiveness of policy will therefore be a key determinant of abatement achieved. We consider policies in the next subsection.

(vi) Policies to support residential energy efficiency improvement and lifestyle change

Given the barriers identified, effective policies should meet at least some of the following criteria: (i) provide information which increases awareness of potential; (ii) strongly encourage individual households to take action (e.g. with impetus coming from government and energy suppliers); (iii) reduce hidden costs associated with undertaking measures to improve energy efficiency; (iv) improve financial incentives for action through provision of implicit or explicit subsidies; (v) require action through direct regulation where this is the most appropriate policy lever.

A range of policies are currently in place to achieve these ends with three in particular delivering a large proportion of emissions reduction: the Supplier Obligation, Energy Performance Certificates, and a range of policies relating to Appliance Standards.

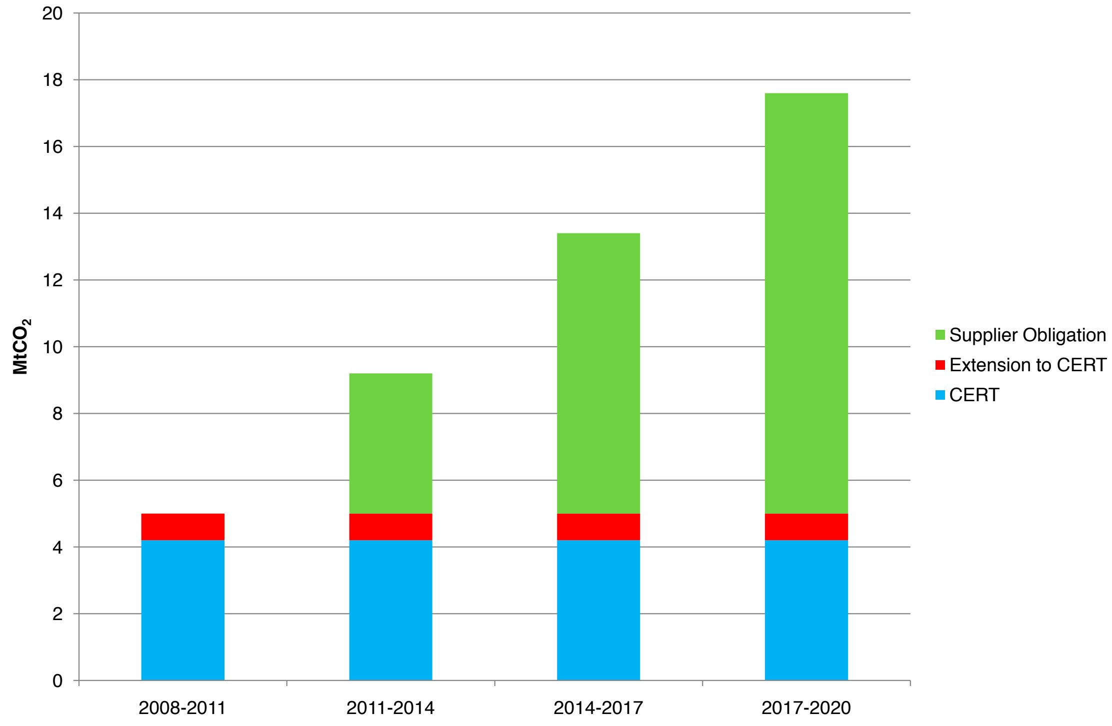
The Supplier Obligation is the continuation of a policy originally called the Energy Efficiency Commitment (EEC) introduced in 2002. The first phase of EEC ran until March 2005, with a second phase from April 2005 to March 2008. The third phase of EEC, called the Carbon Emissions Reduction Target (CERT), started in April 2008 and will run to 2011. Beyond this time CERT will become the Supplier Obligation; for simplicity, we use the term Supplier Obligation below to cover all of these phases, past and future.

The Supplier Obligation works by setting targets for energy (electricity and gas) supply companies to implement measures that will reduce emissions. Energy companies offer these measures to customers at discounted rates which are financed by spreading the resulting costs across the customer base. The companies are incentivised to deliver measures through a system of fines for failing to meet targets. The Supplier Obligation therefore meets the first four criteria listed above for effective policy design.

The level of ambition of the Supplier Obligation programme is illustrated in Figure 6.15. By 2011 the Supplier Obligation aims to deliver 5 million tonnes of CO_2 emissions reduction versus business as usual[6]. By 2020, the Supplier Obligation aims to deliver an additional 11-15 $MtCO_2$. Table 6.1 sets out the indicative set of specific measures by which DECC believes reductions of this scale could be achieved.

6 This includes a 20% extension to the original CERT targets announced in September 2008.

Figure 6.15 Emissions reduction path from Supplier Obligation policies[7]



Source: DECC

Table 6.1 Illustrative mix of emissions reduction from the Supplier Obligation

Measure	Carbon Savings ($MtCO_2$/year)	Number Installed/other comments
Insulation	4	This equates to: 5.1m cavity wall insulations (all technical potential) plus around 500,000 loft top ups from <100mm depth
Lights and Appliances	3	-
Behaviour/Cutting Waste	4	This represents roughly 2.5% of all domestic carbon emissions (from electricity, gas, oil and solid fuel)
Fuel Switching	2	450,000 installations. The technically feasible estimate is around 3.3 $MtCO_2$/yr or 790,000 installations
Microgeneration	1	1.9m installations predominantly Micro CHP and solar thermal, but also significant numbers of heat pumps and community biomass
Total	**13**	

Source: DECC

7 Graph based on central estimate of 12.6 $MtCO_2$ being delivered between 2011 and 2020 (which is equivalent to the level of effort outlined by CERT). The range stated above (11-15$MtCO_2$) is based on the stated range of 3-4 MtC (Defra (2007) *The Household Energy Supplier Obligation from 2011: A Call for Evidence)*.

The Supplier Obligation has been successful in meeting targets to date. Going forward, however, targets will be increasingly difficult to deliver as the types of measures required change from low cost measures such as energy efficient light bulbs or insulating cavity walls and lofts to expensive or difficult measures such as solid wall insulation, microgeneration and lifestyle change. This presents a significant challenge which will require changes in attitudes and behaviour of households if targets are to be met.

There is therefore some risk in relying entirely on current arrangements to deliver the planned Supplier Obligation reductions to 2020. Incentives placed on energy companies will be an important part of any solution, but it is not clear that they alone will be able to overcome the range of constraints that undermine the willingness or ability of households to act. The Supplier Obligation may therefore need to be reinforced by policies to stimulate customer demand for the measures which energy supply companies are required to deliver.

Stimulating customer demand – Energy Performance Certificates and other policies: Energy Performance Certificates are designed to provide standardised measures of the energy efficiency of properties. From December 2007 they are required whenever a house or flat is sold, and from October 2008 whenever one is rented. The requirement for EPCs aims to increase consumer awareness of energy efficiency, and to create incentives for owner occupiers and landlords to improve energy efficiency in order to enhance the attractiveness of a property to future buyers or tenants. The impact of such information provision in stimulating emission reductions is inherently difficult to estimate, and will have to be assessed over time. The introduction of EPCs, however, creates an information base on which stronger financial and regulatory incentives – e.g. variation in stamp duty by EPC rating, or mandating that rented properties must achieve a minimum rating – could be built. The Committee therefore proposes in subsequent reports to look in detail at the effectiveness of the Supplier Obligation and EPCs in delivering the emissions reduction which is technically possible, and to consider if reinforcement of policy with more direct fiscal and regulatory incentives is likely to be required.

Appliance standards, labelling and voluntary agreements: The MACC analysis has shown significant technical potential to improve the energy efficiency of appliances often at low, zero or negative cost to the consumer. But many consumers continue to buy energy inefficient appliances. Policies to drive more rapid adoption of new appliances combine the provision of information, mandatory regulation and voluntary agreements (Table 6.2). In particular:

- The European energy efficiency labelling scheme for domestic white goods, lamps and air conditioning has achieved significant success in recent years in raising the performance of goods sold (e.g. 70% of fridges and freezers sold in the UK in 2007 were A-rated or above compared to only 5% in 2006). The policy can be used to drive continual improvement by periodically introducing still higher performance categories.

- The EU directive on energy using products will establish and regularly review mandatory minimum standards of energy efficiency for 20 selected product categories, precluding access to the EU market to those products that do not meet the agreed standards. So far Member States have agreed on mandatory standards for energy consumption by domestic appliances on stand-by, set-top boxes, external power supplies, office and street lighting.

- The UK has introduced a voluntary initiative led by manufacturers and retailers to phase out inefficient incandescent light bulbs.

Table 6.2 Policy interventions aimed at improving efficiency in appliances

Interventions at the EU level		
Type of lever	**Description**	**Target emissions reduction**
Labelling	The European mandatory A-G energy efficiency labelling scheme for domestic white goods, lamps and air conditioning is well established and recognised. The EU is currently reviewing this with the aim for this to keep driving market transformation.	Residential buildings
Mandatory standards	The EU directive on energy using products will establish and regularly review mandatory minimum standards of energy efficiency for 20 selected product categories, precluding access to the EU market to those products that do not meet the agreed standards (so far Member States have agreed on mandatory standards for energy consumption by domestic appliances on stand-by, set-top boxes, external power supplies and tertiary lighting – i.e. office and street lighting)	Residential buildings/ Non residential buildings
Voluntary initiatives	The EU operates voluntary 'Codes of Conduct' which set voluntary performance targets in collaboration with manufacturers for a limited number of appliances. These are increasingly likely to be replaced by mandatory measures under the Ecodesign for Energy Using Products Framework Directive.	Residential buildings/ Non residential buildings/ Industry
Labelling / Voluntary initiatives	In Europe and internationally the voluntary Energy Star Scheme identifies the best ICT equipment. There are also voluntary EU Ecolabel criteria for light bulbs, refrigerators, dishwashers, washing machines, heat pumps, vacuum cleaners, televisions, personal computers and laptops, although these are not very common on the market.	Residential buildings/ Non residential buildings
Voluntary initiatives	The EU-driven data centre code of conduct aims to reduce data centre electricity consumption.	Non residential buildings
Voluntary initiatives	The International Energy Agency is proposing a new Implementing Agreement as a mechanism for cost-shared projects, to share information and develop benchmark energy efficiency standards, policies and programmes, as well as improved international co-ordination of activities.	Residential buildings/ Non residential buildings/ Industry

Interventions at the UK level		
Type of lever	**Description**	**Target emissions reduction**
Innovation	The Technology Strategy Board invests in key technology areas such as advanced materials, electronics, photonics and electrical systems to help the UK maintain a core expertise and leading-edge capability to underpin UK business growth.	Residential buildings/ Non residential buildings/ Industry
Pricing and trading	Enhanced Capital Allowance schemes for certain commercial products such as motors and air conditioning allow businesses to claim a 100% first-year tax relief on efficient machineries.	Non residential buildings/ Industry
Voluntary initiatives	In September 2007 a voluntary initiative led by UK retailers and energy suppliers to phase out inefficient incandescent light bulbs was announced.	Residential buildings/Non residential buildings
Procurement	The Energy Saving Trust have developed 'Buyer's Guides' for professional buyers of appliances about what to look for when procuring sustainable products.	Non residential buildings/Industry
Public sector procurement	'Quick Wins' is a list identifying mandatory environmental standards across a range of commonly purchased products. It is backed by government procurement bodies such as the Office of Government Commerce. The Government is also committed to develop a Green IT strategy. Finally, the National Health Service and Defra are developing a toolkit and procurement guidance for assessing the energy impacts of medical devices.	Non residential buildings
Labelling / Voluntary initiatives	In the UK the voluntary endorsement label scheme *Energy Saving Recommended* is run by the Energy Saving Trust.	Residential buildings
Public information	The Energy Saving Trust works to promote consumer awareness and understanding about energy efficient appliances.	Residential buildings

Source: Defra

This combination of EU and UK measures is likely to deliver significant emissions reduction from household appliances and lighting (as well as from non-domestic appliances such as office ICT). Given the speed with which energy consumption by ICT and consumer electronics has grown this will be an increasingly important area. The Committee therefore urges the Government to keep pushing for ambitious and wide ranging mandatory standards at a European level. The Government should also ensure that the initial momentum behind the voluntary agreements to phase out inefficient incandescent light bulbs is maintained, and should consider the scope for extending these agreements to cover other appliances.

(vii) Realistic potential from residential emissions reduction from energy efficiency improvements and lifestyle change

Table 6.3 presents our summary assessment of the realistic potential for emissions reduction from energy efficiency and lifestyle change in the residential sector by 2020. While the technical potential for change regardless of cost could be as high as 43 $MtCO_2$, we estimate that realistic potential lies in the range of 9 to 18 $MtCO_2$. This range relates to existing buildings: in addition there are 4 $MtCO_2$ emission reductions relating to newly built homes, which we regard as realistic given the proposed zero carbon new homes policy (see Section 2(iii) above). The aggregate figures for energy efficiency and lifestyle change assumed for the residential sector in Chapter 3: *The first three budgets* are Current Ambition 13 $MtCO_2$, Extended Ambition 19 $MtCO_2$, and Stretch Ambition 22 $MtCO_2$. With the exception of zero carbon homes (which has a phased introduction) we have assumed a linear reduction in emissions over the period to 2020. This reflects the fact that most of the measures rely on established technologies with developed supply chains that can respond rapidly.

To reach this assessment of realistic potential we have, for each of around 50 different measures, made assumptions which reflect:

- The level of technical potential identified by the MACC analysis.
- The social research evidence on the willingness and ability of people to change and our assessment of which types of change are most likely to face opposition.
- The policy framework, both as it currently exists, and as it might be extended to strengthen incentives and increase the level of ambition.

The assessed realistic potential, relative to technical potential, is significantly affected by the degree of disruption involved in implementation:

- **Less disruptive measures:** There is a set of measures where we assume that a large proportion of technical potential can realistically be achieved because they need not require major disruption to households, and because ambitious policies targeted at these measures are already in place. These include loft and cavity wall insulation, purchase of more efficient appliances and lights, and minor lifestyle changes.
- **More disruptive measures:** There are other measures where we have been more conservative in our estimate of what can realistically be achieved. Specifically:
  - Insulating solid walls is disruptive and as a result is likely to be unpopular. We therefore assume in our Extended Ambition scenario that only 10% of technical potential can be achieved.
  - We have assumed that few people will replace boilers before the end of their useful life, even though early replacement may be financially beneficial. As a result only about 15% of the technical potential is included as realistic in the Extended Ambition scenario.

Policies to drive solid wall insulation should however be given serious consideration, with a possible role for financial incentives or for mandatory requirements at time of sale or renting. We therefore include a more ambitious assumption that 4 $MtCO_2$ emissions reduction is achieved through solid wall insulation in our Stretch Ambition scenario. The early replacement of inefficient boilers also offers savings at low cost and, although not included in our Stretch Ambition scenario, is worthy of further consideration.

Table 6.3 Emissions reduction potential from energy use in residential buildings ($MtCO_2$)

	Technical Potential	Current Ambition	Extended Ambition	Stretch Ambition
Insulation Measures	26	4	5	9
of which solid wall	*13*	*1*	*1*	*4*
Heating Efficiency	3	0	0	0
Lights and Appliances	8	4	5	5
Lifestyle Measures	6	1	4	4
Total for efficiency measures	**43**	**9**	**15**	**18**
Zero Carbon Homes	N/A	4	4	4
Renewable Heat and Microgeneration*	62	0	10	10
Total**	**105**	**13**	**29**	**32**

Source: CCC
*Renewable heat is covered in Section 2(viii)
**Totals may not sum due to rounding errors

(viii) Microgeneration and renewable heat in residential buildings

The subsections above have covered opportunities to improve energy efficiency and to change lifestyle/behaviour. This subsection considers the potential to reduce emissions through the production of renewable electricity or heat at local level. These opportunities were identified on the MACC (see Figure 6.10) as more expensive per tonne of CO_2 saved, but it may still be appropriate and necessary to pursue these opportunities to help achieve overall objectives.

In considering potential for emissions reduction through increased deployment of renewable technologies in the residential sector we have adopted a similar approach to that for energy efficiency described above. We start by assessing the technical emissions reduction potential, and then assess realistic potential through considering behavioural constraints and the policy context.

Technical potential: In considering technical potential for increased microgeneration, we have used a model that has been developed for us by BRE and AEA. The model comprises data on capital costs, ongoing and maintenance costs, and potential fuel cost savings following microgeneration installation.

The model covers electricity generation from small scale wind turbines, photovoltaic solar panels, and upgrading of boilers to CHP, and heat generation through solar thermal water heating, biomass heating, heat pumps and district heating schemes.

Estimates of technical potential coming from the model include:

- There are around five million properties where it might be suitable to add small scale wind turbines. This could result in emissions reduction of 5 $MtCO_2$ relative to a situation where electricity is generated centrally based on firing of gas. The cost associated with this emissions reduction averages £355/tCO_2, reflecting the relatively high upfront costs of installing wind turbines when considered against ongoing cost savings.

- Solar PV could in principle be added to around 25 million properties in the UK. This would result in emissions reduction of 20 $MtCO_2$ relative to gas-fired power generation, at a cost of £265/tCO_2 saved.

- Solar thermal water heating could be added to 18 million households in the UK in the period to 2020. This would reduce emissions largely through displacing current gas-fired water heating. The emissions reduction would be 6 $MtCO_2$, at a cost of £425/tCO_2.

- Burning of biomass in boilers could substitute for current fossil fuel and electrical heating systems, which would be particularly attractive for properties that are currently off the gas grid. Up to four million off gas grid households could potentially move to biomass heating, resulting in emissions reduction of 21 $MtCO_2$, at a cost of just under £60/tCO_2.

- Around nine million properties with gardens could be fitted with ground source heat pumps with an associated emissions reduction of 3 $MtCO_2$ at a cost of £190/tCO_2. There may be additional opportunities for emissions reduction from air source heat pumps, particularly where space constraints preclude ground source heat pumps.

- CHP could deliver just over 1 $MtCO_2$ by 2020 at a cost of over £250/tCO_2 in larger and older homes with high heat demands.

- District heating schemes have the potential to save over 5 $MtCO_2$ by 2022. This would be delivered by retrofitting over 3,800 urban areas with district heating schemes.

Realistic potential: The first thing we have considered in moving from technical to realistic potential is the social research evidence base:

- Defra's social research evidence base suggests that there is both limited willingness and ability to install microgeneration, given the range of constraints that are currently in place (financial barriers, hidden costs, lack of information, and fear of the unknown etc.).

- An additional source of evidence that we have considered is a model developed by Element Energy and based on econometric analysis of survey data relating attitudes to microgeneration[8]. The various scenarios that we commissioned from Element Energy suggest that, based on current attitudes, the level of likely microgeneration uptake would not be significant in the period to 2020 even with very substantial upfront financial support.

The second factor we have considered is the UK's commitment, as part of the EU renewable energy strategy, to generate 15% of energy from renewable sources by 2020. The UK's draft Renewable Energy Strategy (RES) sets out scenarios to meet this target that include significant deployment of biomass heating, ground source heat pumps and solar thermal water heating in both residential and business sectors (Box 6.3). In particular, the draft RES sets out a scenario where up to 14% of heat is delivered through renewable energy by 2020, saving almost 24 $MtCO_2$[9]. The bulk of emissions reduction in the residential sector is driven by biomass and solar water heating.

8 Element Energy (2008) '*The growth potential for Microgeneration in England, Wales and Scotland*'

9 This figure includes significant abatement from the use of biogas. We do not include this in our scenarios because we have not been able to properly assess potential for increased use of biogas. We will, however, return to this issue as part of our ongoing work programme. Our scenarios are, therefore, conservative in terms of potential for emissions reduction.

Box 6.3 Summary of draft renewable energy strategy - renewable heat

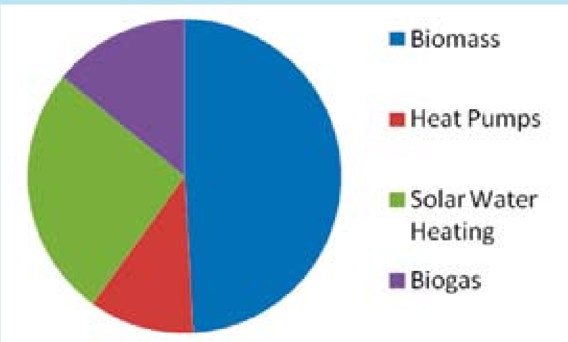
The draft Renewable Energy Strategy (RES) sets out how the UK might meets its share of the EU's 20% renewable energy target. The European Commission has proposed that the UK's contribution to this target should be that 15% of our energy should come from renewable sources.

Given estimates of the cost of renewable energy in both transport and electricity generation there is likely to be the need and potential for a considerable amount of energy used for heat generation to come from renewable sources. The draft RES suggests a target of 14% might be appropriate. This will require a significant ramp-up to renewable heat uptake given that only 0.6% of heat came from renewable sources in 2006.

The consultation sets out a number of possible technologies that would be needed to meet different levels of renewable heat. These include:

- **Biomass:** The burning of biomass crops (e.g. wood chips) and biodegradable waste represents a significant portion of the renewable energy set out in the consultation. Whilst there are many issues over the sustainability of supplies and air quality, there is significant scope to use biomass as it is one of the most cost-effective potential sources of renewable heat.
- **Heat pumps:** Working like a 'fridge in reverse', heat pumps use compression and expansion of gases or liquid to draw heat from the natural energy stored in the ground or air. These can offer very efficient ways of generating heat, but can have significant constraints in terms of the space they require and the way heat is distributed that can make them expensive to retrofit in existing properties. These tend to work best in well insulated houses with under floor heating.
- **Solar water heating:** This technology uses the sun's warmth to heat water and are most effective on south facing roofs. Often this will not provide all hot water demand and will require an alternative heat source as a backup.
- **Biogas:** This is a gas produced by the 'natural process whereby organic material (such as food waste, livestock slurries, sewage sludge or energy crops) is broken down by bacteria in the absence of oxygen'. This gas can be burnt to produce energy or refined to produce biomethane which can be used in the same way as natural gas and 'injected' into the national gas grid.

To deliver a 14% target for renewable heat, a mix of technologies will be needed across residential, business and public sectors. The mix of energy put forward in the draft RES is shown in the graph below.



The draft RES recognises the need for government action to encourage the switch to renewable heat from fossil fuel alternatives. Proposed measures among others include a financial incentive mechanism and measures to address non-financial constrains such as awareness raising, training of installers and building regulations.

Source: BERR (2008) *UK draft Renewable Energy Strategy*

Precise policies to achieve these objectives have not yet been defined, but the draft RES sets out high level options that the Government is considering. These include new financial incentives, together with a range of measures aimed at changing attitudes to renewable heat and microgeneration.

Bringing together the social research and the policy commitment, we have developed a range for realistic emissions reduction potential:

- In our Current Ambition scenario, we assume that policy effort is limited to financial incentives without action to address other barriers, such that uptake is very limited in the period to 2020.

- In our Extended Ambition scenario, policy effort to change attitudes and provide financial support is successful in delivering the level of renewable heat envisaged in the draft RES[10].

- We also assume a level of district heating that reflects the level identified by BERR in its call for evidence on the heat sector.

In total, the realistic emissions reduction potential from renewable heat in the Extended Ambition scenario is up to 10 $MtCO_2$ in 2020, with the cheapest option being residential biomass at just under £60/tCO_2[11].

For the years before 2020 we have used modelling from Element Energy and the draft RES to identify the speed with which these technologies could be installed. We have assumed that most of the potential is back ended, reflecting the difficulty of rapid action in this area.

10 The technologies in the draft RES scenario are indicative. Plausible variants on this scenario, with more or less of particular technologies, could deliver a similar overall level of renewable heat. However the overall level of renewable heat is likely to be required to meet the EU target given what can be achieved through the use of renewable energy in electricity and transport.

11 This does not include potential air quality costs. Preliminary analysis suggests these are not significant for off gas-grid homes.

3. EMISSIONS REDUCTION IN NON-RESIDENTIAL BUILDINGS AND INDUSTRY

This Section assesses the potential for emissions reduction in non-residential buildings and in industry. It covers in turn:

(i) Emissions trends and projections in non-residential buildings and industry

(ii) Technical emissions reduction potential in non-residential buildings

(iii) Technical emissions reduction potential in industry

(iv) Realistic potential and the policy framework for emissions reduction in non-residential buildings and industry

(i) Emission trends and projections in non-residential buildings and industry

Emissions for non-residential buildings and industry fell by 15% over the period 1990-2006. (Figure 6.16). Direct emissions fell by 16% and indirect (i.e. electricity-related) emissions fell by 13% (Figure 6.17). By sector the key trends were (Figure 6.18):

- Industrial emissions fell by 18%. This was primarily due to falling direct emissions, resulting from the decline in heavy industry and from switching to less carbon intensive fossil fuels. In addition, indirect emissions fell slightly, due to the declining carbon intensity of electricity generation.

- Commercial sector emissions grew by 4%. This was primarily due to a 6% rise in indirect (electricity-related) emissions, with electricity demand growth more than offsetting the declining carbon intensity of electricity.

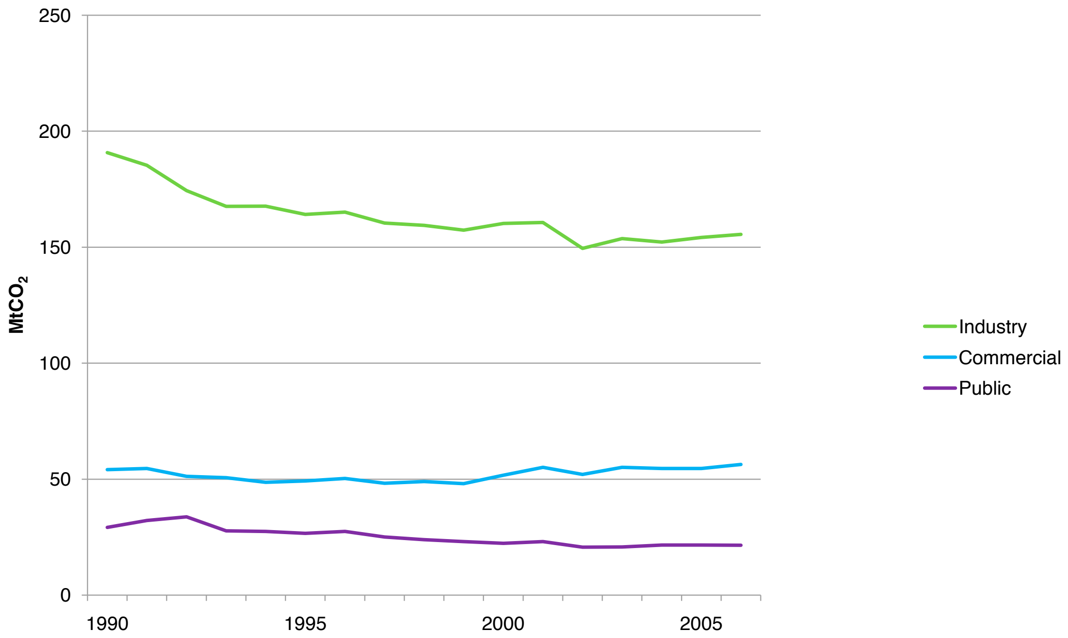
- Public sector emissions fell 26%. Direct emissions fell due to energy efficiency improvements in heating and a switch to less carbon intensive fossil fuels. Indirect emissions fell as the declining carbon intensity of electricity more than offset rising electricity demand.

Looking forward, as Figure 6.18 illustrates, DECC Energy Model projections suggest that total emissions will fall by a further 15% by 2020. This fall results from the combination of:

- A forecast 2% rise in direct emissions. This results from (i) forecast output growth of 50% in commercial buildings which means energy demand growth outweighs future efficiency gains and; (ii) forecast output growth in industry no longer offset by the decline of heavy industry seen over the period 1990 to 2006.

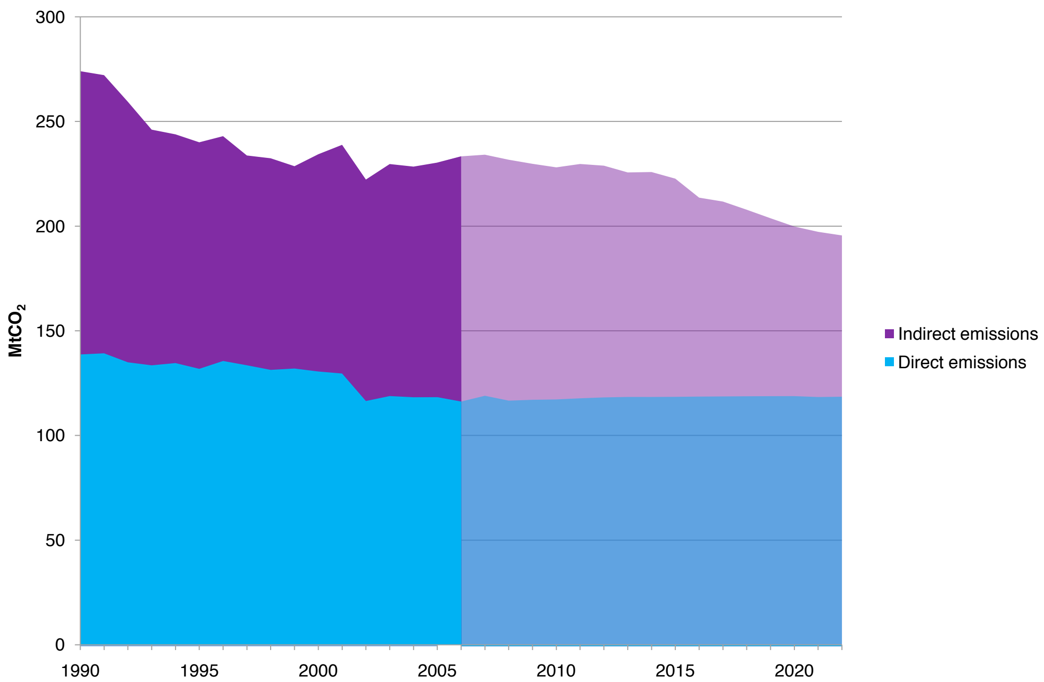
- A forecast reduction of 30% in indirect (electricity-related) emissions. Electricity demand is forecast to increase in all three subsectors, but this is offset by the predicted 40% fall in the carbon intensity of electricity.

Figure 6.16 Historical emissions in industry, commercial and public sectors 1990 to 2006



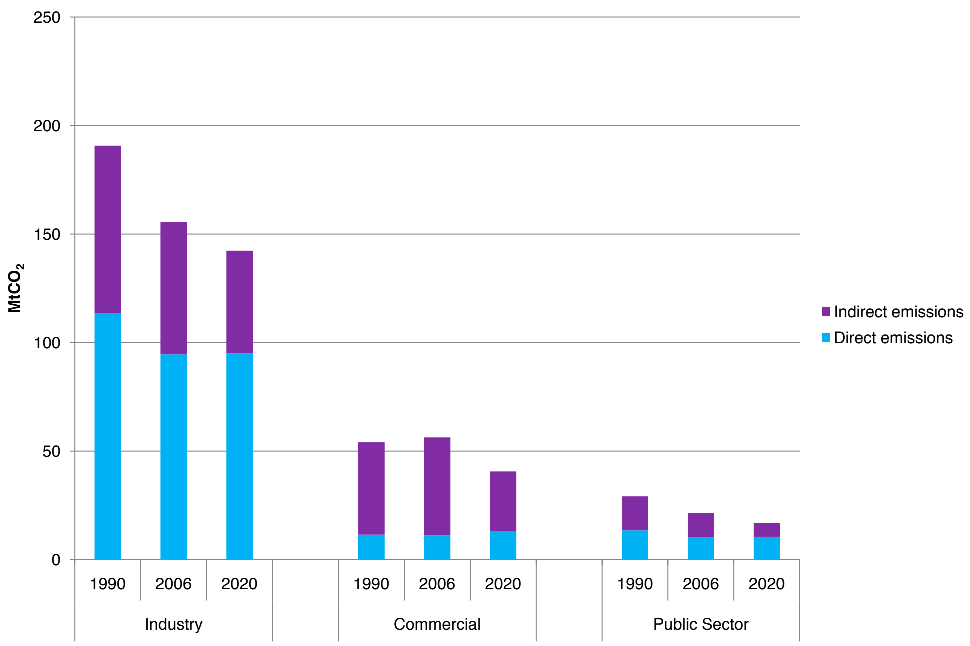
Source: NAEI (2008)

Figure 6.17 Projected emissions from energy use in non-residential buildings and industry by source: 1990 - 2022



Source: DECC modelling on behalf of CCC

Figure 6.18 Projected emissions by sector and source



Source: DECC modelling on behalf of CCC

(ii) Technical emissions reduction potential in non-residential buildings

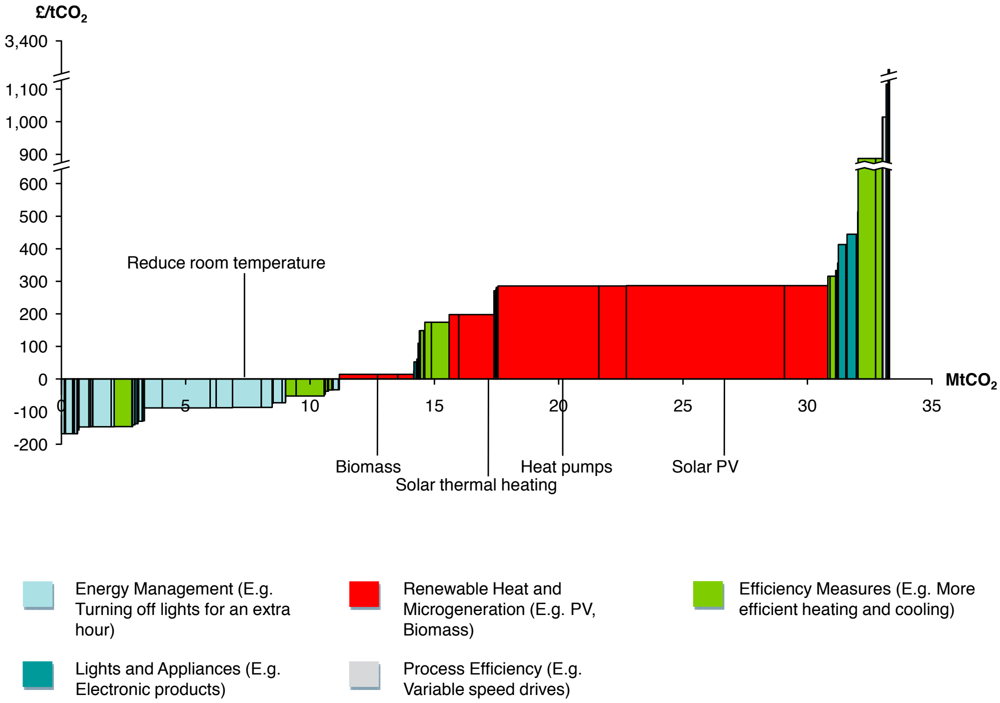
In developing our assessment of potential for emissions reduction in non-residential buildings, we have used MACC models that we commissioned from the Buildings Research Establishment and updated by AEA. These models include a similar range of options as for residential buildings and identify the following emissions reduction potentials:

- Improving efficiency of heating/cooling buildings could save over 5 $MtCO_2$ in 2020.
- Better management of energy – from motion sensitive lights to optimising heating temperatures and timing – could save over 8 $MtCO_2$ in 2020.
- Use of more efficient lights and appliances have the potential to reduce emissions by around 1.5 $MtCO_2$ in 2020.
- Microgeneration technologies have significant technical potential and could reduce emissions from buildings by up to 18 $MtCO_2$ comprising:
  - Biomass boilers – 3 $MtCO_2$
  - Heat pumps – Up to 5 $MtCO_2$
  - Solar thermal – Around 2 $MtCO_2$
  - Solar PV – Over 8 $MtCO_2$

In total a technical emissions reduction potential of almost 33 $MtCO_2$ is identified for non-domestic buildings (Figure 6.19), of which 14 $MtCO_2$ is available at a cost below £40/tCO_2, and 11 $MtCO_2$ available at zero or negative cost. The extent to which these are realistically achievable will depend on the policy framework, which we consider in Section (iv) below.

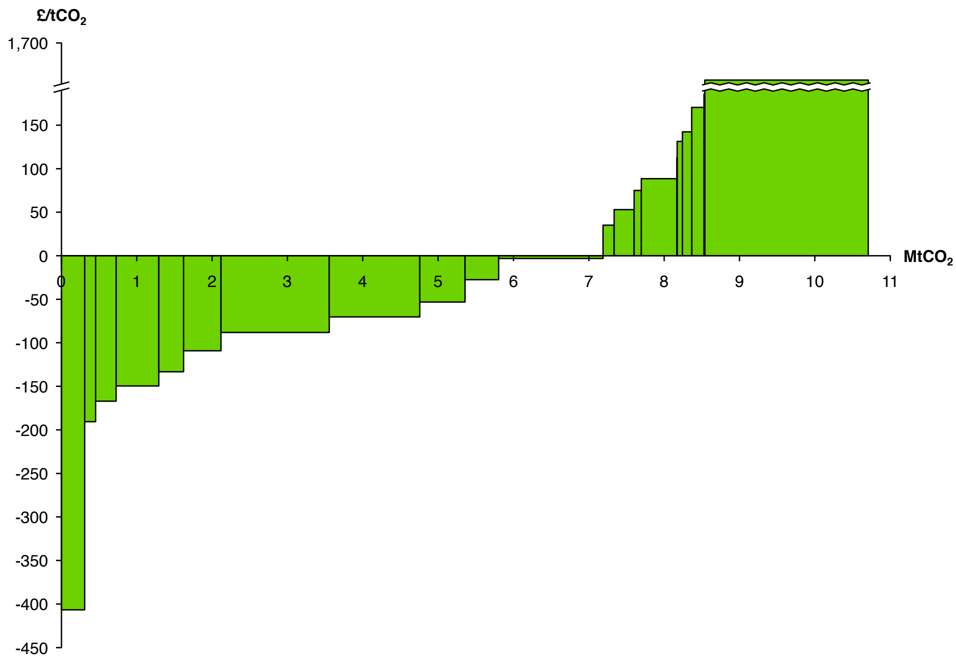
As with the residential sector, this model applies to existing buildings. It is possible to apply packages of measures to reduce emissions from new buildings and the Government has announced an ambition that all new non-domestic buildings should be zero carbon by 2019. Given the rate of new build this is unlikely to provide significant carbon savings by 2020 and has therefore not been included in our modelling. It will, however, be an important policy for the longer term.

Figure 6.19 Non-domestic buildings MACC – technical potential in 2020



Source: CCC

Figure 6.20 Industry MACC – technical potential in 2020[12]



Source: CCC

12 Due to the number of technologies it is not possible to show individual bars for each measure. Instead the industry MACC aggregates technologies to provide a simple representation of the shape of this curve.

(iii) Technical emissions reduction potential in industry

In coming to a view on the level of industrial abatement potential, we have used DECC's ENUSIM model which we commissioned AEA to update. The model considers in excess of 1000 measures for reducing emissions from industrial energy use and generates a MACC as shown in Figure 6.20. Two features of this MACC are worth noting:

- First, the potential to reduce emissions at a negative cost, or even at a cost below the possible £40/tCO_2 price of carbon, is much smaller relative to the size of the sector than it is in the case of residential or commercial buildings. The 7 MtCO_2 available at negative cost represents just 4% of industrial sector emissions, whereas for commercial and public sector buildings the figure is 18% and for residential buildings 27%. This may reflect the fact that energy costs are already professionally managed in business but not in residential homes, and are much more intensively managed in industry than in commercial and public sector buildings because of the larger share of energy costs in total costs.

- Second it is not possible to identify on the MACC major blocks of opportunity resulting from specific technologies. This reflects the fact that the opportunities in industry lie in multiple relatively small process improvements. These improvements encompass (i) improvements in efficiency in the use of electricity through multiple enhancements to electrical machinery and (ii) improvements in efficiency of heat generation, insulation and heat recovery. These improvements can be achieved either within existing plants via incremental improvement or as part of investment in new plant.

The MACC shown on Figure 6.20 does not include potential from increased deployment of CHP. But we have estimated the scope for increased use of CHP in industry and commercial buildings based on separate MACC models that AEA have developed for us. Drawing on these models, we estimate that there is scope for emissions reduction of a further 8 MtCO_2 in 2020, with around 4 MtCO_2 available below a cost of £40 per tonne of CO_2.

(iv) Realistic potential and the policy framework for emissions reduction in non-residential buildings and industry

In principle organisations where energy consumption is professionally managed should use energy efficiently. Our analysis, however, suggests that there remains significant potential for reducing emissions from non-residential buildings at negative or low cost with some but more limited potential also in industry.

This apparent inconsistency is explained by the large body of evidence highlighting a range of non-price barriers to uptake of cost-effective abatement potential which are similar in many respects to the barriers discussed with reference to the residential building sector in Section 2(v) above, and including[13]:

- Hidden costs relating to the adoption of new technologies (e.g. delivery risk and ongoing management/supervision time);

- Market and regulatory failures that can prevent organisations from reaping the benefit of investment in energy efficiency (e.g. the landlord-tenant problem or information problems which can apply to companies and public sector organisations);

- Bounded rationality and split incentives within organisations (e.g. rules of thumb for investment, engineers responsible for upgrading of equipment pursuing different objectives from the energy managers).

13 For a summary discussion see The Carbon Trust (2006). The UK Climate Change Programme: Potential evolution for business and the public sector

All these barriers can be tackled by a suitably designed policy framework which creates price incentives through an effective carbon price while addressing non-price barriers through regulation, information and support for technology deployment. We have therefore based our assessment of realistically achievable emissions reduction in the non-residential buildings and industry sectors on a high level assessment of the policy framework. This framework is wide ranging, covering both binding policy measures (which set either emissions caps or binding targets) and other measures, such as Energy Performance Certificates and support/information provided to firms by the Carbon Trust.

Sectors with binding policy levers: There are three mechanisms by which non-residential and industrial emissions are capped or could become capped in the future. The EU ETS is discussed in more detail in Chapter 4: *Carbon markets and carbon prices*. Two further policies – the Carbon Reduction Commitment (CRC) and Climate Change Agreements (CCA) – represent trading mechanisms and binding targets for business to deliver carbon abatement (Box 6.4)

Box 6.4 Detailed description of CRC and CCA policies

Carbon Reduction Commitment

The CRC is an obligatory emissions trading scheme covering large, non energy-intensive businesses and public sector organisations. The CRC is designed to provide the wide range of organisations involved in the scheme with the financial incentive to reduce their emissions in the most efficient way and raise the corporate profile of energy and carbon management.

Inclusion in the scheme will be a legal requirement for commercial and public sector organisations whose annual half-hourly metered electricity use in the UK is above 6,000 MWh per year. Emissions regulated under the scheme will however include all energy end use emissions, including emissions from use of gas and (subject to *de minimis* thresholds) other fuels such as fuel oils and Liquid Petroleum Gas (LPG). Organisations include any UK based parent companies and the UK subsidiaries of those organisations.

The CRC will begin to operate in April 2010 with an introductory period during which organisations will be required to calculate all their energy use and surrender carbon allowances to cover the emissions they generate. In the introductory phase emissions will be sold at a fixed price. From 2013 onwards the CRC will operate as a cap and trade emission trading scheme, thereby directly limiting the amount of emissions from participant organisations. Carbon allowances corresponding to the set cap will be sold at an auction. The CRC will also feature a moderated buy-only link to the EU ETS, through which the CRC participants will be able to buy allowances at the higher of the prevailing EU ETS price and a minimum CRC floor price.

Revenues from the sale or auction will not be kept by Government but will be returned to participants in proportion to their performance in reducing their emissions from their energy use, which will determine their position in a league table. Government analysis suggests that if organisations perform well the money they get back should exceed the cost of buying allowances. Organisations that are successful in reducing their emission may also gain reputational benefits.

The CRC design aims at pulling several levers to change behaviour among participant organisations. Direct financial levers introduced by CRC (the additional carbon price element and the risks and rewards implied by the revenue recycling mechanism) would play a role in attracting sustained management attention. Other levers include better information (through the monitoring and reporting requirements), raising emissions up the organisational hierarchy (through the proposed league table and the target setting process that organisations would need to engage with) and reputational drivers (again, through the proposed league table).

Climate Change Agreements

CCAs were introduced in 2001 alongside the Climate Change Levy in recognition of the need to maintain the competitiveness of energy-intensive sectors subject to international competition or covered by the requirements of the Integrated Pollution and Prevention Control (IPPC) directive. They provide businesses in over 50 energy-intensive sectors with an 80 per cent discount on the Climate Change Levy in return for improving energy efficiency and/or reducing emissions.

In order to claim the discount, installations or sectors covered by the CCAs have to meet their CCA target milestones, which are negotiated emission reductions from a given (sector specific) baseline. CCA participants are allowed to buy and sell allowances in the UK Emissions Trading Scheme (while the scheme ended for direct participants in 2006, it still continues for CCA participants).

The current set of CCAs are negotiated through 2013, and is expected to reduce emissions by a little below 7 $MtCO_2$ per year by 2010.

Some evaluation evidence[1] suggests that in addition to the financial incentives provided by the CCL discount the process of engaging in negotiations with government on the level of the targets has been a powerful driver in increasing awareness of opportunities for cost-effective energy savings among participant organisations.

As announced at Pre-Budget Report 2007, the Government intends to extend the CCA scheme until 2017, subject to state aid approval.

[1] Ekins, P. and Etheridge, B. (2006), 'The environmental and economic impacts of the UK Climate Change Agreements', *Energy Policy*, vol. 34, pp. 2071–86.

Source: DECC

For sectors covered by one of these three mechanisms, we have assumed that caps and targets (supported by building rules and appliance standards in the non-residential building sector) are set so as to unlock all of the potential that we have identified as being available at a cost below £40/tCO_2. We therefore assume that all of this potential is realistically achievable by 2022.

Defining realistic potential for microgeneration and CHP technologies warranted a different approach, as the three key policies mentioned above are not expected to be a key driver of uptake. In the case of microgeneration we relied on uptake scenarios developed by Element Energy to define our Current Ambition scenario for emissions reduction, with the draft RES scenario defining our Extended Ambition scenario (see Box 6.3).

For CHP, feedback that we have received from stakeholders suggests that there are a number of barriers to investment including:

- Considerable uncertainty over future energy prices which results in the use of very high discount rates to assess benefits.
- The fact that energy production is outside the core business for many firms where there is scope to introduce CHP. This again tends to mean that firms apply much higher discount rates than they would apply to core business projects.

Based on this feedback, we have assumed that only CHP projects with very high potential returns are implemented. This results in the assumption that only 1 $MtCO_2$ of abatement from CHP will be achieved even in the Extended Ambition scenario. This may understate the potential, and the Committee intends to look more closely at CHP potential in subsequent work[14].

Overall we estimate that almost 10 $MtCO_2$ emissions reduction can be achieved by firms covered by these binding policy levers in 2020 through the range of measures for energy efficiency improvements, microgeneration and CHP (Table 6.4).

Table 6.4 Emissions reduction potential for firms covered by binding policy levers ($MtCO_2$)

		Technical Potential	Realistic Potential
Non-Residential Buildings	Process Efficiency	0	0
	Energy Management	4	3
	Energy Efficiency (incl. insulation)	3	1
	Lights and Appliances	1	0
	Renewable heat and microgeneration	8	0-1
CHP		8	1
Industry		9	4

Source: CCC
*Potential assumed to be the same in Current and Extended Ambition scenarios except microgeneration.

Sectors not covered by binding policy levers: These comprise small non-energy-intensive firms, of which there are many but which collectively account for up to 45% of total emissions reduction potential from non-residential buildings and industry.

For these sectors, we have defined a range for realistic emissions reduction potential (Table 6.5). The Current Ambition scenario assumes that minimal energy efficiency improvements are made. The Extended Ambition scenario, however, assumes that there is significant progress, with 90% of technical potential available at a cost less than £40/tCO_2 assumed to be realistically achievable by 2022. This would deliver over 7 $MtCO_2$ in addition to emissions reduction potential covered by binding policy levers.

14 For example Poyry have looked at the scope for very large-scale CHP in a few industrial locations with very high heat demands. This suggests there may be further potential for emissions reduction from CHP. (Source: Poyry 2008 *Securing Power: Potential for CCGT CHP Generation at Industrial Sites in the UK*)

Table 6.5 Emissions reduction potential from firms not covered by binding policy levers ($MtCO_2$)

		Technical Potential	Realistic Potential
Non-Residential Buildings	Process Efficiency	<0.5	<0.5
	Energy Management	4	0 - 3
	Energy Efficiency (incl. insulation)	3	0 - 1
	Lights and Appliances	1	<0.5
	Renewable heat and microgeneration	10	0 - 1
Industry		2	0 - 2

Source: CCC
*Range reflects different potential for emissions reductions in Current and Extended Ambitions scenarios.

Achieving these reductions may require new policy levers applied to small business and small organisation sectors where in the past there has been very little policy focus. There are various means by which incentives could be strengthened, from providing information and grants, to including small firms in the Supplier Obligation, to designing a tailored scheme. The Committee recommends that the government considers a wider range of policy options in these sectors; the Committee intends itself to look more closely at these policy options in future work.

4. OVERALL CONCLUSIONS: SCENARIOS FOR EMISSIONS REDUCTION FROM ENERGY USE IN BUILDINGS AND INDUSTRY

In each section of this chapter we have defined a range for emissions reduction. We now bring these ranges together to define current, extended and far reaching scenarios (Table 6.6):

- The Current Ambition scenario includes energy efficiency improvement and abatement in homes and in businesses covered by binding policy levers but with very limited levels of microgeneration. This scenario delivers almost 23 $MtCO_2$.
- The Extended Ambition scenario also includes the emissions reduction expected to result from delivering the draft RES as well as emissions reduction from lifestyle measures in the residential sector, and emissions reduction from those non-residential and industrial sectors not currently covered by binding policy levers. This increases the emissions reduction potential to over 47 $MtCO_2$.
- The Stretch Ambition scenario adds increased uptake of solid wall insulation and delivers around 50 $MtCO_2$.

We build these scenarios into the wider current, extended and far reaching economy wide scenarios in Chapter 3: *The first three budgets.*

Table 6.6 Emissions Reduction Potential from Energy Use in Buildings and Industry ($MtCO_2$)

	Technical Potential	Current Ambition	Extended Ambition	Stretch Ambition
Residential	105	13	29	32
Non-Residential Buildings	33	5	11	11
Industry	11	4	6	6
CHP	8	1	1	1
Total	**152**	**23**	**47**	**50**

Source: CCC

CHAPTER 7:

REDUCING DOMESTIC TRANSPORT EMISSIONS

This chapter covers domestic (primarily road and rail) transport in the first three budgets, i.e. to 2022. Issues relating to aviation and shipping are dealt with in Chapter 8: *International aviation and shipping*; and the longer term technological vision for surface transport was discussed in Chapter 2: *Meeting a 2050 target*.

The chapter presents estimates of emissions abatement opportunity: these feed in to our conclusions on feasible overall emissions reduction scenarios (Current Ambition, Extended Ambition and Stretch Ambition) which were set out in Chapter 3: *The first three budgets*. It also notes the policy levers which are already in place or which would need to be in place to grasp these abatement opportunities. The key conclusions are that:

- Abatement opportunities from surface transport could lie between 5 $MtCO_2$ and 32 $MtCO_2$:
  - These opportunities are dominated by the scope for improving fuel efficiency of cars (both due to technology innovation and changing car purchase behaviour), but there are also opportunities for improving fuel efficiency of vans and HGVs based on conventional technologies.
  - On the demand side, there is significant emissions reduction potential from a range of measures including eco-driving (e.g. smoother acceleration and braking), modal switch, and better journey planning.
  - There is additional abatement potential from more far-reaching measures including widespread introduction of electric and plug-in hybrid technologies to vans, and possible reductions in and effective enforcement of the speed limit.
- The abatement achieved in practice will reflect the rigour of the policy levers used.
  - Unlocking the full potential for emissions reduction from cars will require a legally binding EU target that fuel efficiency of new cars is no more than 100 gCO_2/km in 2020, supported by a range of domestic policy measures (e.g. awareness raising, fiscal levers). Unlocking the full potential in vans will also require a legally binding framework at the EU level. The Committee's view is that the UK Government should strongly support development and subsequent implementation of these European frameworks which will help us to be on the path to meeting our 2050 emissions reduction goals.
  - On the demand side, a range of levers (e.g. better information, driver training) will be important in delivering deep cuts from changed driver behaviour, modal shift and better journey planning.

The quantity of abatement that we have identified is based on detailed modelling and reviewing the literature. It is not, however, exhaustive of all options for reducing transport emissions. Policies for transport infrastructure access and land use planning could, for example, be designed in ways that would further reduce emissions. It is our intention to explore scope for emissions reduction via these levers as part of our work programme going forward.

The analysis that we have carried out feeds in to the Current Ambition, Extended Ambition and Stretch Ambition scenarios for economy wide emissions reduction in Chapter 3.

The analysis that we have carried out is set out in five sections:

1. Present transport emissions, historic trends and reference emissions projections.
2. Abatement opportunities: supply side improvements in carbon efficiency.
3. Rebound effects and demand side policy levers to achieve supply side potential.
4. Abatement opportunities: possible dimensions of demand side reduction.
5. Overall conclusions: reasonable assumptions on attainable abatement for budget purposes.

1. PRESENT EMISSIONS, HISTORIC TRENDS AND REFERENCE EMISSIONS PROJECTIONS

While the UK has achieved reductions in emissions overall, domestic transport emissions have increased 9% from 1990 to 2006 and now account for over 130 $MtCO_2$ (i.e. about 24%) of all CO_2 emissions in the UK's national inventory[1] as shown in Figure 7.1 (in addition, the UK's share of aviation emissions, considered in Chapter 8, amounts to around 38 $MtCO_2$).

Private road transport (cars, vans and HGVs) currently accounts for 86% of total transport emissions, with 4% from buses, 2% from rail and 2% from domestic aviation (Figure 7.2). Our main focus in Sections 2 to 4 below is therefore on abatement opportunities in private road transport, covering cars, vans and heavy goods vehicles (HGVs). But we also consider the issue of whether modal shift to less carbon intensive public transport can contribute to emissions reduction, and refer briefly to abatement potential in rail.

We now cover in turn historical trends and reference emissions projections for:

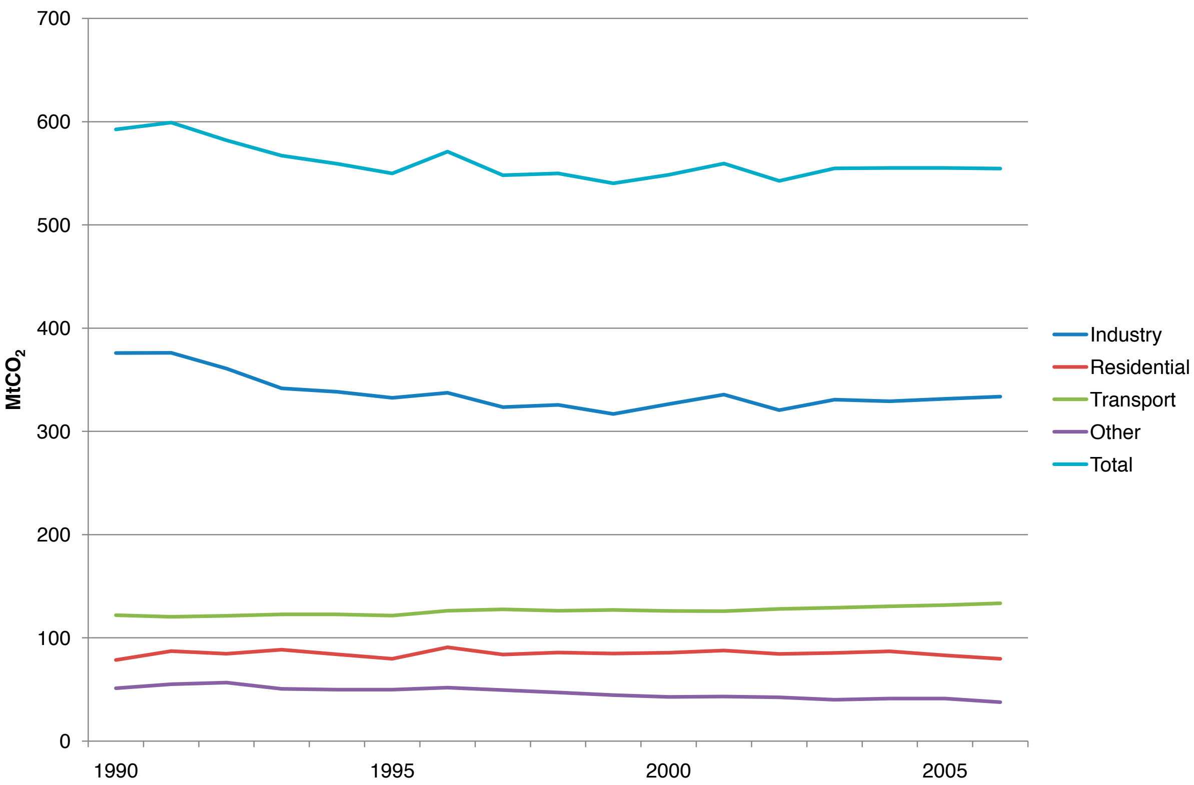
(i) Cars, vans and HGVs

(ii) Bus and rail

(iii) Domestic aviation

(iv) Overall reference emissions projections

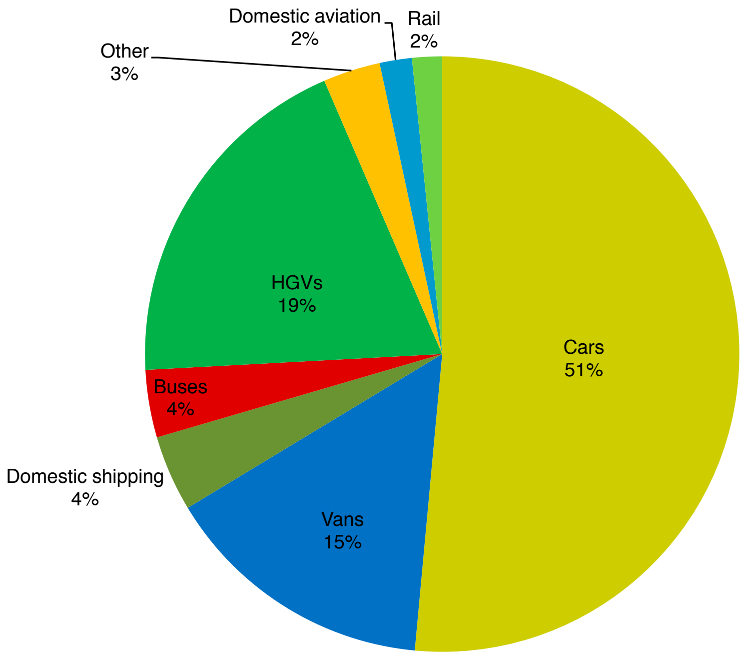
Figure 7.1 Total UK Emissions from all sectors 1990-2006



Source: NAEI.
Note: Emissions by source.

1 UK National Atmospheric Emissions Inventory (NAEI); emissions data by source category.

Figure 7.2 Breakdown of transport emissions by mode, 2006



Source: NAEI

(i) Cars, vans and HGVs

For each of these categories of private road transport it is useful to distinguish clearly between trends in demand growth (vehicle-km or tonne-km) and trends in carbon efficiency (gCO_2/vehicle-km or tonne-km) which together drive total emissions.

- **Passenger cars:** Demand for passenger car travel, whether measured in passenger-km or vehicle-km, increased by 20% between 1990 and 2006, and is on a trend growth path of 1% per annum. Demand growth has, however, been offset by falling gCO_2/vehicle-km travelled, with total emissions as a result on a roughly flat trend. Falling gCO_2/vehicle-km have been achieved through the Voluntary Agreements to reduce new car emissions between the EU and car manufacturers, supported by measures aimed at raising customer awareness and differentiation of both company car taxation and Vehicle Excise Duty (VED) by carbon intensity (Box 7.1). Looking forward the reference emissions projection reflects a modest trend increase in carbon efficiency[2], but assumes no successor policy to the Voluntary Agreements; mandatory EU targets currently being negotiated – discussed in Section 2 below – are not included in the reference case. In the reference emissions projection, demand growth is likely to more than offset a declining rate of carbon efficiency improvement, with total emissions therefore rising as Figure 7.3 illustrates.

- **Vans:** Vehicle-km travelled by vans (also called light goods vehicles; defined as non-passenger cars with a weight of less than 3.5 tonnes) have grown very rapidly over the last 15 years, and projections suggest that they will continue to grow at 2% per annum (Figure 7.4). The precise causes of this growth are not well understood. Usage of vans is balanced between delivery journeys and travel to and between jobs by a wide variety of business trades (Figure 7.5) but it is unclear which categories have contributed most to the growth. Available data on gCO_2/km suggest an erratic pattern, which may reflect imperfect information, but it is clear that there is not a strong downward trend in carbon intensity equivalent to that seen for cars. Although much of the technology for cars developed under the VAs could have been

2 The reference emissions projection is generated from DfT's National Transport Model (NTM). It includes use of biofuels rising to 5% by volume in 2013/14 and then staying at this level until 2022; biofuels are discussed in Section 2 below.

used to reduce emissions from vans, the lack of a clear European policy framework to drive change in this area has meant that efficiency improvements have been offset by increasing van size and weight. If new policy measures are not taken, emissions can be expected to grow significantly over the next 10 years, reaching as much as 22 $MtCO_2$ by 2022.

- **Heavy goods vehicles (HGVs):** Over the long term, HGV traffic has grown, with vehicle-km up 17% since 1990, but with a roughly flat trend over the last 5 years (Figure 7.6). Tonne-km have however continued to grow slightly (Figure 7.7). Looking forward reference projections for demand suggest further growth, but at a considerably slower pace than for cars or vans. Carbon efficiency for HGVs has improved with a long-term trend of around 0.8-1% per year[3], but there is a question over the extent to which this will continue given negative carbon impacts from EU legislation aimed at air quality improvements[4]. On balance, emissions are projected to be roughly flat over the next two decades. HGVs are therefore less likely to be a key cause of emissions increase than cars and vans, but a clearer policy framework would still be desirable to ensure emissions reduction.

Box 7.1 Current EU framework on reducing new car emissions

The decrease in new car gCO_2/km since 1998 is due to the existing EU framework. This ensures that the demand side supports the supply side changes agreed by manufacturers, as it is based on three pillars:

- targets for new car emissions
- Member States' fiscal frameworks
- improved information to consumers on emissions of cars.

The current **targets on new car emissions**, in place since 1998, are Voluntary Agreements (VAs) between the EU and vehicle manufacturer associations to reduce the EU-wide sales-weighted average new car emissions to 140 gCO_2/km in 2008-09. The VAs are between European, Japanese and Korean manufacturer associations which sell cars in the EU with the target applying to cars only (M1 vehicles).

As the target is for the sales-weighted average new car emissions, there is not a specific target by Member State and progress will depend on the performance of models sold by each manufacturer and the fuel used across the whole of the EU.

Fiscal frameworks are within the competency of individual Member States. In the UK, since 2001, car tax has been linked to emissions through Vehicle Excise Duty and since 2002 company car tax has been linked to emissions. These tax systems support consumers willing to purchase the lower emissions vehicles on offer through the VA.

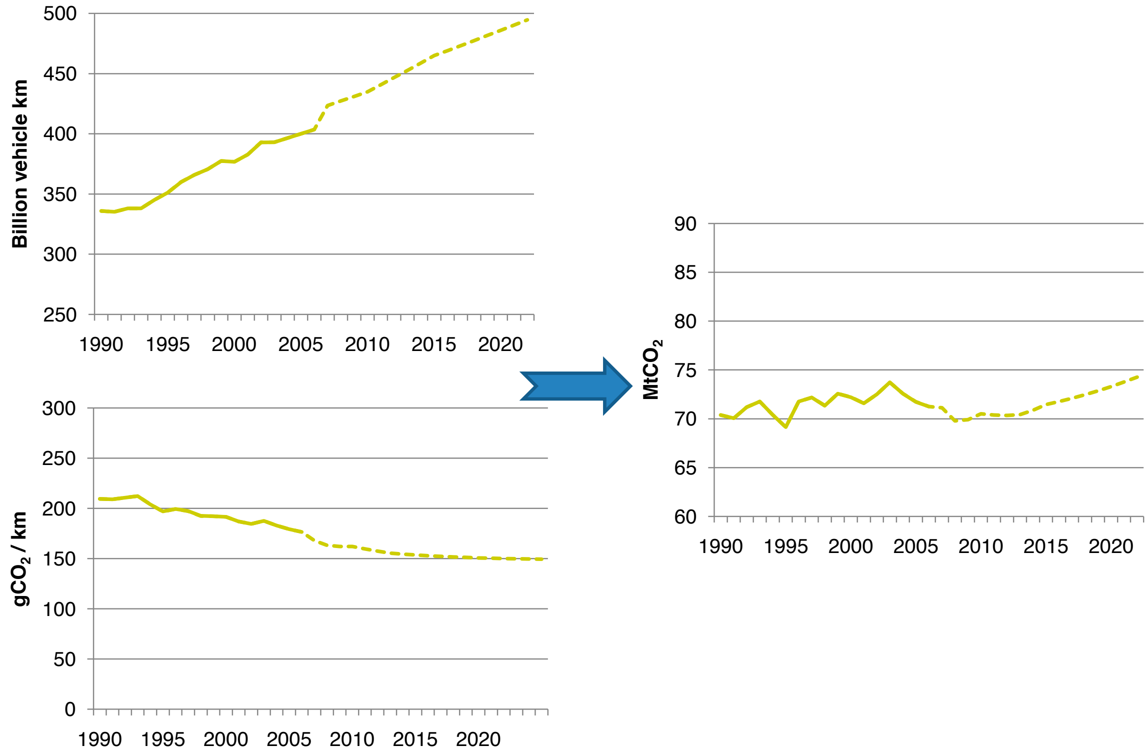
The **improved information to consumers** takes the form of fuel efficiency labelling for new cars. This is covered in more detail in Section 3 below.

Although the EU framework has reduced new car emissions, it is now recognised that the VA target will not be met. In the UK, new car emissions have fallen from 190 gCO_2/km in 1997 to 165 gCO_2/km in 2007, an improvement of 13%. The EU-average new car emissions have fallen from slightly lower starting levels to 160 gCO_2/km in 2007.

Source: http://ec.europa.eu/environment/air/transport/co2/co2_home.htm

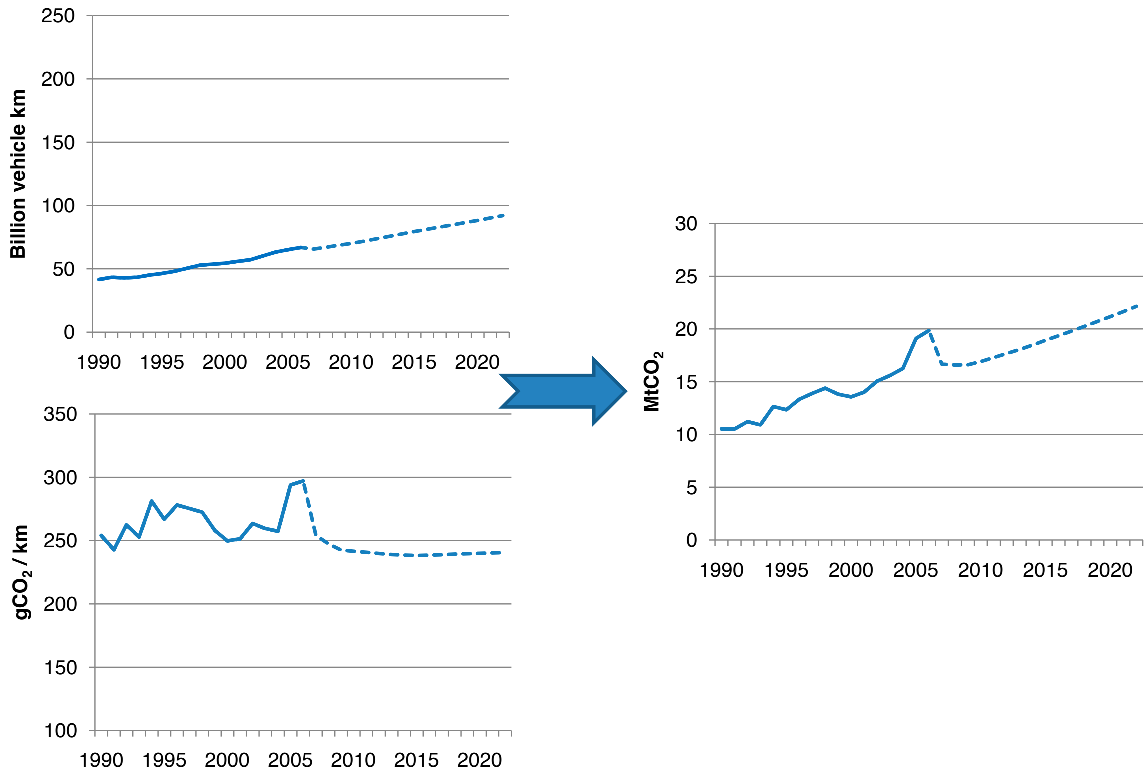
3 McKinnon, A (2008) *Advice on CO_2 Emissions from the UK Freight Transport Sector.* Committee on Climate Change.
4 The Euro standards are aimed at reducing emissions from diesel vehicles, such as vans, HGVs, buses and coaches, which reduce air quality. The filters introduced on new vehicles to ensure that emissions meet Euro standards to improve air quality work to increase CO_2 emissions.

Figure 7.3 Historical trends and reference projections of vehicle-km, $MtCO_2$ and gCO_2/km for cars



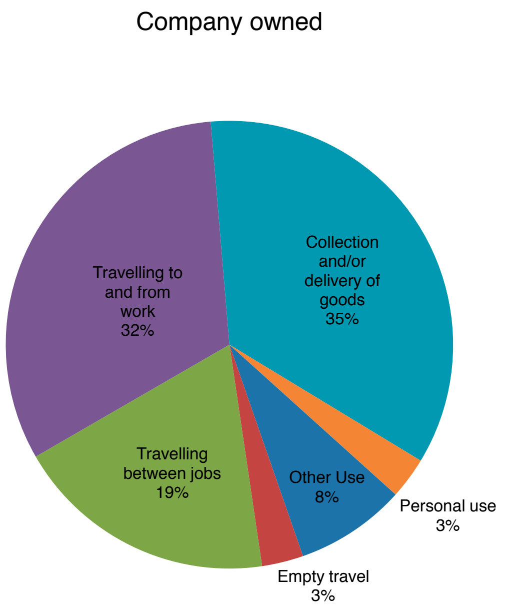
Source: DfT, NAEI.

Figure 7.4 Historical trends and reference projections of vehicle-km, $MtCO_2$ and gCO_2/km for vans



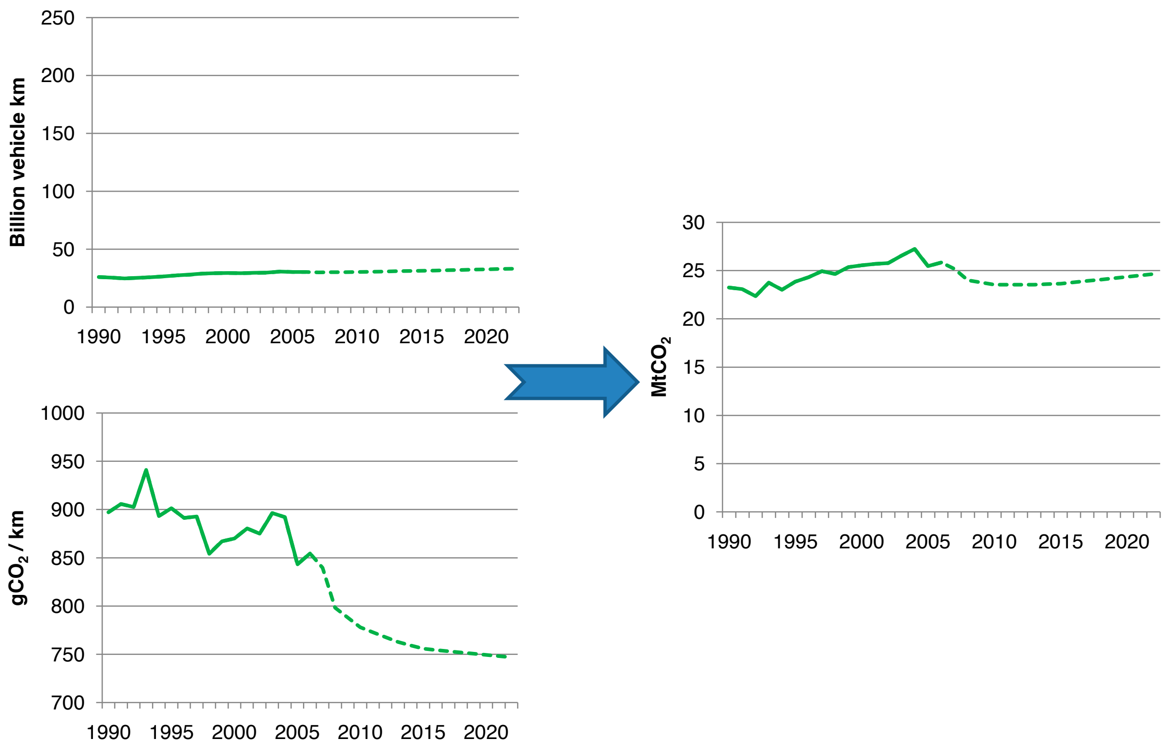
Source: DfT, NAEI.
Note: The jump in emissions is due to moving from historically recorded to modelled figures.

Figure 7.5 Breakdown of van vehicle-km by purpose of travel



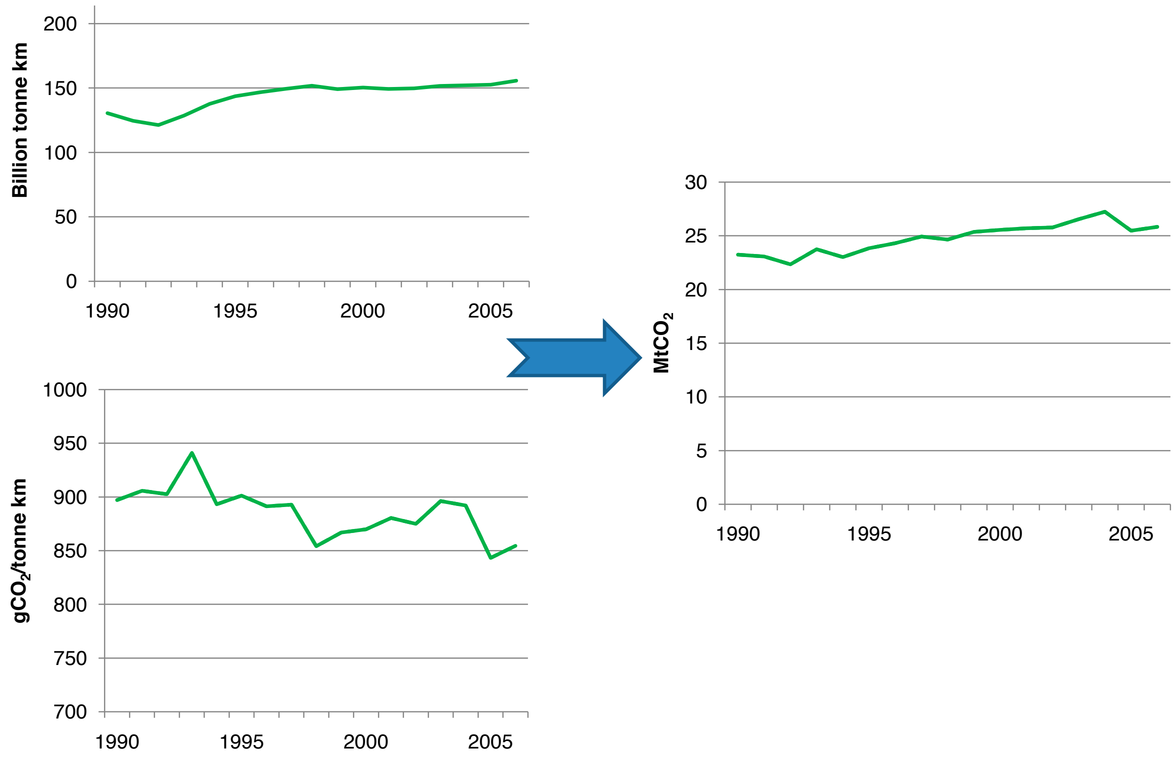
Source: DfT (2003/4).

Figure 7.6 Historical trends and reference projections of vehicle-km, gCO_2/km and $MtCO_2$ for HGVs



Source: DfT, NAEI.
Note: Note the fall in projected gCO_2/km is due to moving from actual to modelled figures and use of biofuels; slower improvements from 2014 are due to the Euro fuel standards.

Figure 7.7 Historical trends in HGV tonne-km, gCO_2/tonne-km and $MtCO_2$



Source DfT, NAEI.

(ii) Bus and rail

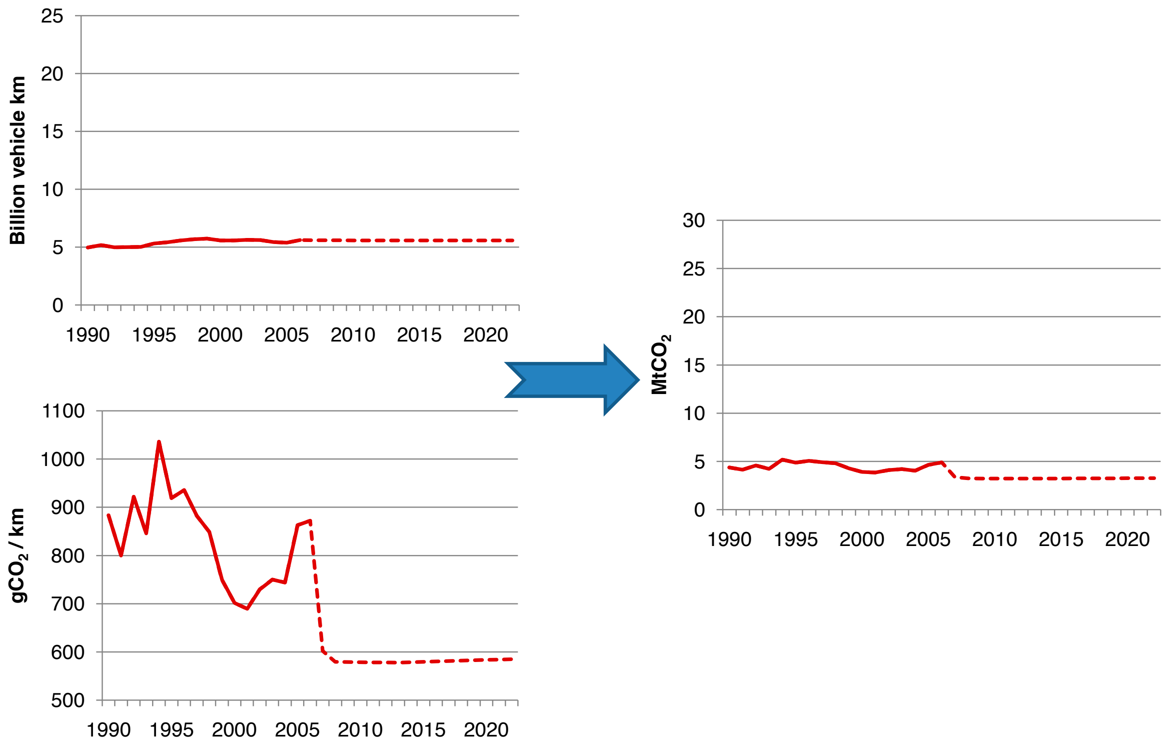
As we have shown in Figure 7.2, private road vehicles (cars, vans and HGVs) are responsible for 86% of all domestic transport emissions, and our key focus must therefore be abatement opportunity in that sector. Other transport modes are of interest, however, given scope for efficiency improvements to reduce emissions by mode; and modal shift which could reduce total transport emissions, even if emissions from lower emitting modes increase.

Bus transport vehicle-km have been relatively stable historically, while average carbon efficiency has steadily improved; emissions have therefore fallen slowly, as shown in Figure 7.8. Reference projections suggest that emissions will remain flat, as there is little projected change in vehicle-km or efficiency.

Passenger rail km, after declining to the mid 1990s, are now on a strong upward path, growing at over 4% per year, and could be up 40% by 2022 relative to 2006 (Figure 7.9). Freight tonne-km are growing at over 4% per year[5]. The historical data does not allow us to distinguish between passenger and freight emissions, but it is likely that the former dominate total rail emissions given that passenger services account for the vast majority of total train km. The overall trend is that rail emissions have grown 29% over the period 1990-2006, driven by increasing demand. Looking forward, reference emissions are projected to increase by 14% over the period from 2006 to 2020 (Figure 7.10).

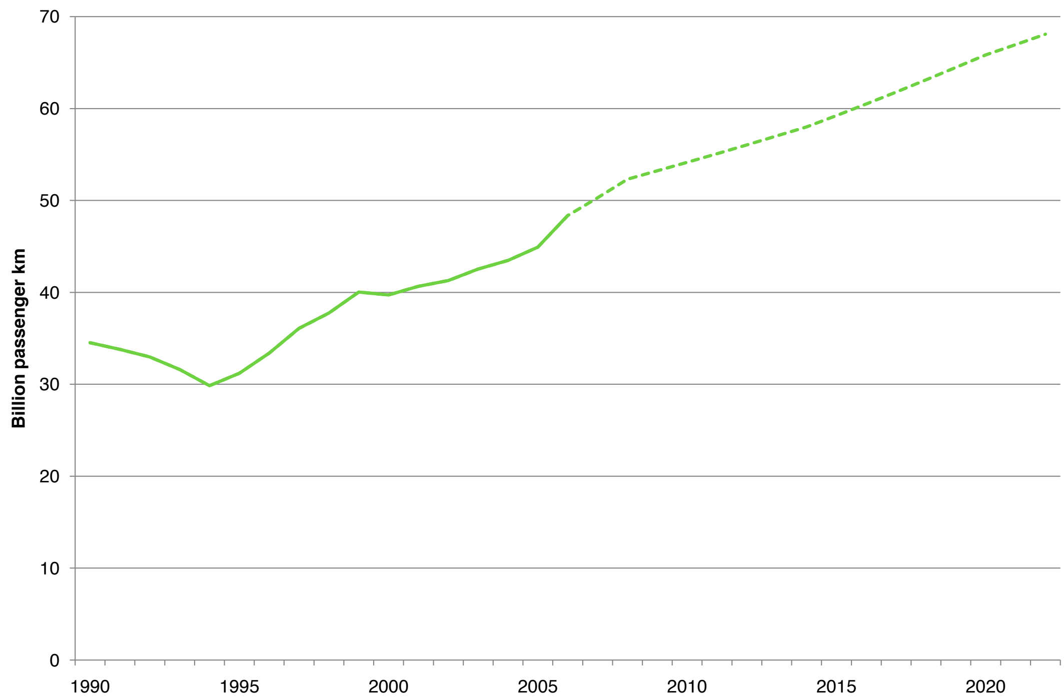
5 Passenger-km and tonne-km figures are average annual growth 2003-2006.

Figure 7.8 Historical trends and reference projections for bus vehicle-km, gCO_2/km and $MtCO_2$



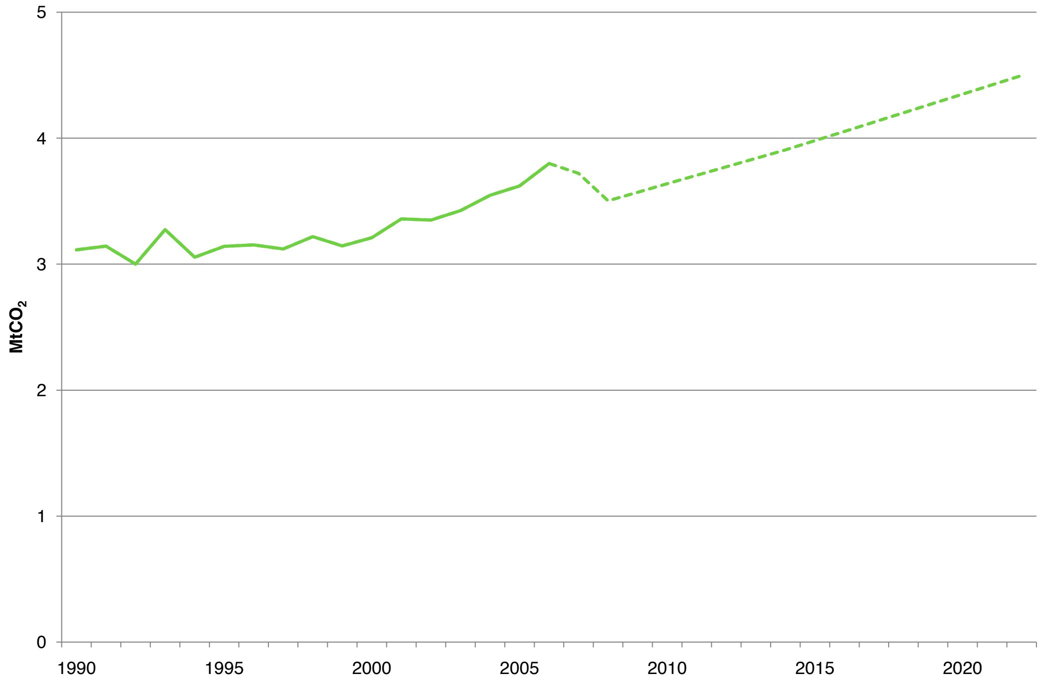
Source: DfT, NAEI
Note: Fall in carbon efficiency due to move from actual to modelled figures.

Figure 7.9 Historical trends and reference projections for rail passenger-km



Source: DfT; Excludes London Underground and other urban metros

Figure 7.10 Historical trends and reference projection of CO_2 emissions from rail

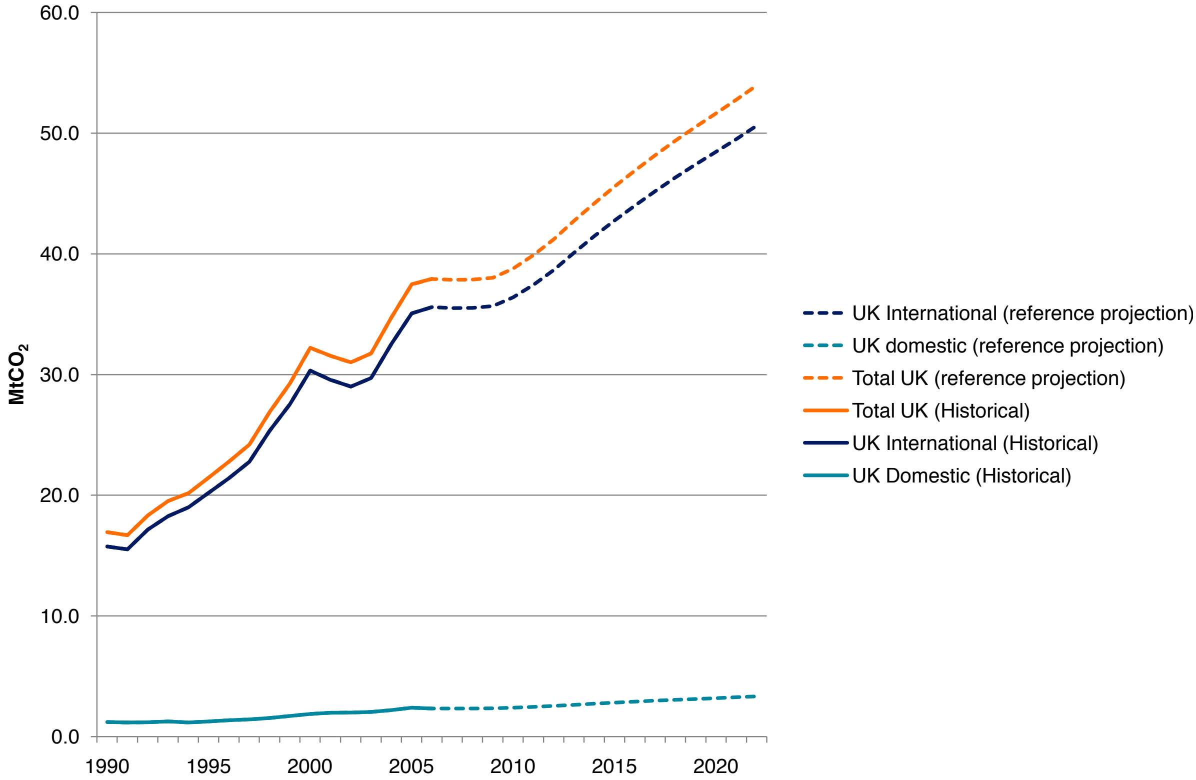


Source: DfT, NAEI
Note: There is a mismatch between inventory data and projections that causes the drop 2006-2008. Total rail emissions from diesel and electric rail.

(iii) Domestic aviation

UK aviation emissions are dominated by international travel flows (Figure 7.11). The trends in total aviation emissions (domestic and international) and the opportunities for abatement are considered in Chapter 8. We mention it here to provide a context for the discussion of modal switch in Section 4 and, in particular, possible scope for switching domestic aviation to rail. Domestic aviation accounts for about 2.3 $MtCO_2$ of emissions, rising at around 2% per annum as demand grows.

Figure 7.11 Historical trends and reference projections of CO_2 emissions from domestic and international aviation

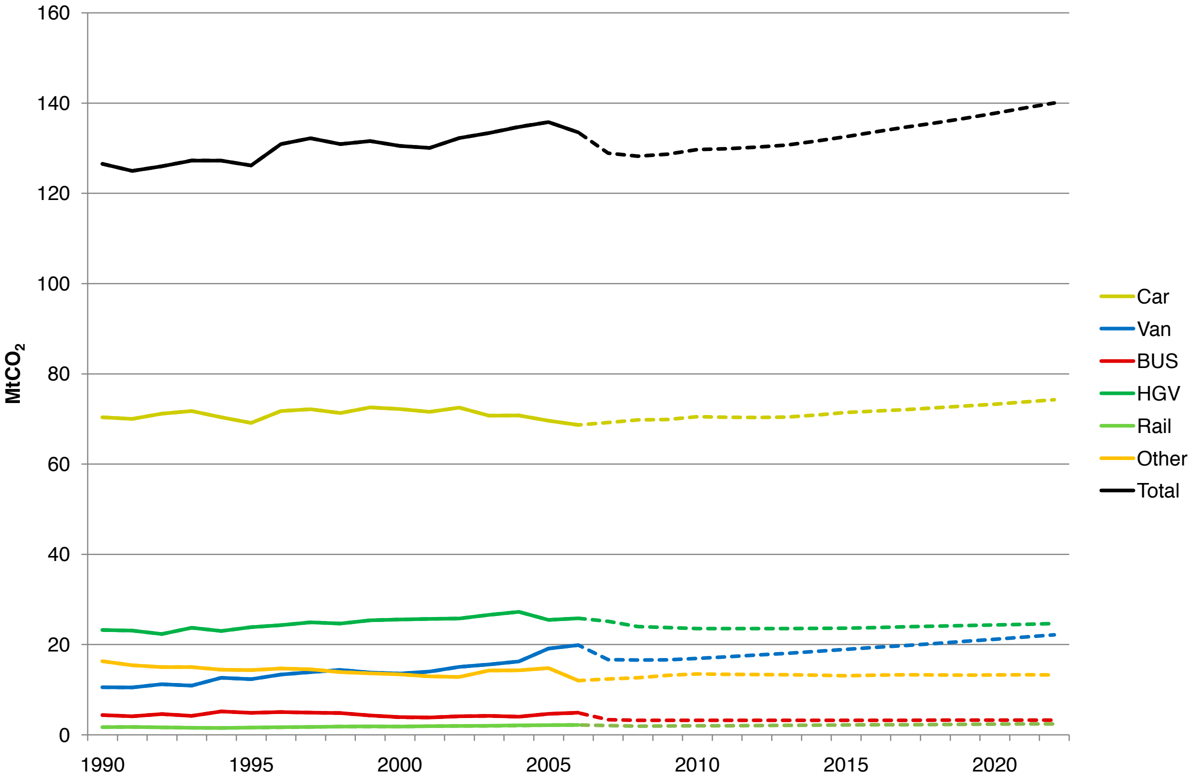


Source: DECC, NAEI.

(iv) Overall reference emissions projections

The overall trend in reference emissions projections is illustrated on Figure 7.12. If abatement opportunities are not achieved beyond those implied by reference projection assumptions, emissions from domestic transport will grow from 134 $MtCO_2$ to 140 $MtCO_2$, with transport's share of total emissions increasing from 24% in 2006 to 30% in 2022.

Figure 7.12 Breakdown of historical trends and reference emissions projections of transport by mode



Source: DfT, NAEI.
Note: Reference projections are not calibrated to the NAEI.

2. ABATEMENT OPPORTUNITIES: SUPPLY SIDE IMPROVEMENTS IN CARBON EFFICIENCY

A wide range of opportunities exist to reduce emissions via supply side measures (i.e. by improving the carbon efficiency of transport without changing either the total level of transport demand or the balance between different modes). The opportunities are largest for cars, but major potential may also exist in vans and HGVs.

We cover below:

(i) Key technological developments in road transport

(ii) Supply side abatement opportunities in cars

(iii) Supply side abatement opportunities in vans

(iv) Supply side abatement opportunities in HGVs

(v) Supply side abatement opportunities in rail

(i) Key technological developments in road transport

There are a range of technology developments which can drive improved carbon efficiency in road transport, and which are, to different degrees, applicable to cars, vans and HGVs.

Possible long-term technological developments in road transport have already been discussed in Chapter 2. In the first three budget periods, three categories of technology development are relevant.

Improvements in carbon efficiency without a change in energy source. Within this category there are opportunities for:

- More widespread penetration of diesel vehicles, which are more fuel efficient than petrol vehicles. For example, a medium car with a conventional diesel engine would have average emissions around 15 gCO_2/km lower than the same vehicle with a conventional petrol engine[6].

- Improvements in the efficiency of petrol and diesel internal combustion engines. For example, compared to a conventional petrol engine in a medium sized car, emissions could be reduced by around 20 gCO_2/km using a second generation advanced petrol engine, and by around 25 gCO_2/km using a stop-start engine.

- Wider use of hybrid engine technologies, which improve the fuel and carbon efficiency of engines by capturing the energy otherwise dissipated in decelerating and braking. A full hybrid petrol engine (for a medium car) would have around 50 gCO_2/km fewer emissions than a conventional petrol engine.

- Non-powertrain measures including improvements in aerodynamic design, weight reduction, and more widespread use of gear shift indicators and low rolling resistance tyres, which together might have potential to reduce emissions by around 10-15%[7].

6 All efficiency figures in this section were provided by the consultants Ricardo as part of the assignment to develop a model of supply side opportunity, discussed in subsection (ii) below.

7 A conservative estimate is that each non-powertrain measure can save around 2% of emissions. Reductions in emissions are not, however, additive across measures, given falling fuel consumption as more measures are added.

All of these types of technology development can be applied to cars, vans and HGVs.

The use of electricity as an energy source. Chapter 2 described the potential role of two different new vehicle technologies: electricity-based and hydrogen. In the long-term, either may play a significant role, but in the first three budgets, hydrogen vehicles are unlikely to be deployed on a significant scale because of the lack of low-carbon sources of hydrogen and an associated hydrogen supply infrastructure.

Electrical power however could play a significant role in the new car market, whether as an ancillary energy source to petrol or diesel (plug-in hybrids) or in fully electric vehicles.

As discussed in Chapter 2, electric cars have inherent performance and carbon efficiency advantages; and the only – but important – issue holding back their growth is battery capacity, weight and cost. But progress is being made on battery performance, and there are some major manufacturers planning new electric car launches. A major role for plug-in electric cars and for full electric cars in the new car market is possible by 2020.

Electric technologies (whether plug-in or full) are also potentially applicable to some of the van market, particularly where distances travelled are relatively small and where there are central depots to facilitate recharging. Electric technology is however unlikely to make any significant contribution to HGV emissions reduction in the first three budget periods, given the large distances travelled and the limitations of battery capacity. There is some potential for electric technology for small HGVs, which we consider in our Stretch Ambition scenario as described below.

Biofuels as an energy source. Chapter 2 described some of the issues relating to the potential growth of biofuels as an alternative energy source. At present fossil fuel prices, some variants of 'first generation' biofuel are already at or close to competitive, as shown in Box 7.2.

There remain, however, significant issues relating to the true carbon efficiency of some biofuels and there are concerns about their impact on other aspects of environmental sustainability and food supply. These issues have been addressed in the Gallagher Review[8], which recommended a range for use of sustainable biofuels in the UK from 5%-10% of total fuel consumption (4-8% of total energy for road transport) in 2020 (Box 7.3).

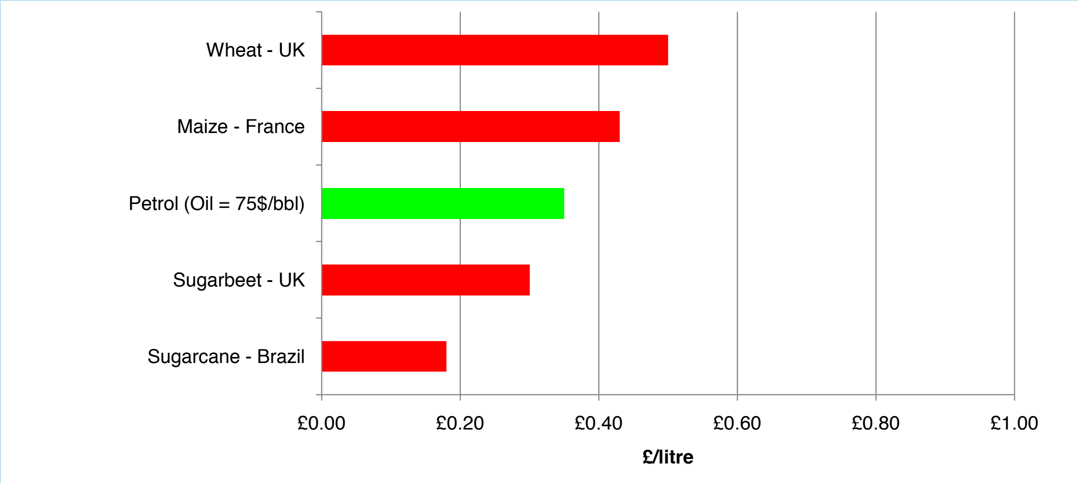
The Committee concurs with the judgements reached by the Gallagher Review and has therefore treated recommended targets in the review for biofuel penetration as a reasonable basis for carbon budget setting[9]. EU and UK policies, which have set targets above the Gallagher recommended use, are currently being reconsidered following the Gallagher Review (Box 7.4).

Biofuels are equally applicable to cars, vans and HGVs, and may be particularly important in the long-term in the HGV sector, given the greater difficulties of applying electricity in that sector than in cars and light vans; in the analysis below, we assume that biofuels are used for each of these vehicle types.

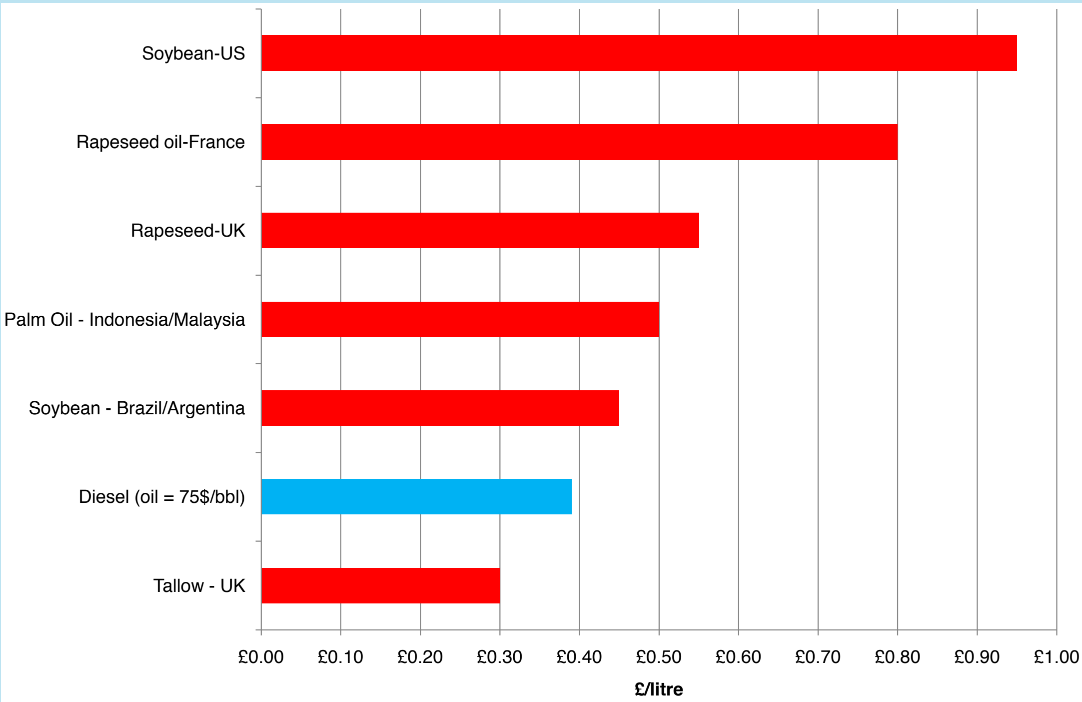
8 Gallagher, E.(2008) *The Gallagher review of the indirect effects of biofuels production*. Renewable Fuels Agency.
9 Specifically, our reference emissions projections include 5% biofuels by 2014. Our Current Ambitiion scenario assumes no additional biofuels relative to the reference projection. The Extended Ambition scenario includes additional uptake, which reaches a total of 10% by volume (8% by energy) in 2020.

Box 7.2 Comparison of the pre-tax costs of biofuels with conventional fuels

Comparison of the unit pre-tax cost of bioethanol with conventional petrol



Comparison of the unit pre-tax cost of biodiesel with conventional diesel



NB: $/£ exchange rate of 1.75 is assumed

Source: E4Tech, DECC

Box 7.3 Recommendations of the *Gallagher Review of the Indirect Effects of Biofuels*

The Gallagher Review called for a slow down in the growth of the use of biofuels. This recommendation was grounded on uncertainties surrounding the role of biofuels in rising food prices, its contribution to deforestation, the future availability of land for cultivation of feed stocks and doubts about the net greenhouse gas impact of biofuels when indirect land use change is considered.

The specific recommendations are as follows:

- The current Renewable Transport Fuel Obligation (RTFO) target for 2008/09 should be retained. This means 2.5% (by volume) of fuel sold on UK forecourts should be biofuels.
- The proposed per annum rate of increase under the RTFO of biofuels should be reduced to 0.5% (by volume); rising to a maximum of 5% (by volume) in 2013/14. Under the RTFO 5% (by volume) would be reached in 2010.
- The RTFO is reviewed in 2011/12 to complement and coincide with the 2011/12 EU review of Member States' progress on biofuels targets.
- Targets higher than 5% (by volume) should only be implemented beyond 2013/14 if biofuels are shown to be demonstrably sustainable. Failure to deliver demonstrably sustainable biofuels should result in a reduction in the target after 2013/14.
- The proposed EU biofuels target of 10% by energy is unlikely to be met sustainably and the introduction of biofuels should therefore be slowed. New targets should be set of between 5% and 8% (by energy) for the EU for 2020 including 1-2% from advanced technologies.
- There should be a specific EU-wide obligation to encourage advanced or second generation technologies to commence in 2015 rising to 1-2% by energy in 2020.
- If a global policy framework were in place to ensure sustainable production of biofuels **and** new evidence was to provide further confidence in the net greenhouse gas savings of biofuels then a higher trajectory could be embarked upon starting in 2016 and rising to 10% by energy in 2020.
- However, if the industry fails to deliver demonstrably sustainable biofuels by 2013/14 the level of the target could also be reduced for subsequent years with a portion of growth from advanced technologies implemented in 2015 rising to 1-2% by energy in 2020.

Source: Renewable Fuels Agency.

Box 7.4 Current EU and UK policy on biofuels

In 2003, the EU Biofuels Directive on the promotion of the use of biofuels or other renewable fuels for transport set a reference target of 5.75% (by energy) of biofuels of all petrol and diesel for transport placed on the market by 31 December 2010. This aim of increasing the use of biofuels was extended in January 2008 when the EU proposed the Renewable Energy Directive on the promotion of the use of energy from renewable sources which includes a mandatory target for all Member States that 10% of transport fuel come from renewable sources by 2020, although the proportion from biofuels or renewable electricity or hydrogen wasn't specified.

In light of evidence and recommendations of the Gallagher Review, in September 2008, the European Parliament's industry committee approved reduced targets for biofuels:

- 2015 goal of 5% of road transport fuel from renewable sources, of which a fifth should be alternatives to biofuels

- 2020 goal of 10% of road transport fuel from renewable sources, of which at least 4% should be achieved through renewable electricity or hydrogen; or from second-generation biofuels from waste. The remaining 6% would come from biofuels from crops.

In the UK in 2007, the government had committed to a national target of 5% biofuels sales by volume of total road transport fuel sales by 2010, in its Renewable Transport Fuel Obligation (RTFO) policy. This is lower than the reference target set out in the EU Biofuels Directive, due to continuing government concerns about the sustainability of increased biofuel supply and existing EU fuel quality standards on biofuel blends.

In light of evidence and recommendations of the Gallagher Review, the UK Government now believes a more cautious approach to biofuel production than currently implied in the RTFO may be necessary. It has recently launched a consultation which considers three options:

(i) Leaving the RTFO unchanged

(ii) Freezing the RTFO at 2.5%

(iii) Adopting the Gallagher recommendations (reaching 5% by volume in 2013).

If further legislation is appropriate, a draft of the Renewable Transport Fuel Obligations (Ammendment) Order will be laid before Parliament in early 2009.

Source: Euractiv.com; DfT.

(ii) Supply-side abatement opportunities in cars

Given the range of technologies outlined above, we believe that it is possible that the carbon intensity of new cars purchased[10] could be reduced from the present UK average of around 164 gCO_2/km to below 100 gCO_2/km by 2020. This could drive average fleet (old and new cars) carbon intensity from over 170 gCO_2/km to around 130 gCO_2/km, and could result in emissions 12 $MtCO_2$ tonnes lower than in the reference emissions projection.

10 Assuming that people continue to buy the same size vehicles as currently but that more people buy the fuel efficient vehicles within size category.

We arrived at this conclusion using a model which we developed in conjunction with a consortium of consultancies including AEA, Ricardo, Metronomica, E4Tech, IEEP and CE Delft. Specifically, we developed a model which provides Marginal Abatement Cost Curves (MACCs), relating emissions reductions and associated costs for a range of technology options, and for cars, vans and HGVs.

Focusing first on cars, the model works by defining various technology bundles, with each bundle comprising a set of technology options (e.g. 10% more efficient conventional engines, 5% more hybrids, non-powertrain measures applied to 75% of new vehicles). The model can be used to generate scenarios based on technology bundles for new cars which are absorbed into the car stock as this turns over.

Working with the consortium, we defined a range of scenarios reflecting judgements on feasible production and uptake rates of technologies under various possible policy frameworks. These should not be regarded as predictions of how the car industry will develop, but rather plausible indicative scenarios. The range of scenarios we have developed feeds into the Current Ambition, Extended Ambition and Stretch Ambition presented in Chapter 3[11].

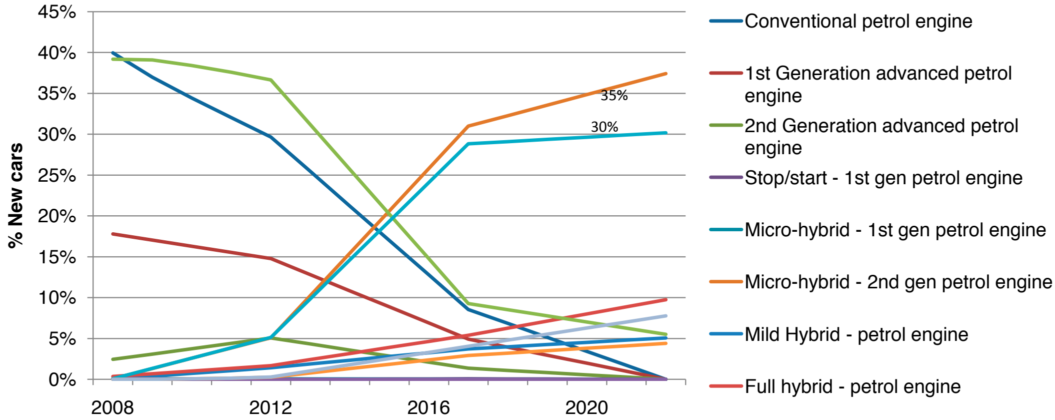
Focusing first on the Current Ambition scenario, this is defined by increasing uptake of hybrid vehicles and limited use of non-powertrain technologies (Figure 7.13). There are no plug-in hybrids or electric cars in this scenario. This scenario delivers an emissions reduction of 4 $MtCO_2$ in 2020, and an average new car fuel efficiency of 130 gCO_2/km.

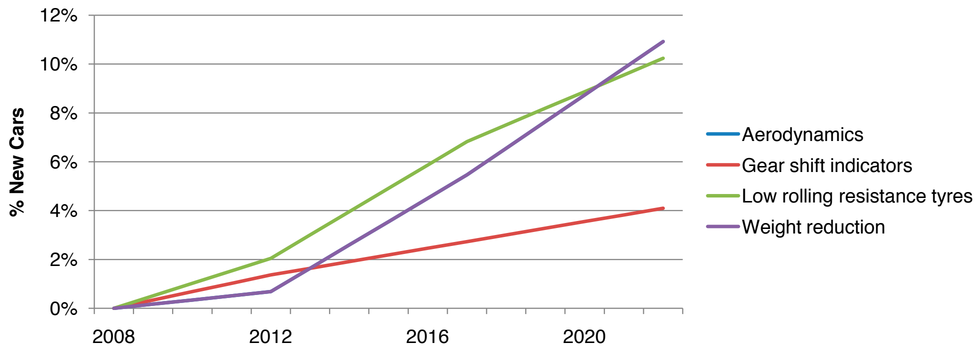
The Extended Ambition scenario is defined by increased uptake of hybrid vehicles and the introduction of plug-in and electric vehicles in later budget periods, with extensive use of non-powertrain technologies (e.g. widespread incorporation of improved aerodynamic design) in new vehicles by 2020 (Figure 7.14). This scenario delivers an emissions reduction of 12 $MtCO_2$ in 2020, and an average fuel efficiency for new cars of 95 gCO_2/km[12].

11 In this chapter, we have used the 'Current' and Extended' terminology not to indicate current and extended policy ambition but to ensure consistency with other chapters.

12 Both the Current Ambition and Extended Ambition estimates for emissions reduction are adjusted to take account of possible rebound effects, discussed more in Section 3 below.

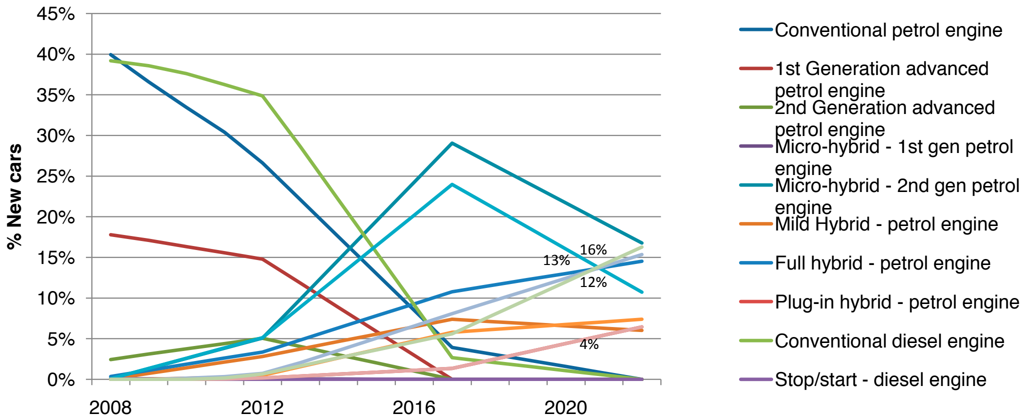
Figure 7.13 Car technology uptake rates (Current Ambition)

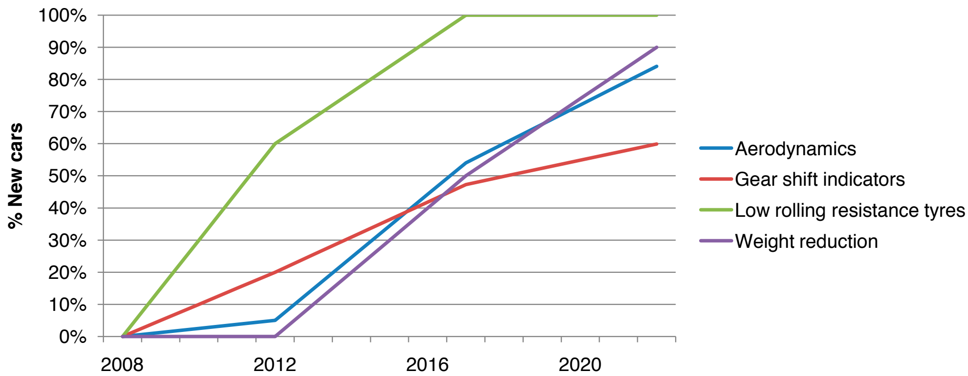




Source: CCC.

Figure 7.14 Car technology uptake rates (Extended Ambition)





Source: CCC.

Box 7.5 Summary of EU framework on new car emissions 2012 and 2020

Mandatory EU target of 120 gCO_2/km in 2012

In December 2007, the European Commission adopted a proposal for legislation for a mandatory successor to the VAs, with a target of 120 gCO_2/km sales weighted average new car emissions for the EU by 2012. This target is to be achieved through:

- a mandatory objective of 130 gCO_2/km for the EU-average new car fleet through improvements in vehicle motor technology.
- additional specific measures (including non-powertrain technologies such as low rolling resistance tyres) and use of biofuels contributing 10 gCO_2/km. These could apply to vans as well as cars.

Setting targets for manufacturers

As the 130 gCO_2/km target is the responsibility of the manufacturers, under the proposed legislation the Commission will produce specific emissions targets for each of the manufacturers, based on a linear relationship between vehicle emissions and mass. Under the proposed legislation, the Commission sets the curve such that heavier cars will have to reduce emissions more than small cars, as the costs for emissions reductions are likely to be lower for these cars. Each manufacturer (or pool of manufacturers) needs only to meet its own target, rather than reach 130 gCO_2/km from its own sales.

Penalty charges

If manufacturers (or pools of manufacturers) do not meet the target in 2012, from that year onwards they will have to pay penalty charges. The charges are based on the amount that the manufacturer's emissions are above their own target and the number of vehicles sold. The excess emissions premium is 20 Euros in 2012, rising to 95 Euros in 2015 and subsequent years.

The level of penalties is expected to be crucial in determining whether or not the 2012 target is met. It is possible that the level of fines will not incentivise introduction of technologies for emissions reduction in 2012 as this is likely to still be below the cost of the technologies to manufacturers. There is some expectation therefore that the 130 gCO_2/km target will be met in 2015.

2020 target

In March 2008, Part II of the King Review of Low Carbon Cars recommended an EU target of 100 gCO_2/km on the basis that it is realistic technologically. In September 2008, MEPs indicated support for a 2020 target of 95 gCO_2/km, subject to a review to take place in 2014. As with the 2012 target, it is expected that the structure of the target and levels of penalties will be important in delivering technological improvements.

The EU framework: The EC is presently finalising mandatory standards for fuel efficiency of new cars that will apply across the EU. The current proposal is that average emissions from new cars should on average be 120 gCO_2/km in 2012[13]. In addition, the EU is considering setting a legally binding target that average emissions should fall to 95 or 100 gCO_2/km by 2020 (Box 7.5).

Our analysis suggests that the UK could meet a 100 or 95 gCO_2/km target in 2020. Meeting this target would require mandatory rules on manufacturers at the EU level. It would also likely require the use of other policy levers (e.g. taxation incentives). Fiscal and other measures might also be required to prevent the rebound effect of increased efficiency (i.e. people travelling more because improved fuel efficiency reduces cost per km travelled). These issues are therefore discussed in Section 3 below.

Meeting this target is desirable in the context of introducing new technologies to the mix that will be increasingly required on the path to an economy-wide 80% emissions reduction in 2050 (see Chapter 2). From a nearer term perspective, meeting the target would be very helpful in providing emissions reduction to meet the non-traded budgets that we have proposed in Chapter 3. It is the Committee's view, therefore, that the UK should strongly support the setting of a legally binding EU target of at the most 100 gCO_2/km for new cars in 2020, which would drive required technology innovation, and that the UK should then aim to meet this target[14].

Abatement costs. The cost of meeting this target for cars (and for reducing emissions from vans, HGVs or biofuels) varies dramatically according to whether we take a 'social' or 'private motorist' perspective. In particular:

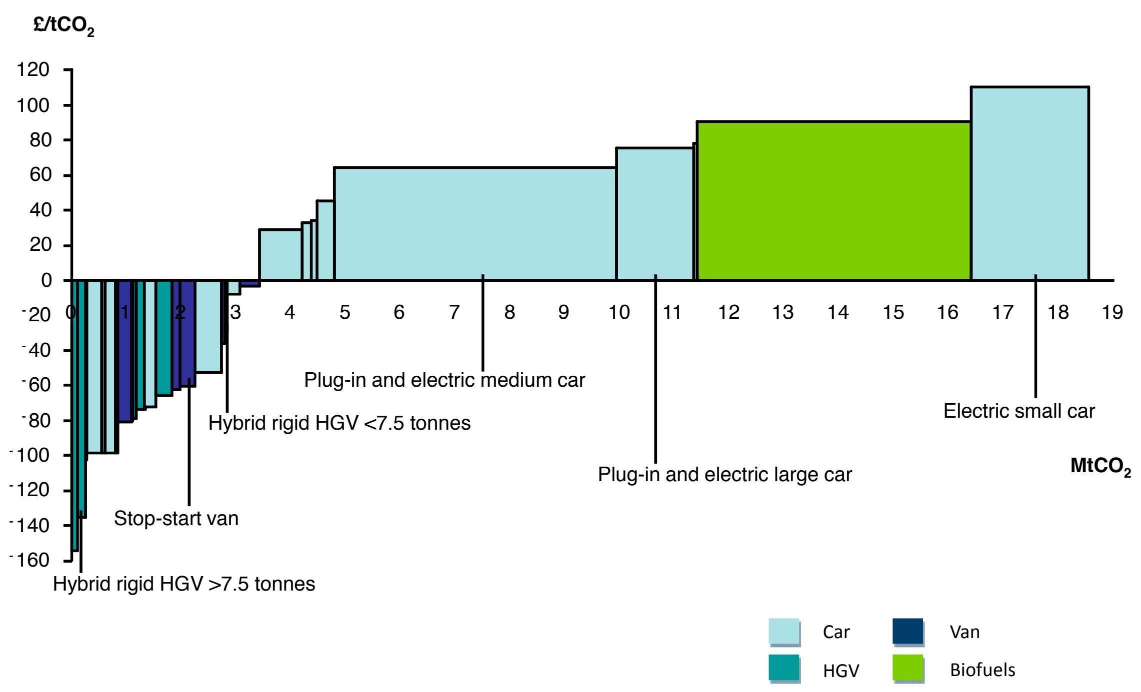
- In the 'social' perspective MACC, we use a real discount rate of 3.5%[15] but we do not count reduced fuel duties as a cost saved, since at the level of the overall society there is no cost saving (the individual motorist gains, but government loses). On this basis, there are up to 4 $MtCO_2$ of abatement which have a negative cost (i.e. net benefit), and then a series of positive cost actions ranging up to £110 per tonne saved (Figure 7.15). Although this is above the marginal cost of abatement theoretically implied by the carbon price estimated in Chapter 4: *Carbon markets and carbon prices*, the Committee believes it appropriate to pursue these higher cost opportunities given the need to drive new technologies and given that, unlike in some other areas with theoretically cheaper abatement opportunities, there exist feasible and effective policy levers to achieve these abatements.

- The 'private motorist' perspective MACC differs in two respects. First, it assumes a higher real discount rate of 7% (equivalent to around 11-12% nominal): this tends to make abatement options look more costly. But, secondly, it counts fuel duty saved as a benefit, which significantly improves the attractiveness of any options which reduce fuel purchase, whether through improved internal combustion engine efficiency or through use of electricity. The net effect is to improve dramatically the apparent attractiveness of all options, except biofuels[16] (Figure 7.16).

These dramatic differences, and the reduction in fiscal revenues which could result (discussed in Chapter 11: *Economic costs and fiscal implications*) suggest complex issues relating to the long-term taxation of different transport energy sources, balancing the need for revenue and the desirability of creating incentives for low-carbon transport. In the immediate future however, it illustrates that the existing fiscal regime creates strong incentives for the adoption of fuel efficient technologies and in particular for plug-in and fully electric cars.

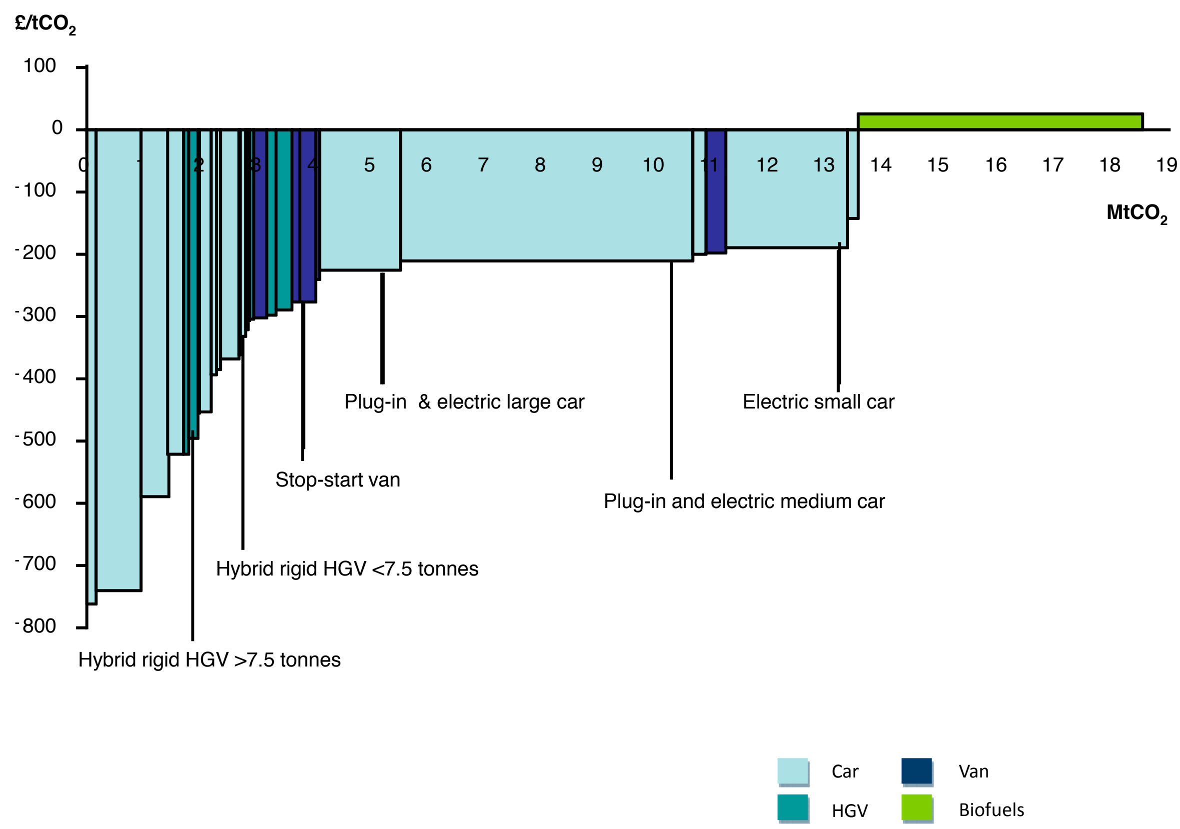
13 Consisting of a 130 gCO_2/km target for the vehicle, plus an additional 10 gCO_2/km through other measures, for example non-powertrain technologies such as low rolling resistance tyres.
14 The fact that EU targets apply across Europe allows the possibility that individual Member States could be above the EU average, discussed more in Section 3 below.
15 This is the Treasury Green Book discount rate that we have used more generally, see Chapter 3.
16 The marginal difference in costs is the same for biofuels in both cases. The difference in discount rates between social and private perspective changes costs.

Figure 7.15 Marginal abatement cost curve for road transport (2020, social perspective)



Source: CCC.

Figure 7.16 Marginal abatement cost curve for road transport (2020, private perspective)



Source: CCC.

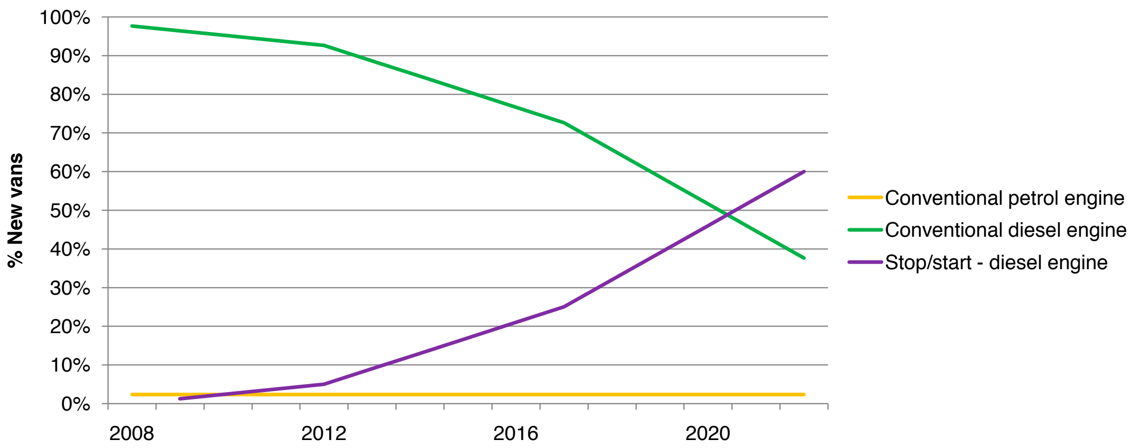
(iii) Supply side abatement opportunities in vans

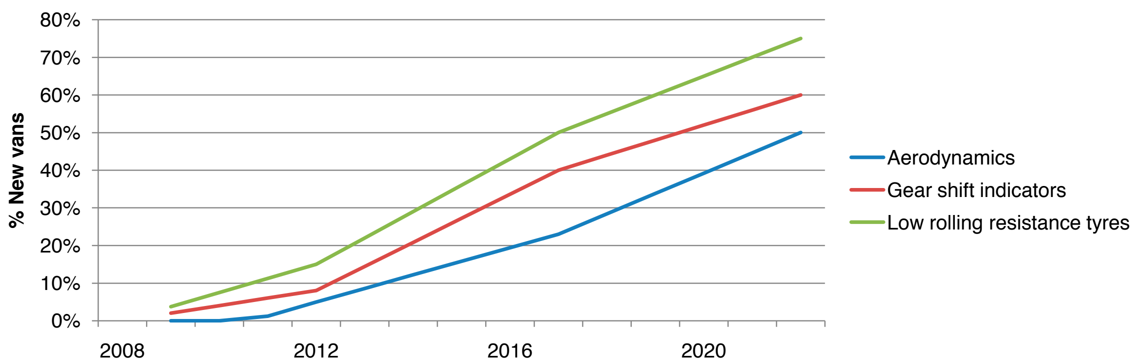
Many of the technical possibilities which can drive supply side abatement opportunities in cars are also relevant to vans. We have used our model to illustrate emissions reduction that might be available from these opportunities using a similar approach to that described for cars above. In particular, we have defined sets of technology bundles, and an illustrative range for emissions reduction.

Our Current Ambition scenario assumes that there is only limited uptake of technologies for improving fuel efficiency. Specifically, we have assumed that only those abatement options with negative cost (i.e. where any upfront cost is more than offset by reduced fuel bills over time) are deployed[17]. In this scenario, which is characterised by stop-start engines and non-powertrain measures (see Figure 7.17), emissions reduction is 0.4 $MtCO_2$ in 2020 (Figure 7.18), with average emissions for new vans falling from 271 gCO_2/km in the reference emissions projection to 249 gCO_2/km.

Our Extended Ambition reduction scenario includes more aggressive deployment of stop-start and non-powertrain measures (Figure 7.19). Emissions reduction in this scenario is 1 $MtCO_2$ in 2020 (Figure 7.20), with average emissions of new vans falling to 240 gCO_2/km.

Figure 7.17 Van technology uptake rates (Current Ambition scenario)

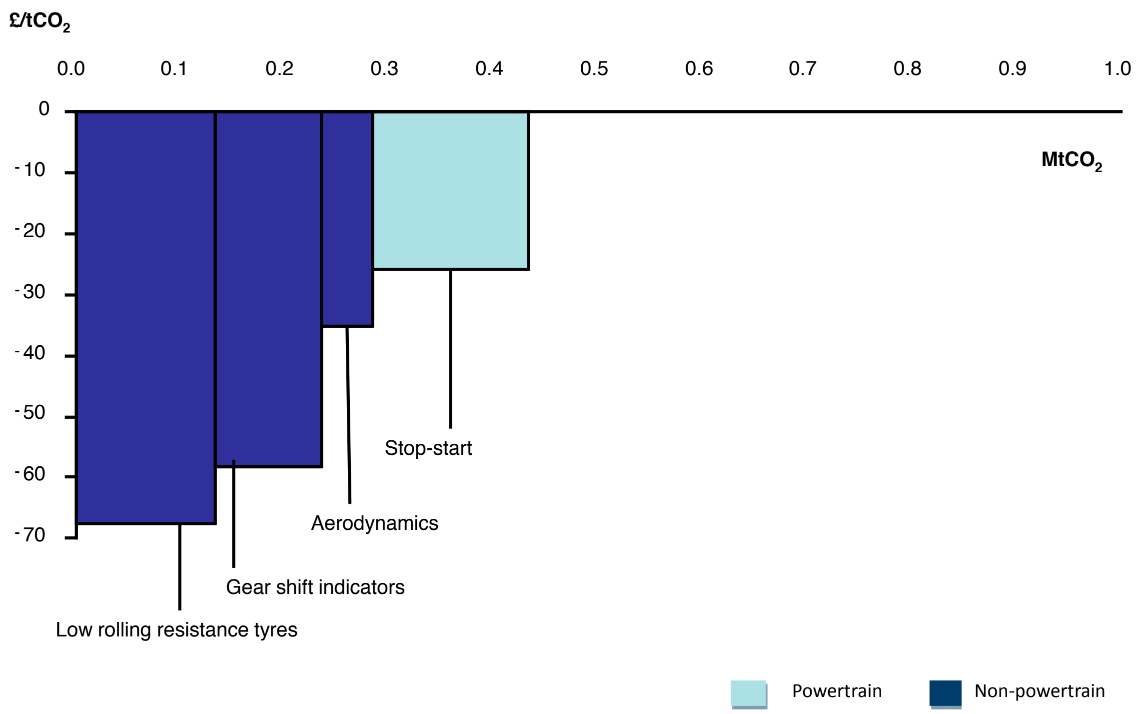




Source: CCC.

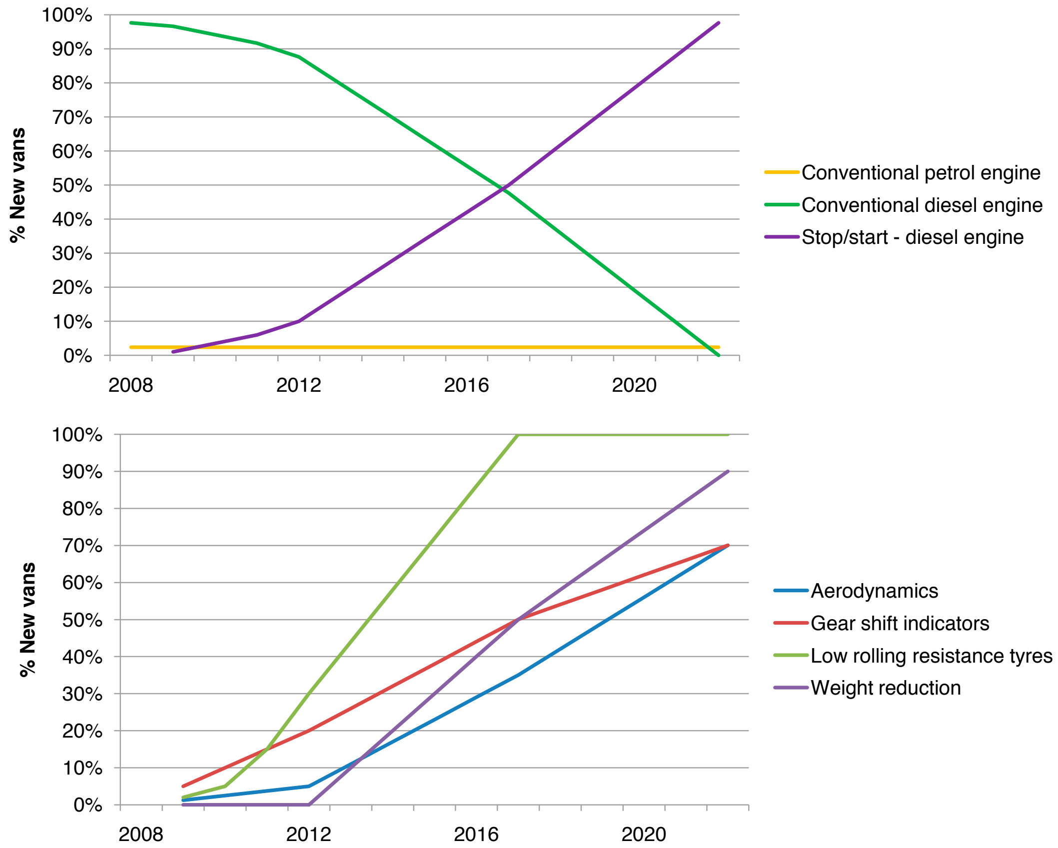
17 Measures included are negative cost from both the social and private perspectives.

Figure 7.18 Marginal abatement cost curve for vans Current Ambition scenario (2020; social perspective)



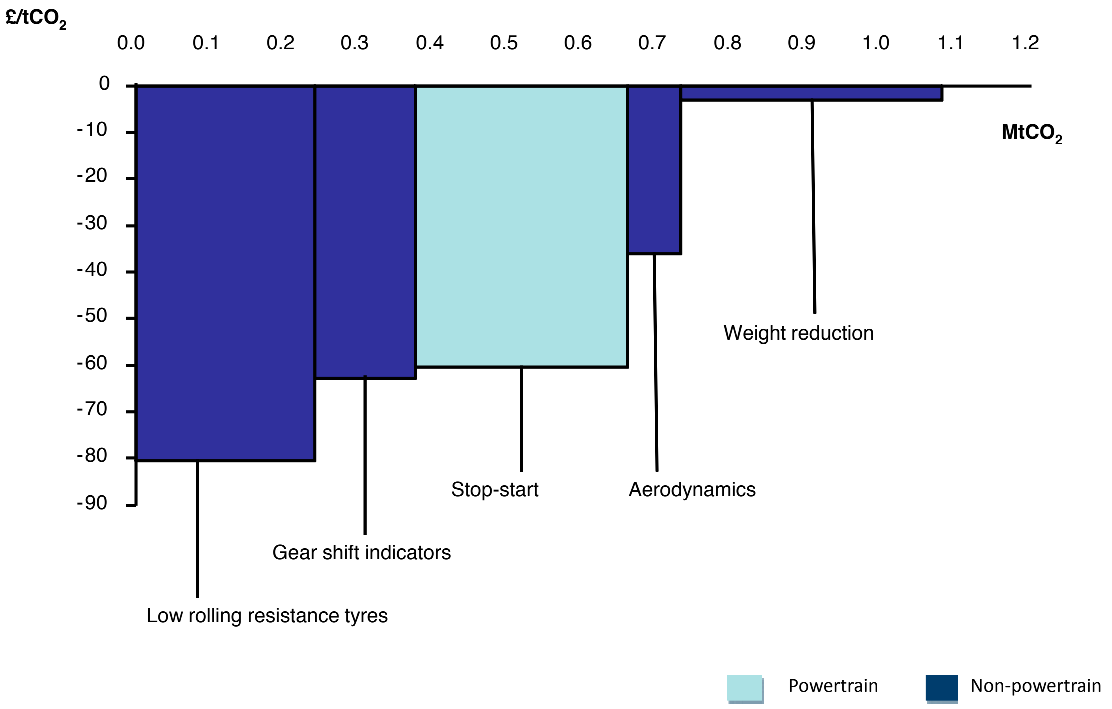
Source: CCC.

Figure 7.19 Van technology uptake rates (Extended Ambition scenario)



Source: CCC.

Figure 7.20 Marginal abatement cost curve for vans Extended Ambition scenario (2020; social perspective)



Source: CCC.

There is in fact more potential for abatement potential than is illustrated by these scenarios. In order to model this, we have developed a Stretch Ambition scenario where there is widespread deployment of plug-in and hybrid vans. In this scenario, emissions reduction in 2020 is 3 $MtCO_2$ and emissions of new vans fall to 196 gCO_2/km.

Which of these or other scenarios prevails in practice will depend on the policy framework. Currently this is undeveloped, with weak incentives for uptake of lower emission technologies; our Current Ambition and Extended Ambition scenarios may be a reasonable approximation of the likely range of outcomes in this world. There is, however, the possibility that stronger policy levers such as a mandatory target for new van efficiency could be introduced, and the EU is currently considering what a framework for vans might look like.

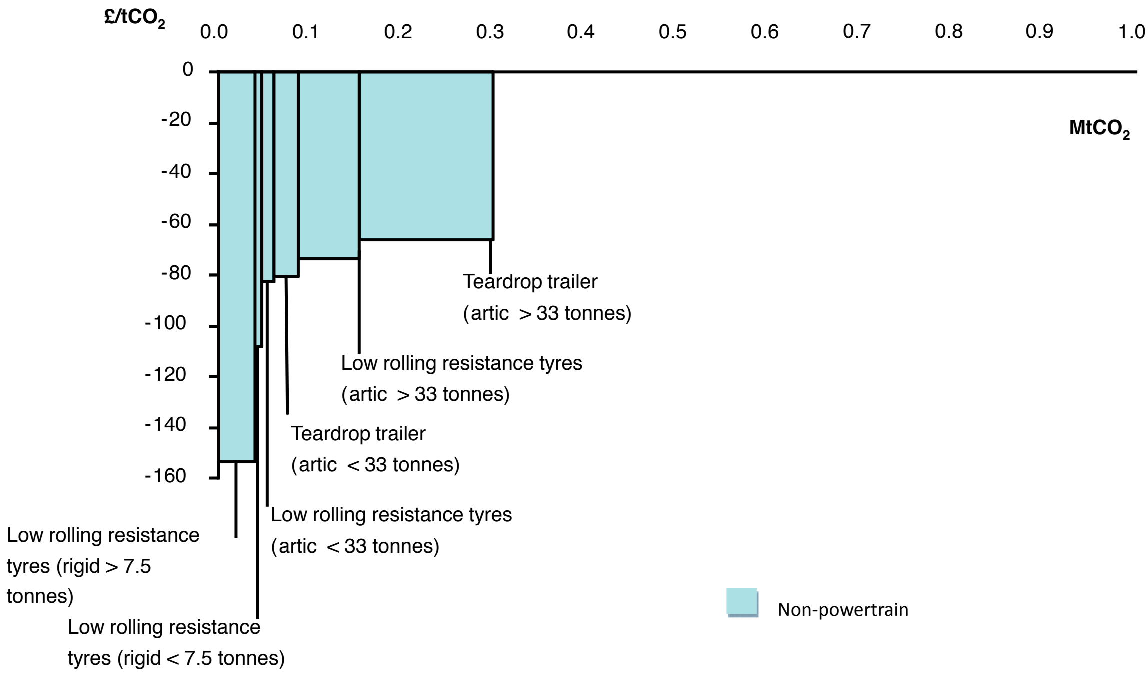
Given the potential for emissions reduction that we have identified, it is the Committee's recommendation that major focus be placed on developing a framework for van fuel efficiency at the European and UK levels. Significant reductions may be possible within the first three budget periods and will almost certainly be necessary to maintain transport sector abatement in subsequent budgets.

(iv) Supply-side abatement opportunities in HGVs

It will be inherently more difficult to achieve a major supply side emissions reduction in HGVs than in cars or vans given more limited potential for application of some technologies. Some emissions reduction is, however, available, through uptake of non-powertrain technologies and the introduction of hybrid rigid HGVs. As for cars and vans, we have developed Current Ambition and Extended Ambition emissions reduction scenarios for HGVs. The Current Ambition scenario is characterised by some uptake of non-powertrain technologies and achieves emissions reduction of 0.3 $MtCO_2$ in 2020 (Figure 7.21). In the Extended Ambitiion scenario, there is more aggressive uptake of non-powertrain technologies, and rigid hybrids are introduced, resulting in emissions reductions of 0.8 $MtCO_2$ in 2020 (Figure 7.22).

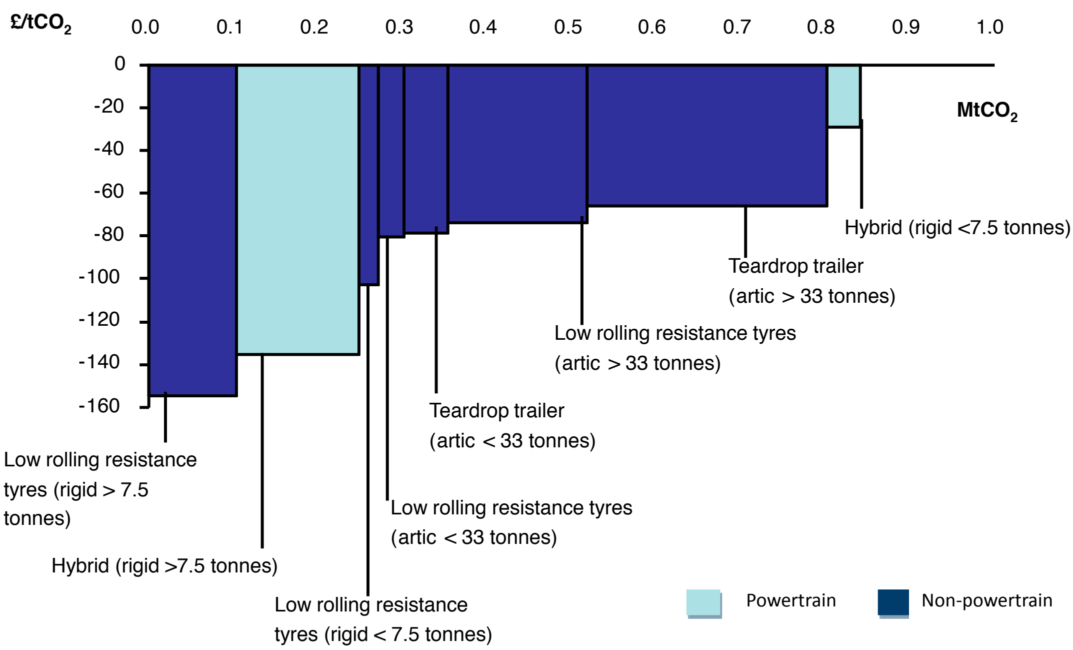
These scenarios represent the likely range of outcomes under the current lack of a policy framework for HGVs. It is possible, however, that a European policy framework could be introduced and additional measures involved. We have modelled a Stretch Ambition scenario in which there is aggressive uptake of non-powertrain technologies and some uptake of plug-in and electric small HGVs (Figure 7.23), which together reduce emissions by 1 $MtCO_2$ in 2020. And in the longer term, if concerns about biofuel sustainability can be resolved, their deployment in the HGV sector may be the key to significant decarbonisation. The Committee will therefore look in detail at the options for the HGV sector in our work relating to the fourth budget (2023-27) which we need to complete by 2011.

Figure 7.21 Marginal abatement cost curve for HGVs Current Ambition scenario (2020; social perspective)



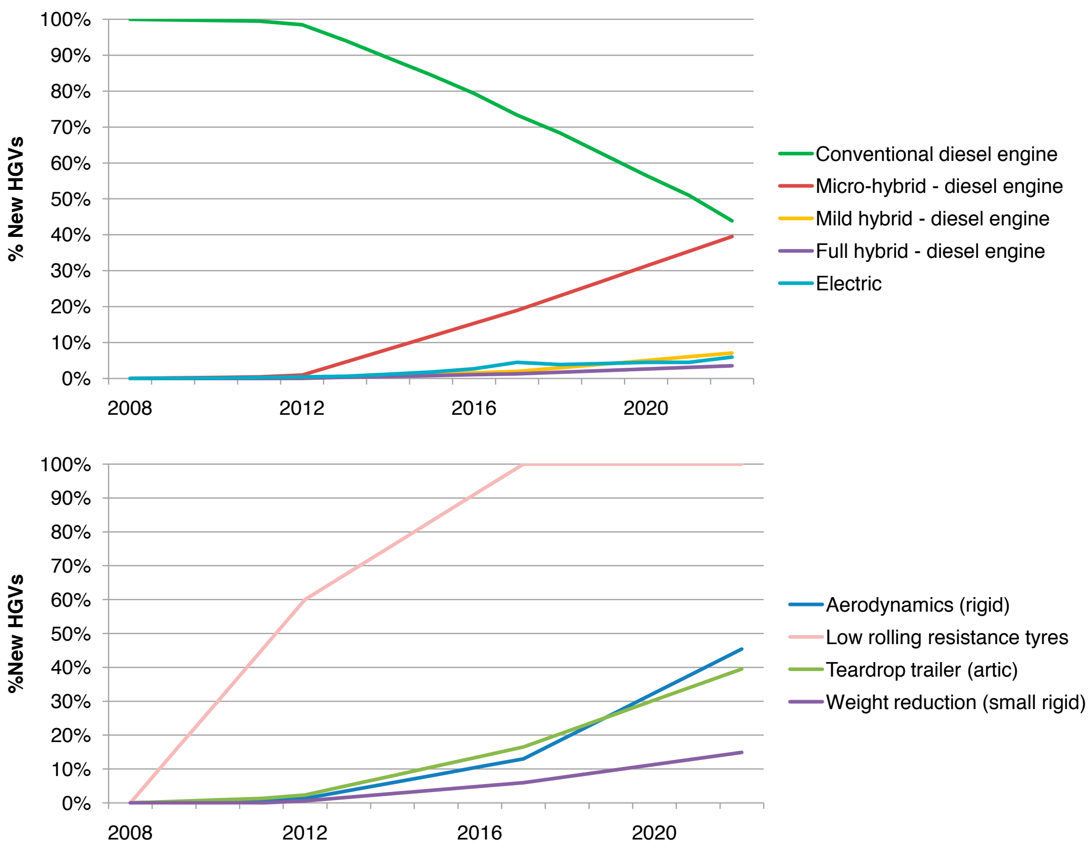
Source: CCC.

Figure 7.22 Marginal abatement cost curve for HGVs Extended Ambition scenario (2020; social perspective)



Source: CCC

Figure 7.23 HGV technology uptake rates (Stretch Ambition scenario)



Source: CCC.

(v) Supply-side abatement opportunities in rail

Rail is not part of the MACC model discussed above, but carbon trajectories for rail to 2022 have been developed by a cross-industry working group, chaired by the Department for Transport, which has submitted a report to the CCC[18]. This group covers passenger and freight rail, and has assessed abatement opportunities from electric and diesel traction rail.

Compared to a reference emissions projection ('do nothing'), there is abatement opportunity of 0.6 $MtCO_2$ in 2020, which is included in our Extended Ambition scenario. This abatement comes from an increased emphasis on energy efficiency – through new trains that come into service and from passenger and freight operating companies introducing a range of energy saving initiatives. It is also assumed that diesel rail (passenger and freight) will use biofuel blends, in line with the reference assumptions on biofuels outlined above.

There are other short-term abatement opportunities in rail:

- Additional efficiency measures; for example, energy metering, such that operators have better information on how their trains use energy and have incentives to improve efficiency, and further introduction of regenerative braking[19].

- Improved performance of the existing rolling stock, including upgrading to more efficient diesel engines and introducing on-board energy storage (analogous to hybrid car technology).

In the medium to long term there is further scope for abatement from rail, including:

- Opportunities for efficiency improvements through new rolling stock replacements. These are limited before 2022, due to the long life of rolling stock (30-35 years) and the currently young age of rolling stock in the UK.

- Network optimisation around energy efficiency and emissions.

- Increased electrification. Even given the current average carbon intensity of electricity generation, electric rail is much more carbon efficient than diesel rail, with emissions of around 50 gCO_2/passenger-km compared to 75 for diesel. This advantage will increase as electricity is decarbonised. An accelerated programme of electrification could therefore deliver significant emissions reduction.

The Committee has not quantified abatement potential from these additional opportunities, but intends to assess these more closely in subsequent work.

18 Department for Transport et al. (2008) *Rail transport submission to the Committee on Climate Change*. Committee on Climate Change.

19 Regenerative braking is a system that recovers energy from trains as they brake that would otherwise have been wasted. This system is already in place on all trains capable of regenerative braking (AC electric trains). It could be rolled out to all electric trains, including the DC network with time as technical obstacles are overcome; and possibly to diesel trains over the longer term.

3. REBOUND EFFECTS AND DEMAND SIDE POLICY LEVERS TO ACHIEVE SUPPLY SIDE POTENTIAL

In Section 2 we have identified up to 12 $MtCO_2$ of supply side abatement opportunity relating to cars; this could be achieved if new car carbon intensity could be reduced to 95 gCO_2/km by 2020, with average fleet intensity down from 170 to 130 gCO_2/km. But it also referred to two complexities which require us to link supply and demand side considerations: (i) the fact that to achieve this carbon efficiency improvement we may need to pull demand side levers (e.g. fiscal incentives); (ii) the danger of a rebound effect, with improved fuel efficiency reducing the marginal cost of travel and thus inducing more demand.

This section therefore considers in turn:

(i) Achieving reduced carbon intensity: technical potential and customer car purchase

(ii) Non-price levers in customer car purchase decisions: information and awareness raising

(iii) Price elasticities, fiscal incentives, and choice of car

(iv) The rebound effect

(i) Achieving reduced carbon intensity: technical potential and customer car purchase

The European policy for mandatory corporate average carbon efficiency is a vital policy lever to achieve carbon-intensity reduction. But other levers may also be important, especially since the average carbon-intensity reductions can be achieved via customer car purchase changes as well as via technical improvement.

- The cost curve analysis presented in Section 2 suggested that very significant improvements in carbon intensity could be achieved via technological progress without customers having to accept smaller size or lower performance vehicles. The estimates of the cost per tonne of carbon saved presented in Figures 7.15 and 7.16 are based on the assumption that customers continue to buy the same type of car – defined by size and performance – as today.

- It would also be possible however to achieve the required emissions reduction via a change in customer choice, i.e. customers buying slightly smaller cars or ones with lower performance (speed and acceleration).

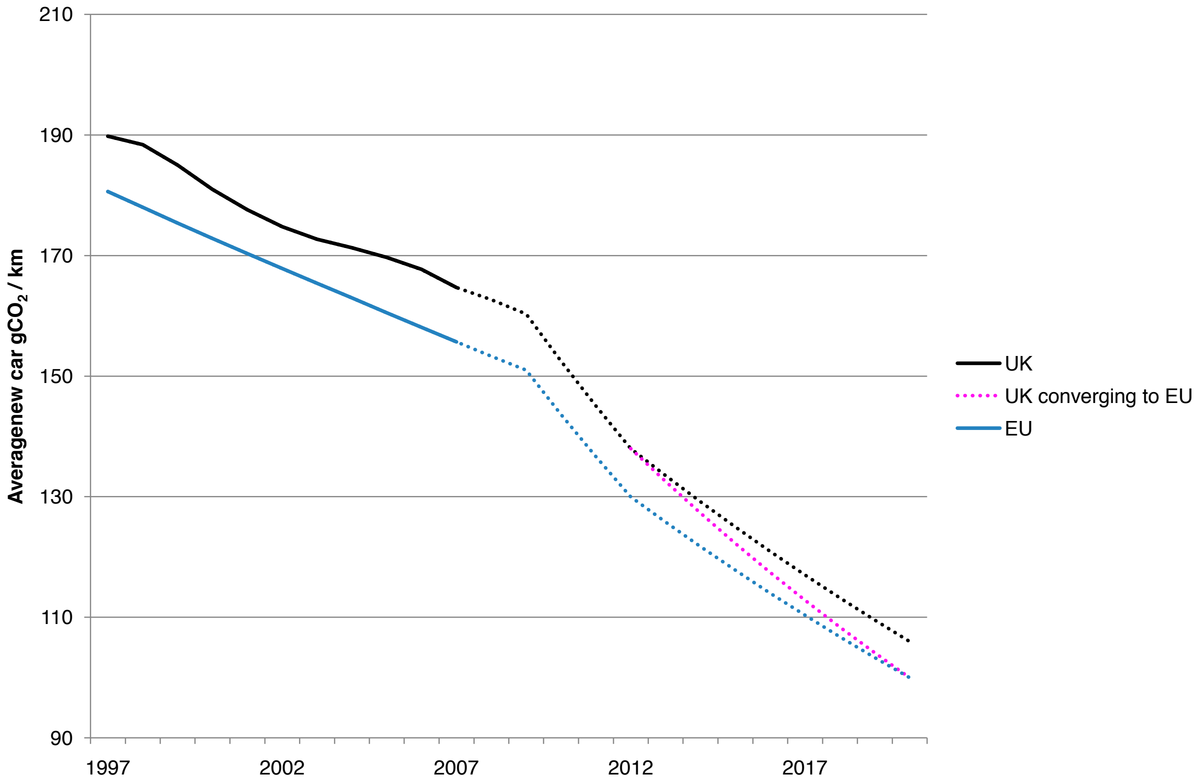
- European industry standards on average new car emissions could drive change on either dimension[20]. In practice, manufacturers are likely to meet their targets both by producing more fuel efficient cars with unchanged performance (i.e. through technology) and by shifting the relative mix of their production towards smaller cars.

20 We assume that these are alternatives for meeting a given fuel efficiency target, rather than opportunities for going beyond a target.

- Targets will be delivered in part through marketing and pricing policies of manufacturers. There will also be an important role, however, for information and policy levers to encourage customers to purchase the lowest emitting vehicles without changing vehicle class, and to reach additional potential from changing customer choice.

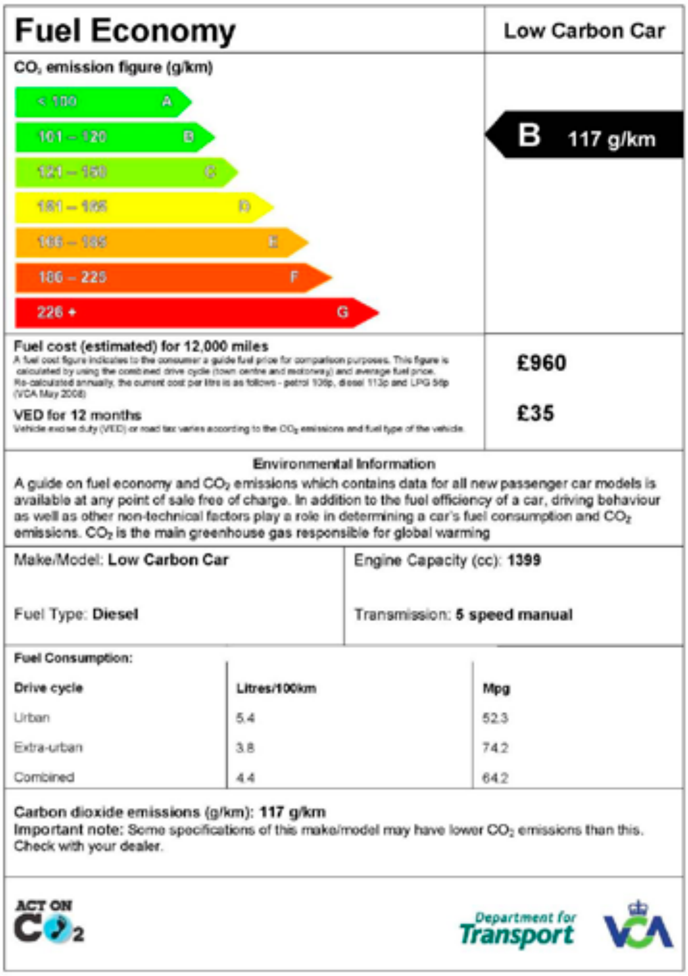
- These levers may be particularly important in the UK given that the UK currently tracks above the EU average for new car efficiency due to a relatively low proportion of diesel cars and a relatively high proportion of larger cars, and could fail to narrow the gap between its carbon intensity and the European average (Figure 7.24); indeed without other policy levers the gap could widen.

Figure 7.24 Possible pathways for future new car CO_2 emissions



Sources: Society of Motor Manufacturers and Traders, DfT

Figure 7.25 An example of a fuel efficiency label for new cars



Source: Low Carbon Vehicle Partnership

(ii) Non-price levers in customer car purchase decisions: information and awareness raising

Car purchase decisions, whether on efficiency, size or performance, could be influenced by information provided at point of sale. The EU has recognised this, and has put in place legislation that requires dealers selling new passenger cars to display information on vehicles' fuel consumption and CO_2 emissions. Colour-coded fuel efficiency labels, showing average fuel efficiency and fuel expenditure over 12,000 miles of typical use, matching the graduated VED (Vehicle Excise Duty) structure, were introduced into UK car showrooms in 2005 (Figure 7.25). The 'Act on CO_2' campaign, launched in 2007, also promotes information about purchasing more fuel efficient vehicles.

Evidence suggests, however, that it may take some time before the benefits of colour-coded fuel efficiency labels are felt. Salesroom staff knowledge is variable, coverage is incomplete and consumer awareness of labels is limited[21]. In addition, evidence shows that buyers are more likely to be influenced by the cost of purchase and driving performance rather than environmental concerns[22], though there is some evidence that fuel efficiency (which correlates closely with carbon efficiency) is an important factor in recent car purchasing decisions amongst UK drivers[23].

21 Society of Motor Manufacturers and Traders (2007) *Motor Industry facts – 2007.* London: SMMT.
22 Anable, J., Lane, B. and Kelay, T. (2006) *An evidence base review of attitudes to climate change and transport.* Report for the UK Department for Transport
23 Angle, H., Brunwin, T., Gosling, R. and Buckley, K. (2007) *Climate Change campaign benchmark stage: Driving behaviour and car purchasing*. Report by British Market Research Bureau (BMRB) to the Department for Transport

On balance, therefore, better information alone is unlikely to result in changed purchase behaviour, but is still likely to have an important role to play as part of a package of mutually supporting interventions.

The potential impact of the labelling scheme could be increased if it were made mandatory and also covered second-hand vehicles. The King Review[24] proposed that a colour-coded tax disc would also reinforce the link between vehicle model, CO_2 emissions and fuel use by enabling people to see how emissions vary between and within vehicle class. Subsequently the Government in the Budget 2008[25] signalled its intention to explore this idea and the possibility of making compulsory the current fuel efficiency label. If successfully implemented, these measures would support meeting of EU targets for fuel efficiency.

(iii) Price elasticities, fiscal incentives and choice of car

Both consumer choice of car and the extent of car use (km travelled per car per year) are likely to be significantly influenced by the taxation regime. Analysis of estimates of price elasticity (through which fiscal measures operate) suggest that:

- **Fuel duties** can be quite powerful levers to affect choice of car, especially over the long-term and against the background of high awareness of oil prices.
  - A major review of elasticity studies conducted for the erstwhile Department for Transport, Local Government and the Regions (DTLR) in 2002[26] suggests the elasticities shown in Table 7.1 The overall long-term effect of a 10% increase in prices (whether driven by oil prices or the impact of taxes) could reduce fuel use by 6.4%. The effect derives from (i) a non-trivial (-2.5%) decrease in car ownership: this is likely mainly to take the form of families deciding to forego a second or third car, but also includes a proportion of people who choose to live in areas where owning a car is less essential; (ii) a (-3%) decrease in km travelled per car; (iii) a significant (-4%) decrease in fuel used per kilometre, achieved via choice of more fuel efficient cars.
- Price elasticity may be itself a function of the price level. The price elasticity observed in the high oil price period of the late 1970s was significantly higher than that observed in the low oil price 1980s and 1990s. The recent high oil price environment and extensive public discussion of its implications for motorists may therefore have increased the sensitivity of consumer buying behaviour to any given difference in price. Anecdotal evidence over the last six months suggests that an increased awareness of future motoring costs may have produced a bigger switch in buying behaviour towards smaller cars (in both Europe and US) than previously observed elasticities would have predicted; Box 7.6 presents some data on car purchases over the last year.

Table 7.1 Fuel Price elasticities

If the real price of fuel goes up and stays up by 10%:		
	Short run (1yr)	Long run (around 5yrs)
Total number of vehicles owned	-0.8%	-2.5%
Total volume of traffic	-1.0%	-3.0%
Total efficiency of fuel used	1.5%	4.0%
Total volume of fuel consumed	-2.5%	-6.4%
Vehicle kilometres per vehicle	-1.0%	-3.0%

Source: Hanly, Dargay and Goodwin.

24 King, J (2008) *The King Review of low-carbon cars Part II: recommendations for action*. HM Treasury.
25 HM Treasury (2008) *Budget 2008 Sustainability and opportunity: building a strong, sustainable future.* HM Treasury
26 Hanly, Dargay and Goodwin (2002), Review of Income and Price Elasticities in the Demand for Road Traffic: Final Report, 2002.

Box 7.6 Impacts of high fuel prices and the credit crunch on car purchase and driver behaviour

Changes in car purchase behaviour can be seen in some indicators for 2008, as people respond to high fuel prices and the credit crunch financial crisis.

UK: The latest monthly sales figures produced by the Society of Motor Manufacturers and Traders (SMMT) show that new car registrations fell 21.2% in September with year-to-date volume down 7.5%. In September, new car registrations fell for the fifth consecutive month.

Alternatively fuelled vehicles saw their market share rise from 0.7% to 0.8% of the market, with volumes up 1.5% over the year to date.

US: In July 2008, the *Economist* reported that sales of cars and light trucks in America in June fell by 18% compared with the same period a year earlier. Chrysler's sales were down by 36% and Ford dropped by 28%. Honda sales, by contrast, increased by 1.1% – probably because it is not part of the American pick-ups market.

- Annual fixed charges (e.g. VED or company car tax) that are differentiated by carbon intensity, may also have a significant effect – indeed there is some evidence to show that private customers may weight fixed annual costs (which includes VED along with insurance premiums) more than future prospective fuel costs in their decision making[27]. Evidence on the emissions-linked company car tax reform suggests that average emissions of company cars bought in 2004 fell by around 15 gCO_2/km (compared to a no-reform counterfactual) although there was some reduction in the number of company cars, with those opting out of company cars buying private vehicles with emissions on average 5 g higher[28].

- Finally, it is possible that upfront charges (e.g. first year VED) differentiated by carbon intensity could also impact on car purchase decisions. In the UK, these are planned to be introduced from 2010/11[29]. Whilst the evidence is not comprehensive; the introduction of upfront charges, with a very strong differentiation between high and low-carbon-intensity cars in some European countries appears to have produced major shifts in buying behaviour. Box 7.7 describes the experiences of the Netherlands and France.

Overall, therefore, it is likely that the tax regime, whether in the form of fuel duties or differentiated VED charges (ongoing or first year), will need to play a key role, alongside information provision, in incentivising consumer choice of car consistent with the target of achieving an average below 100 gCO_2/km for cars purchased in 2020.

27 Eftec (2008). *Demand for cars and their attributes*. *Final report to DfT.* DfT
28 HMRC (2006), *Report on the Evaluation of the Company car tax reform: Stage 2.* HM Revenue and Customs.
29 HM Treasury (2008) *Budget 2008 Sustainability and opportunity: building a strong, sustainable future*. HM Treasury

Box 7.7 Impacts of purchase prices and tax incentives in Europe

The Netherlands

In 2002 the Dutch government introduced a scheme whereby buyers of the lowest emitting passenger cars labelled 'A' and 'B' received an incentive: 1,000 euros for 'A' labelled cars and 500 euros. for 'B' labelled cars.

- The percentage of purchases of class 'A' cars increased disproportionately from 0.3% in 2001 to 3.2% and class 'B' from 9.5% in 2001 to 16.1%
- In January 2003 the Dutch government abolished the fiscal incentive again for budgetary reasons. The market share of 'A'- and 'B'-labelled cars in 2003 decreased substantially after abolishing the incentives: 'A' fell to 0.9% and 'B' to 11.5%

The French 'Bonus-Malus' scheme

The French Government recently introduced a scheme that involves taxing purchases of new cars with high-carbon intensity heavily and offering a subsidy to drivers who scrapped their old cars in favour of a car with a low carbon intensity.

- The amount of the bonus or malus depends on the gCO_2/km emitted by the vehicle:
  - *bonus*: 200-1,000 euros for vehicles emitting a maximum of 130 gCO_2/km and 5,000 euros for those emitting no more than 60 gCO2/km. It will be higher still for even greener vehicles.
  - *malus*: 200-2,600 euros for those emitting over 160 gCO_2/km and even more for the least green vehicles.
- The scheme was designed so that income from the *malus* strictly matches the cost of the incentives to buy clean cars and so reduces the number of polluting vehicles on French roads. However, the scheme has been far more successful than expected and cost to the exchequer is projected to be around 200 million euros.
- Sales of cars emitting no more than 130 gCO_2/km have risen by 50% compared with the same period in 2007 and sales of cars emitting more than 160 gCO_2/km have fallen by 40% overall sales have risen by 3%.
- However, the dramatic effects seen may also be due to high oil prices and the credit crunch financial crisis, rather than from the efficacy of the scheme of itself.

Source: Les Echos, ADAC, Low Carbon Vehicle Partnership.

(iv) The rebound effect

If a combination of technical progress and consumer choice drive the significant reduction in gCO_2/km which is required to achieve our proposed budget assumption, the marginal cost of additional km travelled will on average fall. There is therefore a danger of a 'rebound effect', with increases in km travelled offsetting some of the emissions reduction from efficiency improvements. The economics and the carbon impact of this effect will differ by type of car.

- In the case of petrol and diesel engine cars, km per litre will increase and costs per km travelled fall, so distance travelled will increase.
- In the case of plug-in hybrids and full electric cars, this effect would also ensue, although the carbon impact of this would be less than for conventional engines given the relatively lower emissions of electricity.
- And in the long run, once electricity is fully decarbonised, a rebound effect focused on electric cars would be less concerning from an emissions point of view than one which involved greater use of petrol and diesel engines.

The modelling results presented for road transport in Section 3 above were already adjusted to take account of the potential rebound effect from increased distance travelled[30]. The adjustment was made based on an elasticity of vehicle-km to fuel cost consistent with estimates from the literature. It reduced our estimates of emissions reduction by around 15% in 2020 (e.g. whereas in our Extended Ambition scenario for cars we estimated an emissions reduction of 12 $MtCO_2$, this would have been 14 $MtCO_2$ had we not made the adjustment for the rebound effect).

There are a range of policy options for limiting the rebound effect on distance travelled which could be deployed to ensure greater abatement from improved vehicle emissions performance. For example:

- Road pricing (varying by time of day and location) would ensure that road users faced the full marginal social costs (including emissions and congestion impacts) of their behaviour encouraging them to use the road network more efficiently. This could help prevent the rebound effect on driving[31], were the challenge of public acceptability to be overcome.
- Non-price levers around network use (e.g. pedestrianisation, dedicated bus lanes, parking policies) could disincentivise increased car travel; these are discussed in more detail in Section 4 below.

The Committee would like to draw attention to the necessity of developing over the long term the policies which ensure that the reduction in supply side emissions is not offset by rebound effects.

30 There are two other possible rebound effects in response to improved efficiency: people could buy larger cars, or people could buy more cars (more likely to impact on second car purchases than owning a car at all). The response to larger car purchase is mitigated by the mandatory EU targets on new car emissions and by supporting policies such as VED. Possible increased car ownership could again be mitigated through policy levers such as VED.

31 Which would not only mitigate emissions impacts, but also tackle the congestion impacts of plug-in and electric cars (where congestion impacts may be more important than emissions impacts).

4. ABATEMENT OPPORTUNITIES: POSSIBLE DIMENSIONS OF DEMAND SIDE REDUCTION

Section 2 considered the potential to reduce transport emissions through supply side improvements in gCO_2/km, without any change in consumer behaviour. Section 3 introduced the possibility of changes in consumer choice over size and type of car. This section considers other possible demand side and consumer behaviour changes under four headings:

(i) Changes in driver behaviour: 'eco-driving' and effectively enforcing speed limits

(ii) Modal shift to less carbon intensive transport and better journey planning

(iii) Network access, land use and planning

(iv) Measures to constrain transport demand.

(i) Changes in driver behaviour: 'eco-driving' and effectively enforcing speed limits

The way in which people drive any mode of transport can have a major influence on fuel efficiency. Two types of change can be distinguished: the style in which people drive, and the speed at which they drive.

Eco-driving: Fuel efficiency can be significantly improved by adopting a smoother style of driving, with less aggressive use of accelerator and brake, even without reducing average or maximum speeds: in certain traffic conditions indeed, if followed by a significant proportion of all drivers, eco-driving of this sort can actually increase average traffic speeds. Greater attention to tyre pressure, the removal of unnecessary weight, and the intelligent use of heating and air conditioning systems can also have an appreciable impact. Evidence suggests that average fuel efficiency can be improved by 5-10% when the range of eco-driving principles are adopted together[32] (Box 7.8).

Box 7.8 Examples of carbon savings from eco-driving

- In 2004 the UK's Driving Standards Agency carried out eco-driving trials by comparing drivers' fuel consumption over a given course before and after they received two hours of eco-driving training. The trials demonstrated average fuel savings of 8.5%[1].
- In 2002 a study was undertaken with a car panel of the Dutch Consumer Organisation, consisting of approximately 6,000 drivers. Members were divided into eco-drivers and non-eco-drivers based on their own self-reported behaviour and the groups were compared against each other. Over the year-long duration of the study the eco-drivers consumed 7% less fuel per km than the non-eco-drivers[2].

Sources:

1. Energy Saving Trust (2005) *Ecodriving: Smart efficient driving techniques*. Based on the orginal produced by SenterNovem for the EU Treatise project. EST
2. ibid.

32 Commission for Integrated Transport (2007) *Transport and Climate Change: Advice to Government from the Commission for Integrated Transport*

There is emerging evidence that a significant proportion of the population is willing in principle to consider changing their driving behaviour both to save money and mitigate climate change; for example, a recent consumer survey by the Energy Savings Trust suggests that just under 50% of drivers would be willing to pay for eco-driving lessons with a view to reducing fuel bills[33]. Some companies maintain improved driving of employees by, for example, providing a fixed fuel allowance per km so that an 'eco-driver' can keep the difference but a less efficient driver is out of pocket. It is also likely that increased awareness of high fuel prices has created a more favourable context for persuading people to change their driving behaviour.

A number of initiatives to provide information and encourage eco-driving are already in place. These include the 'Act on CO_2' advertising and awareness campaign, the inclusion of eco-driving in the theory element of the driving test and more recently in the practical element, and a variety of policies aimed at the road freight sector (Box 7.9). There is a great deal of uncertainty, however, as to what level of emissions reduction these initiatives and policies will deliver. In addition, although the initial effect of eco-driving is well documented it is less clear whether this change persists in the long term. It may, however, be possible to increase the likelihood of lock in by the use of in-car technologies such as fuel economy meters or gear shift indicators[34].

Box 7.9 Driver efficiency policies for vans and HGVs

As part of the Department for Transport's aims on sustainable distribution, it funds:

- the Safe and Fuel Efficient Driving (SAFED) demonstration project providing advanced driver training, for both vans and HGVs.
- the Freight Best Practice (FBP) programme which provides free information to the haulage industry, including guides to saving fuel, developing skills, equipment and systems, operational efficiency and performance management. An impact assessment of FBP found that in 2005-2006, 9% of organisations were using at least one aspect of the programme, resulting in 0.24 $MtCO_2$ of abatement. DfT estimates that across FBP and all industry-led initiatives on best practices, emissions savings could have been 1.7 $MtCO_2$ in those two years. From 2008, FBP will be extended to all modes in the freight sector.

From September 2009, there will be a mandatory HGV driver Certificate of Professional Competence, requiring drivers to undertake 5 days of training every 5 years. It is expected that this will significantly increase emissions reduction from efficient driving techniques. By 2014, all drivers (of HGVs and buses) will have received the training.

SAFED is continuing for both van and HGV drivers. Typical fuel savings during training are 10%, although it is not clear how much of this is retained during normal operation. As there is no equivalent compulsory driver training or certification for vans (unlike HGVs) the take up – and therefore emissions abatement – from van driving efficiency improvements is expected to be smaller and take longer to achieve before a policy is put in place.

Source: DfT.

33 Energy Saving Trust (July 2008) *Running on Empty – Green Barometer Issue 5: Measuring environmental attitude*
34 Anable, J and Bristow, A (2007) *Transport and Climate Change: Supporting document to the CfIT report.* Report prepared for the Climate Change Working Group of the Commission for Integrated Transport.

Given these uncertainties, we have defined three scenarios for emissions reduction through eco-driving. In our Current Ambition reduction scenario, we make a conservative assumption that there is no emissions reduction from eco-driving. In our Extended Ambition scenario[35], we have assumed that car drivers who are trained achieve fuel efficiency increases of 3% (to avoid double-counting with speed limiting and gear shift indicators) and that 1% of car drivers per year adopt eco-driving behaviour, which results in 2020 in emissions reductions of 0.3 $MtCO_2$. The Extented Ambition scenario also includes eco-driving for vans (a 3% efficiency gain taken up by 1% of drivers per year) and for HGVs (a 4% efficiency gain, taken up by 100% of drivers from 2014 as there is a policy on HGV driver certification; see Box 7.9) which results in an emissions reduction of 1 $MtCO_2$ in 2020.

In our Stretch Ambition scenario, we still assume that eco-driving for cars increases fuel efficiency by 3% but that many more car drivers adopt the behaviour, reaching 40% in 2020[36]. This results in emissions reduction of 1 $MtCO_2$ in 2020. The Stretch Ambition scenario also includes eco-driving for vans following these same assumptions for cars (implying a strong policy is introduced), which abates 0.3 $MtCO_2$ in 2020.

Speed limits enforcement and possible reduction: Fuel efficiency falls significantly as car, van or HGV speeds are pushed above optimal levels. A typical petrol fuelled car driven at 70 mph emits about 19% more gCO_2/km than when driven at 50 mph (Table 7.2). We estimate that enforcing the existing speed limit would produce annual emissions reductions of over 3 $MtCO_2$ in 2020[37]. Reducing the speed limit to 60 mph on motorways and A roads where the speed limit is currently above this would result in an additional 2 $MtCO_2$ emissions reduction in 2020 (Box 7.10).

The disadvantage of reduced speed limits would be increased journey times. Standard measures of the value of time used in transport evaluation would suggest that the economic and welfare cost of increased journey times may be high, particularly when business journey times are increased (Table 7.3). But the validity of this value of time analysis can be debated: travel time costs are highly variable, for example, by modal quality and reliability, journey length, and traveller preferences. Not all travel time needs have costs attached: time spent on some journeys may be enjoyable, while commuting journeys (particularly longer journeys by train) can be used to work by laptop or phone[38]. The increase in journey time (and therefore costs) from speed limiting might also be over-estimated because, under certain traffic conditions, lower and more strictly enforced speed limits would not actually reduce average journey time significantly, but would produce more smoothly flowing traffic.

Table 7.2 Change in efficiency with speed for a typical car

Speed (mph)	Emissions gCO_2 / km	% Decrease in efficiency for increase of 10mph
40	157	
50	161	3
60	173	7
70	191	10
80	219	15

Source: NAEI.
Note: This is based on a Euro II 1.4–2 litre petrol engine.

35 Modelling eco-driving has also avoided double-counting with gains from technology, as the eco-driving efficiency improvements are applied to the more efficient vehicle stock resulting from the technologies introduced in the Extended Ambition scenario.

36 This is consistent with assumptions by CfIT that 40% of car drivers could be practicing eco-driving by 2020; assuming a strong policy is in place. Source: Commission for Integrated Transport (2007) *Transport and Climate Change: Advice to Government from the Commission for Integrated Transport*

37 Emissions reductions from speed limiting are applied to the more efficient vehicle stock that results from the abatement technologies taken up in our Extended Ambition scenario. This avoids over-estimating the impact on emissions in 2020.

38 See for example, Institute for Transport Studies, University of Leeds (2003) *Value of Travel Times Savings in the UK: Summary report* (DfT); and Lyons, G. and Urry, J. (2004). The use and value of travel time. Unpublished paper.

Table 7.3 Costs of time

Values of time (£per hour)	Mode of Transport				
	Car	Bus	Walk	Cycle	Rail
Work values - assumed wage cost of traveller	30.3	24.5	35.9	20.6	44.7
Non-work values -estimated by surveys	5.5	5.5	5.5	5.5	5.5

Source: DfT Webtag.

Box 7.10 Indicative abatement from speed limit enforcement

The Department for Transport publish figures for vehicles travelling (and vehicle-km travelled) above the speed limit in a range of speed bands, and the differences in emissions per kilometre for each band. These estimates are averaged across all vehicle engines and measured in free-flowing speeds, so could be over-estimating emissions.

From these figures, we've taken the reduction in emissions per vehicle in 2020 from our Extended Ambition scenario and the change in vehicle-km in 2020, but assumed the same proportions of distance travelled above the speed limit. From this data, we calculate the reduction in emissions from speed limit enforcement from the vehicle-km and efficiency data in each speed band.

The calculation applies to cars and vans (there is not a significant proportion of HGVs in the DfT data travelling over the 70mph speed limit), on motorways and A roads. The following table shows the breakdown of emissions saved from speed limit enforcement in 2020, in addition to the Extended Ambition measures.

Total abatement from enforcement of 70mph speed limit in 2020	
	$MtCO_2$
Car- motorway	1.0
Car- A roads	0.4
Van- motorway	0.9
Van- A roads	1.0
Total abatement	**3.3**

The abatement opportunity from speed limiting depends on the efficiency of engines. As technology improves efficiency, fewer emissions can be saved by reducing speeds to 70mph.

On the other hand, the abatement opportunity could be greater if the improvements in efficiency led to a rebound on behaviour, such that people drove faster because it cost them the same to do this in fuel with a more efficient car engine.

A similar calculation for 2020 which looks at lowering and enforcement at 60mph shows that 5 $MtCO_2$ of potential would be available.

In the longer term, with a greater penetration of electric vehicles, the emissions argument for speed limiting will be weakened. There could still remain, however, strong safety reasons for improved enforcement.

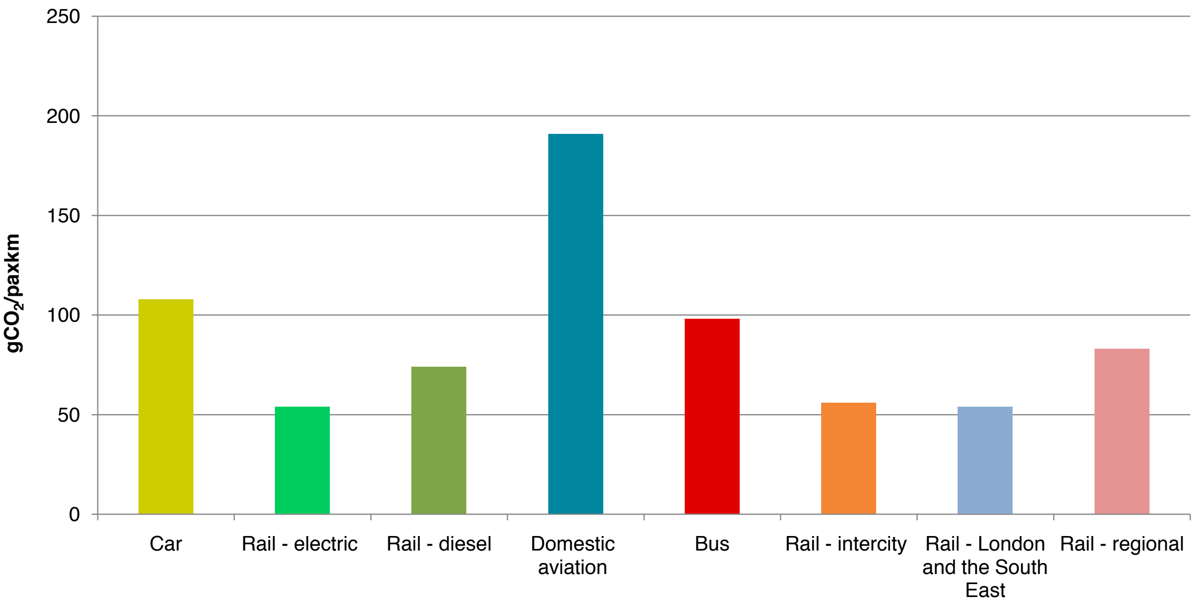
Source: CCC calculations based on DfT data

While recognising that limiting speed is politically contentious, the Committee believes that its potential role in achieving abatement should be kept under review. Motorway speed limits varied in line with congestion levels are likely to play an increasing role. And a more general application of lower speed limits could be a fast acting policy which government could consider if overall carbon budgets were in danger of being breached. We include the possibility of this policy in our Stretch Ambition scenario where 5 $MtCO_2$ is delivered through lowering and effective enforcement of the speed limit, as described above.

(ii) Modal shift to less carbon intensive transport and better journey planning

Different transport modes have very different carbon intensity, (i.e. gCO_2/passenger-km). The figures range from around 190 for domestic air travel, to 53 for electrical rail (given the current electricity generation mix) and zero for cycling and walking (Figure 7.26). If even modest shifts in traffic volume away from high-carbon intensive modes could be achieved useful levels of emissions reduction would result. Box 7.11 presents some purely indicative illustrations of the potential.

Figure 7.26 CO_2 emissions per passenger-km by mode



Source: DfT, Association of Train Operating Companies.

Notes:

1. Rail emissions calculated at current grid carbon intensity;
2. Domestic aviation emissions are calculated not allowing for any impact of additional radiative forcing beyond that produced by CO_2 emissions, see Chapter 8.

Box 7.11 'Ready reckoner' for passenger modal shift from cars

In order to calculate 'ready reckoners' for abatement potential from modal shift the following data and assumptions were used:

- Figures for annual passenger-km by mode are taken from data published by the Department for Transport.
- Figures for total CO_2 emissions by mode are taken from data published by the NAEI.
- It is assumed that all passenger-km for a single mode have the same carbon intensity and that there is a straight transfer of passenger-km from one mode to another with no other effects (e.g. changing load factors or changes in demand for travel)
- It is also assumed that the distance between London and Scotland is 700 km by air and rail and that there are 8 million journeys between London and Scotland per year.

	$MtCO_2$ Abated
Increasing bus and rail passenger kilometres by 50% (all removed from cars)	1.5
Double cycle kilometres (all removed from cars)	0.6
Replace London to Scotland domestic air journeys with rail journeys (current grid mix)	0.7

There are a couple of caveats to these figures:

- An implicit assumption in these figures is that mode switch is possible. Capacity constraints may inhibit switching to buses and rail. Whilst increasing capacity may create additional demand for travel.
- The potential for switch to cycling is limited to short journeys.

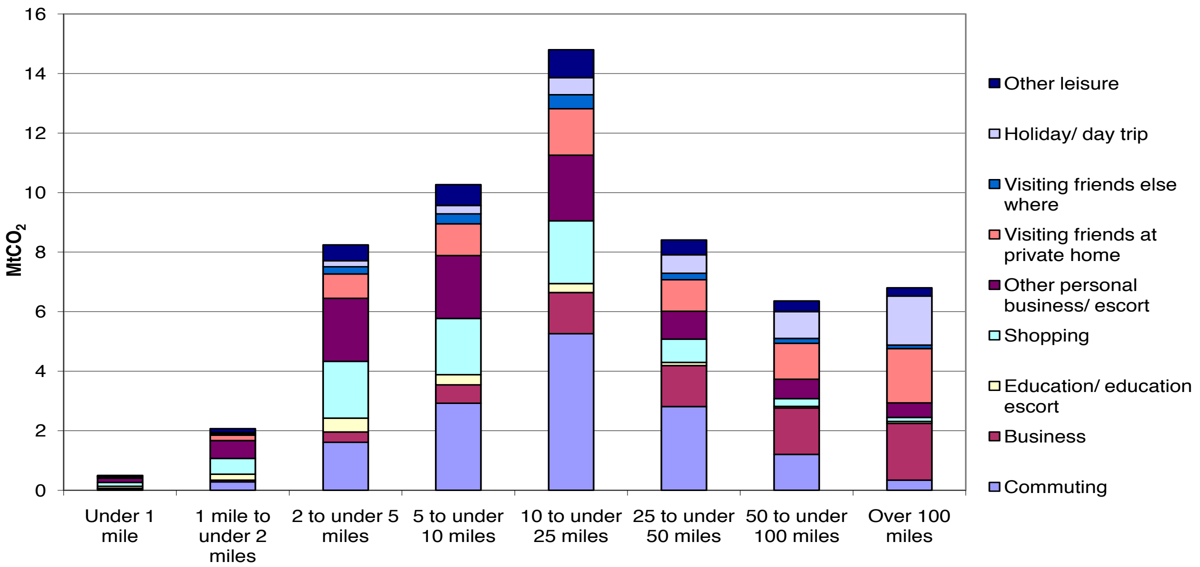
Thus abatement potential from modal switching may be more modest than our calculations reflect.

Source: CCC calculation based on NAEI and DfT data

Estimating realistic potential for modal shift is however a very complex challenge and the Committee has neither had the time nor resources to conduct a detailed analysis. Among the issues which would need to be considered in a detailed analysis are:

- **The pattern of journey lengths and purposes:** which suggest that there are likely to be major differences in the potential for modal shift depending on journey type. Figure 7.27 sets out the distribution of car journeys by journey length and Table 7.4 illustrates the varying importance of different journey purposes. Among the implications of these figures are that:
  - Opportunities to shift journeys to cycling are likely to be limited to journeys less than five miles distance, which are responsible for 19% of emissions.
  - A significant portion of emissions come from longer journeys (over 25 miles) for a wide variety of non business and non commuting purposes (e.g. visiting friends) which may be very difficult to shift given the highly specific and one-off nature of the travel routes.
  - The greatest potential may lie in commuting journeys, and in the large number of medium distance (i.e. 2 to 25 mile personal non commuting) journeys, both through modal shift and better journey planning, but the realistic potential will vary hugely by availability of alternative modes, household and occupation patterns, population density and land use.
  - There may be scope to change trip distribution and modal choice through levers relating to network access and land use planning, discussed in subsection (iii) below.
- **Capacity constraints in public transport systems** and the time which it would take to overcome these. Thus while our 'ready reckoner' illustrates the significant potential for emissions reduction resulting from a 50% increase of rail journeys at the expense of cars (Box 7.11), on many routes this would only be a realistic if there were further investment in capacity, which could result in increasing average gCO_2/passenger-km (for example, if the new capacity was occupied at a lower load factor than existing capacity).

Figure 7.27 Car CO_2 emissions by journey length and purpose



Source: DfT

Table 7.4 Trends in km travelled per year per person (all modes; by purpose of travel)

Journey Purpose	1995/1997	2006	Percentage Growth: 1995/1997 - 2006
Commuting	2,294	2,239	-2
Business	1,176	1,097	-7
Education	310	330	6
Escort education	142	162	14
Shopping	1,476	1,491	1
Other escort	648	785	21
Personal business	770	786	2
Visiting friends at private home	1,889	1,804	-4
Visiting friends elsewhere	377	471	25
Entertainment/public activity	507	597	18
Sport: participate	232	174	-25
Holiday: base	752	845	12
Day trip	582	622	7
Other inc. just walk	80	77	-4
All purposes	11,234	11,479	2

Source: DfT.
Note: 'Escort education' refers to accompanying someone to a place of education. For example the school run.

There are, however, already initiatives in place to incentivise modal shift, encourage better journey planning and reduce the need to travel. The Smarter Choices approach, for example, is aimed at influencing people's travel behaviour toward more sustainable options (Box 7.12). First implemented in the UK in the early 1990s, this approach has now been significantly implemented by around 30% of local authorities[39].

As with eco-driving, however, the level of emissions reduction that will ensue from these policies is uncertain. In addition it is not clear whether Smarter Choices can be implemented on a wider scale and evidence is limited about the persistence of behaviour change. It is clear, though, that harnessing the potential of Smarter Choices is likely to require a mixture of policy levers to lock-in the benefits such as reallocation of road capacity or parking control[40].

Given these uncertainties, in developing a range for potential emissions reduction from modal shift and better journey planning we have drawn on the Smarter Choices analysis used by DfT[41]. This analysis includes low and high scenarios, the former modelling continuation of Smarter Choices at current levels, and the latter modelling much wider implementation of current practice; in a central case, emissions reduction in 2020 is estimated to be 2.9 $MtCO_2$. We have built this central case estimate into our Extended Ambition scenario[42], and adopted a conservative approach in our Current Ambition scenario where we have assumed no savings from Smarter Choices. The Committee will revisit estimates from Smarter Choices policies in light of new evidence and when we look at the demand side in more detail from next year.

39 Department for Transport (2007) *Review of the Take-Up of Smarter Choices in Local Transport Plans*. Case Study Findings prepared by the Operational Unit for Sustainable Travel Initiatives Branch. London: DfT
40 Cairns, S., Sloman, L., Newson, C., Anable, J., Kirkbride, A. & Goodwin, P. (2004) *Smarter Choices – Changing the Way we Trave*l. DfT
41 Defra (2007) *Synthesis of Climate Change Policy Appraisals.* London: Defra
42 We note, however, that even this 2.9 $MtCO_2$ estimate may be cautious, firstly because this assumes 'central' implementation of the policy; and secondly because further abatement is possible from network access and land use planning policies, which also would 'lock in' Smarter Choices. These are discussed in the next section.

Box 7.12 Smarter Choices: influencing people's travel behaviour towards more sustainable options

- Smarter Choices influence people's travel behaviour towards less carbon intensive alternatives to the car such as public transport, walking and cycling by providing targeted information and opportunities to consider alternative modes.
- Smarter Choices can include workplace and school travel plans; personalised travel planning, travel awareness campaigns, and public transport information and marketing; car clubs and car sharing schemes and; teleworking, teleconferencing and home shopping.
- Research commissioned by DfT, based on case study evidence, estimated that Smarter Choice measures under a 'high intensity scenario' have the potential to reduce nationwide traffic volumes by 11% based on a commitment to a programme building up over a ten year period. Under a 'low intensity scenario' a nationwide reduction in all traffic of 2-3% could be achieved[1].
- The DfT has funded three Sustainable Travel Towns in Peterborough, Darlington and Worcester to assess the results of the intensive implementation of packages of Smarter Choices in one locality. The three towns are sharing £10 million of DfT funding over the five years of the project 2004/05 – 2008/09. The evidence to date implies significant modal shift is possible with falls in traffic of over 10% in just two years[2].

Sources:

1. Cairns, S., Sloman, L., Newson, C., Anable, J., Kirkbride, A. & Goodwin, P. (2004) *Smarter Choices – Changing the Way we Travel.* DfT
2. Merron, Gillian. Former Parliamentary Under Secretary of State for Transport. (Letter to Chief Executives on the success of the Sustainable Travel Towns, 23rd May 2007). [Online] Available from: http://www.dft.gov.uk/pgr/sustainable/demonstrationtowns/lettersustainabletraveltowns

(iii) Network access, land use and planning

We recognise that there may be emissions reduction over and above that set out above through a range of levers including changes to network access and land use planning, which could potentially result in deep emissions cuts both within and beyond the first three budget periods:

- **Network access**. Within the existing built environment, it is difficult to change relative locations of residences, amenities, businesses and transport links, but when the network is used and by whom can be altered relatively quickly, changing transport patterns and reducing emissions. For example, road network and town centre access can be designated by use (e.g. buses; deliveries to shops and businesses) and time of day and day of week (e.g. during the school run; or market days) to give priority to people and to lower emitting modes of transport. There has been a significant trend towards implementing such policies, such as dedicated bus or cycle lanes; pedestrianised streets or town centres; and even emissions differentiated parking charges. While, in general, network designation is motivated by factors such as congestion, safety, noise or air quality, CO_2 emissions gains may be an equally important factor to consider.

- **Land use and planning.** New construction presents an opportunity to build in from the start a pattern of transport activity associated with shorter journeys and less emitting modes. Key considerations are settlement size; population density; location of residences, amenities and businesses; and accessibility of public transport modes[43]. As settlement size increases, trips become shorter and the proportion by public transport increases; and as density increases, car trips decrease. Mixed use developments could reduce trip lengths and car dependence. Location of developments near public transport interchanges and corridors, with provision of public transport links at both the journey origin and destination, is also important.

43 Banister, D (2008) *Land Use, Planning and Infrastructure Issues in Transport*. Committee on Climate Change.

We have not yet quantified abatement potential from network access, land use and planning measures. Going forward, however, we will consider further what scope for emissions reduction these may offer in the first three budget periods and beyond. We will do this both as part of our ongoing work programme, and in the context of our advice on the fourth budget to apply from 2023-27 which we will provide in 2011.

(iv) Measures to constrain transport demand

Given increasing travel demand and emissions, there is an important public policy question about whether and to what extent public policy should plan to constrain total growth.

The Eddington Transport Study considered this issue, questioning in particular whether further road building should continue. Its overall conclusion was that there was a case for some limited additional road building, but that in the medium term constraints on total capacity should be accepted, with road pricing used to ensure that constrained capacity is used as efficiently as possible rather than relying on congestion to limit demand growth (Box 7.13). While the Committee has not developed a detailed point of view on long-term transport capacity and demand, it concurs with the Eddington Study judgement that unconstrained growth of capacity is not economically desirable and that road pricing is likely to have a significant role to play both in city centre environments (congestion charges) and on motorways.

Box 7.13 Key recommendations of the Eddington Transport Study

1. To meet the changing needs of the UK economy, Government should focus policy and sustained investment on improving the performance of existing transport networks, in those places that are important for the UK's economic success.

2. Over the next 20 years, the three strategic economic priorities for transport policy should be: congested and growing city catchments; and the key interurban corridors and the key international gateways that are showing signs of increasing congestion and unreliability. These are the most heavily used and economically significant parts of the network.

3. Government should adopt a sophisticated policy mix to meet both economic and environmental goals. Policy should get the prices right (especially congestion pricing on the roads and environmental pricing across all modes) and make best use of existing networks. Reflecting the high returns available from some transport investment, based on full appraisal of environmental and social costs and benefits, the Government, together with the private sector, should deliver sustained and targeted infrastructure investment in those schemes which demonstrate high returns, including smaller schemes tackling pinch points.

4. The policy process needs to be rigorous and systematic: start with the three strategic economic priorities, define the problems, consider the full range of modal options using appraisal techniques that include full environmental and social costs and benefits, and ensure that spending is focused on the best policies.

5. Government needs to ensure the delivery system is ready to meet future challenges, including through reform of sub-national governance arrangements and reforming the planning process for major transport projects by introducing a new Independent Planning Commission to take decisions on projects of strategic importance.

Source: The Eddington Transport Study

5. OVERALL CONCLUSIONS: REASONABLE ASSUMPTIONS ON ATTAINABLE ABATEMENT FOR BUDGET PURPOSES

We have developed three scenarios for transport emissions reduction:

- The Current Ambition scenario includes some increase in vehicle fuel efficiency, but does not include any biofuels above the reference case or demand side emissions reductions; total emissions reduction in this scenario are 5 $MtCO_2$ in 2020.
- The Extended Ambition scenario includes more radical technology options in cars, together with increased biofuels use over the reference case and demand side emissions reduction from eco-driving and Smarter Choices and effective enforcement of the existing speed limit; total emissions reduction in this scenario is 23 $MtCO_2$ in 2020.
- The Stretch Ambition scenario includes more radical technology options in vans and HGVs, emissions reduction due to stronger uptake of eco-driving in cars and vans; and lowering and effective enforcement of the speed limit. Emissions reduction in this scenario is 32 $MtCO_2$ in 2020.

In the Extended Ambition and Stretch Ambition transport scenarios, there is significant potential for emissions reduction. Implementing a domestic and EU framework will be needed to unlock this potential and to meet the economy-wide carbon budgets proposed in Chapter 3.

Emissions reduction from these scenarios, summarised in Table 7.5, is incorporated in economy-wide scenarios for emissions reduction to meet carbon budgets in Chapter 3.

Table 7.5 Abatement opportunities in transport in Current Ambition, Extended Ambition and Stretch Ambition scenarios, in 2020

Measure	Current Ambition	Extended Ambition	Stretch Ambition
Car- powertrain- hybrid	-4.1		
Car- nonpowertrain- large cars	-0.2		
Van-powertrain- stop start (slower uptake)	-0.1		
Van-nonpowertrain (slower uptake)	-0.3		
HGV- nonpowertrain (slower uptake)	-0.3		
Total	**-5.0**		
Biofuels		-5.0	
Car- powertrain- plug-in hybrid and electric		-8.7	
Car- nonpowertrain- all cars		-2.9	
Van-powertrain- stop start		-0.3	
Van-nonpowertrain		-0.8	
HGV- powertrain- hybrid		-0.2	
HGV- nonpowertrain		-0.7	
Rail- efficiency measures		-0.6	
Demand- Smarter Choices		-2.9	
Demand- Eco driving - cars		-0.3	
Demand-Eco driving - vans		-0.1	
Demand-Eco driving -HGV		-0.9	
Total abatement		**-23.3**	
Van-powertrain- plug-in hybrid and electric			-2.4
HGV-powertrain- plug-in and electric			-0.3
HGV- nonpowertrain- incl aero and weightreduction			-0.7
Speed reduction and enforcement at 60mph			-5.2
Eco-driving cars - far reaching			-1.0
Eco-driving vans - far reaching			-0.3
Total			**-31.7**

Source: CCC, DfT

PART III:

EXTENDING THE CARBON BUDGET FRAMEWORK?

The existing Climate Change Act requires the government to set budgets in terms of CO_2 only, and excluding international aviation and shipping. The Secretary of State has asked the Committee to provide advice on whether these currently excluded sectors and the other greenhouse gases should be included in the legal budget system.

The principle which should apply is clear. What matters from the climate perspective is all greenhouse gases from all sectors. The implication is that all categories of emissions must be accounted for in some way within a greenhouse gas reduction strategy, whether or not they are included in budgets.

The inclusion of the currently excluded sectors and gases in the legally defined budgets, however, raises complex practical questions of emissions measurements and allocation, which we address in the next two chapters.

In **Chapter 8: International aviation and shipping,** we conclude that these sectors should not, for the time being, be included in the UK national budgets, but that it is essential that they are covered by other policy levers and monitored by the Committee. We illustrate that both sectors are likely to see very significant growth in emissions under business as usual, and that while there is emissions reduction potential, the percentage cut will likely be less than in other sectors. To the extent that this is the case, larger percentage reductions will be required elsewhere. We show that international aviation is appropriately included in the EU ETS, but that the national allocation treatment under the EU ETS would create significant practical complexities if international aviation was also included on a different basis in the UK national budgets. In the case of shipping, we illustrate the major complexities involved in any national allocation and the strong arguments for seeking a global sectoral approach.

In **Chapter 9: Non-CO_2 greenhouse gases,** we recommend that the budgets should be set in terms of all GHGs, not just CO_2. We identify that there are greater measurement difficulties in relation to some non-CO_2 gases, than apply to CO_2, but conclude that these are manageable and that the arguments for including non-CO_2 gases within the budgets are compelling. We present initial analysis of abatement potential in waste management and in agriculture, which is an important source of N_2O and methane emissions but where only limited analysis has been done in the past and where policy levers to drive emissions reductions are not yet in place.

The Chapter concludes by illustrating how the budget reduction figures set out in Chapter 3 (for CO_2 alone) need to be changed to incorporate non-CO_2 gases. The Intended budget target for all GHGs in 2020 is 42% below 1990 levels (31% below 2005 levels) and the Interim budget requires a 32% cut from 2020 (21% below 2005 levels).

CHAPTER 8:

INTERNATIONAL AVIATION AND SHIPPING

The Kyoto Protocol committed the UK to achieving reductions in greenhouse gases (GHGs) as measured by the NAEI. The NAEI total for the purposes of the reduction commitments includes emissions from UK domestic aviation and shipping, but does not include an estimated UK share of international aviation and shipping emissions. This reflects the absence of an agreed basis for allocating international passenger and freight traffic to specific countries.

Despite this lack of an international approach, emissions from domestic and international aviation (both within Europe and to and from Europe) will be included within this phase of the European Union Emission Trading Scheme (EU ETS) and therefore subject to a total emissions cap. There are not at present, however, any clear plans for a policy instrument to contain shipping emissions, either at the UK or EU level.

This chapter therefore considers (i) the feasibility of allocating international emissions both to the European and the UK level; (ii) the scope for global abatement in these sectors; and (iii) the implications of allocation systems and appropriate policies for the treatment of the two sectors within the UK budget framework.

Our key conclusions are that:

- Whilst aviation and shipping emissions are today both relatively small as a percent of total global emissions they are likely, if unconstrained, to grow to much larger shares. It is therefore essential either to curtail emissions growth significantly or to set more stringent targets for all other sectors which compensate for the difficulty of achieving cuts in these sectors.

- **On aviation specifically:**
  - If unchecked, global aviation CO_2 emissions could reach 2.4 $GtCO_2$ in 2050. At this level aviation emissions would, in 2050, account for 15-20% of all CO_2 emissions permitted under our preferred global emissions reduction scenarios set out in Chapter 1: *Setting a 2050 target*. By 2050 UK related international aviation CO_2 emissions (using the bunker fuels methodology) could, under DfT's central scenario, account for around 35% of the UK's GHG emissions cap implied by our preferred global emissions reduction scenario.
  - The global emissions forecast assumes a significant efficiency improvement consistent with preliminary analysis carried out for us by QinetiQ. This analysis suggests that a new production aircraft in 2025 flying in an improved operational environment will be 40-50% more fuel efficient compared to a 2006 new production aircraft flying in a 2006 operational environment. Reducing emissions below forecast would require use of either biofuels or hydrogen. Aviation biokerosene brings the same sustainability and food supply concerns as other biofuels, but if it could be produced sustainably, significant life-cycle emissions reduction could result. The International Energy Agency (IEA) estimate in their BLUE Map scenario that in a world with a substantial carbon price, biomass-to-liquid fuels could account for 30% of aviation fuel by 2050. Hydrogen is another potential fuel source in the longer term, but there are significant implementation barriers. In addition to infrastructure issues and the need for a sustainable source of hydrogen, the climate effect of increased water vapour at high altitude would need to be investigated.

- We conclude that international aviation needs to be covered by an international agreement. In the absence of a global deal the planned inclusion of international and domestic aviation within the EU ETS makes sense and there are few disadvantages to European unilateral action.
- Given that aviation is included within the EU ETS, it is not essential to have international aviation included within the UK national budgets in order to ensure pressure for emissions reduction.
- Ideally, international aviation would be included in UK national budgets for completeness. But there are complexities related to methodologies by which emissions might be allocated to the UK. Specifically, we do not think that inclusion on the basis of EU ETS allowances administered by the UK would adequately reflect the UK's international aviation emissions. Inclusion on the basis of bunker fuels is attractive in principle, but could not be effectively monitored against emissions and permits given the way that EU ETS has been designed. We therefore recommend that international aviation is not explicitly included in the UK's carbon budget.
- If it is not included, the budget which is set for the other sectors will need, when combined with the trend in EU ETS aviation emissions, to be compatible with overall climate objectives. Aviation (both international and domestic) is included in the EU's 20% and 30% GHG emissions reduction targets. Our budget proposals in Chapter 3: *The first three budgets* which are based on this framework, therefore implicitly take into account international aviation emissions.
- Recognising the importance of including international aviation emissions in the UK's climate mitigation strategy, we propose that the Committee reports annually on UK trends in international aviation emissions (using a range of appropriate methodologies), their climate impact, developments in, and the success of, abatement efforts and appropriate policy levers.

- **On shipping specifically:**
  - Unconstrained growth could result in global CO_2 emissions growing two to three times current levels by 2050 reaching 2.4-3.6 $GtCO_2$. At this level they would, in 2050, account for 15-30% of all CO_2 emissions permitted under our preferred global emission reduction scenarios set out in Chapter 1. It is therefore essential that international shipping emissions are covered in overall emission targets and policy frameworks.
  - There is a wide range of abatement options that could be applied to ships to reduce energy consumption and hence reduce CO_2. There are significant implementation barriers but some of these could be overcome through the introduction of a global carbon market. Our analysis suggests that global shipping emissions could be reduced by 33% relative to a baseline projection in 2050 at a carbon price of 200 Euro/tCO_2. Even in this scenario, however, global shipping emissions in 2050 could be twice current levels – roughly 2 $GtCO_2$.
  - There are not at present any firm plans to include international shipping in the EU ETS and applying a European only approach to shipping could be undermined by carbon leakage effects. Shipping is a clear example of a sector where unilateral, national or even regional action is problematic, and where achieving a global sectoral deal is therefore a priority.
  - We do not therefore believe it appropriate at this stage to include international shipping emissions within the UK budget system.

- Likely trends in international shipping emissions should be taken into account in setting budgets (excluding international shipping) so as to ensure that the budgets are compatible with overall climate objectives. At present, however, the EU 20% and 30% GHG targets exclude international shipping, and this is reflected in our carbon budget proposals. The appropriate action here would be for the EU's targets to take into account international shipping emissions when setting targets for other sectors, rather than for the UK to unilaterally adjust its carbon budgets. In the meantime, our recommendation is that the Committee should report annually on trends in the UK's international shipping emissions (using a variety of different measures), their climate impact, developments in, and the success of, abatement efforts and appropriate policy levers.

The chapter covers first aviation (Section A) and then shipping (Section B). For each sector we cover in turn:

1. Trends and projections at the global and UK level

2. Supply side abatement opportunities

3. Appropriate policy levers at national, European and global level

4. International aviation/shipping and the UK national budget

SECTION A: INTERNATIONAL AVIATION

1. INTERNATIONAL AVIATION: TRENDS AND PROJECTIONS

Although total aviation emissions represent a small percentage of total global emissions today, they represent a more significant proportion of developed country emissions. Unconstrained forecasts suggest that global aviation emissions would, in 2050, account for 15-20% of all CO_2 emissions permitted under our preferred emissions reduction scenarios set out in Chapter 1.

- The precise scale of current global CO_2 emissions (international and domestic) from aviation is uncertain, with different sources suggesting a range from 0.5 to 0.7 $GtCO_2$[1] (roughly half of emissions come from international aviation). This range is equivalent to about 1.9–2.4% of total global emissions of CO_2 (excluding those relating to land-use) (Table 8.1).

- The effect of aviation on the climate is, however, almost certainly somewhat higher than these figures suggest, with further radiative forcing caused by the creation of high clouds and emissions of other non-Kyoto GHGs. The best way of accounting for these additional effects is still a subject of debate for two reasons: first, there is a low level of current scientific understanding regarding some of the processes involved, and second, there is uncertainty about whether traditional metrics for weighting non-CO_2 effects (such as the Global Warming Potential (GWP) metric) are appropriate, as set out in Box 8.1.

- Aviation demand has grown rapidly. Over the last ten years total scheduled demand (domestic and international combined) have increased at roughly 5% per annum, substantially faster than global economic growth (Figure 8.1). Looking forward, rapid growth is likely to continue. Developed country traffic volumes and emissions per capita are today far above developing country levels (Figure 8.2) but air travel in developing countries will increase rapidly as their incomes increase, since estimates of the income elasticity of demand for aviation are very high (Table 8.2).

- There are many projections for global aviation emissions and this makes it hard to establish one 'business as usual' case. Projections vary widely depending on the precise assumptions made about income convergence, traffic growth, fuel efficiency trend and the scope of the study. Other assumptions also relate to the regulatory environment and consumer behaviour. The CONSAVE scenarios (Figure 8.3) show four possible scenarios for the growth of global (domestic and international) aviation emissions. The scenarios range from 'Unlimited Skies' (ULS), which is comparable with an unconstrained demand scenario, but pressure on capacity at airports, to 'Down to Earth' (DtE), which would require strong policy action and regulation. In a world without significant policy action at the global level we are more likely to be on a path resembling the CONSAVE ULS scenario, which would result in 2.4 $GtCO_2$ from global aviation in 2050 under an assumption that fleet efficiency improves by 1.5% annually. Global CO_2 emissions from aviation at around these levels would, in 2050, account for 15-20% of all CO_2 emissions permitted under our preferred global emissions reduction scenarios set out in Chapter 1.

1 The lower end of the range comes from models cited by the IPCC which tend to only cover civil emissions and scheduled traffic, whereas the higher end of the range is the IEA's more recent bunker fuel estimate, which includes all traffic including military.

- Turning to the UK level, there is a variety of possible ways of determining the UK share of international aviation emissions. On a 'bunker fuel basis' (which is reported as a memorandum item in the United Nations Framework Convention on Climate Change (UNFCCC) National Register), UK international aviation emissions were around 30 $MtCO_2$ in 2000 (roughly 8% of the global total). Similar shares result from other allocation methodologies recommended for further consideration by the UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA) (Table 8.3). But demand is growing rapidly, both for passenger traffic (Figure 8.4) and freight traffic (Figure 8.5) and so too are emissions. Figure 8.6 illustrates a 66% increase in international aviation CO_2 emissions over ten years using the bunker fuel definition.

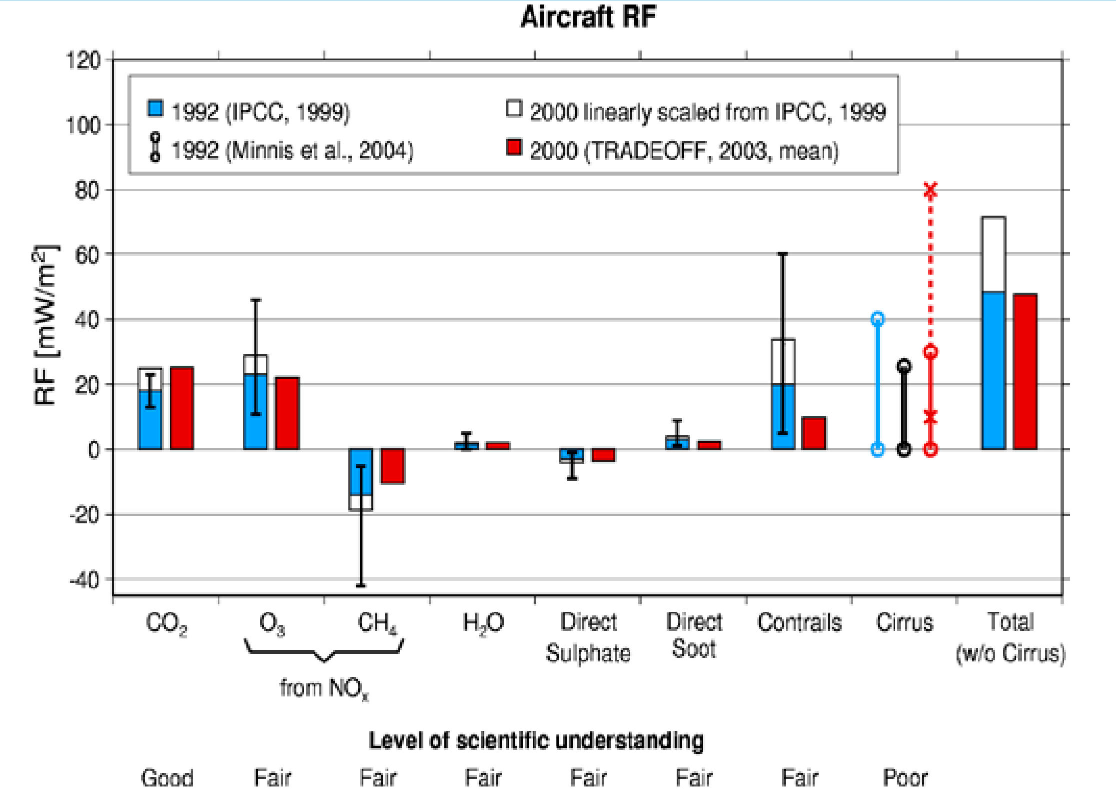
- Looking forward, Department for Transport (DfT) central bunker fuel projections suggest that UK related emissions (both domestic and international) by 2030 could reach around 60 million tonnes (Figure 8.7). Beyond 2030 the projections flatten largely because of infrastructure constraints, and CO_2 emissions from aviation in 2050 are approximately 60 $MtCO_2$. If international aviation emissions remain around the same proportion of emissions as in 2006 then UK international aviation would emit roughly 55 $MtCO_2$, around 35% of a proposed cap of UK GHG emissions in 2050 (see Chapter 1).

Table 8.1 CO_2 emissions from global aviation

Study/Source	Base Year	Total aviation emissions ($MtCO_2$/yr)	Percentage of global emissions in given year
IEA	2005	**730** (416 international)	2.4%
AERO 2K	2002	**492**	1.9%
FAST	2000	**480**	1.9%
CONSAVE	2000	**531**	2.1%
UNFCCC	2005	**475** (covers Annex 1 only)	n/a

Note: IEA estimates are taken from 'CO_2 emissions from Fuel Combustion 1971-2005' and are based on bunker fuel use, other models cited by the IPCC (i.e. AERO 2k, FAST and CONSAVE) represent global aviation, whereas UNFCCC estimates derive from reports from Annex 1 countries only. Global emissions are total CO_2 emissions (excluding those related to land-use) and are taken from CDIAC.

Box 8.1 The current radiative effects of aviation



Source: Sausen, R. et al. (2005) Aviation radiative forcing in 2000: an update on IPCC (1999). *Meteorologische Zeitschrift*, 114, 555-561

The overall effect of aviation on climate is currently the subject of active scientific research. As well as emissions of CO_2, aviation fuel burning leads to emissions of water vapour in the form of contrails, sulphate aerosol and soot, which all contribute small but direct radiative effects. Significant radiative forcing (RF) comes from indirect and short-lived processes not covered by the Kyoto Protocol (see above). And major uncertainties in aviation's forcing are caused by emissions of oxides of nitrogen (NO_x) and cloud formation.

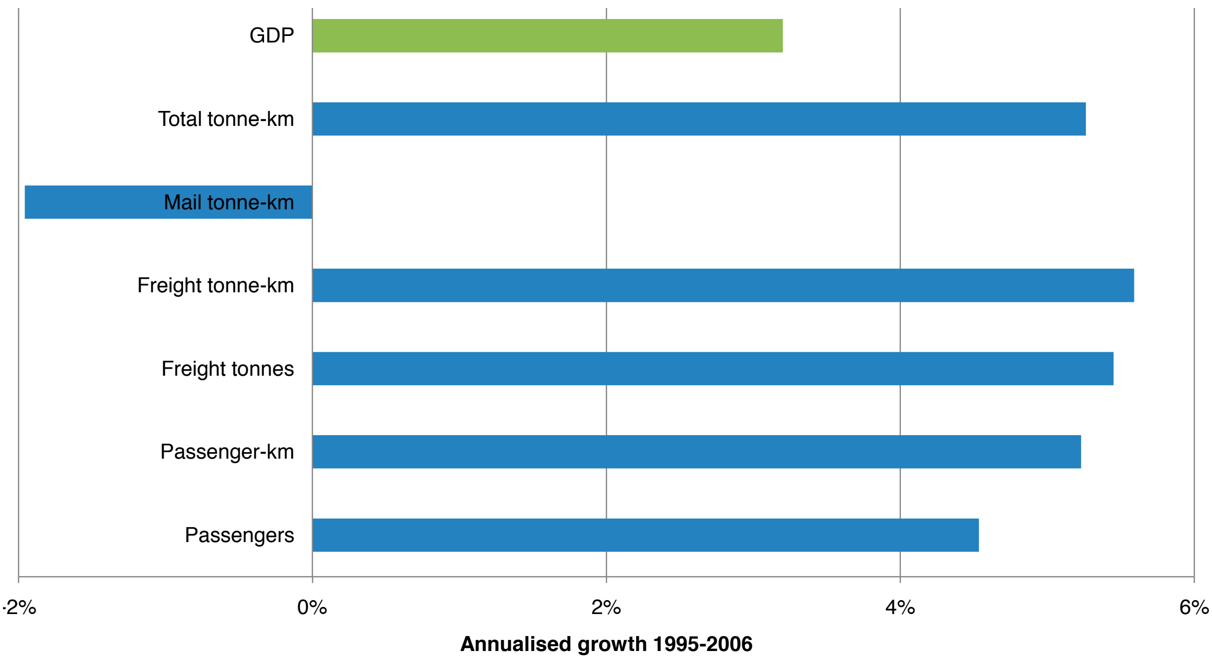
NO_x is known as an indirect GHG because it increases production of ozone (O_3, a short-lived GHG) but also destroys methane (CH_4, a long-lived, Kyoto GHG). These two processes occur over different timescales and different spatial scales, and so the total forcing from NO_x emission can be negative or positive depending on location and air chemistry. Importantly, some methods of reducing CO_2 emissions from aircraft engines lead to an increase in NO_x emissions. Using these methods could therefore be inefficient in reducing radiative forcing from the aviation sector.

Contrail formation is an effect of aviation that can clearly be seen, and it is also thought that aircraft activity may induce more frequent formation of cirrus clouds. Both tend to be very short-lived (on a timescale of minutes to hours), dependent on local weather conditions, and their radiative effect is complex. The level of current scientific understanding of these two processes are thus classed as 'Fair' and 'Poor' respectively.

The traditional GWP metric for comparing GHGs relies on a one-to-one link between the pulse of a mass of emissions and its time-integrated, globally-averaged radiative forcing. Effects of aviation can involve the sum of two different effects acting over different times and areas (in the case of NO_x), or processes which depend on local conditions and last for uncertain lengths of time (in the case of cloud formation). This makes the use of GWPs as a policy instrument for aviation a controversial issue, although the scientific evidence suggests that non-CO_2 effects of aviation should be accounted for in some way.

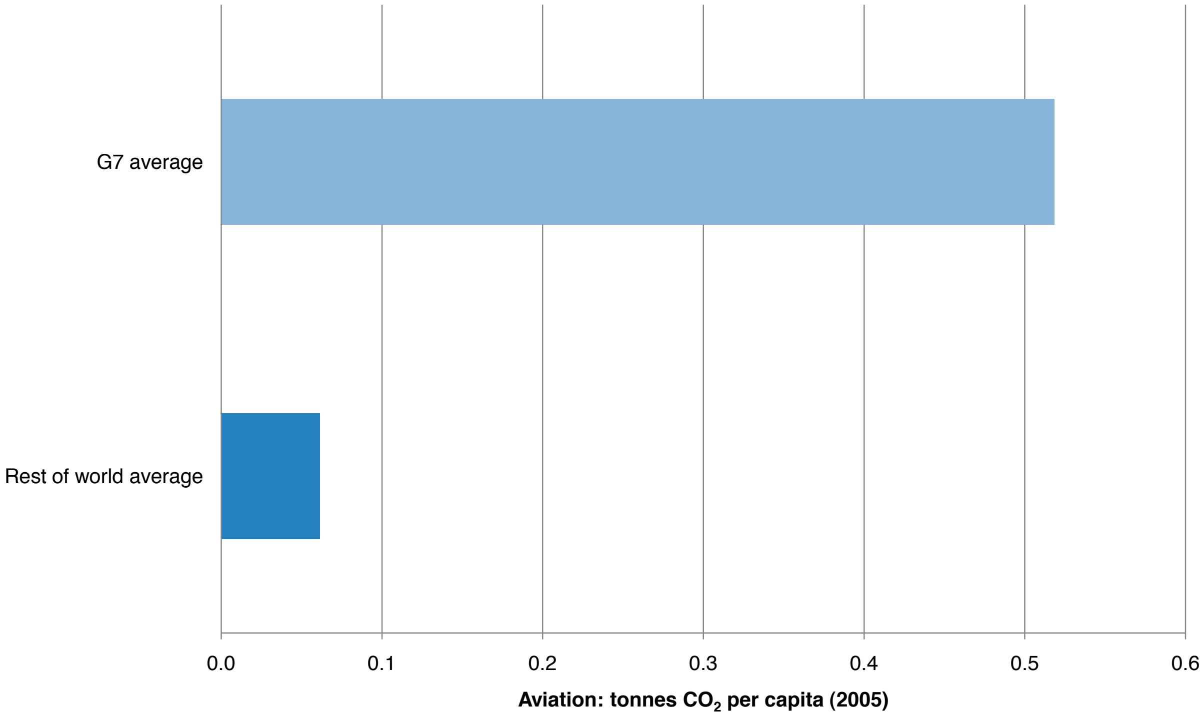
It should be noted that the above figure shows the climate effect of past aviation emissions and therefore, should not be used as a metric to account for the future climate effects of aviation emissions.

Figure 8.1 Annualised growth during 1995-2006 for global aviation revenue traffic (domestic and international) measured using a range of metrics and compared to global GDP growth



Source: ICAO Data. (2008)/UN Statistics Division. (2008)

Figure 8.2 Per capita emissions of CO_2 from aviation (domestic and international) in the year 2005, grouped into G7 nations and the rest of the world



Source: UNFCCC. (2008)

Table 8.2 Estimated income elasticities of passenger demand

Route / Market level	Short-haul	Medium-haul	Long-haul	Very long-haul
US	1.8	1.9	2.0	2.2
Developed economies	1.5	1.6	1.7	2.4
Developing economies	2.0	2.0	2.2	2.7
National level	**Short-haul**	**Medium-haul**	**Long-haul**	**Very long-haul**
US	1.6	1.7	1.8	2.0
Developed economies	1.3	1.4	1.5	2.2
Developing economies	1.8	1.8	2.0	2.5

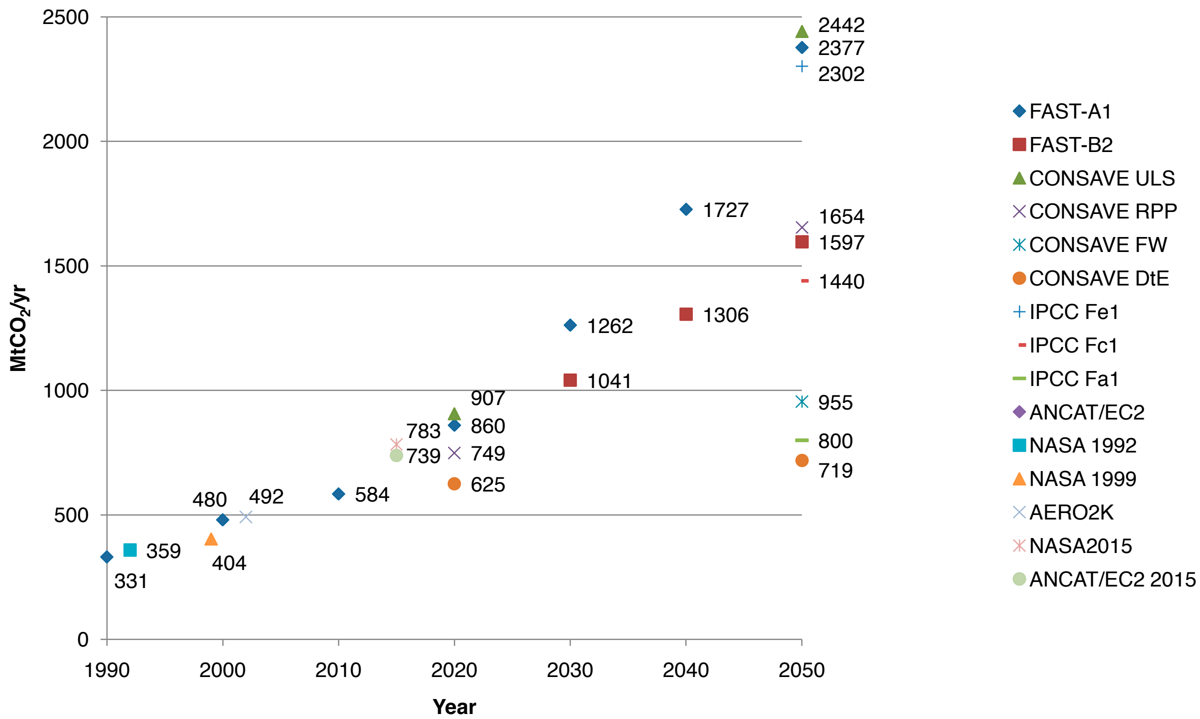
Source: IATA. (2008) *Air Travel Demand*

Table 8.3 Percentage of international aviation emissions that would be allocated to the UK using the SBSTA methodologies

Methodology 'recommended' for further consideration	Owen & Lee UK 1990	CE Delft UK 1990	Owen & Lee UK 2000
Fuel used for international flights (bunker fuels)	7%	7%	8%
Nationality of the airline	no data	8%	8%
International departures/arrivals (aircraft)	7%	7%	8%
International departures/arrivals (passengers)	7%	7%	8%

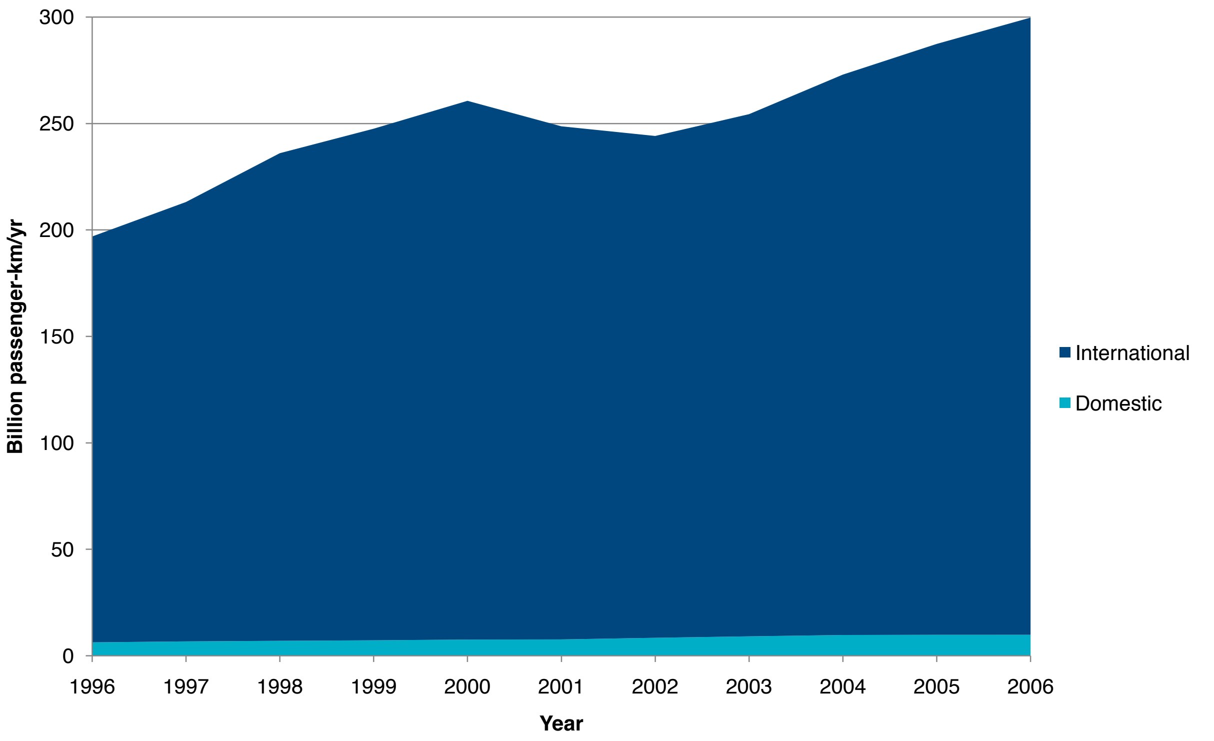
Source: Owen, B. & Lee, D. S. (2005) *Study on the Allocations of Emissions from International Aviation to the UK Inventory/ CE Delft. (2000) National allocation of international aviation and marine CO_2 emissions*

Figure 8.3 Comparison of projections of global CO_2 emissions from civil aviation (domestic and international), 1990-2050



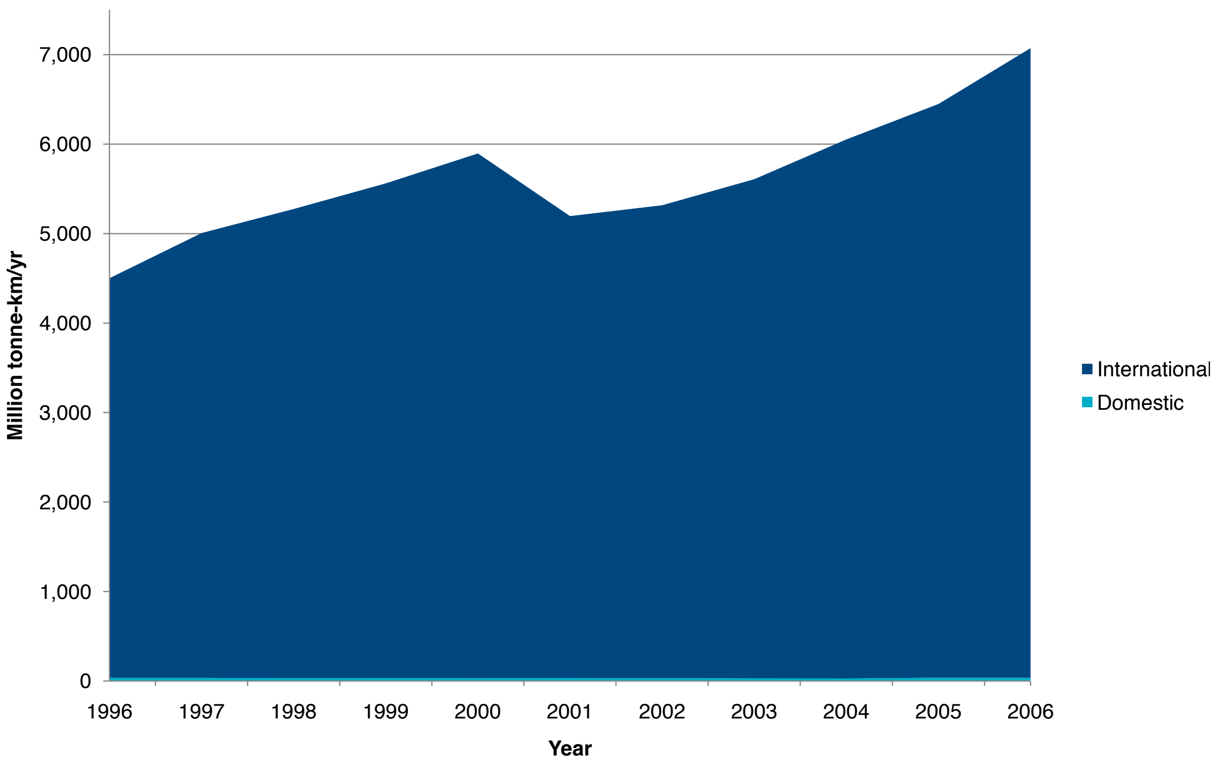
Source: IPCC. (2007) WG3 AR4, Fig. 5.6
Note: This figure shows how the CONSAVE scenarios (ULS, RPP, FW and DtE) fall within the range of projections cited by the IPCC.

Figure 8.4 UK passenger demand for UK airlines during 1996-2006



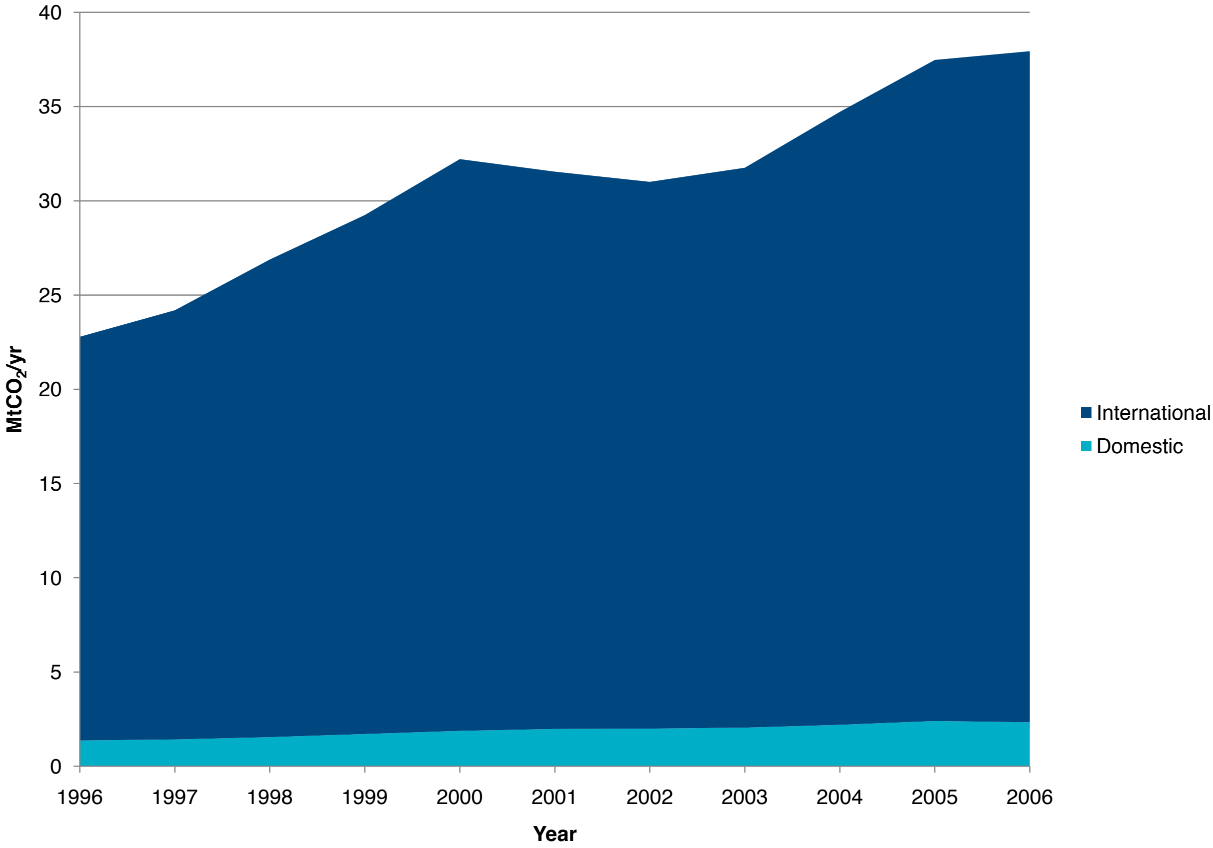
Source: DfT. (2007) *Transport Statistics Great Britain*

Figure 8.5 UK freight demand for UK airlines during 1996-2006



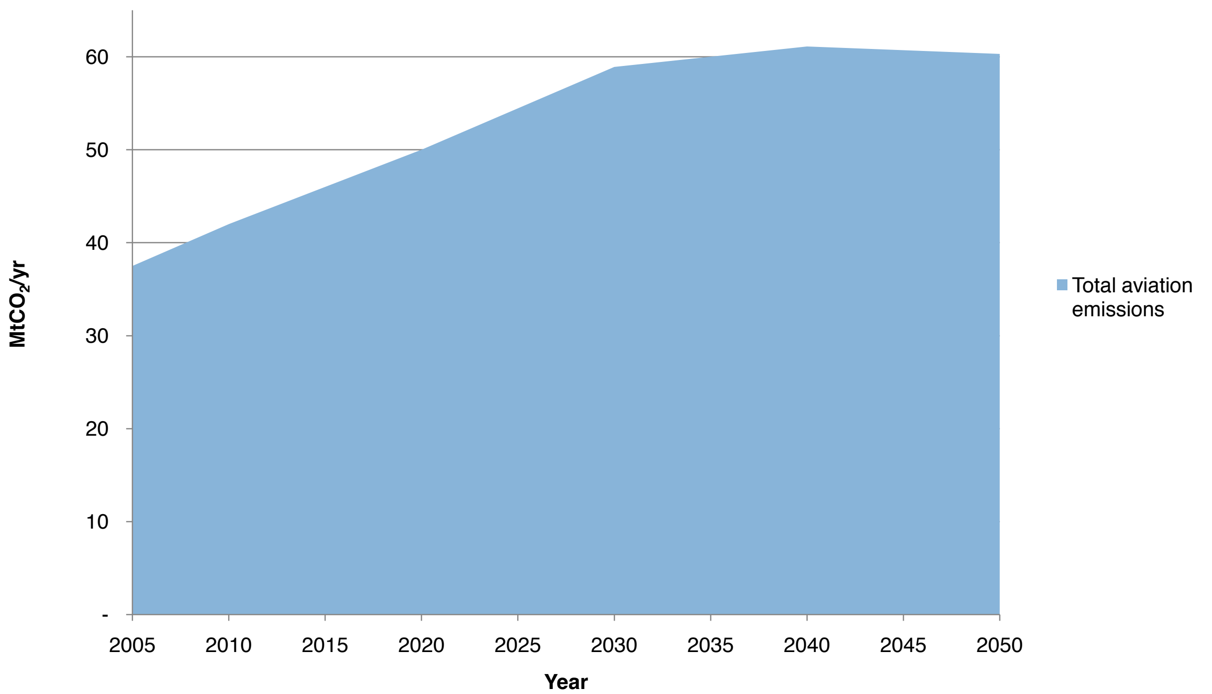
Source: DfT. (2007) *Transport Statistics Great Britain*
Note: Domestic freight demand is only 0.5% of the UK total in 2006.

Figure 8.6 UK CO_2 emissions from aviation during 1996-2006



Source: Defra statistics. (2008)

Figure 8.7 DfT projections of CO_2 emissions from UK aviation (central scenario)



Source: DfT. (2007) *UK Air Passenger Demand and CO_2 Forecasts*

2. INTERNATIONAL AVIATION: SUPPLY SIDE ABATEMENT OPPORTUNITIES

The Committee commissioned QinetiQ to conduct a preliminary review of present and future possible technological options to reduce emissions. Their analysis takes into account, but is not limited to, the efficiency goals that were voluntarily set under the Advisory Council for Aeronautics Research in Europe (ACARE) targets.

This analysis illustrates that evolutionary technological developments and changes in operational practice have the potential to improve aviation fuel efficiency. These developments are however included in 1.5% per annum efficiency improvements assumed in the global emissions forecast, and do not therefore offer additional potential. They imply that a new production aircraft in 2025 flying in an improved operational environment could be 40-50% more fuel efficient compared to a 2006 new production aircraft flying in a 2006 operational environment.

More radical changes (not included in the emissions forecast) to aviation technologies, e.g. Blended Wing Bodied aircraft, are likely to be more expensive, require changes to infrastructure and may not lead to significant additional emissions reduction. New fuel sources, in particular biofuels, may have a significant role to play in reducing life-cycle emissions in the long term, although their full climate impact would need to be considered.

Improving fuel efficiency: There are significant theoretical opportunities to improve aviation fuel efficiency without changing the fuel source. But the limits to what is economically, and indeed technically, feasible still imply major increases in emissions if demand grows in line with projections.

- **Technological possibility:** QinetiQ's report on technological possibilities for the CCC sets out four categories of change and by 2025:
  - Evolutionary changes in airframe technology could conceivably deliver 20-30% improvement in the efficiency of new aircraft coming into service relative to an average new production aircraft in 2006 (Table 8.4).
  - Evolutionary changes in engine technology could deliver another 15-20% improvement relative to an average new production aircraft in 2006 (Table 8.5). The changes above are not fully additive. Taken together they could yield a 35-45% improvement.
  - Changes in the efficiency of aircraft operations might conceivably deliver a 10-15% improvement (Table 8.6). Technical and operational changes together could result in a new production aircraft in 2025 operating in an improved operating environment being 40-50% more fuel efficient compared to a 2006 new production aircraft flying in a 2006 operational environment.
  - More radical long-term technological options might be applicable in the long term, such as blended wing bodied aircraft or distributed engines, but significant barriers exist in some cases.
- **Industry targets:** These estimates are broadly in line with the ACARE efficiency targets, to have at least one aircraft in service by 2020 which produces 50% less CO_2 per passenger-km compared to a benchmark civil aircraft in 2000.

- **Realistic and cost-effective abatement:** Estimates are complex for the following three reasons:
  - The pace at which average fleet fuel efficiency improves will be driven by investment cycles. These tend to be long – up to 55 years[2] – and there is limited scope to retrofit new technologies to existing aircraft. Improvements in fleet fuel efficiency will therefore lag improvements to new aircraft as the global fleet could take several decades to turnover.
  - Whilst estimates and targets suggest significant potential to drive efficiency improvement, it is likely that many of these improvements are already factored into projections of aviation emissions.
  - Improved efficiency of individual aircraft, particularly from operations, may lead to rebound effects, whereby reduced delays and stacking encourage more demand.
  - Work on assessing the cost-effectiveness of abatement opportunities is less developed than for the other sectors of the economy considered in chapters 5 to 7: *Decarbonising electricity generation; Energy use in buildings and industry; Reducing domestic transport emissions*.

Nevertheless, the IEA's BLUE Map scenario, which assumes a carbon price of at least US\$200/tCO_2 in 2050, forecasts abatement uptake that would lead to a 42%[3] cut in aviation CO_2 emissions relative to baseline. However, this would still result in global aviation emissions exceeding 2 GtCO_2 in 2050.

Alternative fuel sources

The crucial requirement for aircraft flight is a fuel source with a very high energy density by weight and which performs at high operating altitudes. For this reason it is extremely unlikely that aviation can be decarbonised through the use of batteries, which Chapter 7 suggested may play a major role in surface transport. Even the most extremely optimistic projections for battery technology do not anticipate achieving more than a small fraction of the energy density by weight ratio of aviation kerosene. Decarbonisation of the aviation fuel source will therefore entail either biofuels or hydrogen.

- **Biofuels:** Biomass can be converted into hydrocarbons by the Fischer-Tropsch process and upgraded to jet fuel. The fuel could be used without significant modification to the existing fleet. This technology, however, is still at an early stage. The disadvantages are that biomass-to-liquid fuels can lead to direct competition for land with food and the cropland could lead to deforestation or losses in biodiversity. Future developments in biofuel are focused more on the introduction of novel feedstocks such as algae. IATA estimate that later generations of biofuels could potentially reduce aviation emissions by 60-100% on a life-cycle basis.

- **Hydrogen:** Compared to kerosene, hydrogen offers a high energy content per unit mass, around 2.8 times, but liquid hydrogen requires four times the size of fuel tank to carry the same energy. This requires a bulkier and longer aerodynamic shape that will require major aircraft redesign. The main emission from hydrogen combustion is water with some emissions of NO_X. The higher water content of the exhaust will cause contrails and cirrus cloud formation. This points to caution in the use of hydrogen before the climate impacts of hydrogen-powered aircraft are properly understood.

2 10 years for development and certification, 20 years from initial introduction to service to final production and a further 25 years of aircraft family operations until final retirement.

3 In addition to technological improvements this reduction includes significant uptake of biofuels, improvements in routing, load factor as well as modal shift. IEA (2008) *Energy Technology Perspectives.* Paris, IEA.

Overall, a combination of fuel efficiency improvements and new fuel sources could significantly reduce aviation emissions, if appropriate policies and incentives are in place. But the likely growth in demand, the limits to feasible fuel efficiency improvement, and the more limited set of fuel decarbonisation options than are available in surface transport, make it likely that aviation emissions will continue to grow significantly unless demand is constrained, and that by 2050 they will account for a very significant proportion of the appropriate target for total global emissions.

Table 8.4 Summary and combination of evolutionary airframe improvements

Technology	Potential Aircraft CO_2 improvement	Earliest Availability	Retro-fit?	Key Technical Barriers
Winglets	1-2%	Now	Y	New – none Retrofit benefit is application dependent, leasing
Riblets	1-2%	2015-2020	Y	New – dev and certification Retrofit is application dependent, leasing
Laminar Flow (wings)	10-20%	Now-2020 Note 2	N	Manufacturing costs, maintenance costs Note 3
Laminar Flow (Nacelles)	1%	Now	Y	As Laminar flow wings but with less significance.
Lighter Materials (Composites)	10-20% Note 1	Now	N	Certification, manufacturing, repair, recycling
Active Airframe Health Monitoring	Up to 12%	2015-2025	N	Development test and evaluation costs, certification.
AVG New Production	**20-30%**	**By 2025**		
Retrofit	2-5%			

Source: QinetiQ. (2008) Aviation CO_2 *Emissions Abatement Potential from Technology Innovation*

Note 1: Generalised composite figures indicate a 10% reduction in fuselage and wing mass, with potential weight saving in the primary structure overall (including fuselage and wing) of no more than 25% and not more than 15% in the secondary structure, in commercial aircraft. Typically a 25% decrease in a/c weight gives ~10-15% savings in fuel usage, hence 25-40% reduction may result in 10-24% saving in fuel, this is conservatively expressed as 10-20%.

Note 2: Hybrid laminar flow control was previously demonstrated on a B757 aicraft in 1991, technically this could be implemented today.

Note 3: Increased sensitivities to surface imperfections, dirt/bugs/damage etc, lead to increased manufacturing and maintenance costs.

Table 8.5 Summary and combination of evolutionary engine improvements

Technology	Potential Aircraft CO_2 improvement	Earliest Availability	Retrofit?	Key Barriers
OPR, Materials, Cooling	3-5%	Now-2025	Y	None
Compressor and Turbine Aero	3-5%	Now-2025	Y	None
Cycle (GTF/UHB) Note	8-10%	2013-2025	N	Dev risk for larger gearboxes
AVG New Production	**15-20%**	**By 2025**		
Retrofit by Module Replacement	*0.5-1%*	*Now*		
Retrofit by new engine to 10 year old airframe	*5-7.5%*	*Now*		

Source: QinetiQ. (2008) *Aviation CO_2 Emissions Abatement Potential from Technology Innovation*

Note: GTF/UHB – Geared turbofan for lower thrust, Ultra high bypass for larger types.

Table 8.6 Summary and combination of operational/ATM improvements

Technology	Potential Aircraft CO_2 improvement	Earliest Availability	Retro-fit?	Key Barriers
Operations				
Ground towing	Up to 2%	2010s	N	Aircraft design, airport capacity
(Stop) Tankering	0.5%	Now	Y	Turn round time
Cabin dead weight reduction	<1%	Now	Y	Brand image, public expectations
Formation flight	1%	2020s	N	Coordination, risk
Optimum stage length	Up to 7%	2015-2040	N	New fleet , extended journey time, more airports, increased LTO risk and noise
Load factor maximisation	9% Max 3-6% feasible	Now	Y	Timetabling, frequency
Point-to-point	Possibly up to 5%	2015-2035	N	Smaller planes, airport size shift, route frequency
Air Traffic Management				
System delays and imperfect trajectories	3-8%	2020	N	System improvements already funded in parallel with capacity increase research
Total Improvement	**10-15%**	**2025**		
	Up to 25%	**2040**		Total aircraft and route redesign
Retrofit	4%			

Source: QinetiQ. (2008) *Aviation CO_2 Emissions Abatement Potential from Technology Innovation*

3. INTERNATIONAL AVIATION: APPROPRIATE POLICY LEVERS

Given the strong projected growth of aviation emissions, it is essential that aviation is covered by a policy framework which (i) faces aviation with an appropriate cost of carbon so as to provide an incentive both for supply side abatement and for demand constraint[4] and (ii) ensures that the total level of emissions (from aviation plus all other sectors) is reduced in line with appropriate scientific targets. There are few impediments to applying this framework at a European level, as now planned under the EU ETS. That framework, and any subsequent binding global agreement to cap emissions, is likely in the long term to drive demand side constraint as well as efficiency improvements.

Aviation within the EU ETS
In October 2008, after some 18 months of negotiations, EU Ministers signed off the deal to include all aviation, international and domestic, in the EU ETS. All flights (both domestic and international) will be included in the EU ETS from 2012. This is an appropriate and essential policy, which will ensure appropriate abatement provided that the total EU ETS cap declines over the long term (i.e. beyond 2020) in line with climate science objectives, whatever the 'business as usual' projections for specific sectors. Including aviation in the EU ETS is a major step forward and provides some pressure for abatement and/or demand reduction, but will not encompass non-price policy levers such as decisions over air-traffic control and infrastructure.

- Leakage concerns regarding inclusion of aviation in EU ETS are likely to be far less pronounced than for some of the industries (e.g. iron and steel) we consider in Chapter 11: *Economic costs and fiscal implications*. Aviation is an international industry, but production cannot be shifted to another country: steel consumed in Europe can be manufactured in Europe or China, but a flight from New York to London cannot be produced elsewhere. Whilst there could be some change in hubbing due to the existence of a carbon price for aviation in Europe, which is most likely to affect non-EU to non-EU routes, this is likely to be of a small order of magnitude.

- Aviation will initially be included in an EU ETS system with a specific allocation, some of which will be allocated to airlines and some auctioned. The total allocation for airlines administered by a Member State will be calculated and a percentage (15% in 2012, then 15% 2013-2020 unless changed by the 2020 package negotiation) top-sliced for auction. However, the Committee agrees with the European Commission's desire for a move towards 100% auctioning of allowances for aviation by 2020. The aviation cap will be based on an average of the emission in the years 2004 to 2006, with 97% of that baseline in the first year 2012 and 95% post, unless the percentage reduction is changed as part of the general review of the ETS. Including aviation effectively adds to the total emissions cap within EU ETS, and results in a percentage rate of reduction in the total which is slightly less than for all covered sectors excluding aviation. The total EU ETS cap, including aviation, has however been set so as to be broadly compatible with the EU's 20/30% GHG targets (Figure 8.8).

- Looking beyond 2020, and assuming that by then 100% auctioning is in place for all sectors (other than those where legitimate competitiveness concerns exist), there will cease to be a specific aviation sector allocation, and what will matter will be simply the overall EU ETS cap. It is essential that this reduces at an overall rate consistent with climate objectives, creating a discipline which ensures that any shortfalls in reduction rate in difficult to reduce sectors (such as aviation) are offset by more rapid reductions elsewhere.

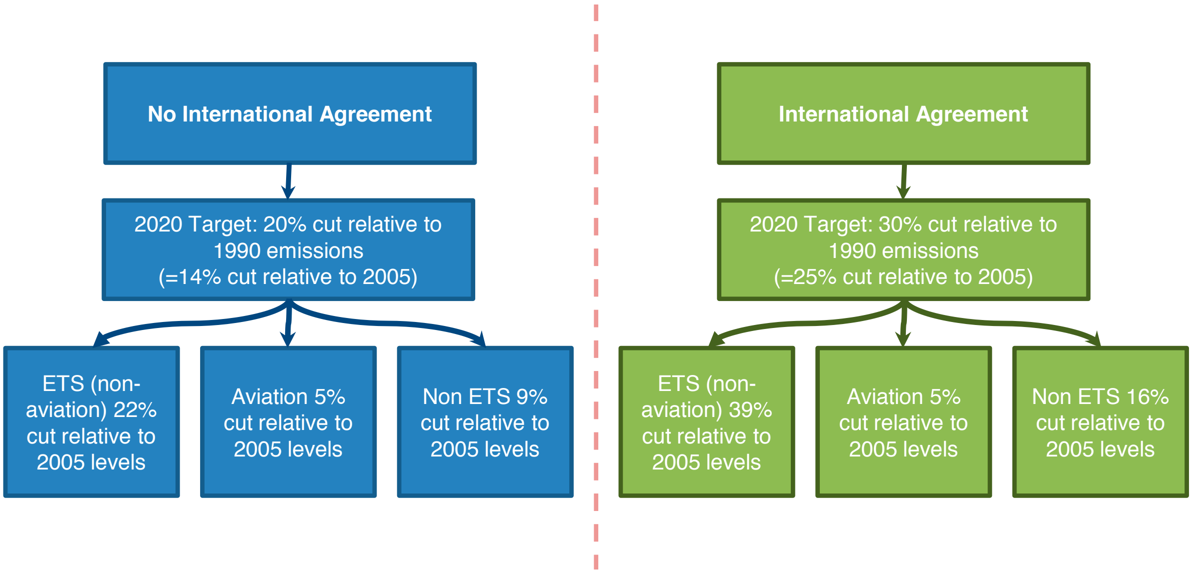
4 The extent of demand reduction depends on the carbon price and the extent to which the extra cost is passed through to customers in the form of higher fares. The extent of pass through has been widely debated and we make no judgement about its extent. Suffice it to say that the greater the potential for pass through the less supply side abatement is necessary and vice-versa.

Aviation demand within a European or global system over the long-term

The ideal long-term solution (which will be debated at Copenhagen) would entail caps applying to all countries and sectors, with international trading to allow the achievement of lowest-cost abatement. It is likely that within such a system, aviation emissions would continue to grow as a percentage of total global emissions, given the greater difficulty of achieving abatement in this sector. As the carbon price grew in line with the expectations set out in Chapter 2: *Meeting a 2050 target*, possibly reaching several hundred US$/$tCO_2$ by mid century, this would almost certainly result not only in the intensification of supply side abatement but also in demand constraint.

Even with such constraints, however, aviation is likely to grow as a percent of all emissions. This is not in itself undesirable: in a carbon-constrained world fossil fuels should be used in those applications where alternatives are least available. But it does reinforce the importance of ensuring that aviation emissions are included within overall caps which decline in line with climate science requirements.

Figure 8.8 EU 2020 emissions caps, with or without international agreement on emissions reduction



Source: CCC calculations. (2008)

4. INTERNATIONAL AVIATION AND THE UK NATIONAL BUDGET

Including international aviation in budgets is not essential to achieve required objectives

- As Europe's share of international aviation emissions is included within the EU ETS, with a total cap (aviation plus other sectors) which is consistent with climate objectives, there is no necessity to include international aviation emissions within the UK national budget. Aviation will be subject to a carbon price which encourages supply side abatement and demand constraint: and growth in Europe's aviation emissions will have to be offset by more rapid reductions in other sectors within Europe.

- And the UK carbon budget can be designed to take account of a reasonable estimate of the UK's international aviation emissions and their likely growth even if international aviation emissions are formally excluded from the budget. In the calculations of an appropriate UK budget presented in Chapter 3: *The first three budgets* we started with the EU's 20% and 30% GHG targets. The UK's share of these targets account for international aviation because the EU targets include international aviation. Our carbon budget proposals in Chapter 3, which are based on the UK's share of the EU's targets, are more ambitious than they would otherwise be if aviation were not included in the EU framework.

But inclusion is appropriate unless practical difficulties are severe

Clearly, however, even if it is **not essential** to explicitly include international aviation in the UK budget, it might be desirable for completeness, and to signal the importance of aviation within the overall climate mitigation strategy. But there are practical complexities which argue against inclusion: these relate to the basis on which emissions would be allocated to the UK national budget, and whether these should be the same for the budget as they are within the EU ETS.

- The practical complexities relate entirely to the basis on which to allocate emissions to the UK level (e.g. should flights from UK to Spain be allocated half-and-half to the UK and Spain, or mainly to the UK since the predominant tourist flow is of UK citizens? And do passengers hubbing via Heathrow belong to the UK or to the ultimate destination country?). This difficulty of allocating international aviation emissions was noted early on by the UNFCCC. Following a preliminary assessment, a UNFCCC body (SBSTA) recommended that four allocation methodologies should be considered further (Table 8.3); these would each allocate around 8% of international aviation emissions to the UK. While, therefore, it is possible to debate the precise appropriate methodologies, the implication for figures that might be included within the budget would not be great.

- Within the EU ETS, however, a different methodology for 'allocating' to Member States (MS) is proposed. At the EU level emissions are calculated on a departures/arrivals basis and this is similar to one of the recommended methodologies above. The problem occurs, however, when disaggregating administration of operators to the MS level. The disaggregation to the MS level will be required until and unless it becomes acceptable for auction revenues to accrue to the European Union rather than to national governments. This is because there has to be a national government which conducts the auction and receives the auction revenue, and therefore a specification of which government each airline has to buy permits from in respect of which flights. Under current proposals, EU airlines are to be administered by the MS in which they are headquartered, with non-EU airlines to be administered by the MS which accounts for the largest proportion of their emissions. The details are yet to be finalised, but the UK could be responsible for between 50-70 $MtCO_2$ emissions.

- At the UK level, there are two allocations which are the most plausible: 1) administration under the EU ETS and 2) bunker fuel estimates. There would, however, be disadvantages to either approach:
  - The chosen EU level allocation is not demonstrably fair as a reflection of national responsibility (e.g. an American airline's flight from New York to Rome could be counted against the UK register just because an American airline has most of its EU operations in the UK). As a result, monitored achievement against budgets could be affected by changes in airline practice (for subsequent phases of the EU ETS scheme, administration could change e.g. non-EU airlines shift the bulk of their EU operations from London to Paris) in the absence of any underlying change in emissions. The indicator is potentially volatile making medium-term changes to the indicator difficult to interpret for policy and other purposes.
  - But an alternative, set as bunker fuels, although fairer, would result in a confusing disconnect between the UK's share of European emissions for national budget and for EU ETS purposes. Specifically, it would not be possible to reconcile a methodology based on, say, UK bunker fuel sales with data relating to surrender of EU ETS allowances to UK authorities, given that the latter would include a significant number of allowances relating to non-UK travel (i.e. from America to other countries in Europe) together with allowances relating to some arriving flights. This would undermine the principal benefit of including international aviation within UK budgets – namely greater transparency of international aviation emissions.

Recommendation on the balance of arguments

The arguments above may be summarised as follows:

- International aviation should be included in any national or international strategy to tackle climate change.

- It is included in the EU's 20% and 30% GHG targets, and therefore indirectly included in our budget proposals, which are based on these targets. It will also be capped through inclusion of aviation (both domestic and international) in the EU ETS.

- Ideally, for reasons of transparency international aviation would be explicitly included in the UK's carbon budgets. But in practice, there are complexities related to methodologies for allocating emissions to the UK which preclude inclusion.

Our recommendation is, therefore, that international aviation is accounted for, but not explicitly included in carbon budgets. But it is essential that trends in the UK's international aviation emissions are included in the UK's climate change strategy. We therefore recommend that the Committee reports annually on UK trends in international aviation emissions (using a range of appropriate methodologies), their climate impact, developments in, and the success of, abatement efforts and appropriate policy levers.

SECTION B: INTERNATIONAL SHIPPING

1. INTERNATIONAL SHIPPING: TRENDS AND PROJECTIONS

Estimates of total global shipping emissions are uncertain but a recent International Maritime Organisation (IMO) study[5] suggests they are around 1 $GtCO_2$ and exceed those for aviation. Forecast of shipping emissions suggest strong growth, and in 2050 they could account for between 15% and 30% of all CO_2 emissions permitted under our preferred global emission reduction scenarios set out in Chapter 1. Bringing international shipping emissions within the coverage of emissions reduction strategies is therefore essential.

- The latest estimates of global shipping emissions of CO_2 are roughly 1 $GtCO_2$, with around 80% of emissions coming from international shipping (Table 8.7). Therefore, shipping emissions are equivalent to about 3.3% of total global emissions of CO_2 (excluding those relating to land-use). However, the overall effect of shipping on the climate may differ from the impression given by these figures (Box 8.2).

CO_2 emissions from shipping are on a strongly rising trend due to gross tonnage of the world shipping growing rapidly, and freight tonne-miles also increasing as world trade volume growth significantly outstrips GDP growth (Figure 8.9).

- Looking forward, the latest range of projections of future emissions growth produced by industry experts suggest that emissions in 2050 could be in the 2.4 to 3.6 $GtCO_2$ range, even after taking into account a significant (one third to a half) efficiency improvement per tonne-km by 2050 (Figure 8.10). They would account for 15-30% of all CO_2 emissions permitted under our preferred global emissions reduction scenarios set out in Chapter 1.

- Allocating global shipping emissions to the national level is difficult and the allocation methodologies listed earlier in the chapter produce a far greater range of emission estimates than for aviation. On a bunker fuel sale basis, the UK was responsible for roughly 9 $MtCO_2$ in 2000 – of which two thirds is international (Figure 8.11). But on a freight tonne loaded basis, UK emissions could already be 17 $MtCO_2$, with a possible rise to 28 $MtCO_2$ by 2020, while the bunker fuel sales estimate could increase to 16 $MtCO_2$ over a comparable period (Table 8.8). Unlike with aviation, these uncertainties about fair allocation exist even at the European level, where 'sensible' estimates of the EU share of global shipping emissions in 2000 can vary from 120 $MtCO_2$ to 159 $MtCO_2$.

Despite the uncertainties, however, it is clear that, if unconstrained, shipping CO_2 emissions are likely to grow to reach significant proportions of UK and European CO_2 emissions implied by our preferred global emissions reduction scenarios set out in Chapter 1. It is therefore essential that they are covered by emission reduction strategies.

5 IMO MEPC. (2008) *Updated Study on Greenhouse Gas Emissions from Ships, Phase 1 report*, 58/4/INF.6

Table 8.7 Estimates of global shipping CO_2 emissions

Region	$MtCO_2$ (2007)
Global Domestic	176
Global International	843
Global Total	**1,019**

Source: IMO MEPC. (2008) *Updated Study on Greenhouse Gas Emissions From Ships, Phase 1 report*, 58/4/INF.6

Box 8.2 The current radiative effects of shipping

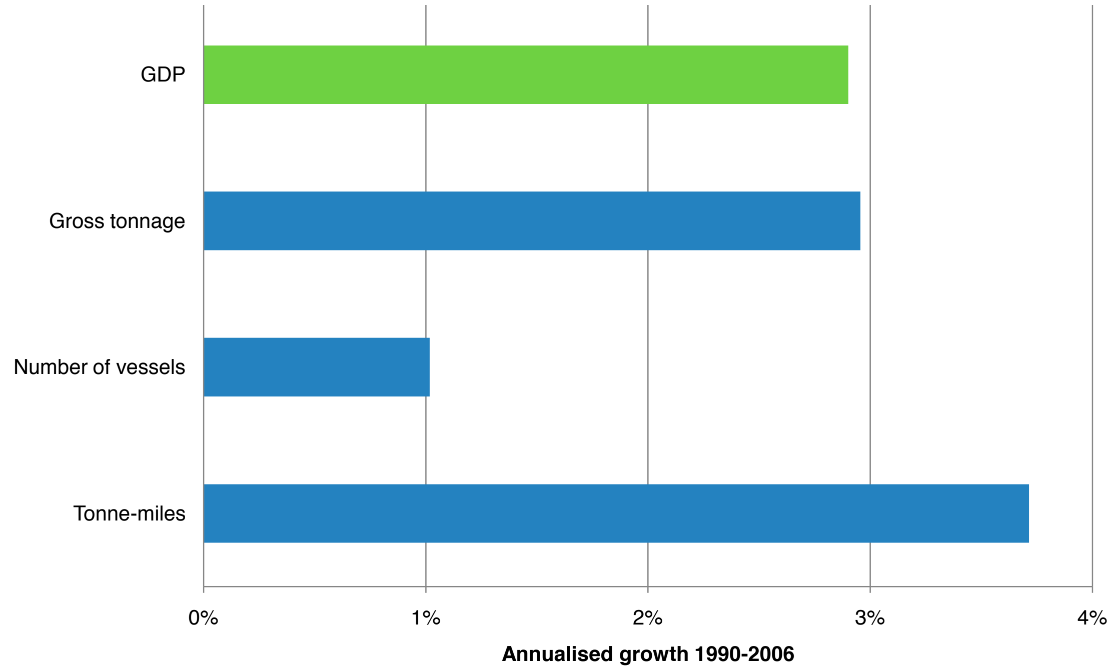
Like aviation, the total contribution of shipping to current radiative forcing of the climate system is made up in large part by emissions of aerosols and non-Kyoto GHGs.

Emissions of CO_2, NO_x, sulphate aerosol and soot are common to both aviation and shipping (see Box 8.1). For shipping however, there is a strong additional indirect effect of aerosol emissions. These small particles can seed the formation of low-level clouds, or alter cloud optical properties to make them reflect more of the sun's radiation, resulting in a significant negative radiative forcing (i.e. cooling). There is still, however, a very low level of scientific understanding about this indirect effect, because the way in which different kinds of aerosols help form cloud droplets is not well known, and the radiative properties of clouds are complex.

It is important to note that an overall negative radiative forcing does not mean the climate effects of shipping are benign. Radiative forcing shows the effect of emissions to date, but does not show that the warming effect of CO_2 will remain for many years longer than the aerosol cooling. The short-lived nature of sulphates also means that emissions do not become well mixed across the globe leading to large variations in regional radiative forcing. Furthermore, policies have been introduced to reduce sulphate emissions because of their impacts on human health and sensitive ecosystems, and this will lead to a steady increase in the overall warming from shipping.

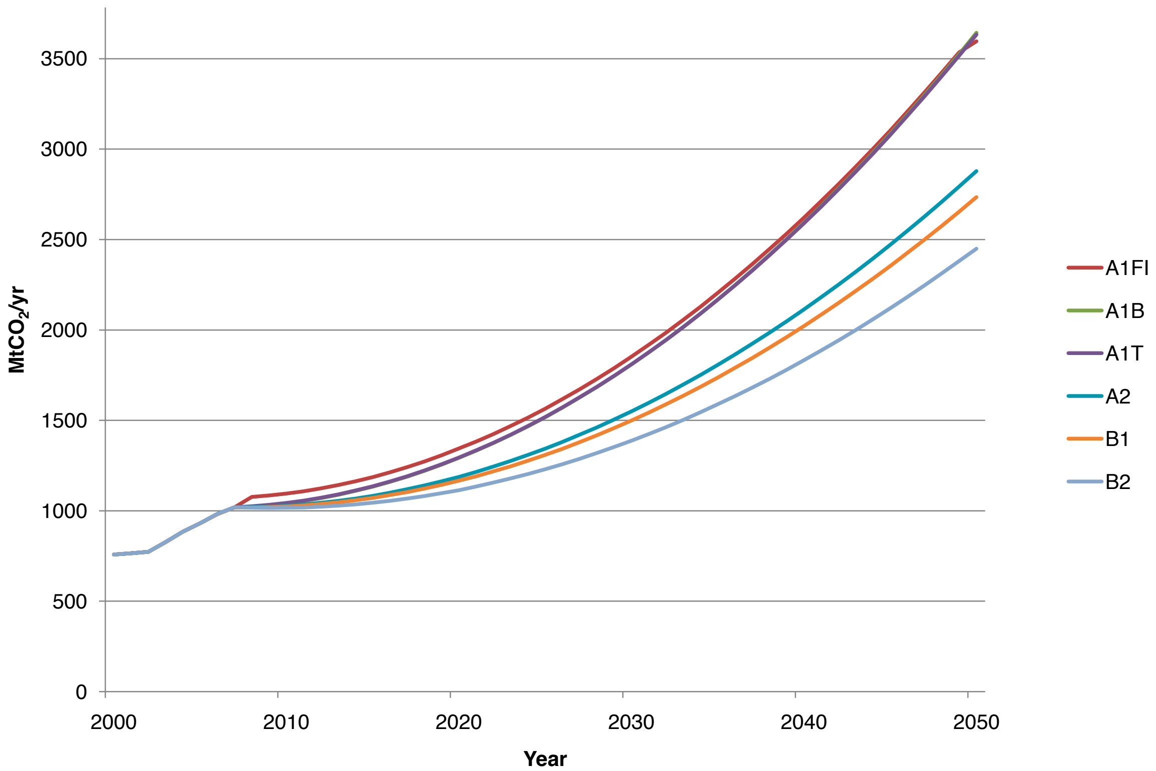
The issues discussed for aviation (see Box 8.1), about how to effectively compare these non-Kyoto radiative effects to the effect of CO_2, are relevant to shipping as well.

Figure 8.9 Annualised growth during 1990-2006 for global merchant shipping fleet, measured using a range of metrics and compared to global GDP growth



Source: ISL. (2007) *Shipping Statistics Yearbook*/UN Statistics Division. (2008)

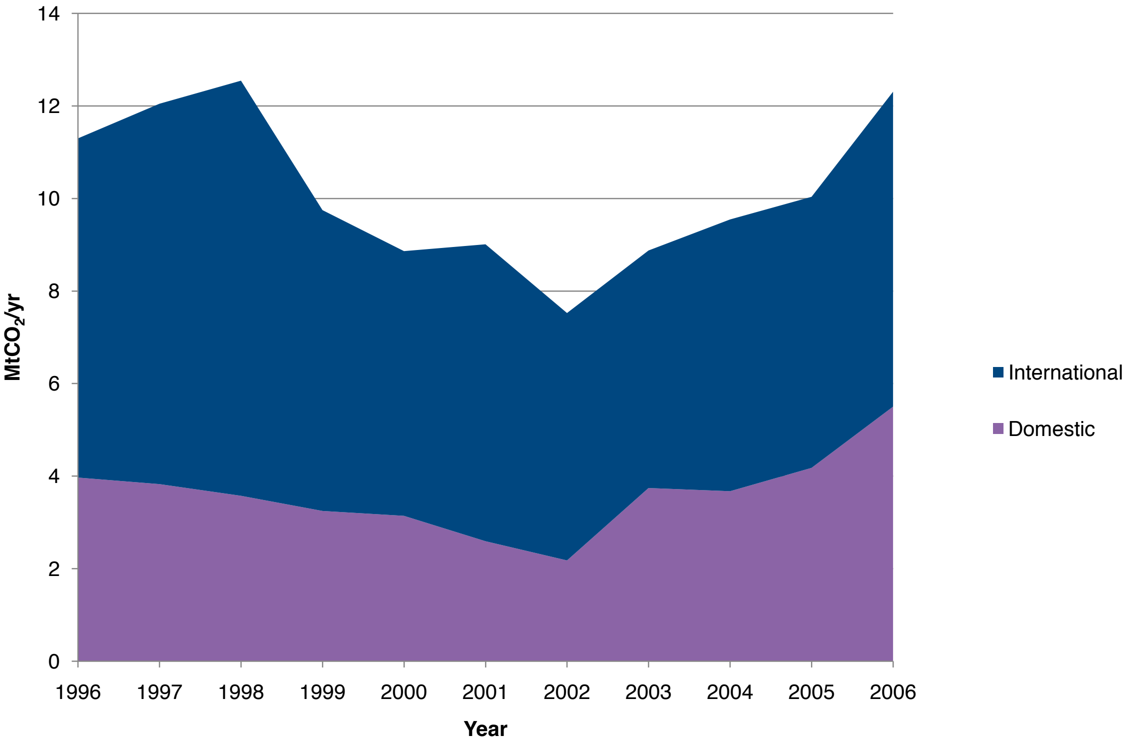
Figure 8.10 Projections of global CO_2 emissions (domestic and international) from ships



Source: MARINTEK. (2008) based on data from the *Updated Study on Greenhouse Gas Emissions From Ships, Phase 1 report*, IMO MEPC 58/4/INF.6.

Note: These projections (AIFI etc) are based on the six marker scenarios set out in the IPCC's Special Report on Emmissions Scenarios (SRES) in 2000.

Figure 8.11 UK CO_2 emissions from shipping during 1996-2006



Source: Defra statistics. (2008)

Table 8.8 European and UK allocation of total shipping CO_2 emissions (domestic + international)

Assignment methodology		Coverage	Method	EU27+2, $MtCO_2$		UK, $MtCO_2$	
				2000	2020	2000	2020
A1	Location of emissions: 12 mile zone	Europe	Vessel activity 500+GT	38.3	63.9	6.0	10.0
A2	Location of emissions: 200 mile zone	Europe	Vessel activity 500+GT	120.6	201.4	13.4	22.2
B	Flag of ship	Global	Vessel activity 500+GT	196.6	328.4	11.8	19.6
C	Bunker fuel sales	Global	Top-down	159.2	266.1	9.7	16.2
D	Reported bunker fuel consumption	Global	Top-down	158.9	265.5	9.5	15.9
E	In proportion to freight tonnes loaded	Europe	Top-down	120.6	201.4	16.6	27.7
F	In proportion to land based national emissions	Europe	Top-down	120.6	201.4	16.1	27.0
G	Country of departure/destination	Global	Vessel activity 500+GT	152.4	254.0	23.8	39.6

Source: Entec. (2005) *Service Contract on Ship Emissions: Assignment, Abatement and Market-based instruments*

2. INTERNATIONAL SHIPPING: SUPPLY SIDE ABATEMENT OPPORTUNITIES

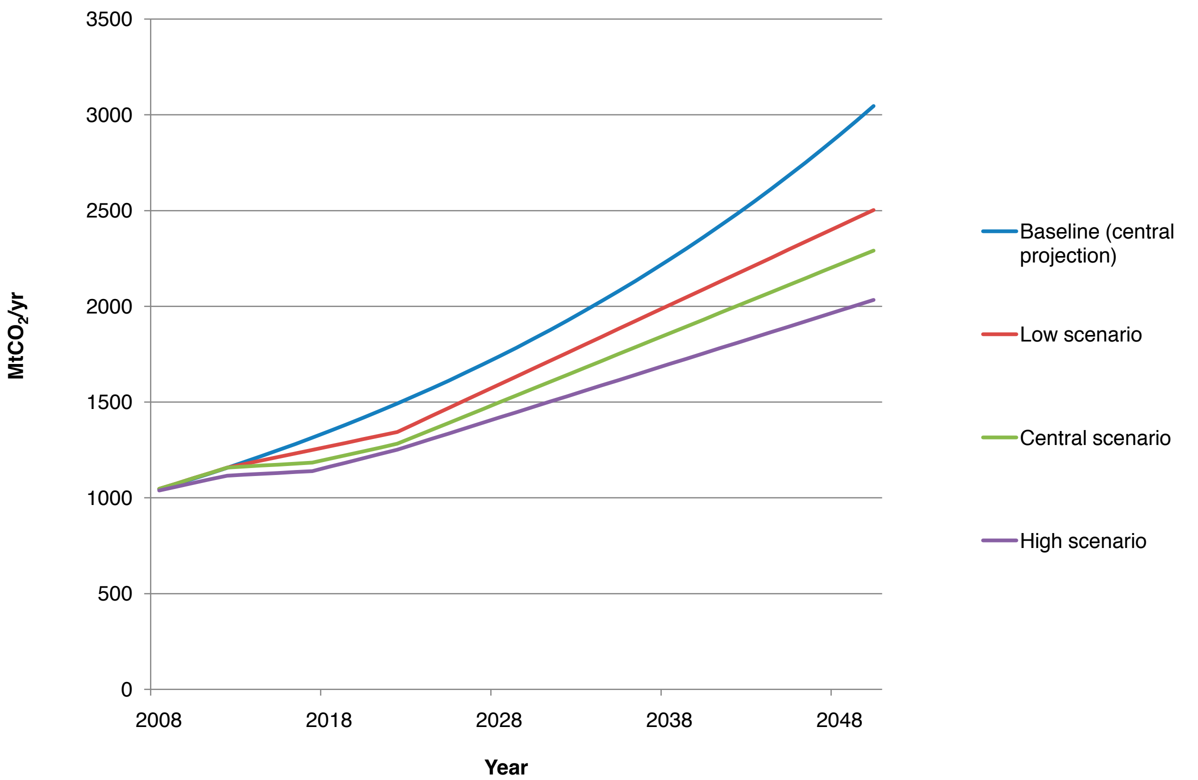
The Committee commissioned a consortium led by AEA[6] to conduct a review of present and future possible technological options to reduce emissions. Their analysis shows that there is a wide range of abatement options that could be applied to ships to reduce energy consumption and hence reduce CO_2. Implementation barriers vary by region and by ship category. In OECD countries the main barriers include the complex arrangements under which ships are owned/registered/operated, lack of information about abatement measures and their exact effects. Shortages of ship yard capacity and the long life of ships also limit uptake. Some of these barriers could be overcome through the introduction of a global carbon market. The analysis suggests that substantial emissions reduction, compared to a baseline projection, is possible for a range of carbon prices. However, even with a carbon price of 200 Euro/tCO_2 emitted global shipping emissions in 2050 could be twice current levels.

- **Technological possibility:** The AEA consortium's report on technical possibilities sets out three types of change:
  - Design improvements which include: optimisation of hull and propeller designs to reduce resistance and increase propulsive efficiency; optimisation of the superstructure for reduced air and wind resistance and recovering energy from the propeller.
  - Operational improvements which include: a shift to larger ships, or operating ships at slower speeds, optimal hull maintenance and upgrades to propellers and engines and improved on-board operations such as better energy management and voyage optimisation.
  - Alternative fuels and renewable energy: the most promising alternative fuels are liquefied natural gas and wind power although other sources of energy, such as solar energy and biofuels, have some potential to be used on ships. In terms of hydrogen, both AEA and the IEA note challenges with storing, handling and distributing hydrogen. In the IEA's BLUE Map scenario out to 2050, international shipping is assumed to adopt alternative fuels produced from non-food biomass feedstocks rather than hydrogen.
- **Cost-effective abatement:** Estimates suggest that there is potential to reduce CO_2 emissions from existing ships by around 10% through operational measures and by retrofitting various technical measures, while a state-of-the-art ship built in 2008 could emit 27–32% fewer emissions compared to a baseline 2008 typical in-service ship. In the future a 2022 state-of-the-art ship might emit 32–35% fewer emissions than a 2008 typical in-service ship. The small differences between 2022 and 2008 state-of-the-art ships arises because most of the technologies are available now and only incremental improvements to these are expected over the next 15 years. However, by 2050 new ships might be emitting half as much CO_2 as current ships.
- **Limits to realistic potential:** The pace at which average fleet fuel efficiency improves depends on a range of factors. These include production bottlenecks–ship yards are currently operating at full capacity and they are reluctant to introduce design improvements on existing orders. This will lead to a delay in the diffusion of new technologies throughout the fleet. Furthermore ships are long-lived assets – with working lives of around 25 years – so the stock of ships changes very slowly. The implementation of some abatement options may also depend on the willingness of port authorities to change existing port infrastructure. A large number of ships are operated by an agent different from the owner and this may lead to difficulties if the owner invests in abatement technologies but is unable to recoup the costs of these from the ship user.

6 The consortium was made up of AEA, Entec, MARINTEK, CE Delft, Manchester Metropolitan University and Deutches Zentrum fur Luft and Raumfahrt.

- **Impact on global shipping emissions under different carbon price scenarios:** Some or all of these barriers might be overcome if there were a global carbon price. The Committee asked AEA to apply expert judgement to assess what level of abatement could hypothetically be achieved under three scenarios of a low, central and high-carbon price: 50, 100, and 200 Euro/tCO_2 emitted. They estimate that, by 2050, CO_2 emissions from domestic and international shipping could be 500 MtCO_2 below baseline with a carbon price of 50 Euro. In the high-carbon price scenario abatement rises to approximately 1,000 MtCO_2. It should be noted however that even in this scenario emissions in 2050 are twice current levels (Figure 8.12).

Figure 8.12 Global CO_2 emissions (domestic and international) under different carbon price scenarios



Source: AEA. (2008) *Greenhouse gas emissions from shipping: trends projections and abatement potential*

3. INTERNATIONAL SHIPPING: APPROPRIATE POLICY LEVERS

Given the strong projected growth of shipping emissions it is essential that shipping is covered by a policy framework which (i) faces shipping with an appropriate cost of carbon to provide an incentive both for supply side abatement and for demand constraint and (ii) ensures that the total level of emissions (shipping plus all other sectors) reduces in line with appropriate climate objectives. But unlike aviation, there could be significant difficulties in applying a carbon price based framework on an EU-only basis. The key policy priority should therefore be to achieve a global sectoral agreement that would contain shipping emissions, with an EU-only approach as a second best solution.

- International shipping traffic and bunkering patterns are different from those of international aviation. Flights arriving in Europe from the US do not stop off en-route: ships arriving in Europe from say the Far East may have called at numerous ports en-route, unloading some cargo and taking on new cargo. And while aircraft arriving in or departing from Europe on an intercontinental flight will almost always have to take on more fuel in Europe, ships can pick up bunker fuel outside Europe (e.g. in north Africa) sufficient to cover their journey into and out of Europe. In addition the structure of the shipping industry is more complex and fragmented than the aviation business, with a multiplicity of complex and changing relationships between ship owners, ship charterers, and ship managers.

- As a result, while the inclusion of international aviation in the EU ETS creates neither major administrative complexities nor the danger of significant 'carbon leakage', the inclusion of international shipping could create both. If carbon permits were allocated or auctioned on the basis of some measure of traffic volumes (e.g. freight tonne-km arrivals or departures) major administrative complexity would arise in estimating what proportion of a complex multi-stage journey into or out of Europe belonged to the European system. If, conversely, shipping were brought into the EU ETS on an 'upstream' basis, using the administratively straightforward measurement of bunker fuel sales, there would be dangers of possible total carbon leakage, with shipping companies bunkering to full capacity before the final leg of the journey into Europe.

- Given the importance of including international shipping in some way within the policy framework, these difficulties should not be seen as automatically ruling out any EU unilateral action if a global approach proves impossible. But they illustrate that shipping is one sector where a global sectoral deal would have huge advantages over a European unilateral approach. The IMO has been charged by the UN with developing a proposed global policy framework, and it looks likely that the European Commission will await the IMO's proposals due next year before taking substantive action at the regional level.

- The Committee believes that this is a sensible way to proceed given the inherent difficulties of designing a European unilateral approach. The ideal solution would be to achieve a global sectoral deal which included all of world shipping within a carbon emission cap regime. This is unlikely to be achieved rapidly but it may be possible to make some progress towards this ideal ahead of the wider agreement of comprehensive binding global caps on all economic activities. In the meantime, IMO proposals for benchmarking of technical potential (the Energy Efficiency Design Index) may eventually begin to drive abatement action, although these proposals have not been finalised.

- If an adequate global deal is not possible, the EU will need to consider the best approach for including shipping in the regional framework. It is possible that the most effective measure may be to include shipping in the EU ETS. However, a recent study[7] suggested two alternative policy options to reduce shipping emissions. The first was differentiation of harbour dues and the second was a requirement of ships calling at EU ports to meet a unitary CO_2 index limit value. Either of these approaches may provide a suitable alternative to inclusion of shipping in the EU ETS.

7 CE Delft. (2006) *Greenhouse Gas Emissions for Shipping and Implementation Guidance for the Marine Fuel Sulphur Directive*

4. INTERNATIONAL SHIPPING AND THE UK NATIONAL BUDGET

The potential problems identified above regarding inclusion of international shipping in EU ETS are magnified when considering potential inclusion in the UK framework. There would be significant administrative complexities, for example, from including international shipping in UK carbon budgets on the basis of traffic volumes. Inclusion on the basis of bunker fuels would be administratively simple, but it is not clear that this reflects the UK's international shipping activity. For example, UK international port traffic has risen 75% over the period 1980-2006, while international shipping emissions from bunkers have only grown 5% over the same period. This is mainly due to ships bunkering where fuel is cheapest and most convenient on their multi-stage journeys. For this reason, we recommend that international shipping emissions are not included in the UK's carbon budgets at the current time.

It is, however, essential that international shipping emissions are allowed for in the setting of the UK's carbon budgets. To the extent that these are not falling, for example, effort in other sectors should be higher to maintain an overall GHG emissions reduction target derived from a climate objective. But, whereas international aviation emissions are included in the EU's 20% and 30% GHG targets, international shipping emissions are not included. The implication is that international shipping emissions are not accounted for in our carbon budget proposals, which are derived from the EU's targets. This raises the question of whether the UK's carbon budgets should be adjusted unilaterally, or whether there should be a multilateral adjustment following inclusion of international shipping in the EU's GHG targets.

There are three key arguments against a unilateral adjustment of UK carbon budgets:

- It is not clear what methodology for estimating the UK's international shipping emissions should be used as the basis for such an adjustment.
- If the UK were to make a unilateral adjustment resulting in a tightening of carbon budgets, this could be offset by a relaxation of targets for other EU Member States that may ensue in negotiations over burden sharing of the 20% and 30% GHG targets. In this event, there would be a financial implication for the UK with no environmental benefit.
- More generally, if there were to be a positive environmental impact (i.e. if other Member States were not to relax targets in response to UK unilateral action), this would be small based on UK action alone. In order to leverage inclusion at the UK level, international shipping should be included at the EU level.

We therefore recommend that the UK should argue that the EU's 20% and 30% GHG targets should allow for a reasonable estimate of the trends in international shipping emissions. As a result of this, emissions reduction targets for other sectors and all Member States including the UK would become tighter, and UK carbon budgets would have to be adjusted to reflect this. International shipping emissions would then be treated in the same way as international aviation: not formally included in the budgets, but allowed for in setting budget targets. And as for international shipping, our recommendation is that the Committee should report annually on trends in the UK's international shipping emissions (using a variety of different measures), their climate impact, development in, and the success of, abatement efforts and appropriate policy levers.

CHAPTER 9:

NON-CO_2 GREENHOUSE GASES

The Government has asked us to recommend whether the UK's carbon budgets should be stated in terms of greenhouse gases (GHGs), rather than CO_2. Moving from CO_2 to GHG budgets would require adding an amount to reflect expected non-CO_2 emissions[1]. This chapter sets out our analysis of the case for and against setting budgets based on GHGs. It also considers abatement potential across the range of activities that produce non-CO_2 gases in the UK, namely agriculture, waste, industry and energy[2].

The main messages from this analysis are:

- We recommend that budgets should be set in GHGs rather than CO_2. This would control an important driver of climate change, and provide additional opportunities for meeting budgets. Although there would be complexities related to uncertainty over measurement of non-CO_2 emissions, in our view these are manageable. We therefore propose an Intended budget based on a GHG emissions reduction of 42% in 2020 relative to 1990. We also propose an Interim budget based on a 34% emissions reduction in 2020 to apply until a global deal to reduce emissions is agreed.

- Initial analysis suggests that there may be realistically achievable abatement potential of up to 15 $MtCO_2e$ in 2020, with significant opportunity for emissions reduction in agriculture and waste, and some opportunity for emissions reduction in forestry, industry and energy.

- We stress, however, that analysis of abatement options in agriculture is at a far earlier stage than analysis of other sectors, and that some of the abatement opportunities in agriculture raise issues (e.g. relating to animal welfare, or local environmental issues) on which there are a range of opinions. We also note that agriculture is a sector where there is no existing policy framework to deliver emissions reductions. We therefore plan to deepen our analysis of agriculture in subsequent reports and recommend that the Government should focus on developing a policy framework for this sector.

- We suggest that there is considerable uncertainty around realistically achievable non-CO_2 emissions reduction. For this reason, we recommend that non-CO_2 options should be developed as part of prudent budget management, rather than relied on as firm measures that will deliver budgets.

We set out our analysis in 6 sections:

1. Non-CO_2 emissions trends and projections
2. Arguments for and against setting budgets in GHGs rather than CO_2
3. Emissions from agriculture, land use, land use change and forestry
4. Emissions from waste
5. Non-CO_2 emissions from industry and energy
6. Restatement of carbon budgets in GHGs.

1 Where this chapter refers to non-CO_2 gases/emissions it refers specifically to non-CO_2 *greenhouse* gases/emissions as defined in the Kyoto basket. It does not refer to non-CO_2 gases that are not greenhouse gases (e.g. air pollutants such as SO_X and NO_X).

2 This chapter also covers land use, to reflect its close links to agriculture, although most of the associated emissions are actually CO_2.

1. NON-CO_2 EMISSIONS TRENDS AND PROJECTIONS

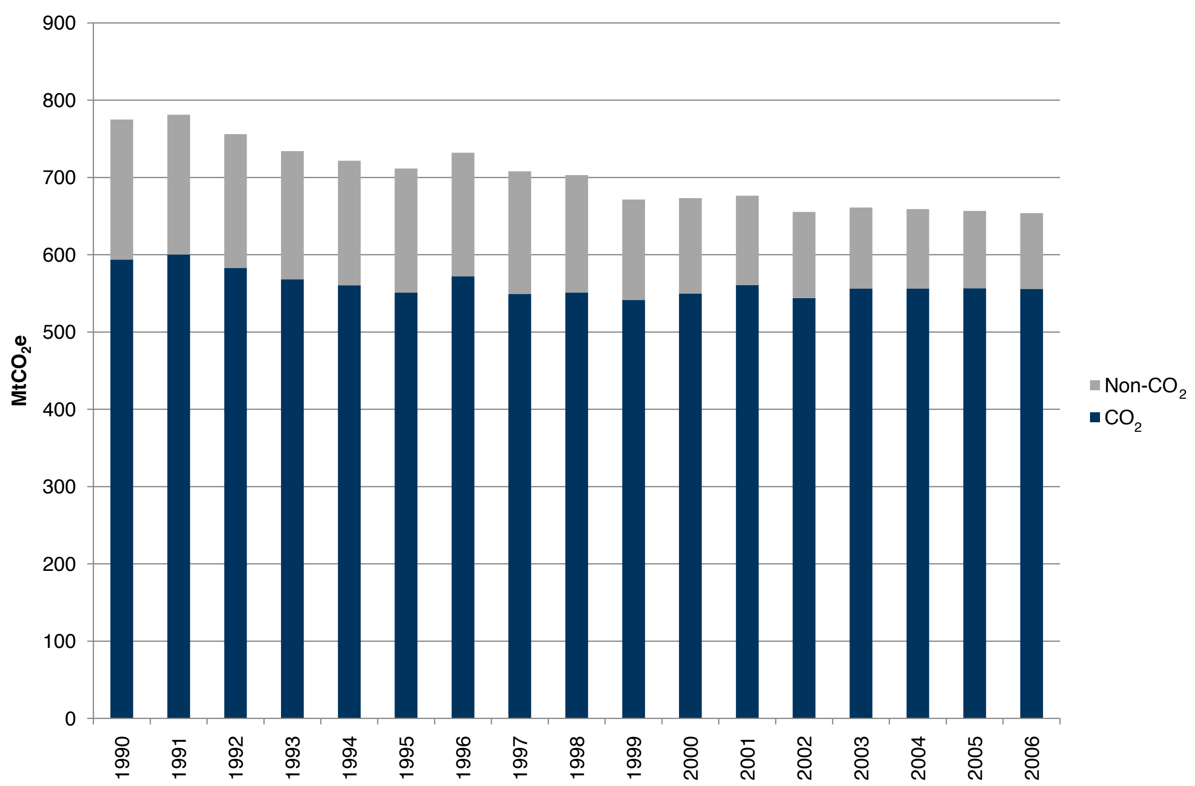
The non-CO_2 emissions that we cover in this chapter are those defined by the Kyoto basket of GHGs: nitrous oxide (N_2O), methane (CH_4) and certain fluorinated gases (F-gases: HFCs, PFCs, SF_6). The main non-CO_2 gases from an emissions perspective are methane and nitrous oxide, which together accounted for 89% of all non-CO_2 emissions in 2006. In turn, non-CO_2 emissions accounted for 15% of total GHG emissions in 2006.

Significant progress has been made in reducing non-CO_2 emissions over the period since 1990. The non-CO_2 emissions reduction achieved between 1990 and 2006 of 46% may be compared to CO_2 emissions reduction of 6% (Figure 9.1). In other words, non-CO_2 gases have contributed disproportionately to the overall GHG emissions reduction of 16% between 1990 and 2006.

The main driver of non-CO_2 emissions reduction has been reduction in methane emissions, which fell by 53% between 1990 and 2006 (Figure 9.2). For the other gases, emissions also decreased over this period, although to a lesser extent than methane.

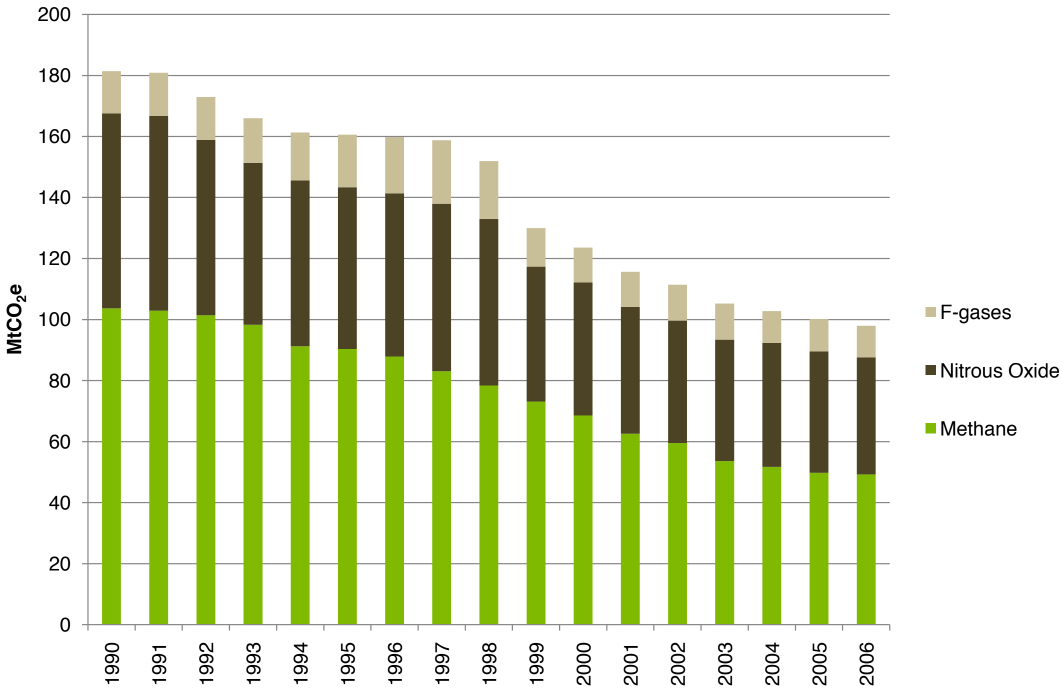
The main driver of methane emissions reduction has been falling emissions from waste in landfill (Figure 9.3). Other areas where emissions have fallen significantly are industrial processes, where reduction of 67% has been achieved through the introduction of low-carbon technologies to abate N_2O emissions, and fugitive emissions from the gas distribution network and coal mines, where emissions reduction of 68% has been achieved. In agriculture, emissions fell by 18% over the period 1990-2006.

Figure 9.1 Non-CO_2 emissions compared to CO_2 emissions, 1990-2006



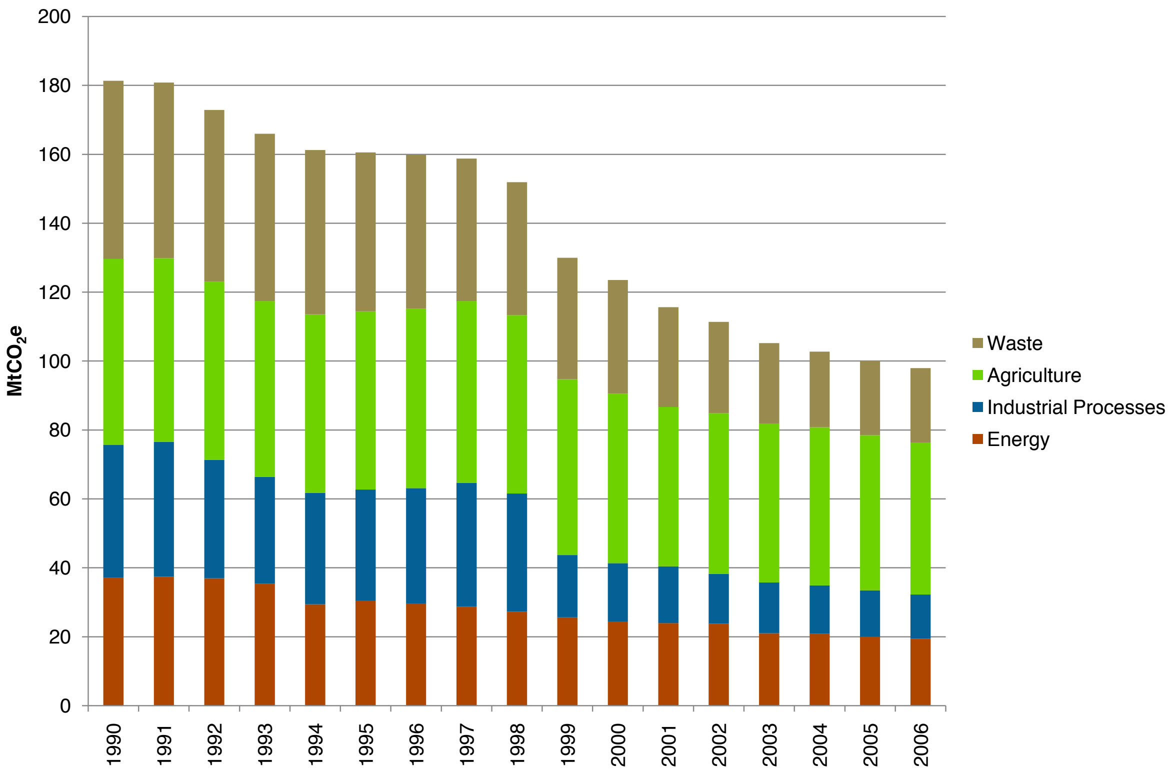
Source: National Atmospheric Emissions Inventory (NAEI) (2008)

Figure 9.2 Non-CO_2 emissions by gas, 1990-2006



Source: NAEI (2008)

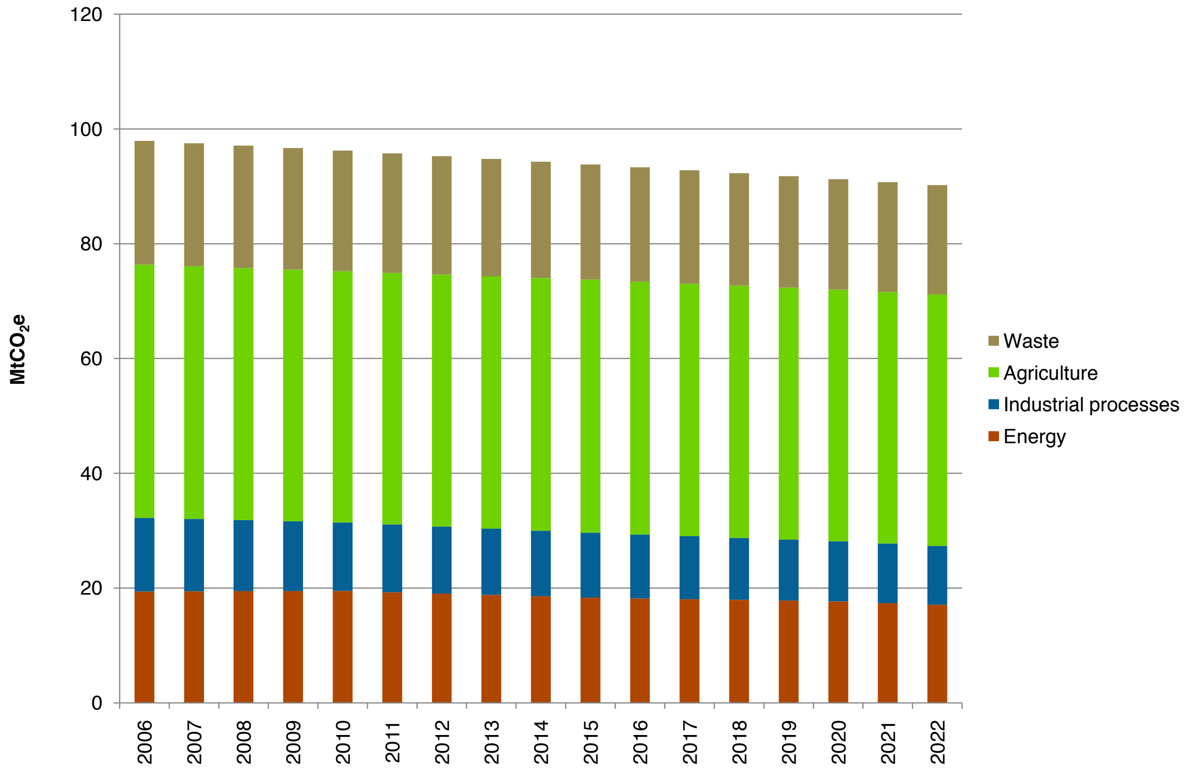
Figure 9.3 Non-CO_2 emissions by sector, 1990-2006



Source: NAEI (2008)

Going forward, Defra has developed scenarios for reference case non-CO_2 emissions projections over the period to 2022[3] (Figure 9.4). The central scenario projects that non-CO_2 emissions reduction over the period 1990-2020 will be 50%, including a 7% reduction projected between 2006-2020. The projections are based on assumptions about policies that are currently in place and emissions reductions that these are expected to deliver.

Figure 9.4 Non-CO_2 emissions projections by sector, 2006-2022



Source: Defra

The projections, however, do not build in the significant additional non-CO_2 abatement potential that our analysis suggests is available. Sections 3-5 set out this analysis in detail. But before moving to these sectoral assessments of abatement potential, we first consider whether the UK's emissions framework should be set in terms of GHGs rather than CO_2.

3 AEA (forthcoming), Projections of non-CO_2 Greenhouse Gases to 2050, *Defra project ED05478*.

2. ARGUMENTS FOR AND AGAINST SETTING BUDGETS IN GHGs RATHER THAN CO_2

Consideration of whether our budgets should be set in terms of GHGs rather than CO_2 involves weighing the benefits of having GHG budgets against complexities that this might involve relating to measurement.

Benefits of having GHG budgets: There are at least three reasons why it would make sense to base the UK budget framework on GHGs rather than CO_2:

- All GHGs, rather than just CO_2, cause climate change. Focusing on CO_2 only without action on non-CO_2 would not limit the relevant set of emissions. This is why our analysis and recommendations in Chapter 1: *Setting a 2050 target* were set out in terms of GHGs rather than CO_2. By extension, it would seem appropriate to set budgets in terms of GHGs.

- The international framework is based on a basket of six GHGs. This is true both of Kyoto, and the EU framework, where EU-wide targets and UK shares are in GHGs (e.g. the non-traded sector target for the UK includes agriculture, waste and other sources of non-CO_2 emissions). The UK's climate change strategy will have to deliver both domestic budgets and international targets, and would be better placed to do this where these share a common metric.

- For a given climate change goal, considering the full range of abatement options across CO_2 and non-CO_2 gases reduces costs and provides flexibility:
  - We will show below that there are cost-effective opportunities to reduce non-CO_2 emissions. Where these are part of the accounting framework, they can be substituted for more expensive CO_2 emissions reduction, thus reducing the cost of meeting a given GHG target/climate change goal.
  - From a risk management perspective, including non-CO_2 emissions provides an additional means for addressing potential shortfalls in CO_2 emissions reduction to meet a given GHG target.

Complexities related to including non-CO_2 gases: The question of whether we should set GHG or CO_2 budgets is complicated by the fact that it is difficult to measure non-CO_2 emissions accurately. Whereas we feel reasonably confident about what the level of CO_2 emissions actually is, there is more uncertainty regarding the level of non-CO_2 emissions.

- In principle, the process of measuring emissions requires measuring the levels of emissions-producing activities, and multiplying these by appropriate emissions factors.

- In the case of CO_2, good data is available on both the level of activity (e.g. consumption of fossil fuels) and related emissions factors (e.g. carbon content of oil, coal, gas, etc.).

- In the case of non-CO_2 gases, however, whilst we feel reasonably confident about the level of activity (e.g. we know how many livestock there are in the UK, and how much waste is landfilled), there is some uncertainty over what emissions factors should be applied to this. This occurs, for example, because we do not have good information about methane emissions from livestock (emissions here depend on specific diet, but we currently use generic emissions factors), or N_2O emissions from the application of fertiliser to soils (where the scientific process is not fully understood and is farm specific, but we do not have farm specific data).

There is an ongoing process to improve measurement of GHGs, which results in periodic updating of the UK's inventory (e.g. to reflect new estimates of emissions factors). Updating of the GHG inventory would have two possible implications if the budget were to be set in GHGs:

- Budget revisions would be required following updating of the inventory.
- More emissions reduction effort could be required to meet a given budget. This would be the case if an inventory update were to leave the budget unchanged but increase the actual level of GHG emissions.

Given that there is a process in place for revising budgets, we do not regard the first of these implications as a good reason not to have GHG budgets.

In principle, the second implication could make budget management more difficult. In practice, however, there are three reasons why this is unlikely to be the case:

- Whilst uncertainty over the level of GHG emissions in any year is considerably more than that for CO_2 emissions, there is less uncertainty over trend emissions.
  - Levels of uncertainty relating to CO_2 and GHG emissions in 2004 are 2% and 14% respectively[4].
  - Ranges for CO_2 and GHG emissions reduction over the period 1990-2004 are 3% to 8% and 11% to 18% respectively.
- The convention for inventory revisions is that any new methodologies are applied consistently over time (i.e. historically and going forward) to the extent possible. If this continues to be the case, the likelihood is that the difference between actual emissions and a budget based on reduction relative to emissions in a base year (e.g. 1990) would be small following any revision.
- To the extent that more emissions reduction effort would be required following a revision, this would be the case anyway in the EU context, since the EU targets are based on GHGs.

On balance, therefore, whilst we recognise that there is a challenging issue regarding measurement, we believe that this could be met through periodic revisions to GHG budgets, the implications of which should not be significant from a budget management perspective.

Recommendation and practicalities: We recommend that budgets are set in terms of GHGs, given the potential benefits that we have outlined, and our view that the complexities are manageable.

In order to operationalise this recommendation, there are issues relating to which GHGs should be included in budgets, and what measurement conventions should be used. In keeping with our analysis in Chapter 1, we propose that GHG budgets should be based on the Kyoto basket of GHGs, and that in converting non-CO_2 emissions to CO_2e it is appropriate to use 100 year Global Warming Potential (GWP), in keeping with the United Nations Framework Convention on Climate Change (UNFCCC) reporting convention[5]; Box 9.1 outlines some of the complexities involved with the choice of this metric. In addition, we propose that GHG budgets should be based on activity data and emissions factors used in the current UK inventory, subject to any future revisions.

4 As reported in the NAEI – 95% confidence interval ranges.
5 Specifically, we recommend that GWP from the Second Annual Report of the Intergovernmental Panel on Climate Change (IPCC) should be used, in keeping with international convention.

Box 9.1 Global Warming Potential as a metric for comparing greenhouse gas emissions

Different greenhouse gases have different characteristics, such as the length of time they reside in the atmosphere and the efficiency with which they trap heat. Various metrics have been proposed which attempt to capture these differences, allowing a comparison between the future climate effects of different GHG emissions. To be consistent with international reporting guidelines we use the 100-year Global Warming Potential (GWP) metric, with values taken from the IPCC's Second Assessment Report (see table below). For emission of an individual GHG, its GWP can be broadly defined as the resulting amount of heat trapped in the atmosphere over a 100-year period, relative to that trapped by the same mass of CO_2 emission. CO_2 equivalent (CO_2e) emissions are defined as the GWP value multiplied by the total mass of GHG emitted, so that 1 tonne of nitrous oxide corresponds to 310 tonnes CO_2e.

Table: 100-year GWPs for gases included in the Kyoto Protocol

Gas	**GWP_{100} (SAR)**	**GWP_{100} (AR4)**
Carbon dioxide (CO_2)	1	1
Methane (CH_4)	21	25
Nitrous oxide (N_2O)	310	298
Hydrofluorocarbons (HFCs)*	140 – 11,700	124 – 14,800
Perfluorocarbons (PFCs)*	6,500 – 9,200	7,390 – 12,200
Sulphur hexafluoride (SF_6)	23,900	22,800

Source: IPCC Second Assessment Report (SAR); IPCC Fourth Assessment Report (AR4)

*HFCs and PFCs are families of gases for which the range of individual GWPs are given.

The change in GWP values since the Second Assessment Report reflects the change in background atmospheric concentrations and increased scientific understanding. It is likely that international reporting guidelines will be updated to reflect these changes in the future. Such changes will have only a small effect on how challenging a given emissions reduction target is, whilst making abatements in certain gases (e.g. methane) slightly more attractive than current analysis suggests.

Whilst the GWP metric is simple and transparent, there has been debate as to whether it is the most appropriate metric for policy use. For example, the choice of a 100-year time horizon is somewhat arbitrary, chosen as a balance to capture both the potency of some short-lived gases and the very long lifetime of CO_2. A shorter time horizon would lend more weight to shorter-lived gases such as methane, and vice versa. Also, GWP focuses on heat trapped (or 'radiative forcing') rather than global temperature increase, and it is now thought that the relationship between radiative forcing and temperature may not be the same across GHGs. As a result other metrics such as the Global Temperature Potential (GTP) metric have been suggested[1], however the IPCC continues to recommend GWP as the best current metric for comparing the future climate effects of emissions of long-lived GHGs.

1 Shine et al, 2005, Alternatives to the global warming potential for comparing climate impacts of emissions of greenhouse gases, *Climatic Change*

At the end of this chapter, we therefore restate our carbon budget proposals (from Chapter 3: *Setting the first three budgets*) in terms of GHGs. Before doing this, however, we consider opportunities for reduction of non-CO_2 emissions that could potentially form important means for meeting and managing GHG budgets.

3. EMISSIONS FROM AGRICULTURE, LAND USE, LAND USE CHANGE AND FORESTRY

Having proposed that budgets be set in GHGs rather than CO_2, it becomes even more important to understand potential for non-CO_2 emissions reduction. We now consider abatement potential in agriculture, and move to a consideration of abatement potential in land use, land use change and forestry, hereinafter referred to as LULUCF.

We set our analysis out in four parts:

(iii) Background: sources of emissions, emissions trends and projections

(iv) Abatement potential

(v) Emissions reduction constraints and the policy framework

(vi) LULUCF.

(i) Background: sources of emissions, emissions trends and projections

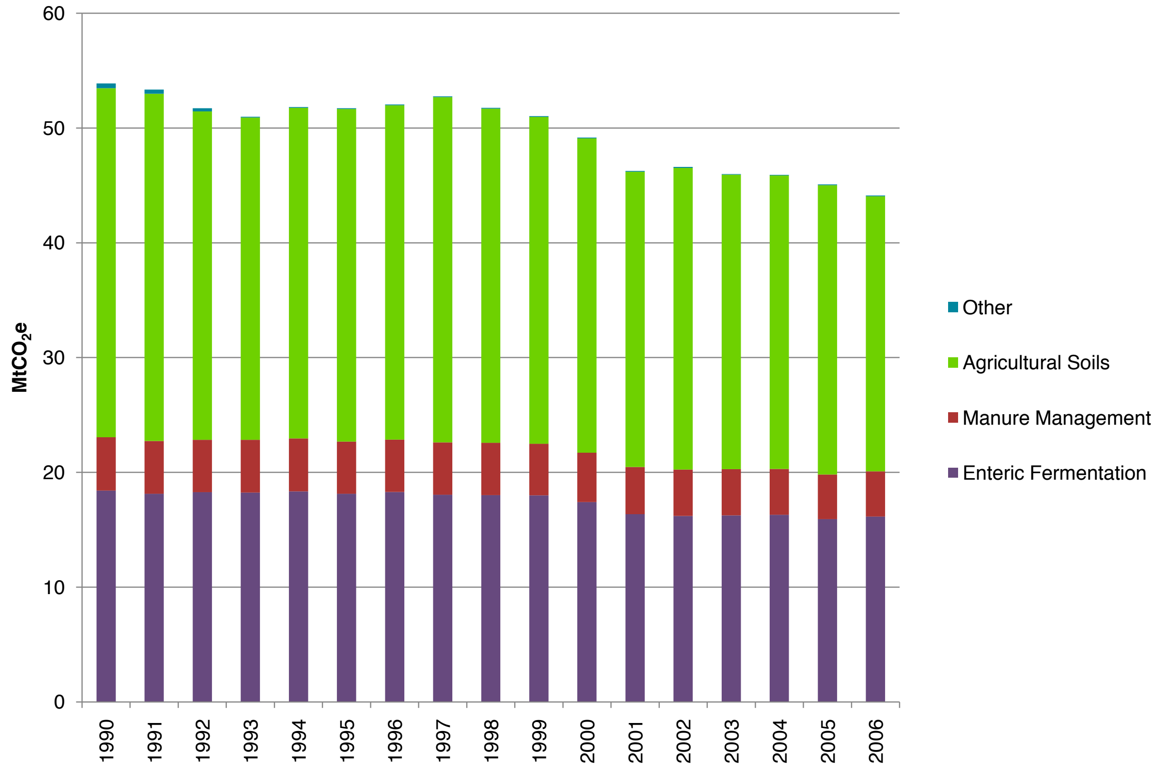
In 2006, non-CO_2 agriculture emissions accounted for 7% of UK GHG emissions, and 45% of all non-CO_2 emissions. They largely comprise emissions from the use of fertiliser on soil (54%), and enteric fermentation (digestive process of livestock) (37%). Remaining agriculture non-CO_2 emissions relate to manure management.

It is important to note that agriculture is also responsible for CO_2 emissions due, for example, to use of machinery, consumption of gas and electricity in buildings, etc. These are not considered further in this chapter, but are an area that we intend to return to in the future.

Emissions trends: Agricultural non-CO_2 emissions have decreased by 18% over the period 1990-2006, from 54 $MtCO_2e$ to 44 $MtCO_2e$ (Figure 9.5). This is a more modest decrease than most other non-CO_2 sectors, but it is more than has been achieved in CO_2 emissions reduction over the same period (6%). Emissions reduction in agriculture is largely attributable to decreasing livestock numbers as a result of Common Agricultural Policy (CAP) reform and reduced use of fertiliser.

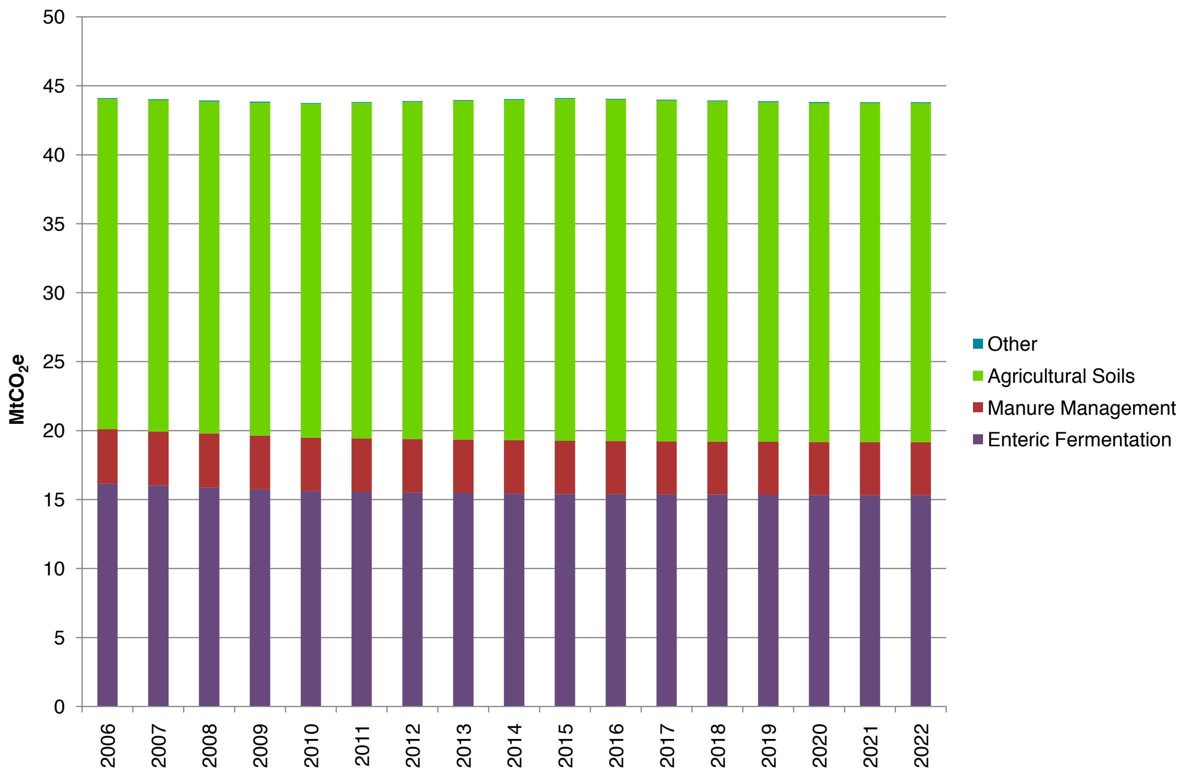
Emissions projections: Going forward, government projections assume that agricultural non-CO_2 emissions will fall by only a further 1%, such that the overall decrease for the period 1990-2020 will be 19% (Figure 9.6). The driver of emissions reduction in the government's projections is a further reduction in the number of livestock resulting from continuing CAP reform.

Figure 9.5 Agricultural non-CO_2 emissions by source, 1990-2006



Source: NAEI (2008)

Figure 9.6 Agricultural non-CO_2 emissions projections by source, 2006-2022



Source: Defra

(ii) Abatement potential

There are three main routes by which emissions can be reduced in the agriculture sector:

- Lifestyle change: less reliance on carbon intensive produce (e.g. beef)
- Changing farming practices
- Using new technology on farms to reduce emissions.

Lifestyle change may offer significant abatement opportunities, for example if diets were to shift towards less carbon intensive food products (see Box 9.2). The analysis that we have carried out, however, does not cover changes in demand. We recognise that this is an important area to consider going forward, and intend that it will form part of our future work programme.

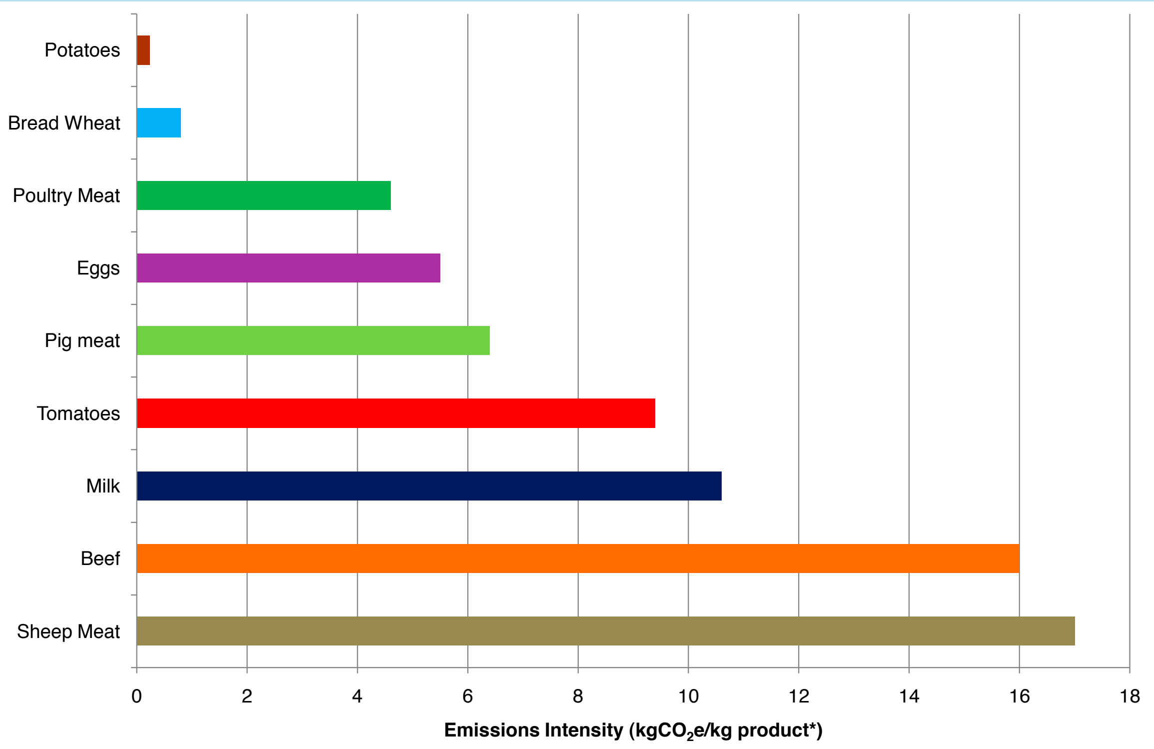
Our analysis focuses on changing farming practices and using new technologies as these relate to crops, soils and livestock. It is based on research that we commissioned from the Scottish Agricultural College. As part of the research, a marginal abatement cost curve (MACC) was constructed, providing assessments of potential emissions reduction and associated costs across a wide range of options. It includes scenarios for *technical* potential (i.e. the level of emissions reduction that would ensue if there were no barriers to unlocking potential) and for *realistic* potential (i.e. a judgement on the level of emissions that might ensue taking into account emissions reduction constraints and ways that these could be addressed). It is among the first MACCs developed for the agriculture sector and the results should be considered as tentative. It also has to be recognised that some of the options identified (e.g. in relation to plant additives and breeding approaches) might raise other issues. The analysis does however illustrate that there is significant potential in agriculture which merits further analysis.

Box 9.2 Abatement opportunity through changing diets

The different foods we eat are responsible for different levels of GHG emissions in their production. The figure below illustrates this based on a life-cycle analysis that accounts for emissions throughout the production stream, for example the emissions intensity for pig meat includes the emissions from fertiliser use in producing crops to feed the pigs.

Cattle and sheep are ruminant animals, able to feed on grass, which results in significant methane emissions from the digestive process. Tomato production entails emissions from energy used for heating and lighting to extend the growing season.

Figure: Estimated emissions intensities for different food products



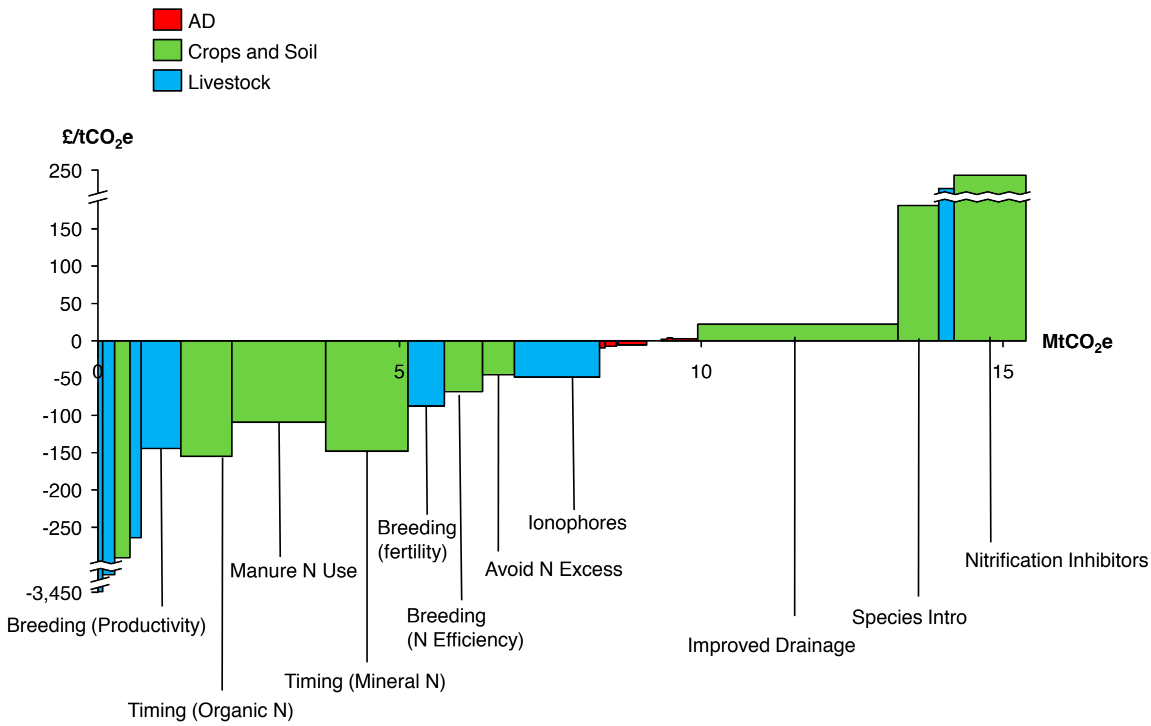
Source: Williams, A.G., Audsley, E. and Sandars, D.L. (2006) Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. *Defra Research Project IS0205.*
Note: * 1kg of product is assumed to be equivalent to 20 eggs or 10l of milk (about 1kg dry matter)

These different emissions intensities imply that there may be an abatement opportunity from shifting diets towards less carbon intensive food products. However, there are a number of complexities, including:

- Food products (and feed inputs) are both imported and exported, so any change in UK food consumption may not impact on UK food production, or therefore UK emissions
- Ruminants (cattle and sheep) have the important advantage of being able to use land unsuitable for arable crops
- Abatement options on the supply side could change these emissions intensities
- Each food product has different nutritional characteristics, so they cannot be treated as direct substitutes
- Consumers are likely to be resistant to changing their diets.

Technical potential: The MACC illustrated in Figure 9.7 suggests that there is around 13 $MtCO_2e$ of abatement potential available at a carbon price of up to £40/tCO_2e (our central carbon price estimate, see Chapter 4: *Carbon markets and carbon prices*), and much of which (around 9 $MtCO_2e$) is available at negative cost (i.e. farmers could potentially save money through implementing these measures).

Figure 9.7 Agriculture non-CO_2 MACC – maximum technical potential, 2020



Source: CCC modelling

Notes: N = Nitrogen, AD = anaerobic digestion
Measures do not appear in exact cost-effectiveness order due to interactions between options. More details and a full measures list is available in the accompanying technical papers.

The technical potential that we have identified at up to £40/tCO_2e comprises:

- 9 $MtCO_2e$ from measures that decrease N_2O emissions from crops and soils, including:
  - reducing fertiliser application where it is applied in excess
  - matching the timing of application with the time when the crop will make most use of it
  - using organic rather than synthetic fertiliser where possible
  - improving drainage of land
  - selectively breeding plants that need less fertiliser.
- 3 $MtCO_2e$ from measures that reduce methane emissions from livestock, including:
  - selecting animals with particular traits for breeding, in order to improve the efficiency of milk and beef production or fertility. The impact of selection both reduces the number of animals required to produce a fixed level of output, and decreases the finishing period of animals, therefore reducing emissions per unit of output.
  - increased use of additives named ionophores that increase productivity and decrease methane production. These are currently banned in the EU but are routinely used as growth promoters in some non-EU countries.
- 1 $MtCO_2e$ from the installation of anaerobic digestion plants (converting agricultural waste to renewable energy) either in a centralised location or on farm.

- **Realistic potential:** Scenarios for realistic potential exclude increased use of ionophores, and constrain remaining technical potential drawing on evidence about current compliance rates for a range of policies:

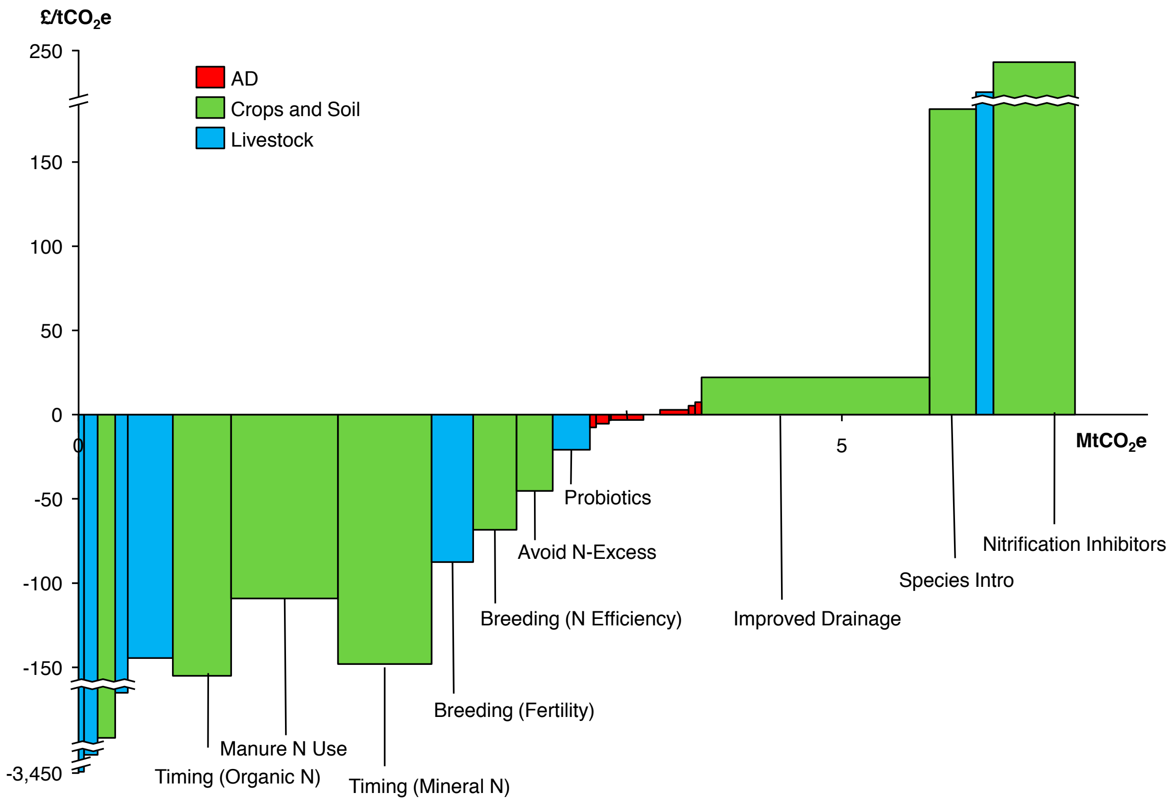
- The central feasible scenario models an incentive-based policy environment, characterised by taxes and subsidies or a cap and trade scheme. Uptake in this scenario is assumed to be 45% of technical potential.

- The low feasible scenario models a policy environment where initiatives are mainly voluntary. In this scenario, measures with negative costs are assumed to have 18% take up, whilst positive cost measures have a lower uptake of 7%.

- The high feasible scenario models a regulation-based policy environment. In this scenario, measures that are defined as easy to enforce are assumed to have an uptake of 92%, whereas measures that are defined to be more difficult to enforce are assumed to have an uptake of 85%.

Under the central feasible scenario, 6 $MtCO_2e$ realistic emissions reduction potential is identified at a cost up to £40/tCO_2e (Figure 9.8). This comprises emissions reduction from crops/soils (70%), livestock (20%), and anaerobic digestion (10%). In the high feasible scenario, estimated realistic emissions reduction potential increases to 11 $MtCO_2e$, driven by higher take up of all three categories of measures.

Figure 9.8 Agriculture non-CO_2 MACC – central feasible potential, 2020



Source: CCC modelling

Note: N = Nitrogen, AD = Anaerobic digestion

Regarding reduction to 2050, there is clear potential from existing options as well as from demand-side changes for agriculture to contribute significant emissions reduction. Further research would be needed to establish if a reduction of 80% on 1990 is possible, but if it is not then other sectors would need to contribute more to the UK's economy-wide target.

(iii) Emissions reduction constraints and the policy framework

Emissions reduction constraints: There are a number of constraints which would have to be addressed through development of the policy framework if agricultural emissions reduction potential is to be unlocked. These are similar to constraints in the context of energy efficiency improvement for households and firms:

- There may be some inertia to changing practices
- Farmers may not be able to invest time in finding out what new practices may be appropriate
- Farmers may lack capital required to invest in new technologies
- The financial benefit of adopting new practices/investing in new technologies may be small at the farm level (notwithstanding that the saving may be large for the sector as a whole).

The policy framework: The agricultural sector does not currently have any policies focused directly on reducing non-CO_2 emissions. We would expect some emissions reduction to occur under the current framework (e.g. due to continuing CAP reform and Environmental Stewardship), but these would not include the bulk of realistic emissions reduction potential that we have identified.

In developing the policy framework to provide more focus on and stronger incentives for emissions reduction, there are at least five options that should be considered:

- **Cap and trade schemes:** farmers or organisations in the agricultural supply chain would have to surrender allowances to cover their emissions. Given a constraint on the number of allowances available, this would result in financial incentives for farmers to reduce emissions.
- **Direct regulation:** practices that have been proven to reduce emissions at reasonable cost would be mandated.
- **Voluntary agreements:** as with direct regulation, but practices would be implemented on a voluntary basis. Incentives for voluntary implementation could be strengthened if emissions reductions were allowed to be sold in carbon markets.
- **Grants, subsidies, charges, levies and taxes:** these would provide financial incentives for emissions reduction.
- **Information provision:** encouraging awareness of best practice could result in emissions reduction.

There are a number of complexities that relate to one or more of these options:

- There is currently limited measurement of emissions at the farm level. This precludes the introduction of systems that provide financial rewards for emissions reductions. Moreover, the use of aggregate factors means that much of the abatement identified in our analysis would not be recognised in the current UK national emissions inventory.
- Introducing a price on emissions (e.g. through cap and trade or taxes) would raise costs. To the extent that agriculture is a globally competitive industry, this could result in displacement of production abroad with no environmental benefit.
- The administrative cost of incentive mechanisms for reducing emissions could be high given the diffuse nature of the farming industry.

- There are multiple policy objectives for agriculture. Policy focused on achieving one objective will often have implications for other objectives. It is not necessarily the case, therefore, that a policy which has positive impacts from a climate change perspective should necessarily be regarded as desirable.

In our view, however, none of these complexities should be seen as prohibitive, and further effort is warranted in resolving them. For example:

- Better measurement of emissions will be available in the future as the UK develops a new smart emissions inventory.

- Whilst competitiveness may be a concern in principle, there is little evidence to say that it should be a concern in practice.

- Regarding administrative costs, there are other areas of the economy where there are diffuse sources of emissions, and where policies have been introduced to reduce emissions (e.g. energy efficiency).

- And it is not clear that policies to support emissions reduction would have sufficiently large adverse impacts for other objectives that they should not be pursued.

The Committee recognises the multiple policy objectives and various sensitivities related to agriculture, but believes that the sector can contribute to tackling climate change whilst achieving other objectives. Given the significant realistic potential that our analysis suggests exists in agriculture, this sector could provide an important means for meeting GHG budgets. Our high level assessment suggests that there are barriers which can potentially be addressed. Our recommendation is that the Government seriously considers developing a policy framework for agriculture focused specifically on climate change and reducing emissions.

(iv) LULUCF

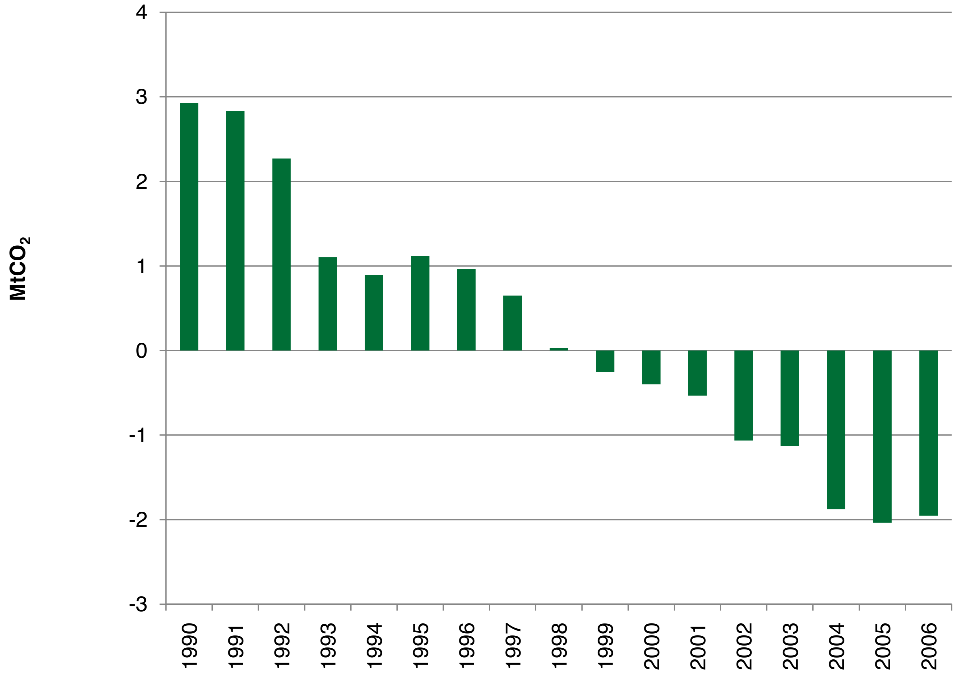
In discussing LULUCF, it is important to start by explaining that most LULUCF emissions relate to CO_2 rather than non-CO_2. It is covered in this chapter, which focuses on non-CO_2 emissions, to reflect close links with agriculture and similarly complex processes. Irrespective of whether the Government accepts our advice in Section 2 above to set budgets in terms of GHGs, LULUCF emissions will be included in budgets, whether these are in CO_2 or GHGs.

Emissions from LULUCF activities are made up almost entirely of emissions from the cultivation of soils and wood harvesting. CO_2 is released from soils due to tillage practices and from forests following harvesting of wood (with possible delay depending on what the wood is used for). Conversely, land management helps to remove CO_2 from the atmosphere through increases in forest and organic matter in soils and avoidance of degradation of those stores.

On a net basis, the LULUCF sector absorbed 2 $MtCO_2$ in 2006, which is less than 0.5% of UK emissions. This relatively small number masks, however, larger figures for emissions and absorptions when these are considered separately. Specifically, LULUCF emissions represent around 4% of the UK's total CO_2 emissions, with absorption representing around 4%-5%.

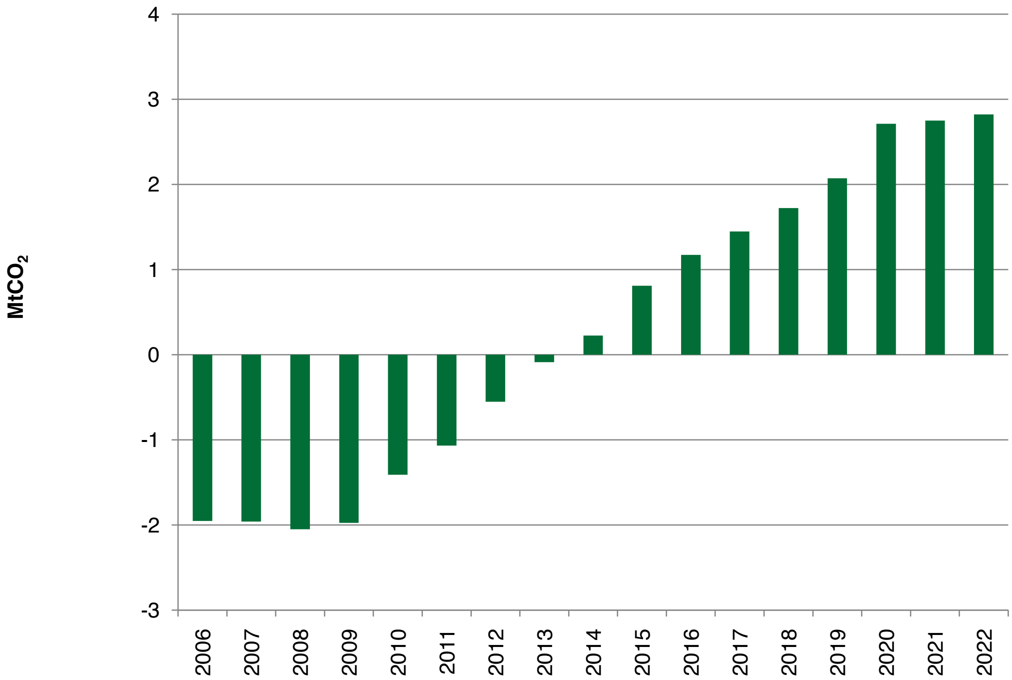
Emissions trends and projections: Net emissions due to LULUCF have moved from adding marginally to reducing marginally the UK's total emissions between 1990 and 2006; this due to changes in land use and forestry practices (Figure 9.9). Going forward, net emissions in 2020 are expected to revert to levels in 1990, with LULUCF becoming a (small) net emitter; this due to the implications of a falling historical tree planting rate (Figure 9.10).

Figure 9.9 LULUCF net emissions, 1990-2006



Source: Centre for Ecology and Hydrology (CEH) (2008) Inventory and projections of UK emissions by sources and removals by sinks due to land use, land use change and forestry, *Defra Contract GA01088*

Figure 9.10 LULUCF net emissions projections, 2006-2022



Source: CEH (2008)

Abatement potential: The analysis that we commissioned from the Scottish Agricultural College to assess scope for emissions reduction in agriculture also covered LULUCF. Within LULUCF, the analysis considered five classes of abatement option:

- Peatland restoration
- Halting liming of organic soils
- Land use transition between grassland and other agricultural uses
- Increasing the number of trees
- More regular harvesting of existing forests.

The analysis suggests that there is not significant abatement potential available from the first three of these measures[6].

The forestry sector, however, can make a potentially significant contribution to emissions reduction. It is possible to increase carbon sequestration[7] by afforesting previously unforested areas, increasing the time a forest is kept standing before it is chopped down, and optimising forest density. Afforestation offers potential to reduce emissions by 2 $MtCO_2$ in 2020 at a small cost saving per tonne of CO_2. This analysis is based on a high planting rate that may be challenging given environmental constraints, licensing regulations and requirements, and limited administrative capacity; we therefore assume realistically achievable potential of 1 $MtCO_2$.

More regular harvesting of existing forests could also increase biomass supply, which would slightly increase net emissions from forestry but reduce emissions elsewhere in the economy through use of biomass in energy supply and substitution for energy-intensive products in construction. In the longer term, increased biomass supply could be achieved through afforestation (i.e. without increased forestry emissions).

As in the case of agriculture, there is no specific policy for LULUCF aimed at meeting a climate change objective. But given the emissions reduction potentially available for this sector, it is our recommendation that the UK Government and national authorities consider how the policy framework might be developed to unlock emissions reduction potential and/or provide additional biomass supply as part of a broader forestry and land use strategy.

6 We note that a range of scientific uncertainties exist in this area and suggest caution is applied to this result.
7 Sequestration refers to CO_2 being removed from the atmosphere, with the carbon being stored instead in biomass and soils.

4. EMISSIONS FROM WASTE

We set out our analysis of waste emissions in two parts:

(i) Background, emissions trends and projections

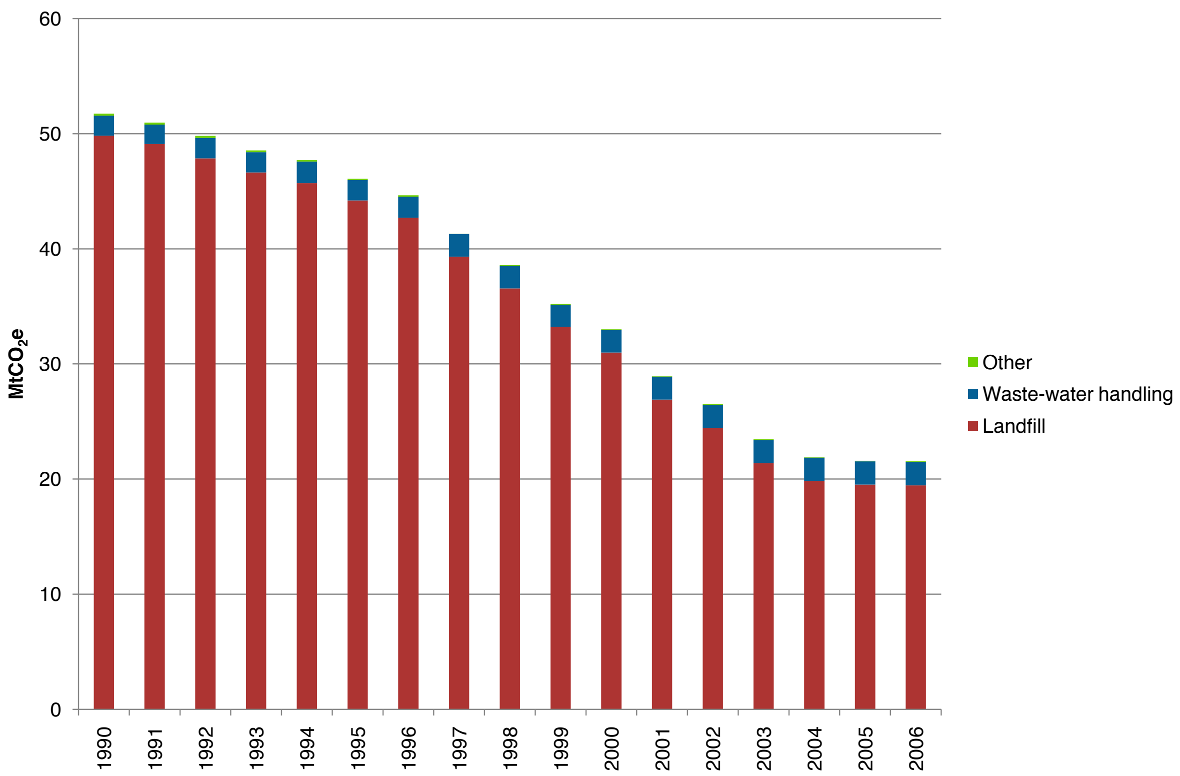
(ii) Abatement potential

(i) Background, emissions trends and projections

Non-CO_2 emissions from waste represented 3% of total UK GHG emissions, and 22% of non-CO_2 emissions in 2006. Waste emissions relate primarily to landfills (89%) and waste-water handling (9%). Landfill emissions result as food, paper and other rotting rubbish biodegrades without oxygen, thus producing methane.

Emissions trends: Emissions from the waste sector have declined 58% over the period 1990-2006, from 52 $MtCO_2e$ to 22 $MtCO_2e$ in 2006. This is due to reduced use of landfills and increased capture of gases from landfill sites, both of which have been driven by a range of EU and UK policies. Other waste emissions have increased slightly over this timeframe but only form a small proportion of emissions from this sector (Figure 9.11).

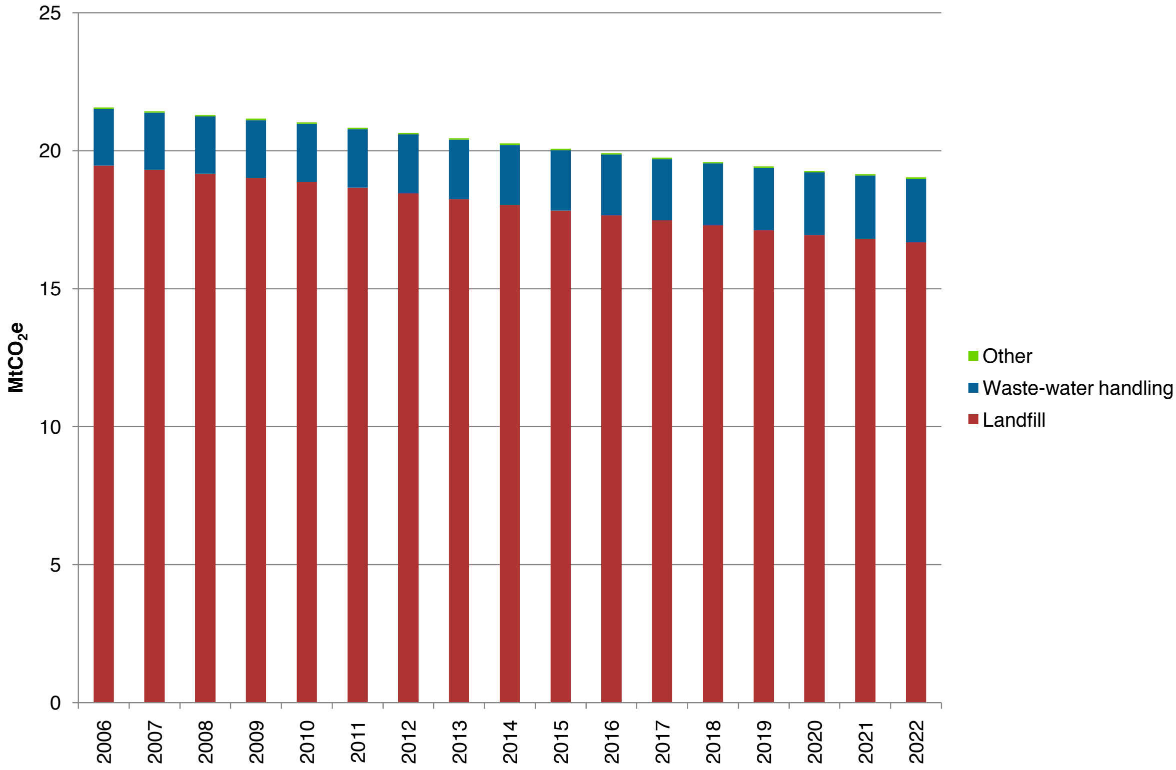
Figure 9.11 Waste non-CO_2 emissions by sub-sector, 1990-2006



Source: NAEI (2008)

Emissions projections: Government projections show waste emissions will fall 11% between 2006 and 2020, by which time they would be 63% below 1990 levels (Figure 9.12). This is due to decreasing emissions from landfill. The driver of emissions reduction in landfill is the EU policy framework, and the assumptions are that the UK meets its commitments in this context.

Figure 9.12 Waste non-CO_2 emissions projections by sub-sector, 2006-2020



Source: Defra

(ii) Abatement potential

There are two main classes of levers for reducing waste sector emissions:

- Downstream, focused on changing the waste management/collection process
- Upstream, focused on changing consumer and producer behaviour either towards producing less waste or disposing of waste in the appropriate manner.

The analysis that we set out in this chapter is focused on the first class of levers (i.e. downstream abatement options), although there is an overlap with the second class of measures given that this will require consumer behaviour change as regards disposing of waste in the appropriate manner. We recognise that changing consumer behaviour as regards producing less waste has an important role to play in reducing emissions from this sector (Box 9.3).

Box 9.3 Importance of behaviour change – reducing emissions from food waste

- It is estimated that we throw away as much as a third of all the food we buy; and at least half of this could have been eaten[1]. A number of reports, primarily by WRAP (Waste and Resources Action Programme), have explored this issue.

- WRAP conclude that the reasons why we waste food are complex, including: buying too much – particularly being tempted by special offers; buying more perishable food; poor storage management; high sensitivity to food hygiene; preparing too much food; not liking the food prepared; and lifestyle factors such as not having the time to plan meals[2].

- The public do not appear to make the connection between the food thrown away and its impact on the environment. The cost factor is more of a consideration, although the public are concerned over packaging waste.

- Recent Defra qualitative research suggests that consumers are open to changing their behaviour in relation to purchasing habits rather than changing diet[3]. However, time, convenience, access, habit, offers and availability remain barriers to consumers adopting more sustainable practices in relation to food.

- Reducing this food waste is the most cost-effective way of avoiding the emissions associated with its disposal. It also offers significant upstream emission and resource savings in production, transport and storage. At the household level reducing waste is cost saving and can help reduce food bills.

1 WRAP (March 2007) *Understanding Food Waste*

2 Brook Lyndhurst (2007) WRAP Food Behaviour Consumer Research (report to WRAP; currently unpublished) quoted in WRAP (March 2007) *Understanding Food Waste*

3 Qualitative research is designed to be illustrative rather than provide statistically representative data. Source: Owen, L., Seaman, H, and Prince, S. (2007). *Public Understanding of Sustainable Consumption of Food: A report to the Department for Environment, Food and Rural Affairs*. Opinion Leader. Defra, London.

Our analysis is based on a MACC model that we commissioned from Eunomia. The model identifies two key areas – both based around reducing methane emissions from landfill and substituting fossil fuel use in energy production – where there may be significant potential for emissions reduction:

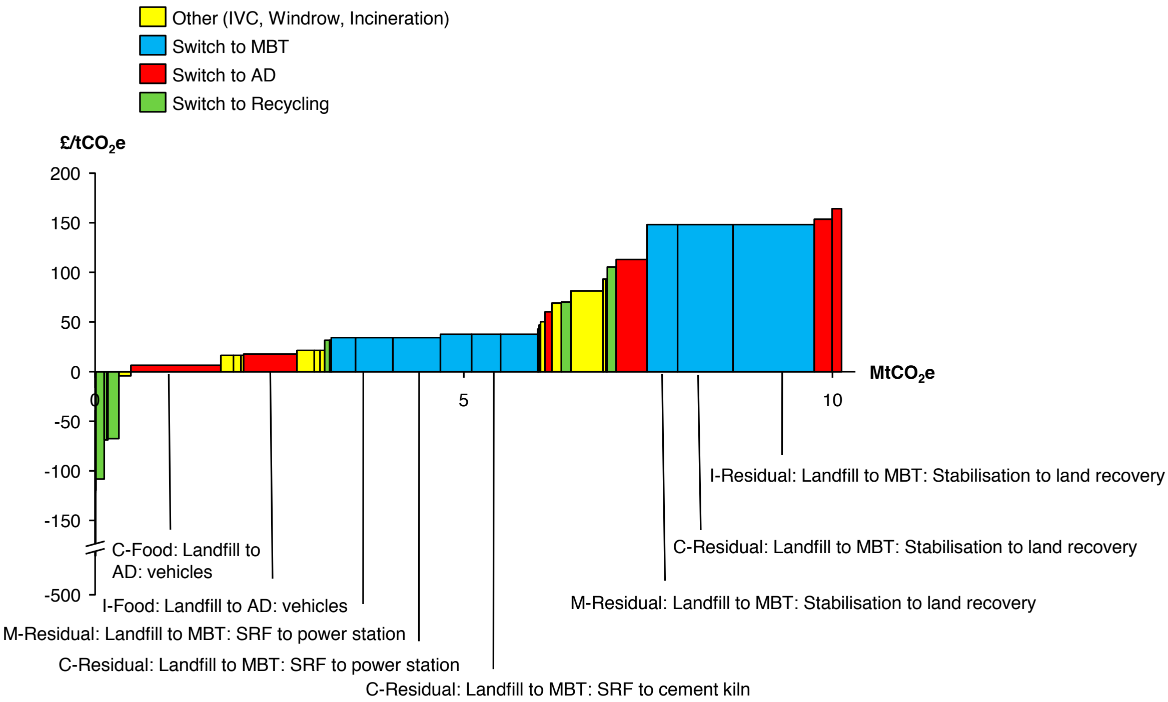
- Processing food waste through anaerobic digestion (AD) to produce biogas, which can for example be compressed for use in vehicles, displacing diesel.

- Processing residual waste through mechanical biological treatment (MBT) to produce either solid recovered fuel (SRF), which can be used in power stations and cement kilns, or an alternative to fertiliser.

A third cost-effective option is increasing recycling. We do not assume significant UK emissions savings from recycling, but the potential to reduce emissions both from UK landfill and from global primary extraction means that the policy framework should cover recycling.

The MACC identifies technical potential to reduce emissions by 6 $MtCO_2e$ in 2020 at a cost of up to £40/tCO_2e; 75% of this potential is accounted for by anaerobic digestion and mechanical biological treatment (Figure 9.13).

Figure 9.13 Waste MACC – maximum technical potential, 2020



Source: CCC modelling
Note: IVC = In-vessel composting, MBT = Mechanical biological treatment, SRF = Solid recovered fuel,
I = Industrial, M = Municipal, C = Commercial

There is a question over the extent to which this emissions reduction may be regarded as realistically achievable. This will ultimately depend on the policy framework for waste, both as it relates to changing consumer behaviour (e.g. as regards recycling food waste) and incentives for moving to alternative treatment options. Our judgement is that 5 $MtCO_2e$ of the potential below £40/tCO_2e can be considered as feasibly achievable.

There is already a policy framework in place in response to EU obligations on waste. New policy is also under development in the context of the wider framework to support investment in renewable energy technologies (see Chapter 5: *Decarbonising electricity generation* and Chapter 6: *Energy use in buildings and industry*); this could, for example, strengthen financial incentives for anaerobic digestion. It is likely therefore that emissions reduction over and above that envisaged in the baseline will occur in practice. But the extent to which this will be the case is uncertain given uncertainty over exactly how the policy framework will develop. Early action is particularly important in this sector due to legacy emissions – once material is landfilled it will continue to emit methane for many decades.

Given the good progress already achieved since 1990, the potential identified to further reduce emissions, and longer-term possibilities in flaring legacy emissions and changing behaviours and materials, a reduction in waste emissions of at least 80% by 2050 appears feasible.

5. NON-CO_2 EMISSIONS FROM INDUSTRY AND ENERGY

We set out our analysis of industrial and energy non-CO_2 emissions in 2 parts:

(i) Background, emissions trends and projections

(ii) Abatement potential and the policy framework

(i) Background, emissions trends and projections

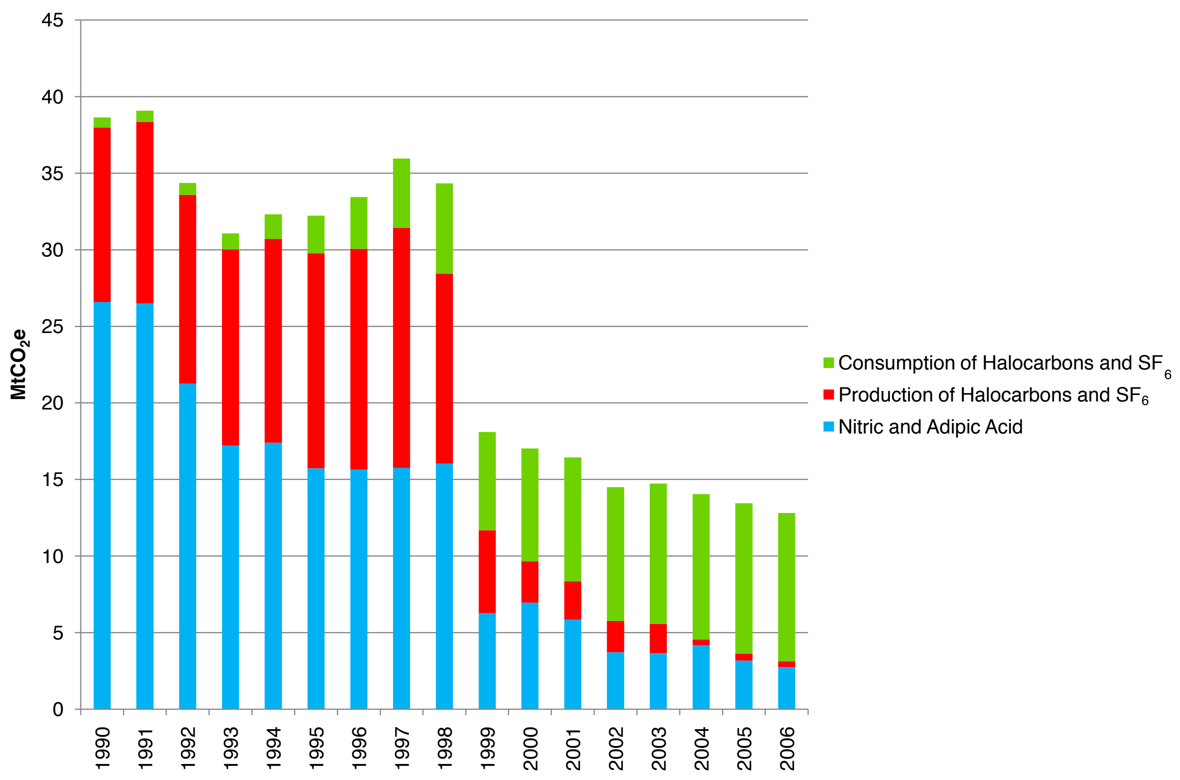
In 2006, non-CO_2 emissions from industrial processes represented 2% of total UK (GHG) emissions, with non-CO_2 emissions from energy accounting for a further 3%:

- Industrial process emissions come primarily from the escape of halocarbons – a type of F-gas – used in applications such as refrigerators, inhalers, fire extinguishers and air conditioning (81%). The majority of the remaining industrial emissions are N_2O and are generated through the production of nitric acid and adipic acid (19%).

- Energy (non-CO_2) emissions come primarily from fugitive emissions from fuels (47%). These emissions mainly come from gas distribution in pipes, methane leaking from coal mines and other leaks that occur during the combustion process. They may also be due to equipment leaks, evaporative processes and windblown disturbances. The other major contributor to emissions in this sector is catalytic converters used in road transport (29% in 2006).

Historic emissions: Non-CO_2 industrial process emissions have declined by 67% over the period from 1990 to 2006, from 39 $MtCO_2e$ to 13 $MtCO_2e$ (Figure 9.14):

Figure 9.14 Industrial process non-CO_2 emissions by sub-sector, 1990-2006



Source: NAEI (2008)

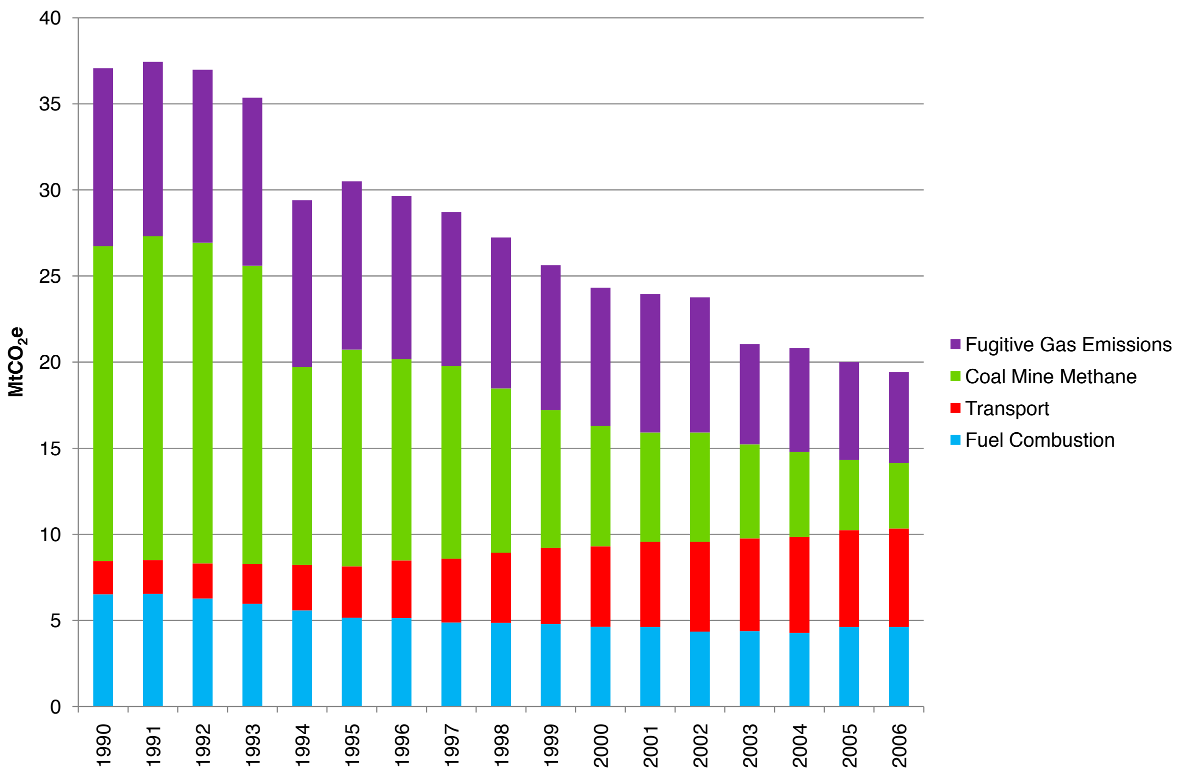
- This is primarily a result of abatement measures introduced to reduce N_2O from adipic and nitric acid manufacture.

- There has also been a sharp decline in the fugitive emissions of F-gases that occur during the manufacture of refrigerants. This change has been driven largely by Integrated Pollution Prevention and Control (IPPC) regulations.

- Offsetting this, the Montreal protocol has phased out the use of ozone gases (with significant climate benefits), but with side effects including their replacement with HFCs resulting in increased F-gas emissions.

Energy (non-CO_2) emissions have declined from 37 $MtCO_2e$ in 1990 to 19 $MtCO_2e$ in 2006, a drop of 48% (Figure 9.15). A fall in coal mine methane emissions (due to industry decline) and a decrease in fugitive emissions from natural gas (due to a health and safety executive enforced gas pipe replacement programme), are the two main contributors.

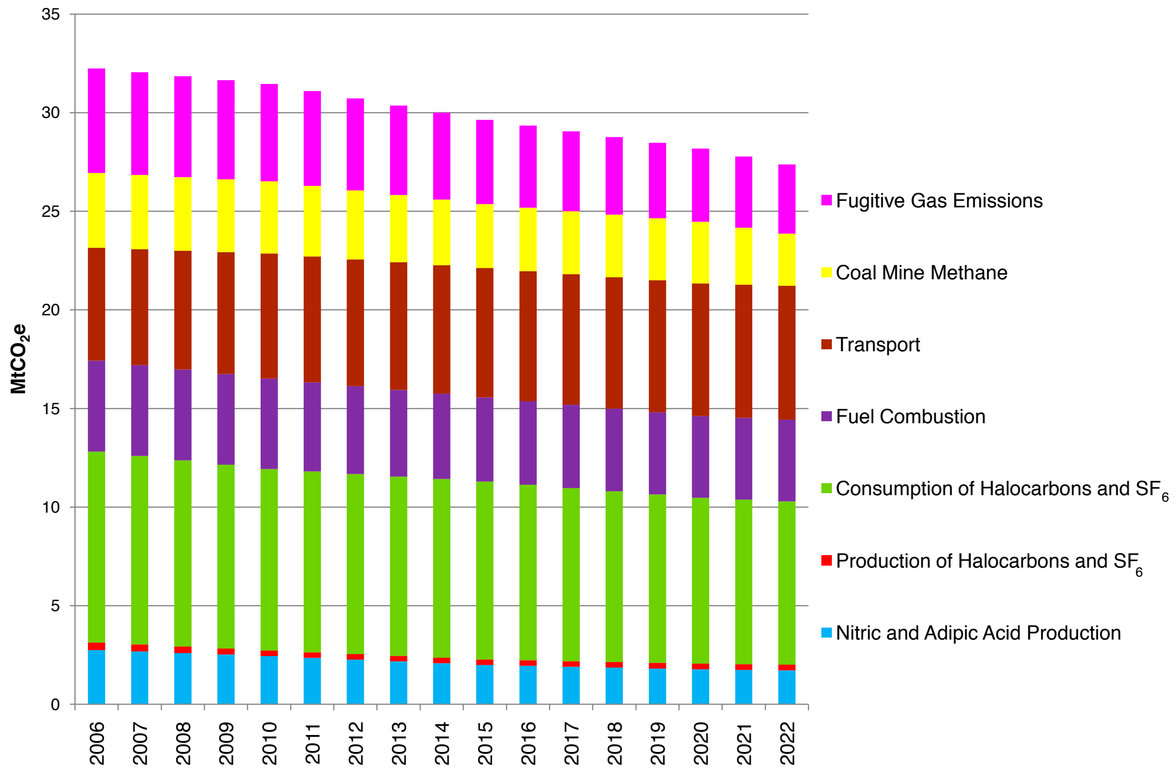
Figure 9.15 Energy non-CO_2 emissions by sub-sector, 1990-2006



Source: NAEI (2008)

Emissions projections: Government projections show industrial process emissions falling by 18% over the period 2006-2020 (Figure 9.16), due to further reductions in adipic/nitric acid emissions, which will be covered by the European Union Emissions Trading Scheme (EU ETS) from 2013, and a decrease in emissions from the use of appliances that emit F gases. Energy non-CO_2 emissions are projected to be 52% below 1990 levels in 2020 based on assumptions that leakage from gas pipes will fall as infrastructure is renewed, with an offsetting increase in N_2O emissions as catalytic convertors are mandated under EU legislation.

Figure 9.16 Industrial process and energy non-CO_2 emissions projections by sub-sector, 2006-2022



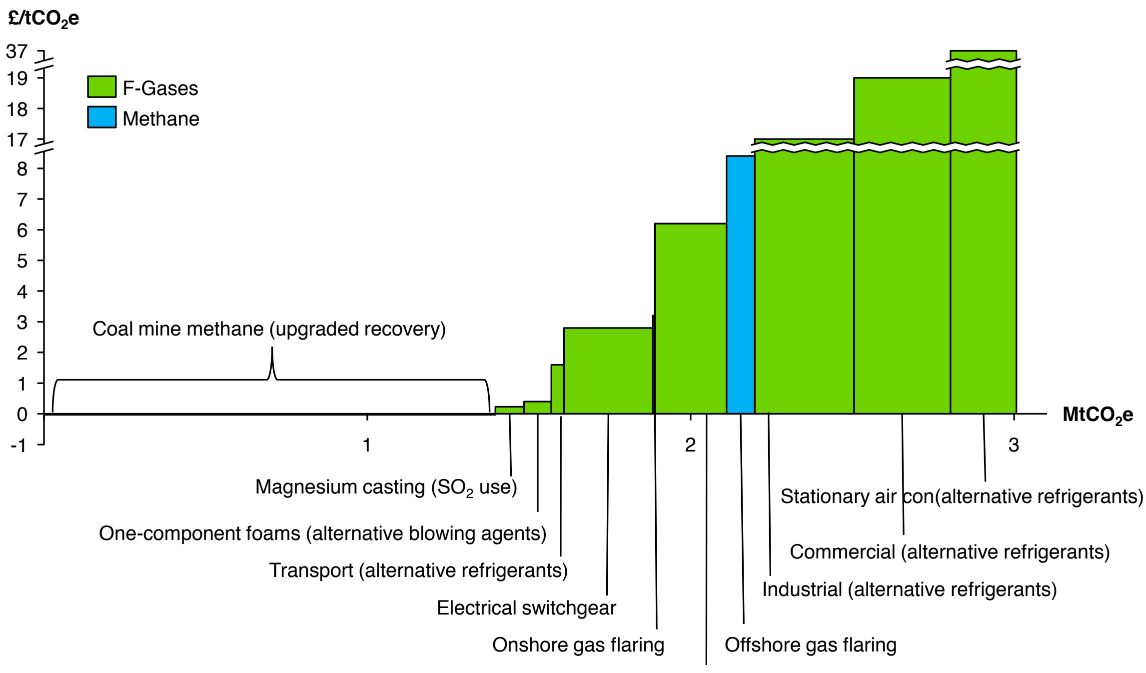
Source: Defra

(ii) Abatement potential and the policy framework

We have not commissioned any new research in the area of industry and energy non-CO_2 emissions. Rather, we have drawn on analysis commissioned by Defra from AEA in this area[8]. AEA have developed a MACC model for non-CO_2 emissions that conservatively suggests there is 3 $MtCO_2e$ abatement potential available at a cost up to £40/tCO_2e (Figure 9.17) from industrial processes and energy:

- Roughly half this saving comes from upgraded recovery and utilisation of methane from coal mines
- The remainder of the saving comes from measures that decrease the leakage of F-gases from appliances or that replace F-gases with less potent gases.

Figure 9.17 MACC for energy and industrial process non-CO_2 emissions, 2020



Source: CCC calculations based Defra project ED05478

Regarding whether this potential is realistically achievable, policy to tackle F-gas emissions is driven at EU level by EC F-Gas regulation and the Mobile Air Conditioning Directive, and it is reasonable to assume that at least some of the emissions reduction potential identified by AEA will ensue. Conversely, there is currently no policy framework in place to encourage reduced methane emissions from coal mines. Whilst this is not a major source of emissions, there is a not insignificant amount of potential available that warrants further consideration of policies that might be introduced here.

8 AEA (forthcoming), Annual Updating of Non-CO_2 Greenhouse Gas Emissions for the UK – Marginal Abatement Cost Curves for Non-CO_2 Greenhouse Gases, *Defra project ED05478*

6. RESTATEMENT OF CARBON BUDGETS IN GHGS

Our CO_2 budget proposals set out in Chapter 3: *The first three budgets* are summarised in Table 9.1. There are two budgets covering the period to 2022: the *Interim budget*, to apply for the period until there is a new global agreement to reduce emissions, and the *Intended budget*, to apply following a global deal. The Interim budget is characterised by an emissions reduction of 29% by 2020 relative to 1990 levels. The Intended budget requires 2020 emissions to be 40% below 1990 levels.

Table 9.1 CO_2 budget proposals, 2008-2022

$MtCO_2$		Budget 1 (2008-12)	Budget 2 (2013-17)	Budget 3 (2018-22)
Interim budget	Traded sector	1233	1114	1011
	Non-traded sector	1304	1235	1103
	Total	**2537**	**2349**	**2114**
Intended budget	Traded sector	1233	1009	800
	Non-traded sector	1304	1201	989
	Total	**2537**	**2210**	**1789**

Source: CCC analysis

We derived our CO_2 budgets based on targets for the UK under the EU's 20%/30% GHG emissions reduction targets for 2020. Specifically, we took these targets, which are expressed in terms of GHGs, and translated them to CO_2 budgets by netting out non-CO_2 emissions under an assumption that these would evolve according to the reference case trajectory (Section 1 above).

To move from CO_2 budgets to GHG budgets, therefore, we simply add back in reference case non-CO_2 emissions[9]. This results in GHG budgets summarised in Table 9.2. The Interim budget is characterised by an emissions reduction of 34% by 2020 relative to 1990 levels; it is this budget that we propose should enter the legislation. The Intended budget requires emissions in 2020 to be 42% below 1990 levels.

9 Note that we have not considered any co-benefits that may result from policies to reduce CO_2. For example, measures reducing road fuel use, such as increased uptake of electric cars, will also tend to reduce N_2O emissions. These are not accounted for in setting budgets, but offer an opportunity to reduce the cost in meeting them.

Table 9.2 GHG budget proposals, 2008-2022

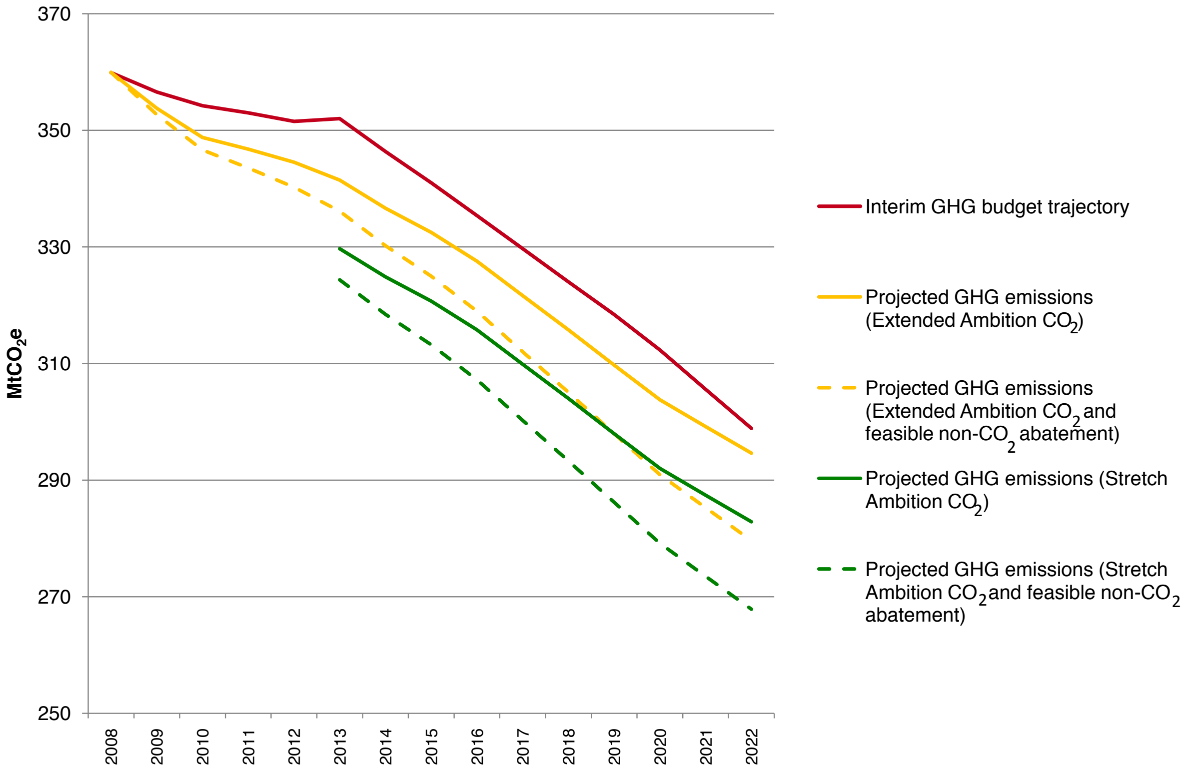
$MtCO_2e$		Budget 1 (2008-12)	Budget 2 (2013-17)	Budget 3 (2018-22)
Interim budget	Traded sector	1233	1114	1011
	Non-traded sector (CO_2)	1304	1235	1103
	Non-traded sector (Non-CO_2)	481	469	456
	Total	**3018**	**2819**	**2570**
Intended budget	Traded sector	1233	1009	800
	Non-traded sector (CO_2)	1304	1201	989
	Non-traded sector (Non-CO_2)	481	469	456
	Total	**3018**	**2679**	**2245**

Source: CCC analysis

We noted in Section 2 above that moving from CO_2 to GHG budgets provides scope for meeting budgets through non-CO_2 emissions reduction, and that this can be attractive from perspectives of cost minimisation and budget risk management.

We illustrate this by comparing emissions in the trajectory under our *Extended Ambition* scenario together with the trajectory under our Interim GHG budget. We do this for the non-traded sector, which is where most of our non-CO_2 emissions occur (Figure 9.18). This comparison shows that whereas feasible CO_2 emissions reduction in 2020 is 9 $MtCO_2e$ more than would be required to meet the budget, this rises to 24 $MtCO_2e$ including non-CO_2 options.

Figure 9.18 Non-traded sector emissions trajectories versus Interim GHG budgets, 2008-2022



Source: CCC analysis
Note: Domestic aviation is excluded throughout for clear comparisons (in reality it will be in the first non-traded budget, but not the second and third, when it will fall in the traded sector)

This has led us to consider the question of whether effort to reduce CO_2 emissions should be relaxed in the context of GHG budgets where there are cost-effective opportunities for non-CO_2 emissions reduction. On balance, however, our view is that given uncertainty over what can realistically be achieved in non-CO_2 emissions reduction and given required CO_2 reduction in the context of progressing towards the 2050 target, CO_2 emissions reduction effort in the period to 2022 should continue at levels proposed in Chapter 3 (i.e. Government should aim to deliver at least the Extended Ambition and consider options in the Stretch Ambition).

This should be complemented by further analysis and development of a policy framework for unlocking non-CO_2 emissions reduction potential. Non-CO_2 emissions reduction would then have an important role to play in mitigating risks related to delivery of CO_2 emissions reduction, allowing budget compliance in the event that some CO_2 emissions reduction is not delivered, and should be regarded similarly to other options in our Chapter 3 *Stretch Ambition* scenario.

PART IV:

WIDER ECONOMIC AND SOCIAL CONSIDERATIONS

In Part IV of the report, we set out our analysis of the impact of carbon budgets on a range of factors that we are required to consider under the Climate Change Act:

- "Economic circumstances, and in particular the likely impact [of carbon budgets] on the economy and competitiveness of particular sectors of the economy."
- "Fiscal circumstances, and in particular the likely impact [of carbon budgets] on taxation, public spending, and public borrowing."
- "Social circumstances, and in particular the likely impact [of carbon budgets] on fuel poverty"
- "Energy supplies", which we have interpreted as relating to security of supply concerns.
- "Differences in circumstances between England, Wales, Scotland and Northern Ireland."

In **Chapter 10: Competitiveness challenges and opportunities**, we consider possible impacts of carbon budgets for energy-intensive industry in the UK. Based on an assessment of energy costs and trade intensity, we conclude that a small number of industries may be at risk of "carbon leakage" (i.e. the danger that production and/or new investment is relocated to other countries with less stringent carbon controls). There are, however, policies available to mitigate this risk: one of these policies should be adopted in the new framework for EU ETS. Amongst potential competitiveness benefits from carbon budgets, we note that the UK might gain an advantage in some low-carbon technologies that could be exported to European and global markets, most notably marine energy and efficient car engines.

In **Chapter 11: Economic costs and fiscal implications**, we present our analysis of potential GDP impacts from meeting carbon budgets. Based on various modelling approaches, we estimate that the impact of meeting our Intended budget could be a GDP reduction in 2020 of less than 1%. We argue that this is affordable when viewed in the context of likely annual average growth of the order 2% to 2020, and that it should be accepted given the potential adverse consequences and costs produced by climate change. We also consider the potential fiscal impact of our recommended budgets, looking at both the revenue and spending side. We conclude that the order of magnitude of any negative impacts will not be large enough to undermine fiscal sustainability, and that there may be significant positive impacts, particularly in the third budget period.

In **Chapter 12: Fuel poverty implications**, we set out our analysis of potential consequences from electricity and gas price increases. We estimate that as a result of meeting carbon budgets an extra 1.7 million households could enter fuel poverty in 2020. We show that energy efficiency improvement has an important role to play in mitigating this impact, with potential for taking around 400,000 households back out of fuel poverty. We estimate that the cost of offsetting adverse fuel poverty impacts is of the order £500 million in 2020.

In **Chapter 13: Energy Security of Supply**, we distinguish between technical and geopolitical security of supply. Technical capacity refers to whether there is adequate capacity on the power system to meet demand. Geopolitical refers to the possibility of energy supply interruptions for geopolitical reasons and to price volatility associated with reliance on oil and gas. We illustrate that the move to a power system based on low-carbon generation should not undermine technical security of supply, notwithstanding any issues around intermittency of wind generation, which can be addressed through ensuring that there is adequate back-up capacity available. And we conclude that the move to a low-carbon economy will have a useful, though difficult to quantity, side benefit as a result of the reduced exposure to unpredictable volatility in oil and gas prices.

In **Chapter 14: Differences in national circumstances**, we consider the different nature and extent of opportunities for emissions reductions in Northern Ireland, Scotland and Wales and identify that there is an important role for national authorities unlocking the potential given the balance of reserved and devolved powers. We also consider adverse regional impacts of carbon budgets for competitiveness and fuel poverty. In both case, we conclude that there are concerns which should be addressed through appropriate policies pursued either at the UK or devolved level.

CHAPTER 10:

COMPETITIVENESS CHALLENGES AND OPPORTUNITIES

The Climate Change Act requires the Committee to take into account 'the likely impact of the decision [on carbon budgets] on the economy and the competitiveness of particular sectors of the economy'. Competitiveness concerns could arise if CO_2 or GHG budgets, and the policies used to achieve them, would disadvantage specific sectors in international competition, driving the location of production to other countries and thus harming profits and employment. Benefits might, however, arise if a new low-carbon economy created new business and employment opportunities.

This chapter analyses both competitiveness threats and opportunities. Its key conclusions are that:

- The possibility of serious competitiveness problems is concentrated in particular industries which in total account for less than 1% of UK GDP and less than 0.5% of UK employment. But these industries are regionally concentrated. And they are responsible for almost 10% of UK emissions. Relocation of production abroad to countries with less stringent environmental standards could therefore undermine the objective of reducing GHG emissions.

- There is therefore a case for designing policy so as to avoid competitiveness effects in the most affected sectors. The crucial issue is the treatment of the most vulnerable sectors within the EU Emissions Trading Scheme (EU ETS). Three broad approaches are possible: global sectoral agreements; border carbon price adjustments; or the continuation of free allowance allocation even when the system overall has moved to auctioning. If global sectoral agreements are not attained, one of these other approaches should be implemented within the EU ETS.

- As the UK economy adjusts to tight GHG targets, new jobs and economic activities will be created to balance jobs lost in high-carbon-intensity activities. There is no long-term employment penalty in moving to a low-carbon economy. And there may be specific sectors where the UK could develop competitively advantaged clusters of high-value activity, for instance in tidal and wave energy.

The chapter analyses these issues in three sections:

1. Defining the sectors subject to competitiveness threats.
2. Policy levers to mitigate competitiveness concerns.
3. Opportunities in a low-carbon economy.

1. SECTORS SUBJECT TO COMPETITIVENESS THREATS

If the UK imposes a carbon price or carbon related regulations which do not apply in other countries, it is possible that some economic activity currently conducted in the UK would become uneconomic and may be relocated elsewhere. The maximum potential impact of this effect is, however, very small. This is because:

- There are many sectors of the economy where 'competitiveness' effects of this sort are almost entirely irrelevant, because the activity is inherently untraded. An increase in the operating cost base of UK retailers, for instance, will not induce a shift of shopping activity to other countries.

- There are many sectors which are subject to international competition but where energy costs are so small as a percentage of total production cost that the impact of carbon related policies is trivial compared with other drivers of location. Financial services is one such sector.

- In some internationally traded sectors, the need for just-in-time delivery and rapid response to customer demand mean that competition is primarily within Europe; therefore as long as carbon prices or regulation are imposed equally across Europe, competitiveness effects in these sectors will not emerge.

- Finally, if production in specific sectors does relocate abroad, the long-term economic impact of this is not given by the gross value added (GVA) of the sector concerned. Instead it will be equal to this GVA minus the GVA of the new economic activities which over time will emerge.

As a result, all analyses of the long-term impact of stringent European climate objectives, even if pursued unilaterally, suggest only very small competitiveness effects. The Carbon Trust's (2008) report *EU ETS impacts on profitability and trade* concludes that 'the EU ETS and other carbon control measures out to 2020 will have negligible impact on the international competitiveness of more than 90% of UK manufacturing activities'. Manufacturing in turn accounts for only about 12% of UK GDP.

It is nevertheless important to identify the specific sectors which might be subject to adverse competitiveness effects: even small macroeconomic costs should ideally be avoided; regional impacts can be much larger than at the UK level; and relocation of industries could have an adverse impact on global carbon emissions, undermining the objective of policy.

The main policy lever which could create adverse competitiveness effects is the EU ETS. The price it sets for emitting GHGs could harm the economics of sectors where energy costs and the imposed carbon price are a large percentage of total GVA, and where international trade beyond the EU is currently or potentially important. Figures 10.1 to 10.4 identify these sectors, drawing on the Carbon Trust analysis.

- Figure 10.1 shows manufacturing sectors identified by the Carbon Trust (2008) which are likely to experience the largest cost penalty as a share of their GVA, either as a result of raised electricity prices or direct CO_2 emissions costs. The Figure shows this cost penalty assuming a carbon price of 40 Euro/tCO_2 (about £31/tCO_2) and a related electricity price increase of 20 Euro/MWh (about 1.5p/kWh)[1]. In most cases the cost penalty would arise from the emissions permits which the industry would have to purchase to cover its direct (i.e. non-electricity) emissions of CO_2 if all emissions allowances (EUAs) were auctioned. In a few cases however – in particular industrial gases, inorganic chemicals and aluminium – the electricity price impact is more important. In total the sectors shown in Figure 10.1 account for 1.1% of GDP. Those seriously at risk as a result of the costs imposed are likely to be a subset of this total.

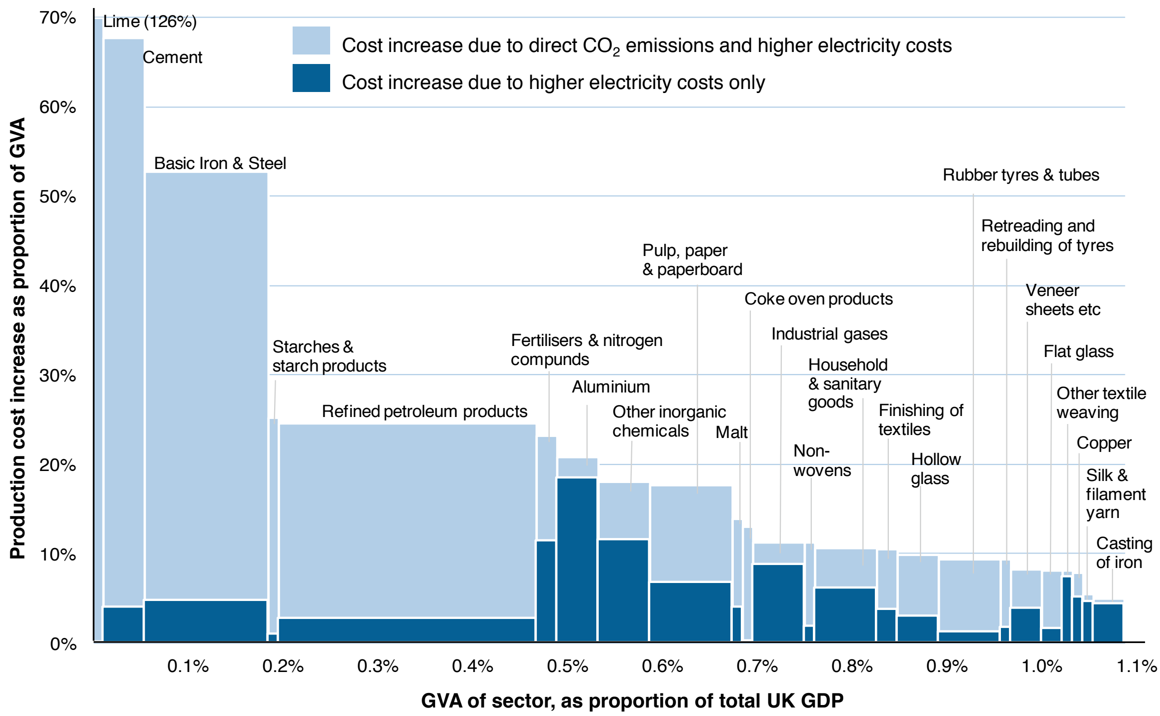
- These sectors, however, are in almost all cases highly capital-intensive. As a result the employment at risk is a smaller percentage of the total: all the sectors shown account for less than 0.6% of UK employment (Figure 10.2). It is important to note, however, that this employment is regionally concentrated. For example, almost 1.4% of Welsh employment lies in sectors shown in Figure 10.2, with a significant portion of this in the particularly vulnerable iron and steel sector, and with this employment regionally concentrated in south Wales (see Chapter 14: *Differences in national circumstances* for more detailed discussion of this and other regional impacts).

- Crucially, moreover, as Figure 10.3 illustrates, these sectors account for over 13% of total UK CO_2 emissions, with lime, cement and iron and steel – three sectors where a 100% auctioned carbon permit system would impose costs of over 50% of current GVA – accounting for almost 6% of the UK total. There is therefore a risk that if a high-carbon price within the EU ETS were to drive a relocation of some industries to countries with less stringent carbon emission controls, this would significantly undermine the objective of climate mitigation policy, even if in the long run the total economic impact of relocation would be very slight at the overall UK level.

- The risk of inducing relocation, however, depends not merely on the potential cost penalty as a percentage of GVA, but on the extent to which each sector is currently or potentially subject to international trade competition from outside Europe. If a sector were not subject to international trade competition, additional costs could be passed on in higher prices. Figure 10.4 sets out the current position, with significant non-EU international trade in, for instance, iron and steel, petroleum products and aluminium, but with non-EU trade intensity in cement very small. This pattern of trade intensity reflects the relative importance of transport costs (very high in cement; much less in extensively traded textile products), and the extent to which customer choice is driven by differentiated product or service features, rather than driven almost entirely by price. The analysis of Figure 10.4 would suggest that only a very few sectors display the combination of significant cost impact and significant trade intensity which would indicate a serious competitiveness threat. But more detailed analysis is required to identify whether some sectors not currently subject to significant trade competition from outside the EU would become so if a high-carbon price was imposed.

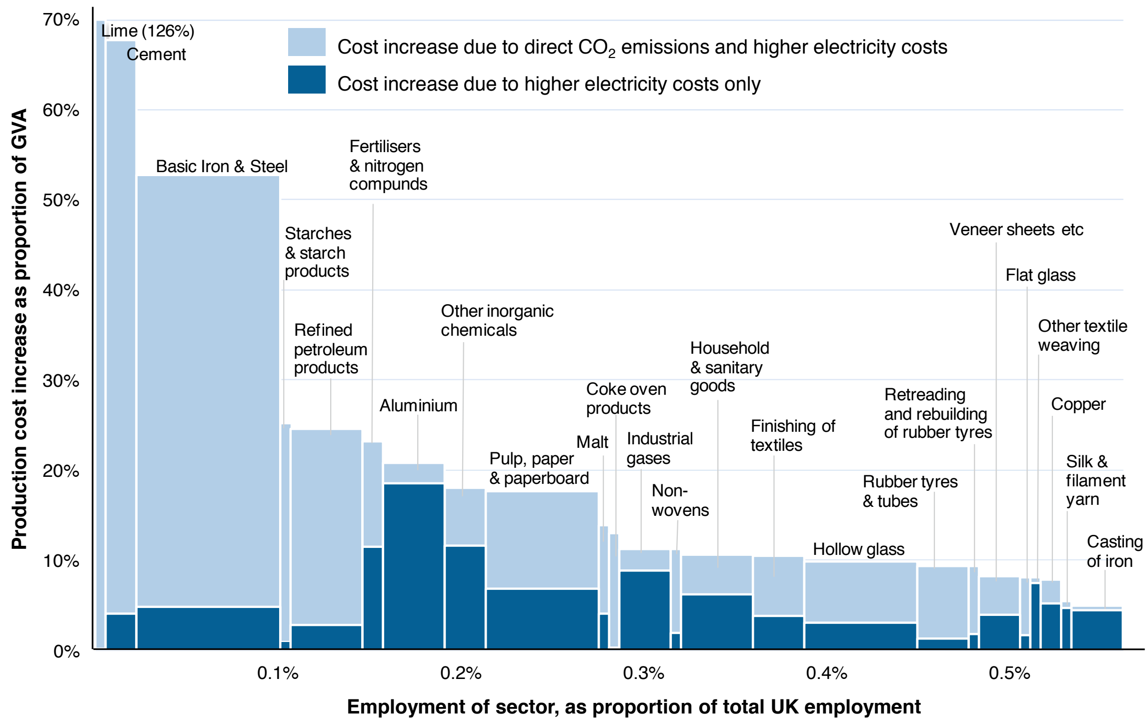
1 The Carbon Trust analysis included sectors whose total cost penalty was 4% or more of GVA, plus those sectors whose electricity cost penalty was 2% or more of GVA, assuming a carbon price of 20 Euro/tCO_2 and a related electricity price increase of 10 Euro/tCO_2. We use a carbon price of 40 Euro/tCO_2 (and a related electricity cost increase of 20 Euro/MWh), which is around our central case forecast for 2015.

Figure 10.1 Manufacturing sectors most cost-sensitive to carbon pricing (GVA as proportion of UK GDP)



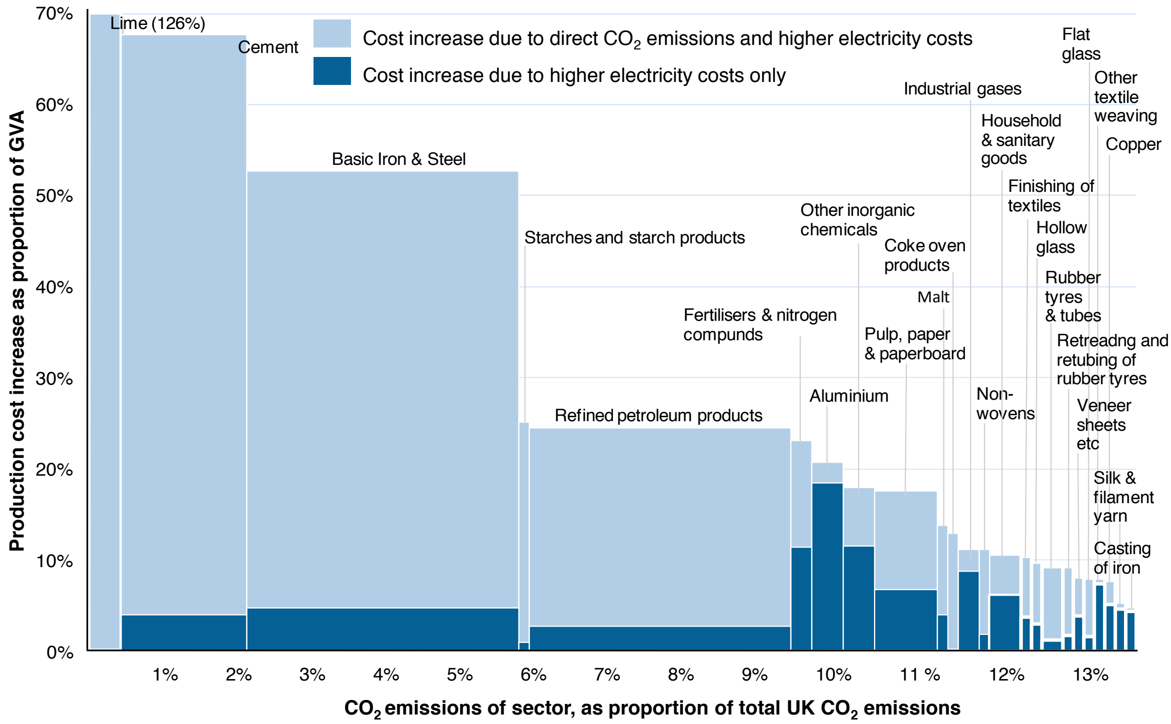
Source: Adapted from Carbon Trust (2008) *EU ETS impacts on profitability and trade*
Note: Based on 2004 industry data

Figure 10.2 Manufacturing sectors most cost-sensitive to carbon pricing (employment as proportion of UK employment)



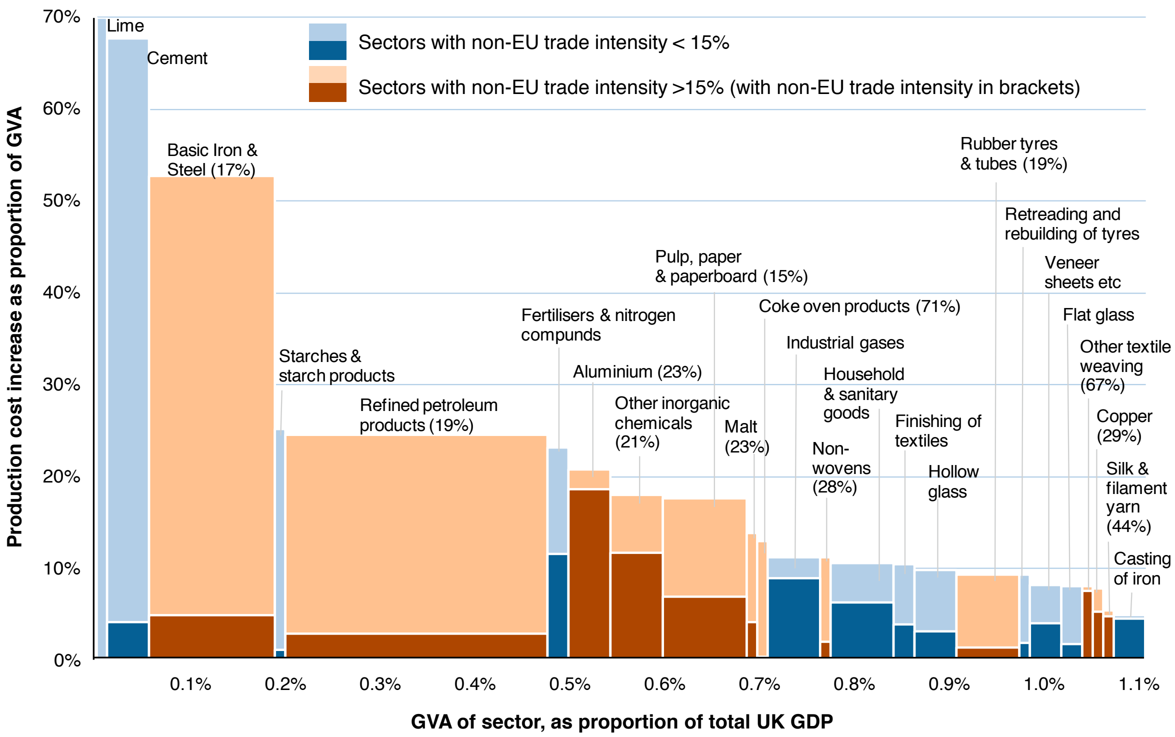
Source: Adapted from Carbon Trust (2008) *EU ETS impacts on profitability and trade*
Note: Based on 2004 industry data

Figure 10.3 Manufacturing sectors most cost-sensitive to carbon pricing (CO_2 emissions as proportion of UK CO_2 emissions)



Source: Adapted from Carbon Trust (2008) *EU ETS impacts on profitability and trade*
Note: Based on 2004 industry data

Figure 10.4 Manufacturing sectors most cost-sensitive to carbon pricing (GVA as proportion of UK GDP) and most traded outside the EU



Source: Adapted from Carbon Trust (2008) *EU ETS impacts on profitability and trade*
Notes: Based on 2004 industry data
Non-EU trade intensity defined as (value of exports to non-EU + value of imports from non-EU/ (annual turnover + value of imports from EU and non-EU)

More detailed analysis is therefore required to identify which precise sectors are subject to a significant competitiveness threat. The best current judgment is that a small subset of the sectors shown in Figures 10.1 to 10.4 is likely to be seriously threatened.

In addition it will be important to consider whether sectors not currently covered by the EU ETS would be subject to serious competitiveness effects if they were covered in future, either by the EU ETS or by other policy instruments. Our analysis in Chapter 8: *International aviation and shipping* suggested that the inclusion of aviation in the EU ETS raises relatively minor competitiveness concerns, but that the inclusion of shipping could be problematic. The extent to which international competition carries implications for appropriate policy in the agricultural sector (considered in Chapter 9: *Non-CO_2 greenhouse gases*) requires more detailed analysis.

2. POLICY LEVERS TO MITIGATE COMPETITIVENESS CONCERNS

To assess the alternative policies available to mitigate competitiveness concerns, it is important for us to be clear about: (i) the possible impact of the EU ETS on output decisions; (ii) whether this impact is different if EU allowances (EUAs) are freely allocated rather than auctioned; and (iii) whether it differs between decisions to produce and to invest. Impacts will differ for firms exposed to international competition who must supply at the global market price, and for firms (such as electricity generators) that set their own price and do not face non-EU competition. Three points should be noted:

- **Marginal output decisions should not logically be influenced by the auctioning/ free allocation decision.** If a production site is directly included within the EU ETS (i.e. it has to present EUAs sufficient to cover its direct, non-electricity-related emissions) then each marginal tonne of CO_2 which it emits will incur a cost equal to the price per tonne within the EU ETS, and each marginal tonne of CO_2 saved will generate a saving equal to this price (either because one fewer EUA has to be purchased or because one EUA can be sold). This is true whether EUAs are auctioned or freely allocated. In sectors where there is a realistic choice about marginal production (e.g. steel but not electricity production) decisions at the margin on whether to produce additional output within the EU or elsewhere should therefore be influenced by the EUA price irrespective of the auctioning/ free allocation choice.

- However, the decision between auctioning and free allocation can influence both the profitability of existing investments and the attractiveness of future investments, but with the precise effects also crucially determined by the nature of competition and thus price setting (i.e. by whether prices are set within Europe irrespective of global competition, as in the case of electricity generation, or set globally as in the case of steel; see Figure 10.5).

  – **Profitability of existing investments can be influenced by auctioning/ free allocation decisions.** Most affected sectors have high fixed costs and high gross margins. As a result companies may continue to produce in Europe using already invested capital rather than investing in new capacity overseas, even if they could potentially reduce production at the margin. In this case the auctioning/ free allocation choice impacts profits rather than output. If auctioning were used in a sector which is subject to intense international competition, and where cost cannot be passed through to prices, a windfall loss could result in relation to existing investments. Conversely if EUAs are freely allocated rather than auctioned in a sector which can pass on marginal cost increases in higher prices (such as electricity generation) then companies will enjoy a windfall economic gain.

  – **Attractiveness of new investments may be influenced by the auctioning/ free allocation decision.** A new investment that is economically viable under free allowance allocation may not continue to be viable where EUAs have to be purchased, particularly where purchase costs cannot be passed on to consumers due to international competition. In this situation, the use of auctioning could drive investment to other countries where there is no carbon constraint. Where allowances are allocated free, however, investments in sectors exposed to global competition could remain viable (depending on the precise allocation method used). The choice between auctioning and free allocation can therefore influence decisions on new investments even if in theory it should have no implications for marginal production decisions. This is because the investment decision is based on the average cost of the planned capacity whereas the marginal production decision is based on marginal cost.

Figure 10.5 Auctioning vs free allocation: the implications of international competition

International Trade Intensity	System Design: 100% Auctioning	System Design: 100% Free allocation
Sector where non-EU competition has no impact on prices	• Marginal cost increase passed through in higher prices • No windfall gain	• Marginal cost increase passed through in higher prices • Companies receive windfall gain (economic rents)
Sector where prices set globally by non-EU competition	• Marginal and average cost increase: profitability cut • Windfall loss to owners of existing capacity • New investment less attractive	• Marginal but not average cost increase; no price increase; marginal profit cut but not average profit • No windfall gain • New investment <u>may</u> still be equally attractive* as before

* Whether the attractiveness of new investment remains unchanged in the 100% free allocation system depends on the precise rules e.g. whether the free allocation for an existing site transfers over within the company to a new production site.

Source: CCC

- **Finally, it should be noted that the auctioning/ free allocation decision has no implications for competitiveness effects which operate via the electricity price** rather than via the price of carbon for direct emissions. Whether or not power companies are allocated EUAs or have to buy them, the electricity price will rise to reflect the marginal carbon price. If a sector which uses electricity intensively is unable, because of international competition, to pass higher electricity costs through to prices, it will therefore face a windfall loss on existing investments and will perceive future investments in the EU as less attractive irrespective of the auctioning/ free allocation policy choice.

Given this context there are three main alternative proposals for policies to address competitiveness concerns:

- **Global sectoral agreements:** In the long run, the ideal solution is for all countries, developed and developing, to be covered by a multi-sector emissions trading system, such as the EU ETS, establishing a carbon price in all major emitting sectors. But if this is not possible for many years, it might still be possible to bring all companies within a specific sector into a global agreement. This could entail developing country firms in that sector (but not others) being part of the EU ETS, or the creation of a sector-specific trading system. Robust sectoral deals are unlikely to be delivered by industry associations alone, and will require developing countries to be willing to impose emissions limits on companies where sectoral agreements apply. But they are likely to be far easier to achieve than an all encompassing trading system agreement.

- **Border carbon price adjustments:** This policy would work by imposing a carbon price on imports into the EU in the most affected sectors. This price could take the form of a tax or could be implemented by requiring importers to purchase EUAs for each tonne of embedded CO_2. In theory this approach has significant attractions. It would enable all sectors in the EU ETS to be covered by 100% auctioning, thus avoiding the emergence of unintended economic rents. It would leave European companies in the covered sectors in the same competitive position as they would have been without the EU ETS, both in respect to marginal production decisions and in respect to new investments. It would allow output prices to reflect carbon costs, thus providing the correct signals to consumers. And it would be a relevant policy response to challenges in electricity dependent sectors, such as aluminium, as well as in sectors where direct emissions are the dominant consideration.

The disadvantages, however, are also significant. Implementing border carbon price adjustments would necessitate the detailed calculation of the embedded CO_2 in multiple different products. It could complicate world trade negotiations. And it would be difficult to place a sensible limit on the number of sectors covered: once the principle was accepted, border price adjustments should logically apply, to different degrees, to all imported products which have embedded CO_2.

- **Free allocation of EUAs**: The alternative approach is to exempt the most vulnerable sectors from the 100% auctioning approach, allocating some EUAs for free in respect to some proportion of current carbon emissions. Variants of this approach can include:
  - Making the free allocation dependent not on existing carbon emissions, but on a benchmark of what emissions would be if best available technology were applied to existing production volumes.
  - Including mechanisms to take free allocations away if production capacity is reduced, thus avoiding the danger that companies close capacity and sell their then surplus EUAs.

  Free allocation, if carefully designed, could help ensure that new investment in the most affected sectors does not move to non-EU countries with weaker or non-existent emission targets. But this approach also has very significant disadvantages:

  - Decisions on the appropriate level of free allocations are as difficult as decisions on the appropriate level of border carbon price adjustments, and as likely to be subject to political lobbying designed to extend the coverage beyond the sectors where significant competitiveness concerns legitimately exist.
  - The difficulty of determining where cost pass through is possible and where not makes it almost inevitable that both windfall economic gains and/or windfall losses will result.
  - Carbon costs will not be reflected in output prices, and so abatement opportunities in downstream customer choices will be missed.
  - It does not provide a solution to the challenges of sectors where electricity costs are the crucial issue, such as aluminium.
  - And while benchmarking and output dependent allocations have an attraction they also introduce further complexity[2].

The decision on appropriate policies to address competitiveness concerns will therefore require careful consideration. The current EC plan is to reach a decision by 2010 on which sectors are vulnerable to significant competitiveness effects and to propose by 2011 an appropriate policy response. It is not within the Committee's remit to propose a specific way forward. But our analysis suggests that:

- Significant competitiveness concerns, and in particular concerns about carbon leakage, apply to a subset (but only a subset) of the sectors shown in Figures 10.1 to 10.4.

- Available policy responses, each in different ways difficult but not impossible to implement, could address these highly sector specific competitiveness concerns within an EU ETS which overall should progress towards auctioning rather than free allocation of EUAs.

2 For example, under simple output dependent allocations a firm might maintain its final output, whilst cutting its intermediate activity (e.g. cement firms could import their clinker instead of producing their own, entailing emissions leakage but without reducing cement output).

3. OPPORTUNITIES IN A LOW-CARBON ECONOMY

The transition to a low-carbon economy will involve changes in technology and consumer expenditure which will result in the disappearance of some existing economic activities and jobs and the emergence of new activities and jobs. The overall impact on employment is likely not to be negative and could be positive. The total impact on income (discussed in detail in Chapter 11: *Economic costs and fiscal implications*) may be slightly negative, but with losses in some sectors offset by potential gains in others.

To assess the likely impact, we distinguish between three categories of economic effects:

(i) Multiple macroeconomic adjustments.
(ii) Negative effects on GDP.
(iii) Emergence of new high-value sectors.

(i) Multiple macroeconomic adjustments

The transition to a low-carbon economy will result in a myriad of adjustments in the balance of economic activity which cannot be and do not need to be described in detail in advance. Consumption of goods and services which are inherently carbon intensive will somewhat reduce and resources will shift to produce those with less carbon and/or switch to other less carbon intense goods and services.

Estimates of possible new jobs created in low-carbon energy production illustrate part of the change that might occur as a result of the transition to a low-carbon economy (Table 10.1). It is important, however, to note that much of the new employment created may not be in energy production, but simply in sectors to which consumption will switch if higher prices encourage people to spend less of their income on high-carbon goods.

Table 10.1 Example estimates of new employment from low-carbon energy production

Low carbon energy sector	Size of opportunity	Source	Assumptions
All renewable energy	160,000 (UK-wide)	BERR. (2008) *Renewable Energy Strategy consultation*	Job creation across all renewable energy sectors (electricity, heat, transport)
Offshore wind	70,000 jobs (UK-wide)	Carbon Trust. (2008) *Offshore wind power: big challenge, big opportunity*	29 GW of offshore wind by 2020
Offshore wind	36,000 - 57,000 jobs (UK-wide)	Bain and Company. (2008) *A closer look at the development of wind, wave and tidal energy in the UK*	27-34 GW of offshore wind by 2020
Marine renewables	7,000 jobs (in Scotland)	The Forum for Renewable Energy Development in Scotland. (2006) *Scottish Renewables Briefing*	Marine accounts for 10% of Scotland's electricity generation by 2020

Source: As given in table

The precise effect on employment of all these changes cannot therefore be predicted in detail at the sectoral level, but the overall macro effect can be predicted with confidence. Provided appropriate macro-economic and labour market policies are pursued there is no reason to believe that overall employment opportunities will reduce. And there is at least a possibility, if increases in fiscal revenue arising from climate policies (whether taxes or auctioning of permits) are offset by decreases of taxation on employment, that the net effect might be slightly to increase the attainable employment rate.

(ii) Negative effects on GDP

It is, however, likely that achieving emissions reductions will have a slight net negative effect on aggregate whole economy productivity and thus income. Some abatement actions will require investment, whether in new energy sources or in energy efficiency improvement, which will deliver a lower rate of return (before subsidy and price of carbon effects) than investments in other sectors of the economy. To the extent that this is the case, GDP growth will be mildly reduced.

It is this effect which is captured in the macroeconomic analysis of the costs of meeting carbon budgets, presented in Chapter 11. This analysis illustrates that costs will be less than 1% of GDP in 2020 (i.e. less than half of annual GDP growth in one from twelve years). In 2050, we estimate that the cost of meeting an 80% emissions reduction target would be of the order 1-2% of GDP (i.e. equivalent to sacrificing GDP growth from one out of forty two years; see Chapter 2: *Meeting a 2050 target*).

(iii) Emergence of new high-value sectors

In some sectors of the economy, however, there may be opportunities for the UK to gain competitive advantage from being a leader in specific technologies with potential for global deployment. To the extent that this is true, the UK will not only create new employment opportunities, but also higher income from high-productivity, high-skilled jobs.

- Countries or economic regions which are early adopters of specific technologies often gain competitive advantage from the creation of self-reinforcing clusters of research, development and manufacturing expenditure. Competitive advantage can sometimes therefore arise as a by product of stretching environmental standards. At the overall European economy level, a commitment to high environmental standards has helped nurture European leadership in a wide range of high-technology sectors. And at national level, specific policy commitments to low-carbon energy development have helped create Danish and German leadership in wind turbine manufacture, and Japanese and German leadership in solar photovoltaic cells.

- One implication of this is that the UK should support ambitious emissions reduction targets at the European level, since this will drive Europe-wide productivity growth. This will benefit the UK economy whether or not UK companies are specifically involved in the relevant technology, both because non-UK companies may develop or manufacture in the UK, or because higher European productivity and incomes will tend to stimulate demand for goods or services in which the UK does have a competitive advantage.

- But it is also possible to identify specific sectors where the UK itself may be well placed to develop competitive advantage if the UK's carbon reduction commitments create strong demand for technical innovation. Key potential sectors are offshore wind energy, wave and tidal, and auto-engines. Development of these and other industries would therefore provide economic benefits to meeting carbon budgets in addition to environmental benefits.

CHAPTER 11:

ECONOMIC COSTS AND FISCAL IMPLICATIONS

The Climate Change Act requires the Committee to take into account 'economic circumstances, and in particular the likely impact of the decision [on carbon budgets] on the economy' and 'fiscal circumstances, and in particular the impact of the decision [on carbon budgets] on taxation, public borrowing and public spending'. In meeting these requirements, we have focused on GDP impacts of carbon budgets, which we have estimated using three alternative models (resource cost, macroeconometric, and general equilibrium). We have also estimated specific fiscal impacts drawing on our analysis of carbon markets (Chapter 4), improved fuel efficiency in transport (Chapter 7) and fuel poverty (Chapter 12).

Our main conclusions are that:

- The macroeconomic impact of meeting carbon budgets in 2020 would be under 1% of GDP. The Committee believes that this cost is affordable and accepts it is necessary if larger climate change costs and consequences are to be avoided.

- There are a number of specific significant fiscal effects of carbon budgets, some positive and some negative. Revenue from auctioned EU ETS allowances could reach £8 billion in 2020, but losses of fuel duty and VED revenue could amount to £4 billion. Overall the impact may be positive by 2020, but mildly negative in earlier years. This reinforces the importance of progressing as rapidly as possible to auctioning rather than free allocation of EU ETS allowances.

We set out the analysis that underpins these conclusions in two sections: macroeconomic impacts of carbon budgets; and fiscal impacts of carbon budgets.

1. MACROECONOMIC IMPACTS OF CARBON BUDGETS

There are four potential ways in which carbon budgets could impact GDP:

- **Higher energy costs** will reflect the need for reallocation of resources to energy production from other sectors of the economy. The resulting net GDP impact will be negative.

- **Energy efficiency improvement** achieved at negative cost in the residential sector will increase disposable income. In the non-residential sector, negative cost energy efficiency improvement will result in reduced costs, particularly for energy-intensive products. Conversely, energy efficiency measures with positive cost (such as many of the road transport measures) will reduce income and increase costs. The overall GDP impact of energy efficiency improvement will depend on the balance between negative and positive cost measures.

- **Lifestyle change** will reduce energy consumption/production, with households reallocating expenditure towards less energy-intensive goods and services; this will have no significant GDP impact.

- **Competitiveness impacts** might ensue for energy-intensive/traded sectors if the UK/EU were to move more quickly in reducing emissions than other countries/regions. We consider competitiveness impacts in detail in Chapter 10: *Competitiveness challenges and opportunities*, where we conclude that the threat is concentrated in sectors that account for a very small proportion of GDP and that competitiveness impacts in these sectors can be offset by appropriate design of adjustments within the EU ETS. The impact of competitiveness effects on GDP is likely therefore to be trivial.

We have used three alternative modelling approaches to capture potential GDP impacts:

- Resource cost modelling which sums cost savings from (negative cost) energy efficiency improvements, and subtracts this from cost penalties (due to positive cost energy efficiency improvement, fuel efficiency improvement, renewable energy, low-carbon power generation, etc.). Essentially this methodology sums the areas under the Marginal Abatement Cost Curves (MACCs) set out in Chapter 5: *Decarbonising electricity generation*, Chapter 6: *Energy use in buildings and industry* and Chapter 7: *Reducing domestic transport emissions*.

- Macroeconometric modelling which accounts for resource costs and second order effects of resource cost increases (e.g. higher energy costs driving a shift of resources from energy-intensive sectors). This type of modelling is based on econometrically estimated historic relationships between prices and quantities. In order to estimate costs using this approach, we have used the Cambridge Econometrics (CE) model (Box 11.1).

- General Equilibrium modelling which also accounts for resource costs and second order effects. In contrast to macroeconometric modelling, general equilibrium modelling assumes the economy adjusts to a new equilibrium in response to higher energy prices, based on theoretical supply and demand functions. We have used the Her Majesty's Revenue and Customs (HMRC) model to estimate costs based on this approach (Box 11.1).

Box 11.1 Alternative macroeconomic modelling approaches

The **Cambridge Econometrics Multisectoral Dynamic Model** of the UK economy (MDM-E3) is used to forecast changes in economic variables, energy demand and resulting emissions in response to a range of environmental policy changes.

The model integrates an energy-environment model (which simulates the UK energy system) with a sectorally disaggregated macroeconomic model of the UK economy. The model uses the accounting relationships of the System of National Accounts and behavioural econometric equations to define the relationship between all of the key variables in the economy (i.e. the price and demand of all current production inputs such as labour, energy and intermediate goods, as well as final goods and services). This allows an assessment of how future environmental policy changes (for example, the introduction of carbon pricing or more expensive renewable energy targets) feed through to changes in energy prices, industry costs and prices, consumer prices and overall demand for goods and services.

The model does not assume that the economy's resources will be fully utilised, or (assuming costly information and bounded rationality) that agents are necessarily able to achieve outcomes that maximise consumer welfare and industry profits. At any given time the economy is considered to be in disequilibrium, with behaviour still adjusting to the consequences of past changes. This makes the model suitable for assessing transitional effects where the economy may not have readjusted to a (theoretical) general equilibrium.

The **HMRC Computable General Equilibrium (CGE) model** is also a sectorally disaggregated model of the UK economy, with explicitly defined linkages in the economy between sectors, the government and households. It uses equations derived from microeconomic relationships which maximise consumer welfare and industry profits, and ensures that (after the economy has adjusted, depending on structural rigidities in the form of factor employment, adjustment costs and time lags) the supply and demand of all factors and products are balanced.

The model has a relatively simple representation of the energy system, distinguishing between industry sectors supplying electricity, oil, gas, coal, nuclear and renewable energy. An environmental extension of the model has been developed for the CCC to allow analysis of changes in economic variables and emissions in response to environmental policy changes (including carbon pricing and a range of abatement measures).

The model describes the behavioural adjustments of the economy back towards a general equilibrium through feedback loops between agents after policies are introduced, incorporating any direct, indirect and induced impacts of relative price changes on the economy. This makes the model suitable for assessing the longer term impact of such policy changes once adjustments back to equilibrium have occurred.

These three modelling approaches result in three estimates of the costs of achieving the recommended Intended budget:

- The resource cost methodology produces a cost estimate of 0.28% of GDP in 2020, resulting primarily from costs incurred in power sector decarbonisation (Table 11.1).
- The CE modelling suggests a GDP reduction of 0.82% in 2020, with the HMRC modelling suggesting a decrease of 0.25% of GDP, close to the estimate from the resource cost modelling. CE's model does not include any automatic mechanism for the economy to return to full resource use. The additional impact in CE's modelling therefore includes effects that might be considered 'transitional'.
- A high fossil fuel price scenario reduces the GDP impact (e.g. the resource cost falls to 0.19% of GDP in 2020), since the cost of moving to lower-carbon energy sources is reduced, and since the cost of energy efficiency improvements is reduced/becomes more negative.

Table 11.1 Resource cost estimate of meeting the Intended carbon budget based on Extended Ambition scenario in 2020

	Cost-saving measures (% of GDP)	Positive cost measures (% of GDP)	Total (% of GDP)
Residential buildings	-0.09%	0.11%	0.02%
Non-residential buildings	-0.05%	0.01%	-0.04%
Industry	-0.03%	0.00%	-0.03%
Transport	-0.01%	0.06%	0.04%
Electricity generation		0.20%	0.20%
Total domestic abatement cost			0.20%
Offset credit purchases (30 $MtCO_2e$ at £13/tCO_2e)			0.02%
Net EUA purchases (25 $MtCO_2$ at £40/tCO_2)			0.05%
Total offset and allowance purchases			0.07%
Total abatement cost			**0.28%**

Source: CCC MACC analysis

Notes: 2020 GDP projected at £1.8 trillion consistent with Budget 2008 forecasts. Figures may not sum due to rounding. Offset credit price may not include all transaction costs; see Chapter 4: *Carbon markets and carbon prices*

These cost estimates are consistent with estimates from previous studies (Box 11.2). The Committee believes that these costs are affordable in the context of an economy where medium-term growth – notwithstanding any short-term macroeconomic considerations – is expected to be at least 2% per annum, with GDP in 2020 likely to be around 30% above current levels; the cost is equivalent to sacrificing around half of one from twelve years' growth.

Box 11.2 Recent studies on macroeconomic impacts of emission reductions in the UK

IPPR. (2007) *80% Challenge: delivering a low-carbon economy*:

- The study explores the costs of meeting a CO_2 emissions reduction target of 80% by 2050, with an interim target of 30% by 2020 (all targets relative to 1990 CO_2 emissions levels). The emissions reduction targets include the UK's share of international aviation emissions, and are achieved through domestic action, with no offset credits purchased from abroad.

- The study uses two models: MARKAL-MACRO (combining the MARKAL model with a simple economic growth model accounting for the impact of carbon prices on energy demands) and a technology cost model developed by the late Professor Dennis Anderson of Imperial College for the Stern Review.

- The MARKAL-MACRO model suggests a cost of 0.5% of GDP by 2020; assuming accelerated energy efficiency take-up, this cost becomes a *saving* of 0.1% of GDP.

- The Anderson model reports costs for 2015 and 2025 of 1.1% and 2.3% respectively. Accelerated energy efficiency brings these costs down to 0.7% and 1.3% of GDP.

Oxford Economics. (2007) *Report on modelling the macroeconomic impacts of achieving the UK's carbon emissions reduction goal*:

- This study assumes that all emissions reductions are achieved by domestic action rather than through purchasing international offset credits. Across a range of sensitivities, achieving a 30% CO_2 emissions reduction by 2020 costs about 1.5% of GDP.

- However, this is based on a relatively conservative estimate of the price elasticity of energy demand – a sensitivity exploring higher elasticity (as might be expected with explicit modelling of energy efficiency measures across a range of sectors, as in the CCC analysis) suggests a reduced cost of about 1% of GDP by 2020.

- Similarly, allowing purchase of CDM offset credits to meet one third of the total emissions reduction effort also lowers the impact, again to about 1% of GDP by 2020.

- This suggests an overall impact of less than 1% of GDP by 2020 when explicitly considering cost-effective energy efficiency options *and* allowing the purchase of offset credits.

- Oxford Economics also modelled the DTI 2006 Energy Review policy package, estimating that a 24% CO_2 emissions reduction in 2020 relative to 1990 levels can be achieved at a cost of 0.2% of GDP, in large part due to explicit consideration of cost-effective energy efficiency measures.

In summary, there are a range of estimates of the GDP impact of emissions reductions. Our estimated GDP impacts for our proposed budgets, which are broadly in line with a 30% emissions reduction through domestic action, with additional effort through international offset credits, are towards the lower end of this range, largely because of our explicit consideration of a number of cost-saving energy efficiency measures.

2. FISCAL IMPACTS OF CARBON BUDGETS

The overall fiscal impact of pursuing emissions reductions is very complex and will change over time. We have not therefore attempted a comprehensive analysis of all the potential direct and indirect effects. Instead we concentrate on identifying the most significant impacts likely to arise as a direct result of the policies used to pursue carbon budgets, and we note the complexities in assessing the overall fiscal impacts of a slightly reduced GDP.

We set the section out as follows:

(i) Increased revenue from the auction of EUAs.

(ii) Reduced fuel duty revenues due to fuel efficiency improvement.

(iii) Reduced VED revenues due to changed car purchase behaviour.

(iv) Purchase of offset credits by the Government.

(v) Support for fuel poor households.

(vi) General fiscal impacts of GDP reduction.

(vii) Synthesis on fiscal impacts.

(i) Increased revenue from the auction of EUAs

Fiscal revenue will increase as EU ETS allowances (EUAs) are increasingly auctioned. The current proposal, made by the EC in January 2008, is that there will be 100% allowance auctioning for the power sector from 2013. For other sectors, we currently expect there will be phased increases in the level of auctioning, with 20% of allowances auctioned in 2013, rising to 100% in 2020.

The UK's auction revenues will be given by its share in total EUAs, proposed to be about 200 $MtCO_2$ in 2020. An estimate of UK revenues can therefore be simply calculated by multiplying this share by the expected carbon price (about £40/tCO_2 in 2020). Auction revenues will be at low levels in the first budget period, and will then rise through the second and third budget periods with the increasing level of auctioning and, to a lesser extent, the increasing carbon price. We estimate that by 2020 auction revenues could be of the order £8 billion[1], although we note that this could be lower depending on the level of auctioning and the carbon price (Box 11.3).

1 All monetary costs in this chapter are in real terms, in 2006 prices.

Box 11.3 Possible auction revenues from the EU ETS

EU ETS auction revenues will depend on the EUA price. The table below shows our forecast carbon price for the central fossil fuel price projection, and the low fossil fuel price projection (included here as a conservative case, since this would reduce the carbon price and hence auction revenues – see Chapter 4: *Carbon markets and carbon prices*).

Table: Central and low-carbon price projections, 2008–2020

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Central carbon price (£/tCO_2)	22	24	25	26	27	29	30	32	33	35	37	38	40
Low carbon price (£/tCO_2)	15	15	16	16	17	17	18	18	19	19	20	21	21

Source: CCC analysis, based on the EC January 2008 proposal.
Note: Chapter 4: *Carbon markets and carbon prices* does not show carbon prices for low fossil fuel price scenarios.

Revenues also depend on the number of the UK's allocated EUAs which are auctioned. At present, we assume there will be 100% auctioning for electricity generators, and 20% auctioned allowances for other sectors in 2013, rising to 100% in 2020. The EC has also stated that some sectors could be exempt from auctioning, due to competitiveness and leakage considerations (as discussed in Chapter 10). The table below illustrates the number of auctioned EUAs with no exempt sectors, and with some exempt sectors. The latter scenario assumes there are 36 million annual free allowances for these sectors throughout Phase III[1].

Table: Number of EUAs auctioned with and without sectors exempt from auctioning

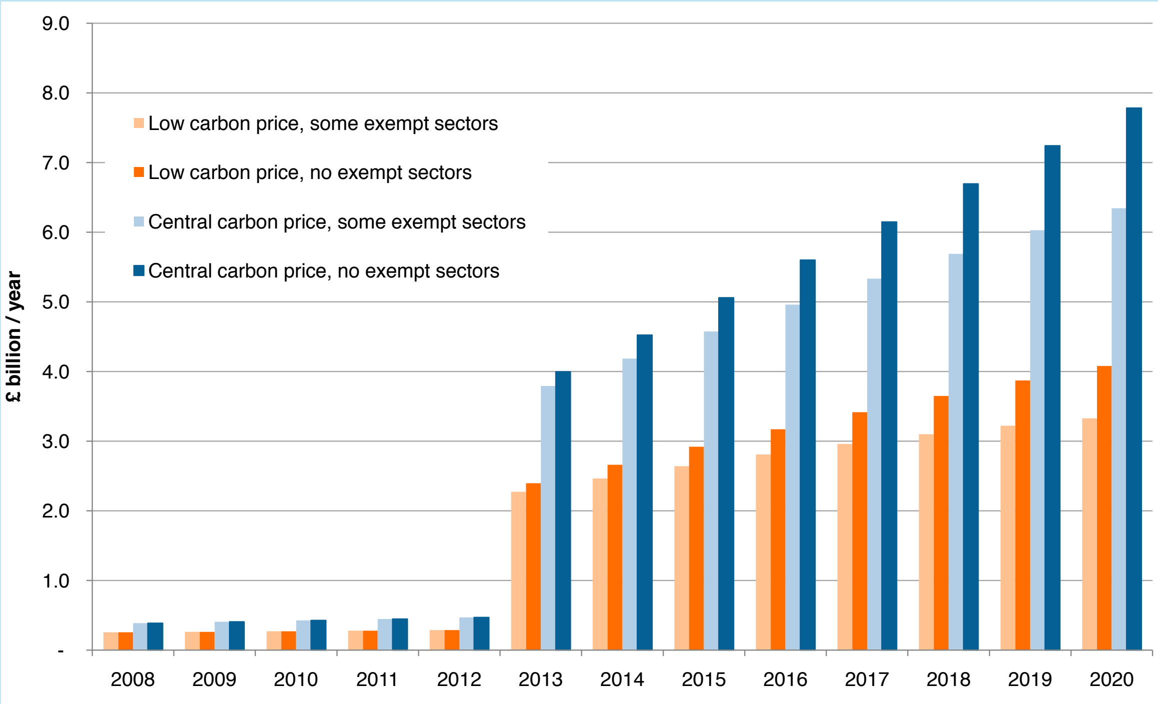
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
UK EU ETS cap (MtCO_2)	246	246	246	246	246	252	243	235	226	218	210	201	193
Auctioned EUAs, assuming some exempt sectors (million)	17	17	17	17	17	132	139	145	149	153	155	157	157
Auctioned EUAs, assuming no exempt sectors (million)	17	17	17	17	17	139	150	160	169	176	183	188	193

Source: CCC assumptions on carbon price and EU ETS cap (assuming EU 30% GHG target in 2020)
Notes: Assumes electricity generators (excluding CHP) receive 44% of allowances, as per Phase II (2008-2012)
Assumes auctioning to aviation sector with same rules as for other (non-electricity) sectors
All figures subject to change on finalisation of EC proposals.

The two scenarios on carbon price and the two scenarios on auctioning lead to four projections of EUA auction revenues. The figure shows that by 2020 auction revenues could reach almost £8 billion (in the central fossil fuel price scenario with no exempt sectors); in the low fossil fuel price scenario with some exempt sectors, this figure is reduced to just over £3 billion.

1 This is an illustrative figure only, based on the number of Phase II allowances allocated to the Cement and Iron & Steel sectors, which were cited by the Carbon Trust. (2008) *EU ETS impacts on profitability and trade* as the most exposed to competitiveness and leakage impacts.

Figure: Projected auction revenues from the EU ETS, 2008–2020



Source: CCC assumptions on carbon price, UK EU ETS cap and proportion of allowances auctioned

(ii) Reduced fuel duty revenues due to fuel efficiency improvement

Chapter 7: *Reducing domestic transport emissions* proposed that the fuel efficiency of new cars could be improved so that emissions fall from current levels of around 160 gCO_2/km to 100 gCO_2/km in 2020. Improvements of this magnitude are required to meet the proposed carbon budgets. Achieving these improvements would, however, have a negative impact on fiscal revenues through reduced fuel duty receipts.

In estimating the potential impact of fuel efficiency improvement, we have made assumptions about what the level of fuel duty receipts would be in a world without carbon budgets, and how this would fall as a result of reduced fuel consumption; we estimate that in a scenario where new car emissions are reduced to 100 g/km, together with emissions reduction for vans and HGVs as set out in Chapter 7, fuel duty receipts would be around £2.5 billion lower than in the reference case in 2020[2].

(iii) Reduced VED revenues due to changed car purchase behaviour

Vehicle Excise Duty (VED) receipts were forecast to be around £6 billion in 2008–09[3]. With unchanged VED bands this could fall over time as fuel efficiency increases. Fuel efficiency increases could result from the introduction of new technologies (e.g. electric cars, plug-in hybrids) or changes in the size composition of the vehicle stock (e.g. through people buying medium rather than large cars). In either case, and under the current VED framework – which we note is likely to change significantly in the period to 2020 – this would result in reduced VED receipts.

2 This reflects an approximate 10% reduction in fuel use across the vehicle stock against our reference case, and assumes the current fuel duty regime (forecast to raise £26 billion in 2008) does not change.

3 According to Budget 2008 projections.

In Chapter 7 we provided an indicative scenario showing how average fuel efficiency for new cars of 100 g/km could be delivered in 2020. This scenario assumed that around 40% of new cars in 2020 would either be electric or plug-in hybrid, and that all new cars would be more fuel efficient than in the reference case. In this scenario, VED would fall for two reasons: electric cars and plug-in hybrids are not currently charged VED; and some more fuel efficient non-electric new cars would move to lower VED bands. We estimate that the combined impact of these two changes could be of the order £1.5 billion reduction in VED in 2020[4].

(iv) Purchase of offset credits by the Government

We have suggested in Chapter 3: *The first three budgets* that the transition between our Interim and Intended budgets could be made in part through the purchase of offset credits (e.g. CDM). In particular, we noted that in moving between budgets the Government may wish to purchase offset credits to meet its non-traded sector budget. The potential cost to the Government if it were to exercise this option can be estimated by multiplying the maximum allowed credit purchase (about 23 $MtCO_2e$ in 2020) by the projected price of offset credits (about £13/tCO_2e in 2020[5] – see Chapter 4): we estimate that this could be up to £300 million in 2020.

(v) Support for fuel poor households

We provide a full discussion of potential impacts from carbon budgets on fuel poor households in Chapter 12 where we argue that:

- Carbon budget impacts on the electricity price could push 600,000 households into fuel poverty. The cost of compensating these households, and those already in fuel poverty, would be up to £160 million in 2022.

- An additional 1.1 million households could be pushed into fuel poverty due to carbon budget impacts on the gas price, if this is increased to finance investments in renewable heat. Offsetting these additional impacts would cost up to £330 million in 2022.

Combining these figures gives a cost of about £500 million in 2022. This indicates the implication for Government spending in a policy scenario where fuel poverty impacts are offset by income transfers or government funded energy efficiency improvements. We note, however, that there are alternative mechanisms for addressing fuel poverty, most notably social tariffs, which are a form of cross subsidy between different groups of energy consumers and are attractive in providing incentives to conserve energy. Given social tariffs, there need not be any fiscal impact from reducing levels of fuel poverty.

(vi) General fiscal impacts of GDP reduction

The carbon budget impact on GDP estimated in Section 1 above will have fiscal impacts, on both revenues and public spending:

- On the revenue side, receipts across the range of taxes (VAT, income tax, corporation tax – all of which yield receipts proportional to the level of economic activity) will fall with GDP. Under assumptions that GDP falls by 0.8% relative to the reference case in 2020 (i.e. the largest of the estimates in Section 1 above), and that tax revenues at that time will account for 40% of GDP, fiscal revenues would fall by about £6 billion[6].

4 This assumes the introduction of about 3 million electric cars and plug-in hybrids by 2020, and the rest of the stock of about 30 million vehicles moving down about one VED band on average, with no change to the VED regime.
5 This price may not include all transaction costs so may be an underestimate; see Chapter 4.
6 Assuming 2020 GDP of £1.8 trillion in line with Budget 2008 forecasts. Tax revenues are currently 38% of GDP, forecast to rise to 39% by 2020 in Budget 2008 forecasts.

- A reduction in GDP, and therefore a reduction in average earnings, will also, however, produce some automatic offsetting reductions in public expenditure. If state transfer expenditures (e.g. pensions or unemployment benefits) are either formally or informally linked to average earnings, they will fall in proportion. Government employment costs will also fall proportionately if the relativity of private and public salaries is unchanged. And the cost of bought-in services will tend to be lower as average earnings throughout the economy are lower.

To an extent therefore any fall in revenue will be offset by a fall in expenditure. The offset is unlikely, however, to be perfect given that:

- There are some categories of public expenditure, in particular public debt service, which do not automatically fall with lower GDP.

- Spending might increase to the extent that there is transitional unemployment as part of the change in sectoral composition of output in response to higher energy prices.

- Tax revenues might fall due to the changing composition of GDP due to meeting carbon budgets. In particular, it is likely that the large investments required in capital-intensive low-carbon power generation could produce an aggregate shift from consumption to investment. The different tax treatment of consumption and investment expenditures would then be important in determining fiscal impacts.

Estimating the full final impact of a fall in GDP resulting from policies to deliver carbon reductions would be extremely complex and we have not attempted such analysis. Given the small scale of the GDP impact, however, and the considerable extent to which revenue reduction is offset by expenditure reduction, it is likely that the net fiscal impact is relatively slight. This impact, moreover, would grow steadily over time, and would be most significant in the third budget, by which time the balance of the direct effects considered above would be likely to have turned positive as a result of EU ETS auction revenues.

(vii) Synthesis on fiscal impacts

In summary, we have identified potentially positive impacts of carbon budgets on Government revenues through auction of EU ETS allowances, and potentially negative impacts through reduced fuel duty and VED receipts, increased spending to purchase offset credits and to provide support for fuel poor households and falling net revenues at lower GDP.

The net of these impacts will depend on a range of factors, all of which are uncertain and some of which are highly uncertain: the level of auctioning in the EU ETS; the UK's auction rights; the carbon price; the pace of fuel efficiency improvement for road vehicles and the technologies upon which this is based; the level of support for fuel poor households; the mechanism chosen to support these households; and the relative impact of GDP changes on tax revenue versus spending.

At a high level there are plausible scenarios where the net fiscal impact might be negative in the first and second budget periods, given low levels of auctioning in the EU ETS and possible spending to support the fuel poor. Further out in time, there are plausible scenarios where the net impact might become positive provided the EU ETS moves to 100% auctioning and given carbon prices in line with our forecasts.

Given the uncertainties involved, we do not attempt to put a specific value on the net impact, either for individual years or groups of years under the same budget. The total scale of any negative impact, however, appears small enough to be manageable, given in particular the potential to divert from the assumption that rates of fuel duty and VED will remain unchanged.

CHAPTER 12:

FUEL POVERTY IMPLICATIONS

The Climate Change Act requires the Committee to take into account 'social circumstances, and in particular the likely impact of the decision [on carbon budgets] on fuel poverty'. Fuel poverty impacts could occur due to electricity price increases to reflect carbon prices and the costs of funding renewable power generation. In addition, higher gas prices that could be required to fund renewable heat would have consequences for fuel poverty. Working in the other direction, energy efficiency improvement would reduce energy bills and hence reduce fuel poverty.

In undertaking our analysis, we have adopted the Government's definition of fuel poverty: a household is regarded as being in fuel poverty if it must spend more than 10% of income on energy in order to maintain an adequate standard of warmth. The Government's most recent estimate is that there were 3.5 million fuel poor households in 2006, with a projection that more than 1 million additional households may have entered fuel poverty between 2006 and 2008.

We have carried out analysis using a model developed for us by the Buildings Research Establishment (BRE). We have first developed a reference scenario where there are no carbon budgets and therefore no related impacts on energy prices. We have then modelled scenarios where there are carbon budget impacts on the electricity price and the gas price, in each case estimating the resulting increase in the number of fuel poor households. And we have considered the reduction in the number of fuel poor households achievable through energy efficiency improvement.

Based on this analysis, our key messages are:

- Electricity price impacts of carbon budgets could increase the number of fuel poor households by 600,000 in 2022. Gas price impacts could further increase this number by 1.1 million households by 2022.

- The cost of taking these fuel poor households back out of fuel poverty and mitigating impacts due to higher electricity and gas prices on those already in fuel poverty would be of the order £500 million annually.

- There is scope to remove almost 400,000 households from fuel poverty through energy efficiency improvement.

- Continuation of current arrangements where costs of energy efficiency improvement are added to energy bills could increase the number of households in fuel poverty by over 400,000, more than offsetting the initial gain. Strengthening of existing policy to provide increased income transfers or introduction of new social tariffs may therefore be required, to offset impacts of higher energy prices and higher energy bills to finance energy efficiency investments.

- Social tariffs (i.e. higher marginal prices beyond a certain per household minimum) have particular attractions since they would simultaneously address fuel poverty effects and increase price incentives for energy saving measures by middle and higher income households.

We set out the analysis that underpins these messages as follows:

1. Trends in fuel poverty.

2. Reference scenario fuel poverty impacts.

3. Fuel poverty impacts due to higher electricity and gas prices.

4. Fuel poverty reductions due to energy efficiency improvement.

5. Fuel poverty consequences from the Supplier Obligation and policy instruments to address fuel poverty.

6. Synthesis and recommendations.

1. TRENDS IN FUEL POVERTY

Fuel poverty is a key issue, reflected in the Government's target to eradicate fuel poverty in England by 2016, with an interim target to eradicate fuel poverty in vulnerable households (those with a disabled person, a person over 60, or a child under 16) by 2010. The national authorities have their own targets: for Northern Ireland and Scotland, this means ending fuel poverty by 2016, and for Wales by 2018.

Fuel poverty is driven by electricity, gas and other domestic fuel (oil, coal) prices, together with household energy efficiency and income. As electricity, gas and other domestic fuel prices increase, energy expenditure increases, and more households become fuel poor. Conversely, as energy efficiency improves and/or incomes increase the number of fuel poor households falls.

We now consider:

(i) Trends in electricity and gas prices.

(ii) Trends in household energy consumption.

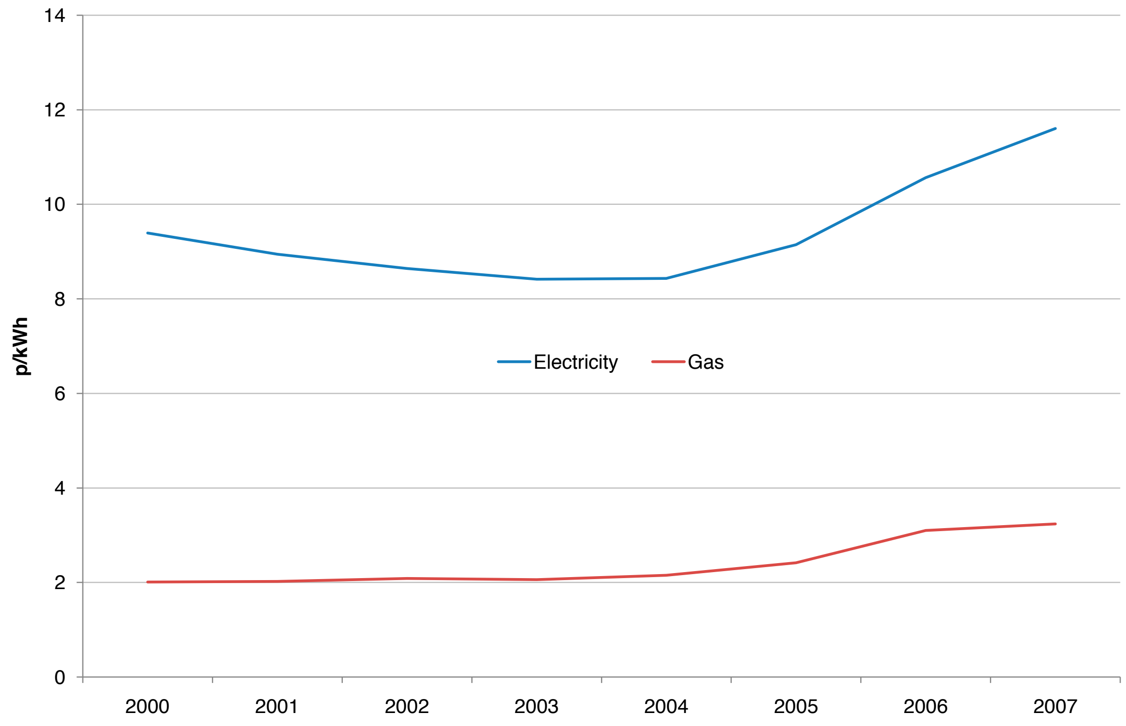
(iii) Trends in household income.

(iv) Trends in fuel poverty.

(i) Trends in electricity and gas prices

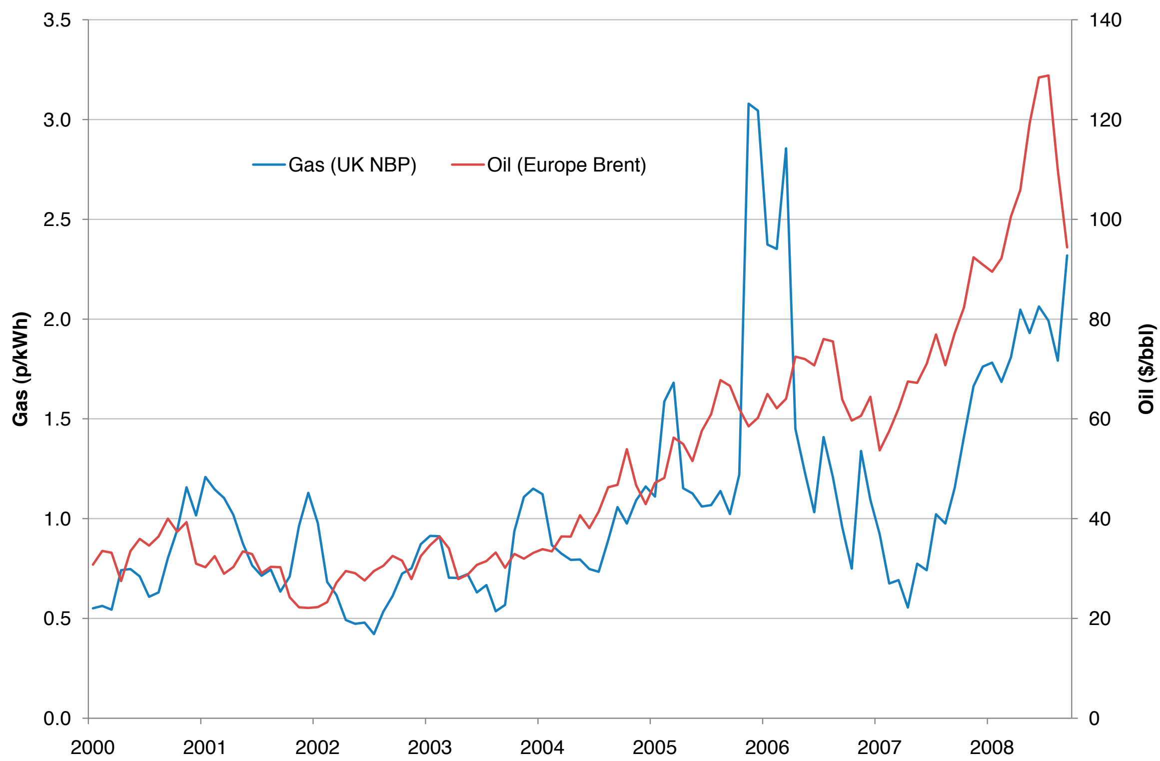
After a number of years of price stability, residential electricity prices have increased by an average 11% annually in real terms over the period 2004-07, with residential gas prices increasing by an average 15% annually in real terms over the same period (Figure 12.1). Both these changes have been driven by wholesale gas price increases, which impacts the residential gas price directly, and the electricity price indirectly through raising the cost of gas-fired power generation (Figure 12.2). Wholesale gas price increases have in turn been driven by oil price increases; standard practice in the gas industry is to index gas contracts on the oil price.

Figure 12.1 Residential electricity and gas prices, 2000-2007



Source: DECC *Quarterly Energy Prices* (2007 prices)

Figure 12.2 Wholesale gas and oil prices, 2000-2008



Source: Monthly gas price (2007 prices) from Platts; Monthly oil price (2007 prices) from US Government Energy Information Administration

In addition to this market-driven effect, current electricity and gas prices are already higher than they would otherwise be due to various policies aimed at reducing carbon emissions:

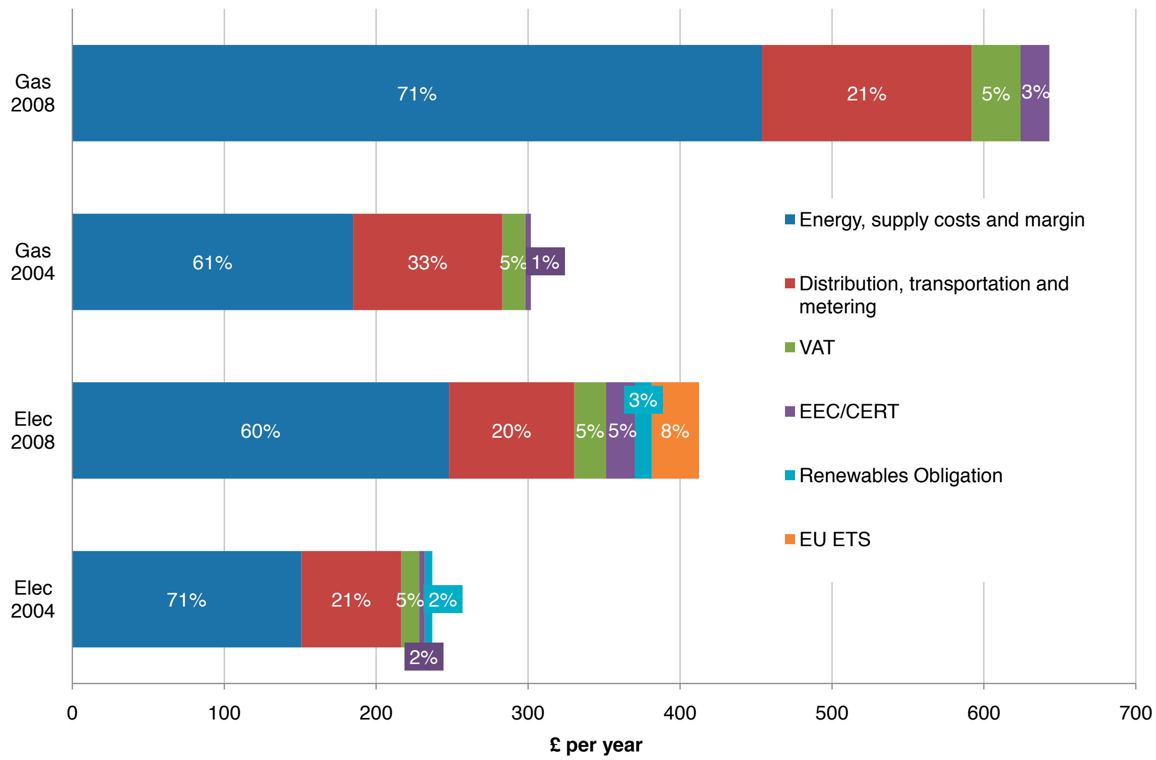
- The electricity price includes the EU ETS carbon price, around £20/tCO_2 in the first half of 2008, which translates to around 1p/kWh (see Chapter 4: *Carbon markets and carbon prices*).

- The electricity price also includes around 0.3p/kWh to finance the cost of the Renewables Obligation (see Chapter 5: *Decarbonising electricity generation*).

- Gas and electricity prices are around 3-5% higher to cover costs associated with delivering energy efficiency improvements under the Carbon Emissions Reduction Target (CERT), the forerunner of the Supplier Obligation (see Chapter 6: *Energy use in buildings and industry*).

Comparing energy bill impacts due to gas price movements and carbon policies, however, shows that the impact of emissions reductions policies has been relatively small to date (Figure 12.3). The main driver of any increase in fuel poverty must therefore have been the changing fossil fuel prices rather than carbon policies.

Figure 12.3 Breakdown of household gas and electricity bill, 2004 and 2008



Source: Ofgem (nominal prices)

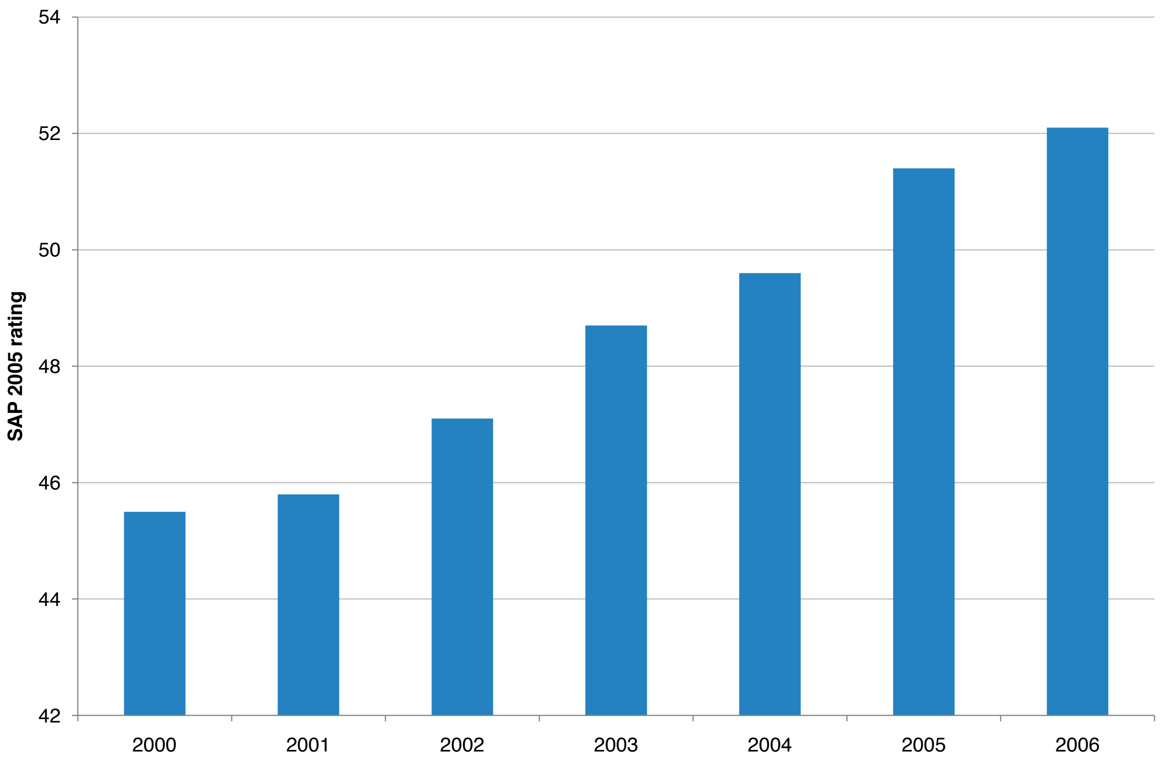
(ii) Trends in household energy efficiency

We discuss trends in household energy consumption in Chapter 6, where we note that household demand for gas has remained broadly flat in recent years, whilst electricity demand has increased by around 10% since 1990. Going forward, we project that gas demand will fall but that electricity demand will increase by over 10% in the period to 2020.

Increasing household energy consumption could have contributed to increasing energy expenditures by poorer households. But this does not necessarily translate to an increase in fuel poverty given the way that fuel poverty is defined in the UK. Specifically, fuel poverty is measured based on a *notional* level of energy consumption that would be required to provide a minimum level of household comfort.

This defined minimum level of comfort has not been increased in line with rising energy consumption. However, improved energy efficiency means reduced energy consumption is required to meet it. We noted in Chapter 6 that energy efficiency has been improved due to better insulation and more efficient boilers (Figure 12.4); BERR analysis suggests that this may have led to a small reduction in the number of fuel poor households[1].

Figure 12.4 Average household energy efficiency, 2000-2006



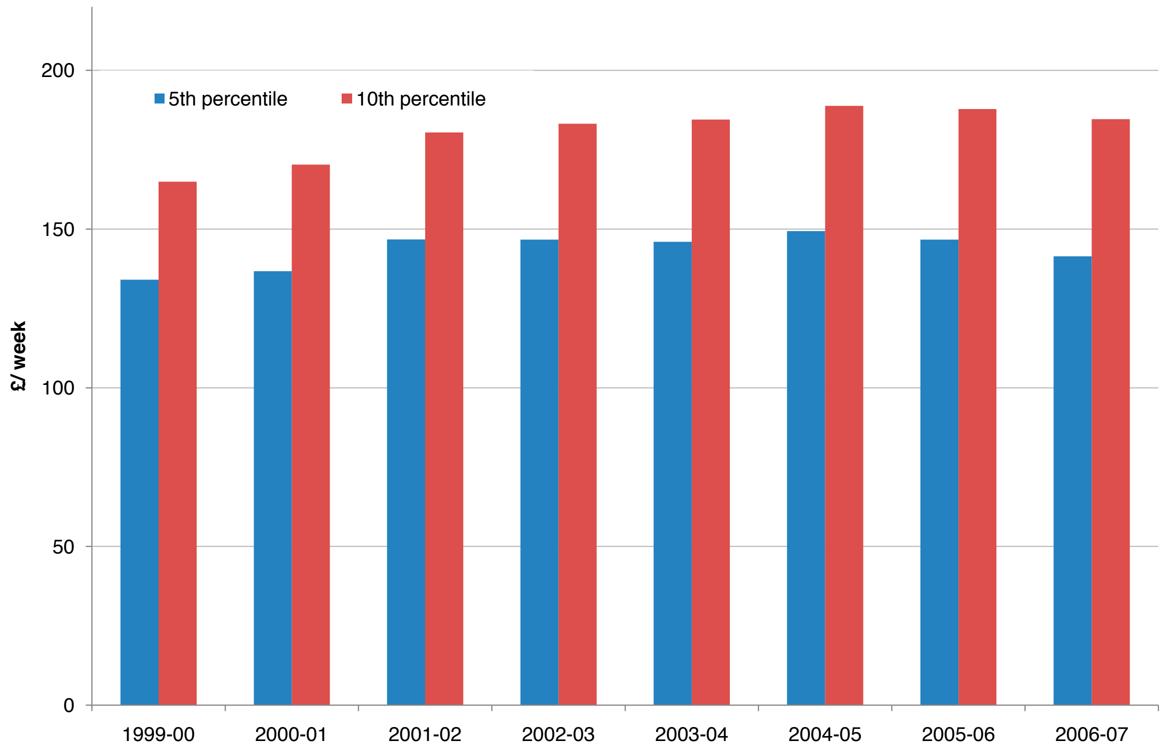
Source: Buildings Research Establishment (using the Government's Standard Assessment Procedure (SAP) 2005 rating of energy efficiency)

1 BERR. (2008) *UK Fuel Poverty Strategy 6th Annual Progress Report*

(iii) Trends in household income

Average household income (before housing costs) growth averaged 1.9% annually for the period 1999-00 to 2006-07 (in real terms); this is much less than real energy price increases over the same period, and has therefore not been sufficiently high to offset the fuel poverty impacts of rising prices. This applies even more to poorer households, for whom income growth has been lower than the average for the population. Figure 12.5 shows that the incomes of the poorest 5% of households grew at an annual rate of 0.8% over the period 1999-00 to 2006-07, with annual income growth of 1.6% for the poorest 10% of households over the same period.

Figure 12.5 Weekly household income, for poorest 5% and 10% of households (GB), 1999-00 to 2006-07



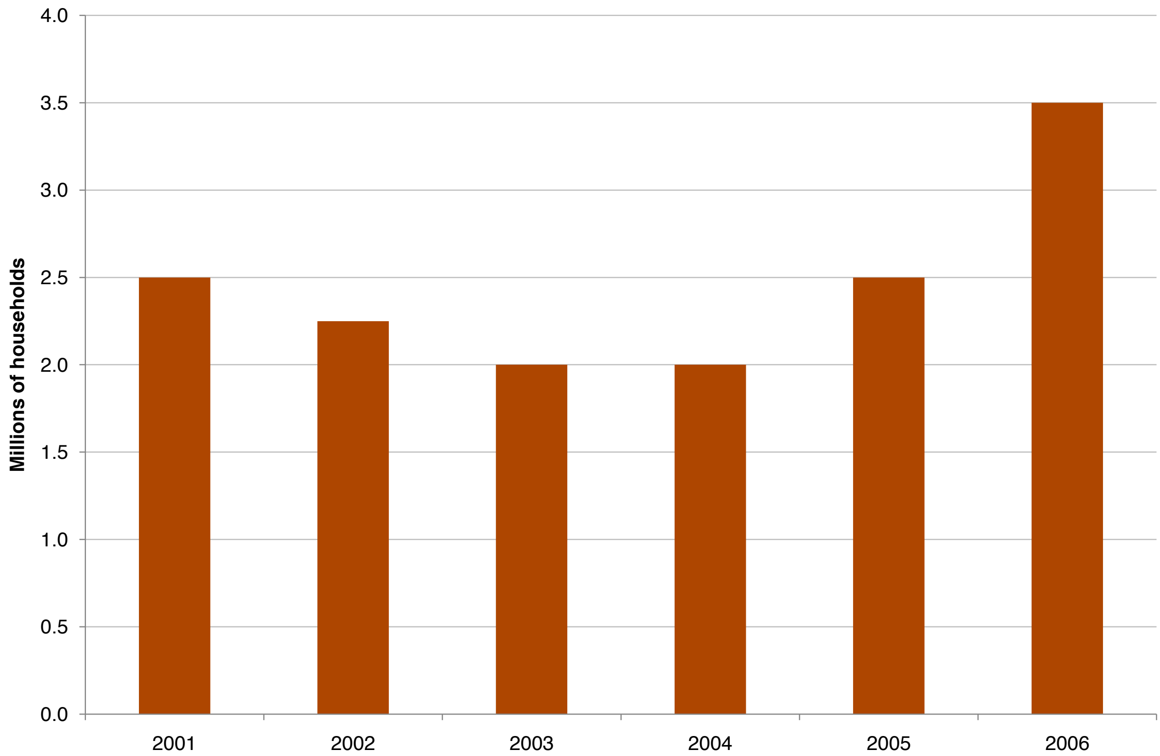
Source: IFS (2006-07 prices, before housing costs)

(iv) Trends in fuel poverty

The number of households estimated by the Government to be in fuel poverty in 2006 is 3.5 million, with a projection that more than 1 million households may have entered fuel poverty in the period between 2006 and 2008. These figures represent a significant increase relative to 2004, when there were 2 million households in fuel poverty (Figure 12.6).

Drawing together the arguments above, the main driver of increased fuel poverty has been increased fossil fuel prices feeding through to residential electricity and gas prices. Though this has been partially offset by energy efficiency improvement and income growth, these impacts have been relatively small compared to energy price increases.

Figure 12.6 Number of UK households in fuel poverty, 2000-2006



Source: BERR. (2008) *UK Fuel Poverty Strategy 6th Annual Progress Report*

2. REFERENCE SCENARIO FUEL POVERTY IMPACTS

Our analysis of potential fuel poverty impacts from meeting carbon budgets starts by defining a reference scenario, under which we estimate the number of fuel poor households to 2022 in a world without carbon budgets and related policies. We then use this as a counterfactual against which to compare fuel poverty impacts from higher electricity and gas prices that result from carbon budgets.

In defining a reference scenario, we make assumptions about wholesale and retail energy prices, together with household income and energy efficiency improvement (Box 12.1). In a central fossil fuel price scenario with annual income growth of around 2% annually and energy efficiency improvement as in our reference projections in Chapter 6, the number of fuel poor households falls to 2.1 million in 2022 (Table 12.1); the drivers of this reduction are rising income and energy efficiency improvement rather than falling energy prices.

Table 12.1 Fuel poverty in the reference scenario, 2006-2022

Year	Number of UK households in fuel poverty (million)
2006	3.5
2012	3.1
2017	2.5
2022	2.1

Source: BRE modelling, based on CCC assumptions

Box 12.1 Assumptions for the reference scenario

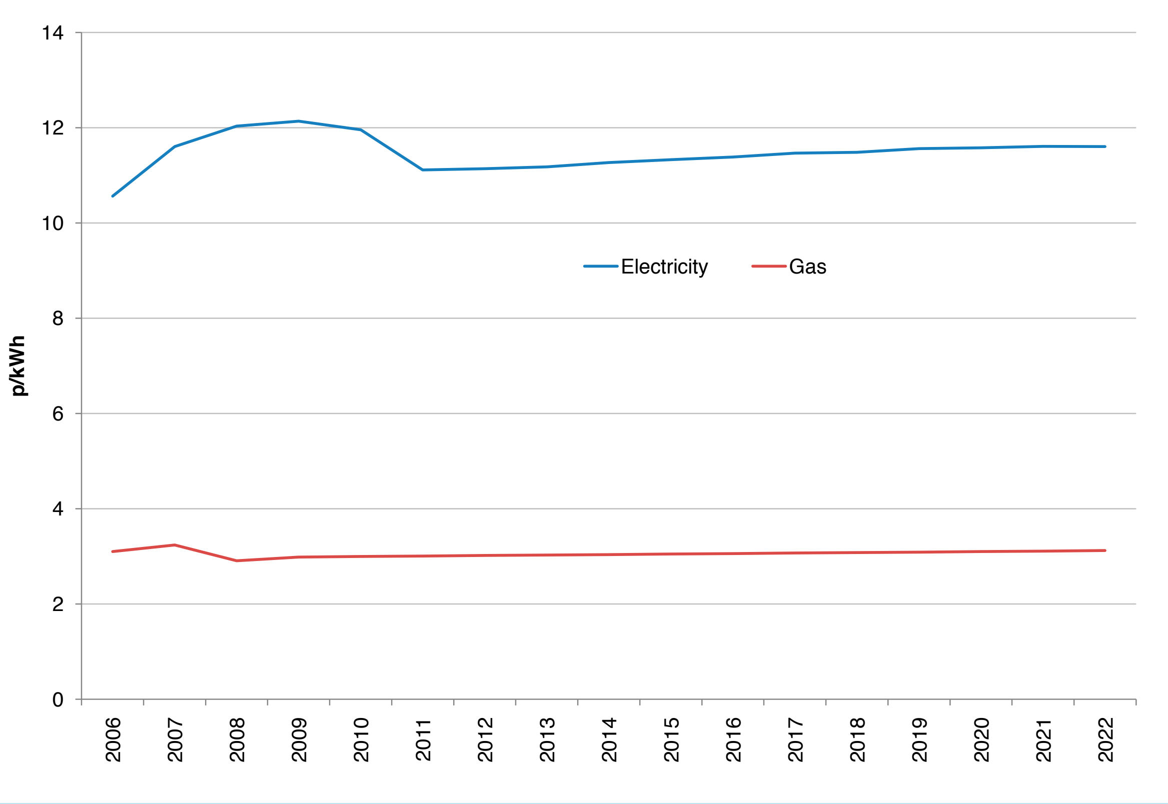
The reference scenario is based on the central case fossil fuel price projection in Chapter 3: *The first three budgets*. It results in the following (also see Figure below).

- residential electricity prices rise to 11.6 p/kWh in 2022, from 10.6 p/kWh in 2006 (in 2007 prices)
- residential gas prices rise to 3.12 p/kWh in 2022, from 3.10 p/kWh in 2006 (in 2007 prices).

In addition, we assume that:

- real disposable household incomes rise at an average growth rate of 2.3% per annum between 2006 and 2022, in line with our core energy modelling assumptions
- energy efficiency measures are taken up in households at a rate consistent with our reference case assumptions, as described in Chapter 6: *Energy use in buildings and industry.*

Figure: Residential electricity and gas prices in reference scenario, 2006-2022



Source: DECC energy modelling, based on CCC assumptions.

3. FUEL POVERTY IMPACTS DUE TO HIGHER ELECTRICITY AND GAS PRICES

Meeting carbon budgets will potentially increase the number of fuel poor households both through its impact on the electricity price (via the carbon price, and the cost of financing significant levels of investment in renewable electricity; see Chapter 5) and the gas price [2] (via the cost of financing investment in renewable heat; see Chapter 6).

Focusing first on the electricity price impact, we estimate that meeting carbon budgets will increase electricity prices by around 25% in 2022 relative to a counterfactual where there is no carbon constraint; this would increase the number of fuel poor households by around 600,000 in 2022 (i.e. the end of the third budget period) relative to our reference scenario (Table 12.2).

We estimate the cost of taking these households back out of fuel poverty, and of mitigating impacts on those already in fuel poverty, as the change in electricity bills of fuel poor households (based on the electricity price increase and average electricity consumption of fuel poor households) multiplied by the number of households in fuel poverty after the price change[3]. The cost of offsetting a 25% electricity price increase on the fuel poor households is therefore around £160 million in 2022.

Table 12.2 Fuel poverty under increased electricity prices, 2006-2022

Year	Number of UK households in fuel poverty (million)	Cost of compensating existing and incremental fuel poor households (£ million/year)
2006	3.5	
2012	3.5	110
2017	3.0	140
2022	2.7	160

Source: BRE modelling, based on CCC assumptions

Turning to gas price impacts, the draft Renewable Energy Strategy (RES) estimates that gas prices could increase by 18-37% by 2020 in order to finance required investment in renewable heat; we estimate that a 28% increase (i.e. the mid-point of this range) could increase the number of households in fuel poverty by a further 1.1 million (i.e. in addition to those households in fuel poverty due to electricity price increases) in 2022 (Table 12.3).

Table 12.3 Fuel poverty under increased electricity and gas prices, 2006-2022

Year	Number of UK households in fuel poverty (million)	Cost of compensating existing and incremental fuel poor households (£ million/year)
2006	3.5	
2012	3.6	140
2017	3.6	320
2022	3.8	490

Source: BRE modelling, based on CCC assumptions

2 We assume this impact is also applied to coal and oil heating fuels. To the extent that this does not ensue in practice, our analysis will overestimate numbers in fuel poverty.

3 This figure is therefore the cost of restoring welfare of fuel poor households. We note, however, that there are complexities around whether it would restore the number of fuel poor households, given the current legal definition of fuel poverty.

We estimate the cost of mitigating electricity and gas price impacts together as the change in energy bills of fuel poor households (based on the change in prices and average electricity and gas consumption of fuel poor households) multiplied by the number of fuel poor households after the price changes. The cost of offsetting increases of 25% in the electricity price and 28% in the gas price on the fuel poor households is therefore around £500 million in 2022.

4. FUEL POVERTY REDUCTIONS DUE TO ENERGY EFFICIENCY IMPROVEMENT

There are several alternatives for addressing these fuel poverty impacts:

- Improving the energy efficiency of fuel poor households and therefore reducing energy bills.
- Transferring income to fuel poor households, or designing tariffs to provide some subsidised consumption.

We now consider energy efficiency improvement, and discuss income transfers and social tariffs in Section 5 below.

We provide analysis of measures to improve energy efficiency in the residential sector in Chapter 6. We show that there are a range of measures with associated negative costs (i.e. where any initial outlay is more than offset by energy bill reductions) including: loft and cavity wall insulation; purchase of more efficient appliances; and replacement of old inefficient boilers.

Implementation of these measures could potentially reduce the number of fuel poor households given the reduced energy consumption that would be required to meet the comfort level upon which fuel poverty is defined, and would be attractive both from financial and environmental perspectives:

- From a financial perspective, energy efficiency improvement can reduce fuel poverty at a lower cost than income transfers, as it can often be achieved at negative cost.
- From an environmental perspective, emissions are lower when energy efficiency is improved.

We have therefore estimated the number of households that could be taken out of fuel poverty through implementation of energy efficiency improvement:

- We have first modelled a situation where energy efficiency measures are targeted at those households in fuel poverty in a world where meeting carbon budgets results in higher electricity prices but not higher gas prices; this results in almost 300,000 households being taken out of fuel poverty in 2022 (Table 12.4).
- In a world where meeting carbon budgets results in both higher electricity and gas prices, energy efficiency measures offer potential to take almost 400,000 households out of fuel poverty in 2022 (Table 12.4).

Table 12.4 Fuel poverty with energy efficiency improvements, 2006-2022

Year	Number of households in fuel poverty (million) due to:			
	Electricity price increases	Electricity price increases and efficiency measures	Electricity and gas price increases	Electricity and gas price increases and energy efficiency measures
2006	3.5	3.5	3.5	3.5
2012	3.5	3.3	3.6	3.4
2017	3.0	2.8	3.6	3.3
2022	2.7	2.4	3.8	3.5

Source: BRE modelling, based on CCC assumptions

Our conclusion from this part of the analysis is that there is a significant opportunity to mitigate fuel poverty impacts through energy efficiency improvement, and that this is attractive as a cost-effective form of mitigation, with climate benefits.

5. FUEL POVERTY CONSEQUENCES FROM THE SUPPLIER OBLIGATION AND POLICY INSTRUMENTS TO ADDRESS FUEL POVERTY

The main existing policy instrument to achieve energy efficiency improvement is the Supplier Obligation, discussed in Chapter 6. In principle therefore, this could be a lever for addressing fuel poverty. In practice, however, this is unlikely to be the case, particularly further out in the period to 2022.

It is important to note that early stages of the Supplier Obligation have to an extent been targeted at fuel poor households (e.g. 40% of required energy efficiency improvement must currently come from 'Priority Group' households[4]). Energy efficiency improvements are paid for by spreading any upfront costs across all consumers. The Supplier Obligation may therefore be seen as having been a means for subsidising energy efficiency improvement for fuel poor households.

Going forward, however, it is not clear that this will continue to be the case. Specifically, as the level of ambition in the Supplier Obligation increases over time, it will not be possible to deliver required emissions reductions through targeting of fuel poor households. As energy efficiency improvements are implemented more widely under the Supplier Obligation, this will therefore cease to be a mechanism for subsidising the fuel poor. In effect, each household will bear the cost of energy efficiency improvement as a larger proportion of the total housing stock is covered, and associated costs reflected in energy bills.

We have estimated the fuel poverty impact that would ensue if costs associated with the Supplier Obligation were to be passed through to consumers on an ongoing basis. Based on our assumption that this would add 0.6p/kWh to electricity prices and 0.2p/kWh to gas prices, we estimate that this would increase the number of fuel poor households in 2022 by over 400,000 (Table 12.5).

Table 12.5 Fuel poverty with Supplier Obligation (SO) costs, 2006-2022

Year	Number of UK households in fuel poverty as a result of electricity and gas price increases, and energy efficiency measures (million)	Number of UK households in fuel poverty as a result of electricity and gas price increases, and energy efficiency measures, plus SO costs to consumers (million)
2006	3.5	3.5
2012	3.4	3.9
2017	3.3	3.8
2022	3.5	3.9

This impact could be avoided under an alternative financing mechanism for the Supplier Obligation, where consumers bear more/all of the costs associated with energy efficiency improvement (see Chapter 6 for a discussion of levers for increasing consumer demand for energy efficiency improvement), and where energy efficiency improvement in poor households is financed under a separate targeted mechanism.

We note, however, in Chapter 6 that financial incentives may be required for the Supplier Obligation to meet its targets. Moving away from the current arrangements could therefore undermine incentives and would not be desirable for this reason.

4 Priority Groups consist of poor, elderly and vulnerable households

The alternative would be to continue the current arrangements, and to address fuel poverty impacts through alternative policy options of income transfers or social tariffs (Box 12.2). We note that social tariffs may have attractive properties from a climate strategy perspective, given that they have high marginal prices and thus provide incentives for energy conservation. We have not, however, considered these alternatives in detail, and intend to return to this as part of our future work programme.

Box 12.2 Example of a social tariff

A multi-block tariff can be designed in such a way as to subsidise the first block of energy usage, with an increase in the price for subsequent blocks of usage. This could tackle fuel poverty on the assumption that fuel poor households use less energy than richer households. There is evidence that this is the case, as presented in the following table which shows increasing consumption of electricity and gas across a range of income deciles:

Table: Electricity and gas usage by income decile

Income decile	1	2	5	6	8	10
Electricity (kWh/year)	1,800	2,611	4,199	4,785	6,356	11,086
Gas (kWh/year)	6,050	11,193	19,409	22,119	28,497	47,221

Source: Centre for Sustainable Energy (2007). *Assessing the social impacts of a Supplier Obligation*

Two-block tariff structures are currently offered in the energy market. A current typical electricity tariff is illustrated in the following table, which shows energy bills for households in different income deciles based on a higher marginal price for consumption up to 900 kWh/year, with a lower marginal price beyond that threshold.

Table: Electricity expenditure with current tariff structure

Income decile	1	10	Revenue to electricity supplier
Block 1 expenditure (20 p/KWh for the first 900 kWh/year)	180	180	
Block 2 expenditure (10 p/kWh for usage above 900 kWh/year)	90	1,019	
Total electricity bill (£/year)	270	1,199	1,469

Source: CCC calculations, with tariff structure based on a range of residential electricity supplier tariffs

An alternative 'social' tariff structure with increasing costs per kWh of electricity consumed could be used to lower the average electricity bill of the lowest income decile, whilst increasing that of the highest income decile and ensuring approximately the same revenue to the electricity supplier, as demonstrated below:

Table: Electricity expenditure with social tariff structure

Income decile	1	10	Revenue to electricity supplier
Block 1 expenditure (8 p/KWh for the first 900 kWh/year)	72	72	
Block 2 expenditure (12 p/kWh for usage above 900 kWh/year)	108	1,222	
Total electricity bill (£/year)	180	1,294	1,474

Source: CCC calculations, with tariff structure based on CCC assumptions

6. SYNTHESIS AND RECOMMENDATIONS

The analysis in Sections 2–5 above may be summarised as follows (Table 12.6):

- Electricity and gas price impacts from meeting carbon budgets could increase the number of fuel poor households by 1.7 million in 2022 to 3.8 million.
- Compensating these households could cost up to £500 million annually.
- Energy efficiency improvements have the potential to take almost 400,000 households out of fuel poverty in 2022.
- Financing energy efficiency improvements under current arrangements would, however, exacerbate fuel poverty.
- Income transfers and/or social tariffs will be required to offset fuel poverty impacts.

Table 12.6 Synthesis of fuel poverty impacts, 2006-2022

Year	Number of households in fuel poverty (millions) due to:					
	Reference projection	Electricity price increases	Electricity price increases and energy efficiency measures	Electricity and gas price increases	Electricity and gas price increases and energy efficiency measures	Electricity and gas price increases and energy efficiency measures, and SO costs to consumers
2006	3.5	3.5	3.5	3.5	3.5	3.5
2012	3.1	3.5	3.3	3.6	3.4	3.9
2017	2.5	3.0	2.8	3.6	3.3	3.8
2022	2.1	2.7	2.4	3.8	3.5	3.9

Source: BRE modelling, based on CCC assumptions

The analysis presented in this chapter focuses on the impacts of carbon budgets on fuel poverty using central fossil fuel price projections. Higher fossil fuel prices in the central case could further increase the total number of people in fuel poverty (see Technical Annex). Their implication for the impact of carbon budgets is however complex. A higher gas price would mean that the cost of subsidy required to stimulate renewable electricity and heat production would be less and the impact of recovery via energy bills reduced. But if increased fossil fuel prices imply a higher coal to gas price differential, this will increase the carbon price, and thus the incremental impact of carbon budgets on electricity prices. In turn, however, this will increase Government revenues from auctioned emissions permits, providing more resources which could potentially be used to offset fuel poverty effects. Overall higher fossil fuel prices must tend to reduce the cost of moving to a low-carbon economy.

CHAPTER 13:

ENERGY SECURITY OF SUPPLY

The Climate Change Act requires the Committee to take into account 'energy policy, and in particular the likely impact of the decision [on carbon budgets] on energy supplies', for which we focus on 'security of supply'. That term is commonly used in two distinct senses, both of which could be relevant to optimal carbon emission reductions. The term covers:

- Technical security of supply (i.e. the degree of certainty that energy supply will be available immediately and on demand when customers want it). The main relevance of this issue in the context of carbon budgets is as it relates to electricity supply (rather than to heat or transport fuel supply), with security potentially undermined by the intermittency of some renewable sources, or by failure to invest adequately in generating capacity given additional uncertainties introduced by levers to deliver carbon budgets.

- Geopolitical and economic security of energy supply (i.e the extent to which the UK can be free of reliance on sources of energy which are geopolitically insecure or inherently and harmfully volatile in price). This issue relates to heat and transport fuel supply as much as to electricity.

This chapter considers these two aspects of security of supply in turn. Its conclusions are that:

- Concerns about technical security of supply do not undermine the case for renewables electricity expansion on the scale outlined in the draft Renewable Energy Strategy (RES), provided sufficient back-up and balancing capacity is supplied.

- Geopolitical and economic security of supply concerns create a significant additional rationale for pursuing a low-carbon economy through improved energy efficiency and the development of renewables, nuclear energy, and carbon capture and storage (CCS).

1. TECHNICAL SECURITY OF ELECTRICITY SUPPLY

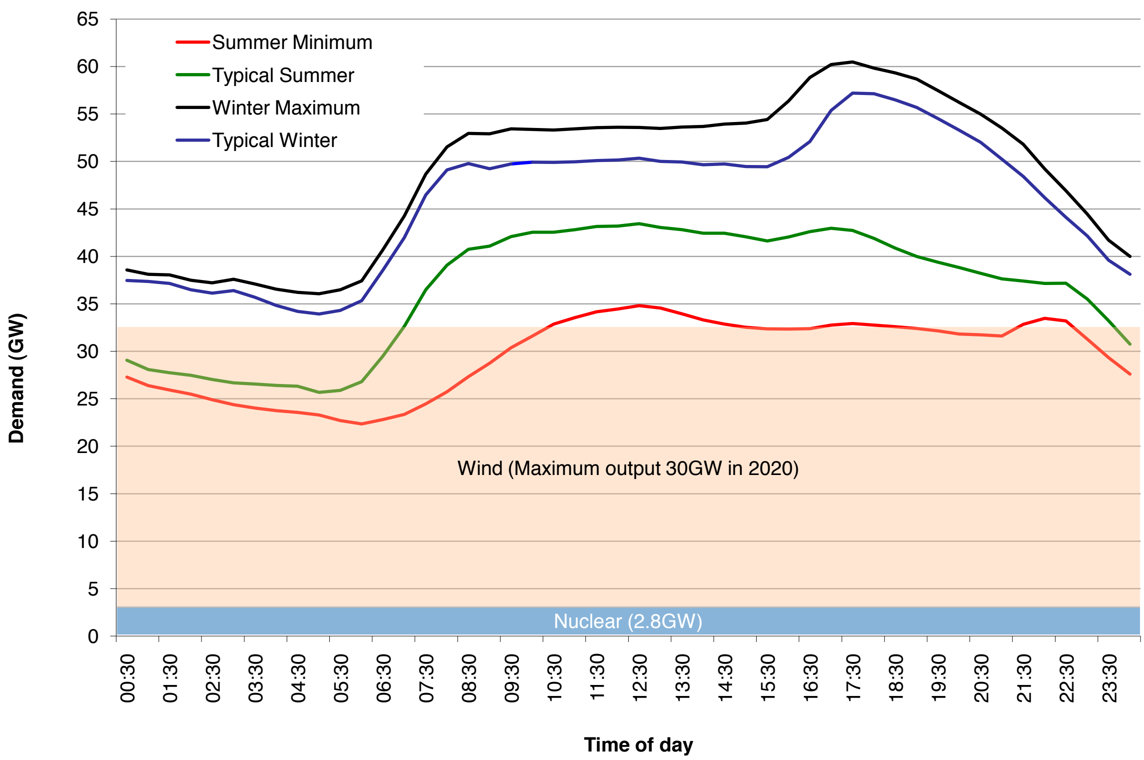
The development of renewable electricity, and in particular of wind power, could theoretically have implications for security of supply in two ways: (i) directly through the inherent intermittency[1] of the electricity supply generated; and (ii) indirectly via the impact of renewable energy on prices (and expectations of prices) and thus on the attractiveness of investment in other required generation sources.

(i) Intermittency

Many potential sources of renewable energy are not intermittent or are intermittent in a predictable fashion. Biomass based electricity production is no more intermittent than fossil fuel based generation. Tidal stream energy sources are much less variable than wind. Tidal range energy (e.g. the Severn Barrage) would vary by time of day, but in a fashion which is precisely predictable in advance.

But wind power, which over the period of the first three budgets is likely to account for the vast majority of the UK's growing renewable energy production, is inherently and significantly variable. The seasonal aspect of this supply variability is usefully correlated with seasonal demand (higher in winter than summer), but hour by hour and day by day, wind power output will not be correlated with the level of customer demand. If the wind power capacity plans in the draft Renewable Energy Strategy are put in place, by 2020 wind power on a windy day in summer could, along with nuclear base load, provide almost all the energy needed even at peak times. On a still day in winter, however, the bulk of electricity demand, not only at peak but for most of the day, would have to be met by other sources (Figure 13.1).

Figure 13.1 GB electricity demand profile in summer and winter 2007-2008



Source: National Grid Seven Year Statement 2008; Nuclear (de-rated) and Wind (full-rated) capacity from DECC energy model

1 Intermittency refers to the tendency of some power sources to be unintentionally unavailable.

It will therefore be essential both to add back-up capacity to the system and to have this capacity available for system balancing in order to maintain security of supply with high levels of intermittent generation. In the very short term (minutes) limited balancing can be provided by pumped storage, but to deal with significant hour by hour and day by day variations significant fossil fuel based back-up and balancing will be required until and unless nuclear plants can run on a more variable basis.

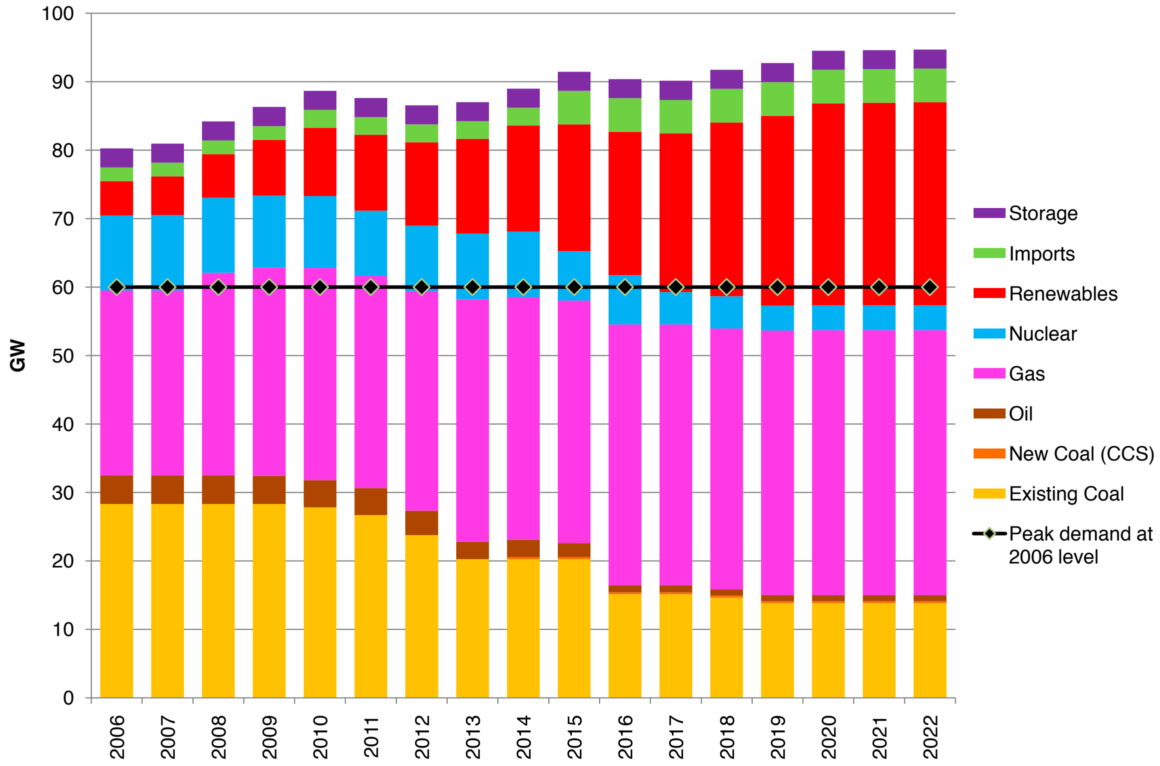
The crucial issue of supply intermittency is therefore not an either/or question of whether a renewable system can deliver energy on demand, but the cost of having extra capacity on the system and of more complex balancing. The total capacity required is significant, but the associated cost is not large enough to undermine the case for wind energy:

- Modelling by DECC (for the CCC) of possible electricity capacity evolution over the next two decades shows that even if peak demand is roughly flat at around 60 GW, total capacity will increase significantly (from around 80 GW to 95 GW), see Figure 13.2. This increase is due in part to significant wind capacity that will be added to the system. Only 20% of this capacity can however be considered as certain (this is sometimes referred to as the 'capacity credit' of wind plant). In order therefore to maintain an adequate reserve margin, significant new fossil fuel fired capacity (primarily CCGT) will also be required. The resulting system capacity, allowing only a 20% capacity credit for wind, is about 65 GW (Figure 13.3).

- Estimates of system back-up and balancing costs produced by Redpoint for the draft Renewable Energy Strategy suggest that these could rise to 1.3p/kWh of renewable energy produced (Figure 13.4). This figure is within the range of estimates from other studies, and the implications of these costs for the overall cost of renewable electricity have been allowed for in Chapter 5: *Decarbonising electricity generation*.

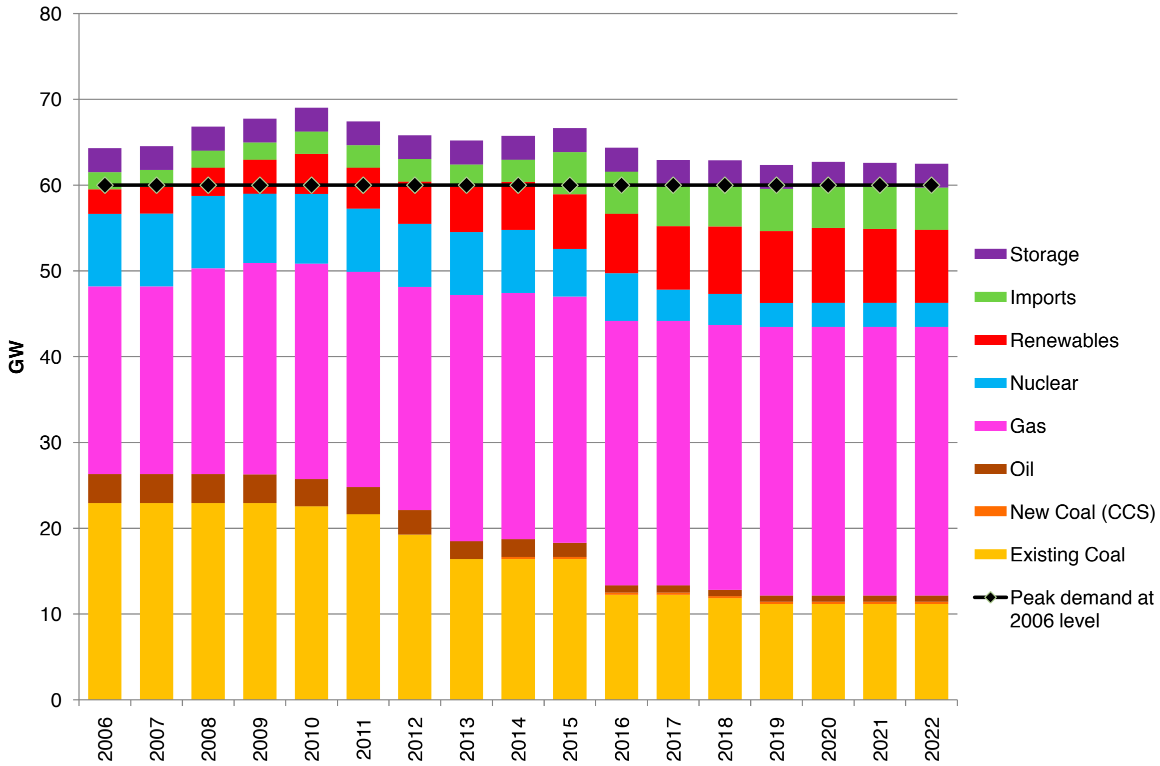
- And provided appropriate back-up capacity is built and available for balancing, technical security of electricity supply will be achieved. Redpoint modelling (described in Box 13.1) suggests that the capacity plans shown in Figure 13.2 and 13.3 would result in only a trivial increase in the danger of peak electricity demand being unmet (Figure 13.5), with likely shortages of generating capacity equivalent to only a small fraction of the outages the system faces from transmission system interruptions alone.

Figure 13.2 Full-rated capacity of power generation technologies, 2006–2022



Source: DECC energy model, based on CCC assumptions (Extended Ambition scenario)

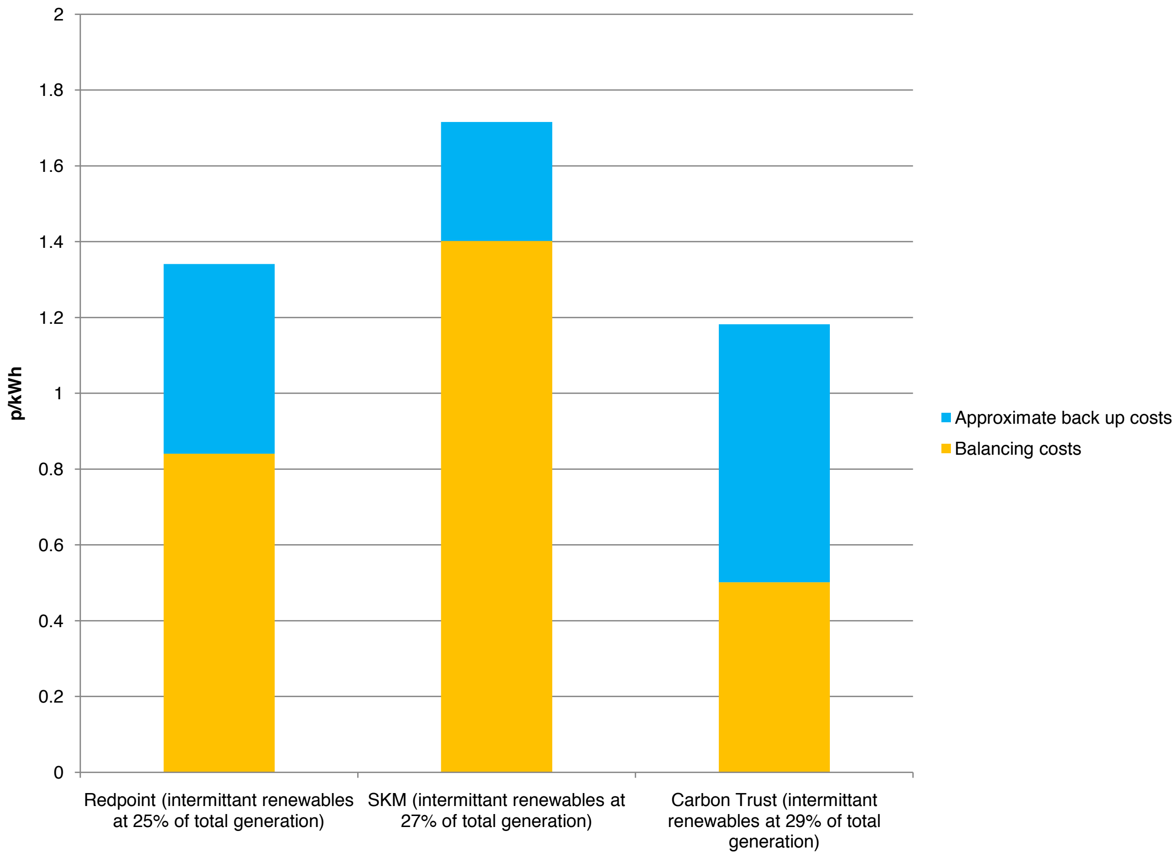
Figure 13.3 De-rated capacity of power generation technologies, 2006–2022



Source: DECC energy model, based on CCC assumptions (Extended Ambition scenario)

Notes: Storage and Imports are not de-rated
Nuclear de-rating factor 0.77
Wind de-rating factor 0.2
Coal, oil, gas and biomass de-rating factor 0.81

Figure 13.4 Additional costs at different penetrations of intermittent renewables



Source: CCC calculations based on SKM (2008), Redpoint et al (2008) and Carbon Trust (2008)
Note: This figure is the same as Figure 5.14.

Box 13.1 Outline of Redpoint modelling approach

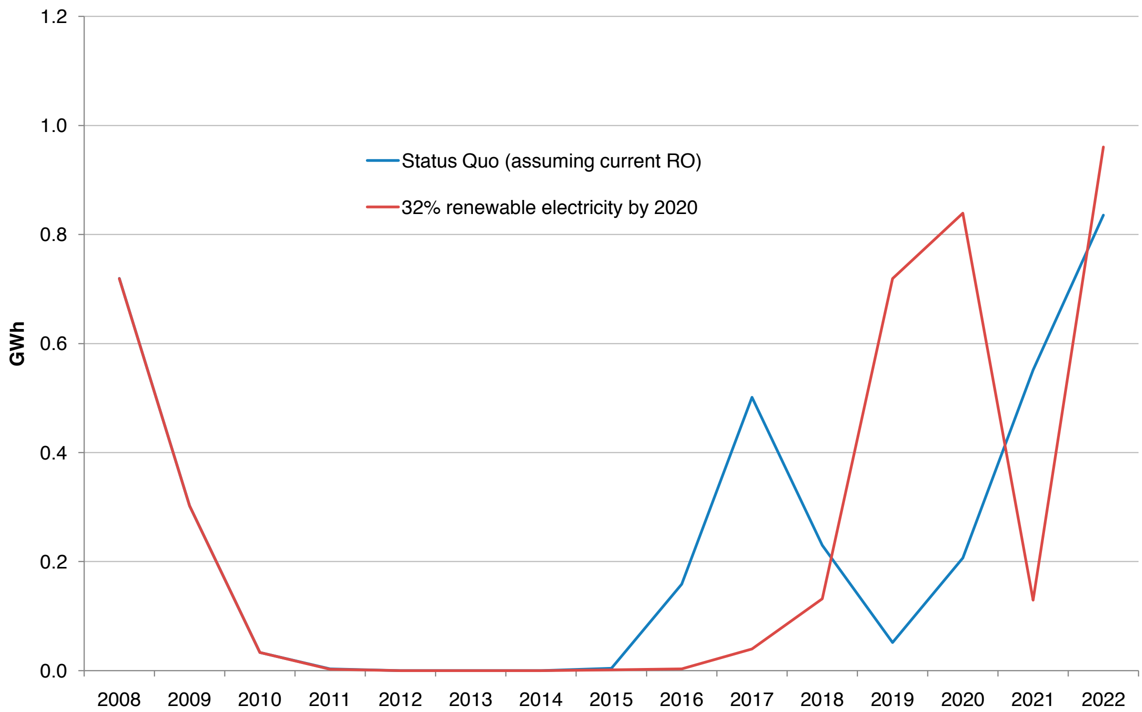
Redpoint Energy were commissioned by BERR to simulate scenarios for the development of the GB* electricity generation system consistent with meeting objectives of the draft Renewable Energy Strategy to achieve 30% or more renewable generation by 2020. Their modelling framework uses an **investment decisions** simulator, which computes risk-adjusted long-run marginal costs (LRMCs) of all generation technologies for different types of electricity generator (including vertically integrated generators with retail supply businesses, as well as merchant generators who supply directly to the wholesale electricity market). Where expected revenues exceed these LRMCs, investors first move new plant to a planning stage, and then to a committed development phase. The subsequent build-out of new plant then impacts on generation output, electricity prices, and short-term electricity demand responses, which feed back into the system to drive future investment decisions.

The simulator allows investment decisions to respond to a range of uncertainties, using a **risk adjustment calculator** to compute the distribution of investment returns given distributions of fossil fuel prices, carbon prices, and other project costs and revenues.

A **volatility model** analyses the market at an hourly level for each year, capturing variations in output due to intermittency and plant outages. The modelling allows an assessment of future shape and volatility of electricity prices that will drive investment in the different types of generation plant, as well as an assessment of the frequency and duration of periods where electricity demand cannot be fully met by available supply, or conversely where supply from inflexible generation such as intermittent renewables exceeds demand.

*The modelling did not cover Northern Ireland, which, with the Republic of Ireland, is part of a separate but connected electricity system. Given the interconnection of the Northern Ireland market with both the Irish and GB markets, we do not envisage that there will be significant additional security of supply risks in Northern Ireland over and above those in GB.

Figure 13.5 Expected annual energy unserved under a 32% 2020 renewable electricity target, 2008–2022



Source: Redpoint
Notes: Assumes the Extended RO32 (no Severn Barrage) scenario from Redpoint et al. (2008) *Implemenation of EU 2020 Renewable Target in the UK Electricity Sector*
Redpoint estimates about 10GWh of energy is lost annually due to transmission/distribution failures

Provided therefore that we accept the costs incurred in securing adequate back-up and balancing capacity, the development of renewable electricity to the 30% plus level described in the draft Renewable Energy Strategy will not create a technical security of supply risk. The separate question of whether current electricity market arrangements will ensure that required back-up is forthcoming is considered in Section 1(ii) below.

Looking forward beyond 2020, it is likely that further development of renewable electricity could occur without disproportionate costs being incurred given that:

- An increasing share of further expansion of renewable electricity may come from sources which are less variable or predictably variable, and/or whose variability is not closely correlated with that of wind (e.g. tidal stream, tidal range, and solar PV).

- The development of electrical storage technologies may reduce the time dependency of electricity demand. These developments might entail large-scale storage within the central transmission system. But they may also include a wide-scale deployment of battery powered electric cars, which will create demand for recharging which need not be highly time-specific, or an increasing use of overnight electricity to heat homes, with appropriate heat storage and release. Chapter 2: *Meeting a 2050 target* set out a technological vision in which it is highly likely that electricity demand will grow significantly beyond 2020, as electricity is applied to surface transport and to heating. This growth in total demand may not, however, imply an equivalent increase in peak electricity demand.

- The development of smart metering and demand management techniques may make it possible to reduce demand when supply is low (e.g. with lower tariffs for people or businesses willing to switch off non time-critical appliances such as freezers and fridges).

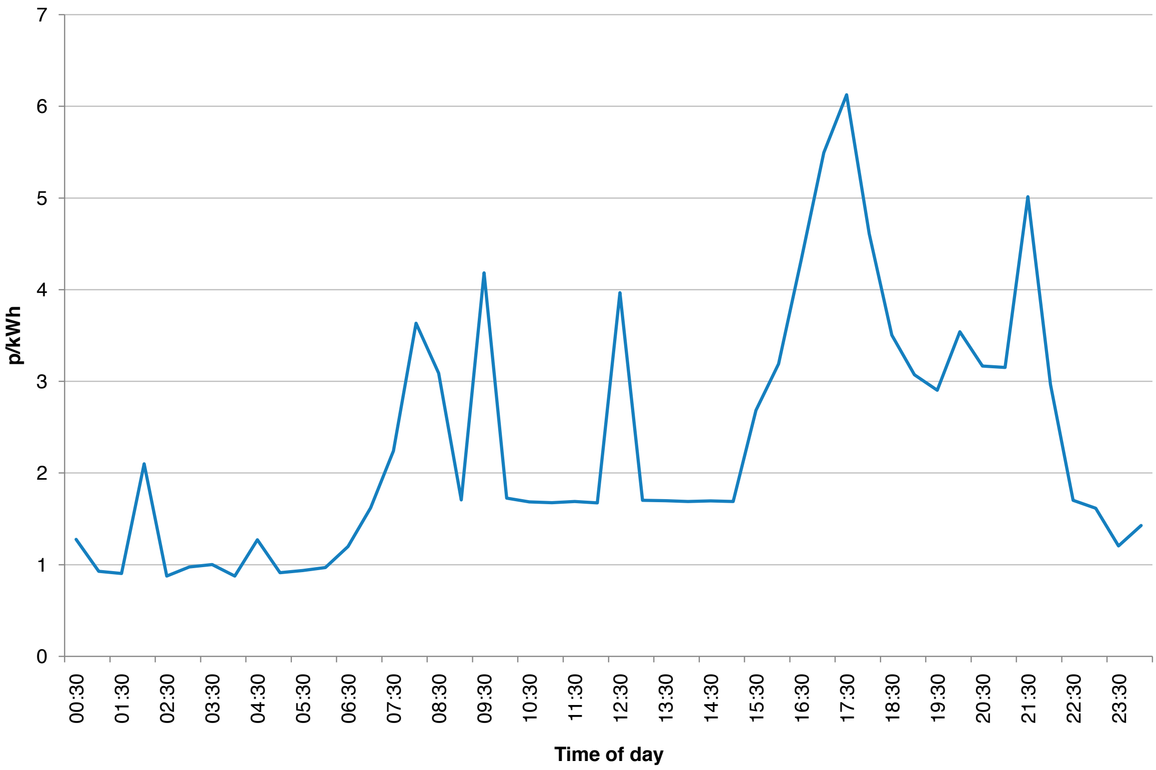
- Greater interconnection between the UK and continental electricity grids could smooth out the variations in wind resource across a wide geographic area (Denmark, for instance, with high capacity links to the Scandinavian and German grids, is already a large exporter of wind energy at some times and an importer of electricity at others).

The Committee does not therefore believe that concerns about technical security of supply argue against the expansion of renewables to 30% of electricity in 2020, or to a higher percentage thereafter. We believe that the carbon budgets which we are recommending, based on a significant increase in the level of renewable electricity, are compatible with technical security of supply, provided adequate back-up capacity is built alongside and is available for balancing.

(ii) The impact of intermittent renewables on prices and incentives to invest

The issue discussed above concerned the potential implications of low wind or windless days. The second issue relates to the impact of windy days on expected wholesale electricity prices and thus incentives to invest. Wholesale electricity prices vary during the day with the extent of variation depending on the profile of total demand. On summer nights, prices fall to very low levels because of low demand but continued nuclear supply (Figure 13.6). The addition of enough wind capacity to supply on average around 30% of total annual electricity demand (as envisaged in the draft Renewable Energy Strategy), together with significant gas-fired generation that must run alongside intermittent wind, will result in more frequent and longer periods of very low electricity prices. For instance, the demand and supply profile shown in Figure 13.1 above, could result in very low prices (well below the marginal cost of fossil fuel based electricity production) for much of the day, and could indeed at times result in negative prices (e.g. as renewables operators pay to stay on the grid to secure Renewables Obligation Certificate (ROC) income; see Chapter 5).

Figure 13.6 Half-hourly electricity price variation throughout a summer's day, July 2007

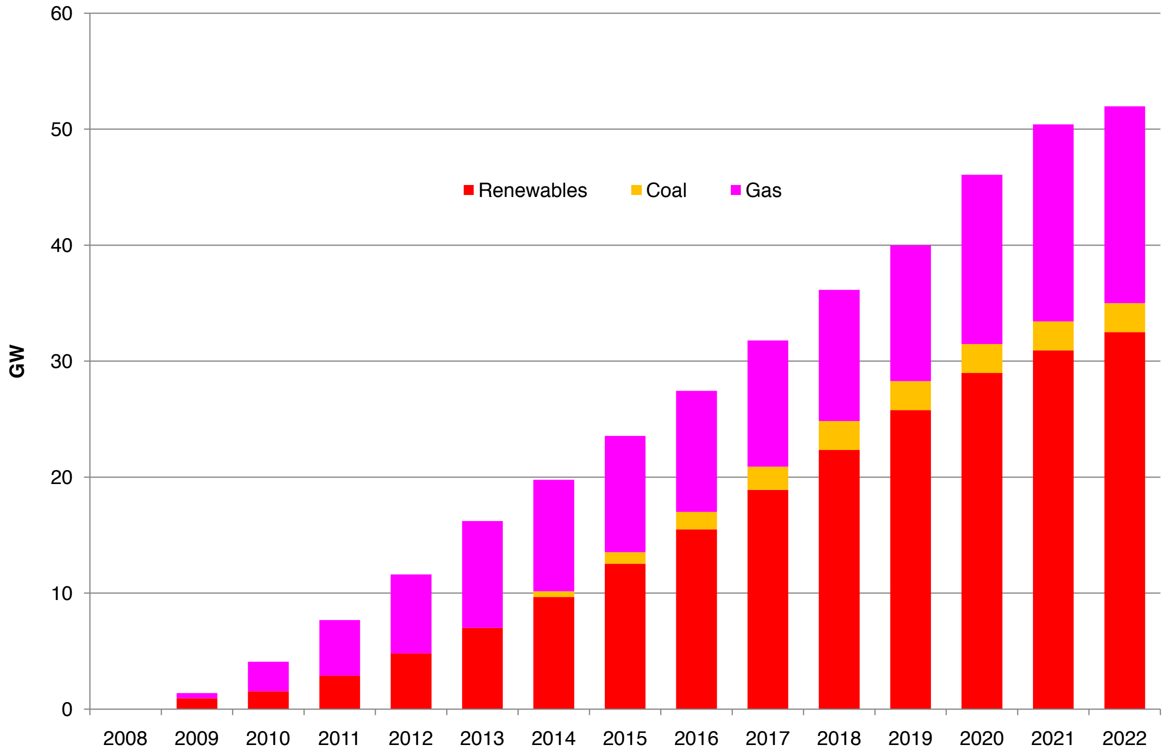


Source: Balancing Mechanism Reporting website, for 4-5 July 2007 (nominal prices)

The issue therefore arises of how the expectation of more frequent periods of very low wholesale electricity prices will change incentives to invest in peak and back-up capacity which will continue to be needed. This is a subset of the wider issue of whether we can be certain that free market decisions will result in sufficient investment in capacity in the face of uncertainty about fossil fuel and carbon prices. Those uncertainties already make decisions about fossil fuel plant investment inherently complex: the spread of renewables supply adds the additional complexity that plant will need (to a greater extent than today) to recover its capital costs from high prices over relatively short periods of operation, but with the frequency and length of these periods difficult to predict in advance.

Modelling by Redpoint for the draft Renewable Energy Strategy suggests that there will be adequate investment even with high levels of renewables, and that the rational investor response to best estimates of future prices and demand patterns would result in appropriate new investment over the next twelve years, most likely in the form of additional CCGT plant (Figure 13.7). It is, however, inherently difficult in such modelling exercises to capture the impact of uncertainty on investment decisions: they illustrate what rational investors should logically do in the face of the best estimate of future conditions, but can only imperfectly predict what actual investors might do in the face of diverse estimates and uncertainty.

Figure 13.7 New plant build to 2020, under a 32% renewable electricity target, 2008–2022



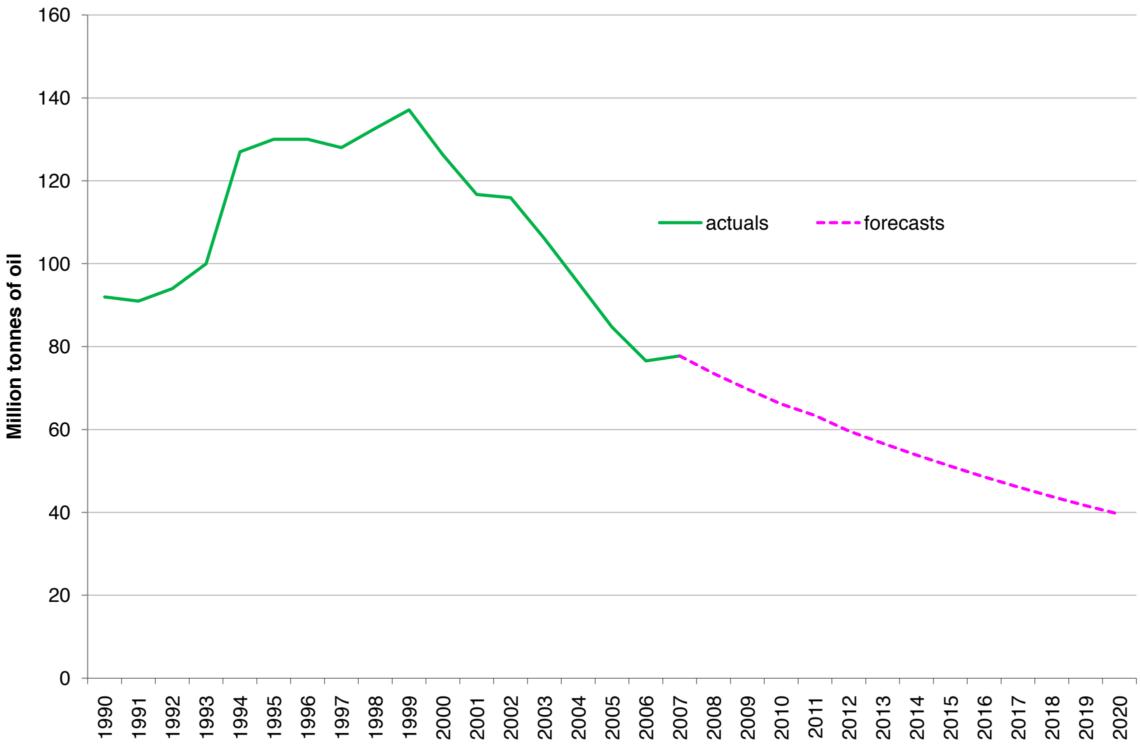
Source: Redpoint et al (2008)

It is possible therefore that some category of market intervention may be required to guarantee security of supply. This could entail the system operator inviting tenders for capacity on a much wider scale than currently practised, or the introduction of capacity obligations as currently used in the United States. And it is likely that current market arrangements may in any case need to evolve to cope with a system in which an increasing share of production will come from close-to-zero marginal cost production, and in which long-term contracts should logically therefore play an increasingly important role. The possible need for these innovations does not change the conclusion, however, that back-up generation can be provided at affordable cost.

2. GEOPOLITICAL AND ECONOMIC SECURITY OF SUPPLY

Over the next several decades the UK, and Europe in general, is likely to become more dependent on imported energy. UK North Sea oil production, having peaked in 1999, is likely to decline significantly (Figure 13.8) and North Sea gas production will fall rapidly from 2008. The percentage of our energy demand supplied by net imports could increase from 16% in 2005 to 73% by 2020 (Table 13.1). A key question is therefore whether this increasing reliance should be treated as a problem, and what action should be taken in response.

Figure 13.8 UK oil production, 1990-2020



Source: BERR (Energy Markets Outlook 2007)

Table 13.1 UK fossil fuels, net import requirements, 2005–2020

Year	Oil	Gas	Coal	Total	Net Import requirement as % of total energy demand
2005	-4	13	26	35	16%
2010	10	32	23	65	30%
2015	42	65	23	130	57%
2020	64	79	26	169	73%

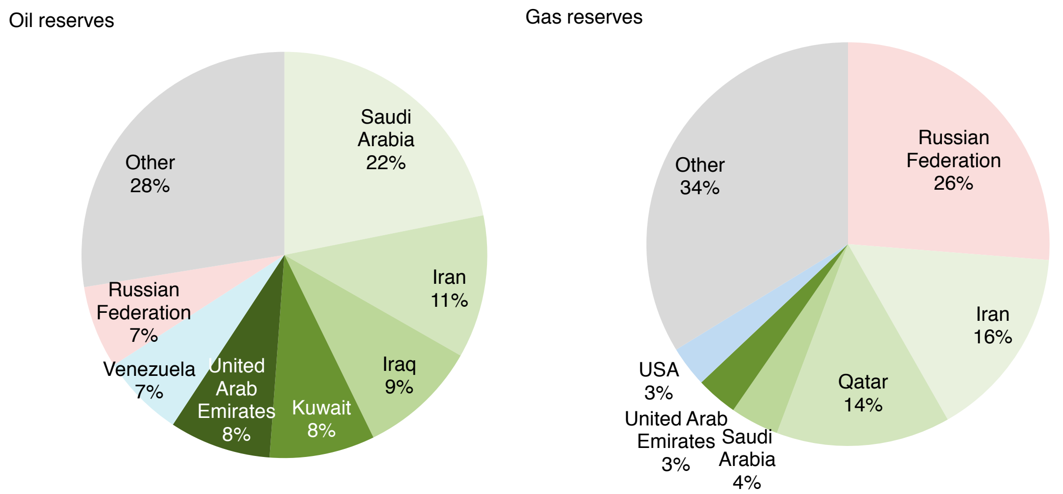
Source: BERR Updated Energy Projections (Feb 2008). Figures in mtoe
Note: Assumes no Energy White Paper policies or EU ETS

Two adverse consequences could result from this increasing reliance on imports: (i) geopolitical vulnerability; and (ii) economic exposure to volatile prices.

(i) Geopolitical vulnerability

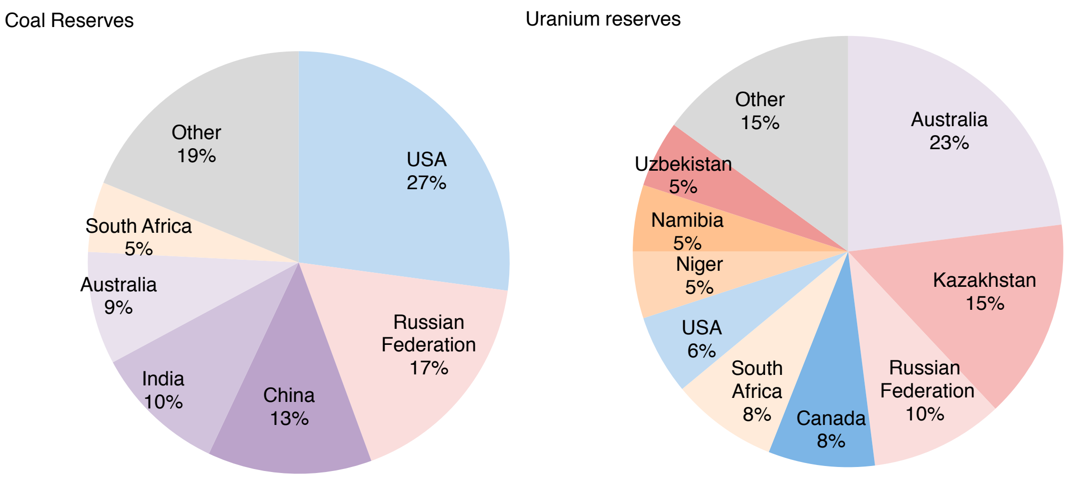
Britain and Europe could be exposed to unwelcome economic pressure related to geopolitical issues, with producer countries using energy supply as a tool in international relations (as for instance the Arab oil exporters did in the aftermath of the 1973 Arab – Israeli war)[2]. This geopolitical issue could be important in relation to oil and gas supplies, which are likely to come increasingly from a small number of Middle Eastern and central Asian countries together with Russia (Figure 13.9)[3]. It is a much less relevant issue in relation to coal and uranium supplies, which are likely to be available from a wide range of alternative potential suppliers (Figure 13.10). In designing an optimal carbon reduction strategy, pursued through energy efficiency and through the development of low-carbon electricity, we should therefore attach some weight to the importance of reducing our reliance on imported oil and gas in order to reduce (but not eliminate) geopolitical vulnerability. Given, however, that such vulnerability is only relevant in extreme political circumstances, deciding how much weight to attach to this concern is an inherently uncertain political judgment.

Figure 13.9 Proven reserves of oil and gas, 2006



Source: BP Statistical Review 2007

Figure 13.10 Proven reserves of coal and uranium, 2006



Source: Coal from BP Statistical Review 2007; Uranium from OECD Nuclear Energy Agency and International Atomic Energy Agency
Note: Uranium is for Reasonably Assured Resources plus Inferred Resources to US$130/kg.

2 In October 1973, during the Arab-Israeli war, OPEC cut production of oil and placed an embargo on shipments of crude oil to the West, causing oil prices to quadruple.

3 It may be more important in the case of gas, given that there are IEA and EU frameworks which require countries to hold oil stocks to mitigate the risk of oil supply interruptions. In the case of gas, the UK has limited storage facilities, although investment in new gas storage is envisaged under proposals in the 2007 Energy White Paper.

(ii) Economic exposure to volatile prices

The more likely adverse consequences of reliance on imported fossil fuels arises, however, from purely economic effects: exposure to sustained periods of high fossil fuel prices (which may at times reflect political uncertainties) and/or ongoing exposure to volatile fossil fuel prices.

- Oil and gas prices have in the past displayed huge volatility (Figure 13.11), and can be expected to do so in the future.

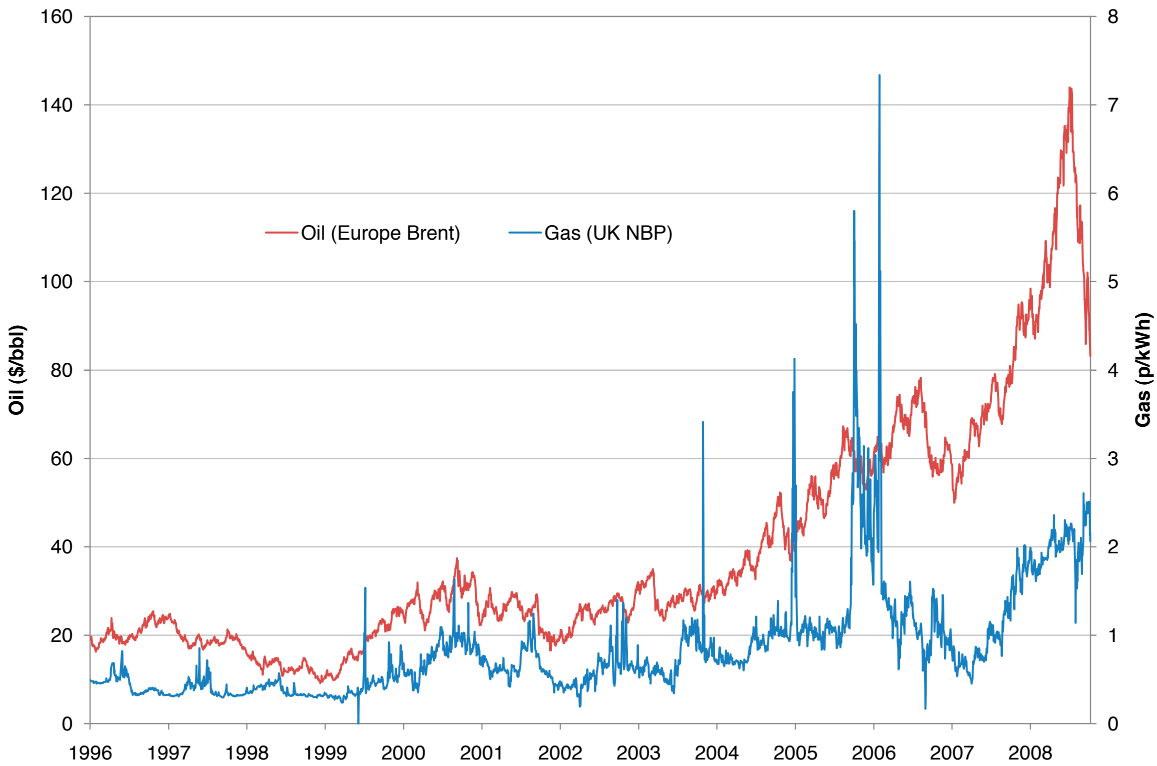
- Oil price volatility arises from the concentration of production in a small number of oligopolistic suppliers, the lumpiness of new production capacity investments, and the relative inelasticity of demand. Latest estimates by the International Energy Agency in its World Energy Outlook 2008 suggest that oil prices, having fallen from a peak of $140/bbl in summer 2008 to around $65/bbl at the time this report went to print, will average $100/bbl (in 2007 prices) over the period 2008–2015.

- In the case of gas, the volatility derives in part from a conventional link between gas supply contracts and the oil price, which could conceivably be loosened in future. Even without this link, however, the gas market is also and will increasingly be subject to potentially oligopolistic concentration of supply, lumpy and uncertain production and distribution investments (e.g. pipelines and LNG terminals) and political uncertainties (e.g. over the role of Iranian supplies). Gas price volatility in the UK might also ensue given limited gas storage capacity and potential vulnerability to loss of critical infrastructure.

- While it is very difficult to predict the future overall level of oil and gas prices (as discussed in Chapter 3: *The first three budgets*) the one reasonably certain prediction is that prices will tend to be volatile and are likely periodically to display the extreme volatility which we have experienced over the last twelve months (Figure 13.12).

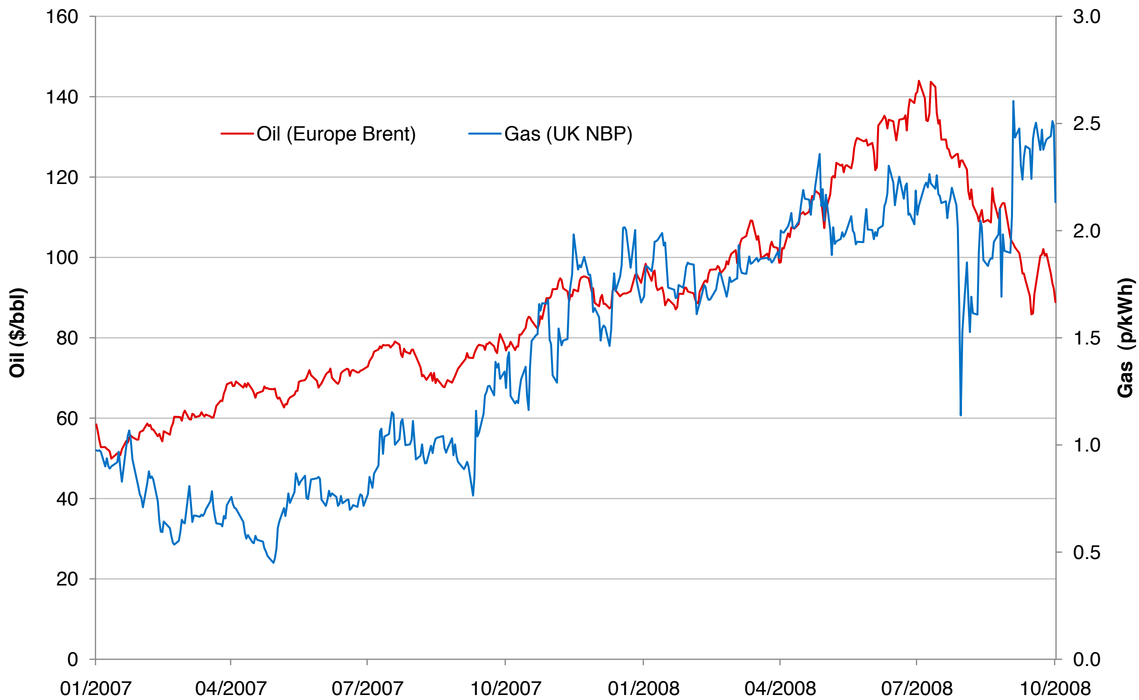
- Over the last two years coal prices have been as volatile as oil and gas (Figure 13.13) with more rapid growth than anticipated in global demand creating supply bottlenecks, particularly in dry bulk shipping. In recent months, however, bottlenecks have eased and significant reductions in coal prices are expected. In the longer term coal prices should in theory suffer less volatility, given the broader range of potential supply sources, the lack of a formal or informal oligopoly, and the lower vulnerability to political uncertainty, given larger supplies in stable developed OECD countries.

Figure 13.11 Wholesale oil and gas prices, 1996–2008



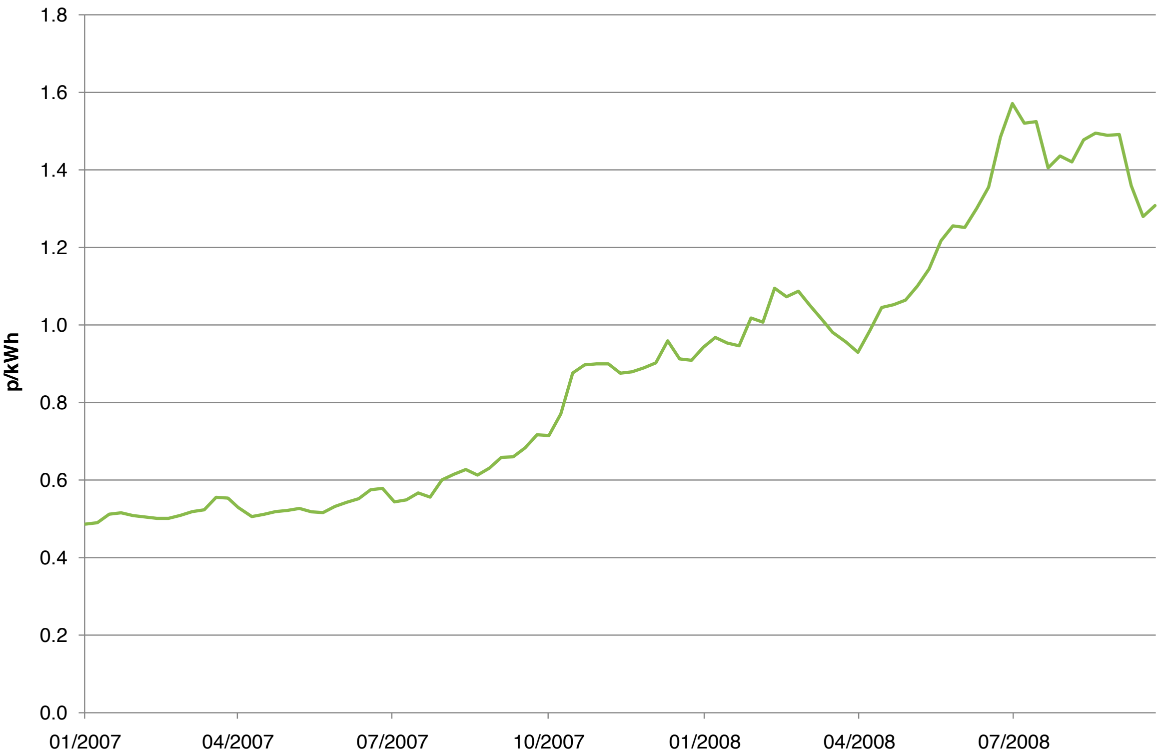
Source: Daily oil price (nominal) from US Energy Information Agency; Daily gas price (nominal) from Platts

Figure 13.12 Wholesale oil and gas prices, 2007-2008



Source: Daily oil price (nominal) from US Energy Information Agency; Daily gas price (nominal) from Platts

Figure 13.13 Wholesale coal prices, 2007–2008



Source: Platts. Weekly ARA coal (nominal prices)

The possibility of sustained high oil and gas prices and their inherent volatility therefore establishes an important economic rationale for favouring measures to move away from dependence on oil and gas, such as energy efficiency and fuel efficiency improvement, and the development of energy sources such as renewables or nuclear[4], where the cost is determined almost entirely by the capital cost of construction and not by a volatile fuel price.

This rationale may also apply to coal-fired generation, which is potentially attractive when viewed from a security of supply perspective. Building of conventional coal-fired generation (without CCS) would, however, seriously undermine climate change objectives. Only where coal generation is based on CCS technology would this security of supply benefit be consistent with a climate change objective.

Benefits for consumers and the macro economy: The economic rationale for moving away from gas-fired generation exists even if it is not necessarily the case that decreased reliance on volatile price energy sources will reduce the volatility of wholesale electricity prices (e.g. because gas remains the marginal, price-setting, plant). Both individual consumers and the macro economy will benefit from reduced vulnerability to volatile prices of oil and gas.

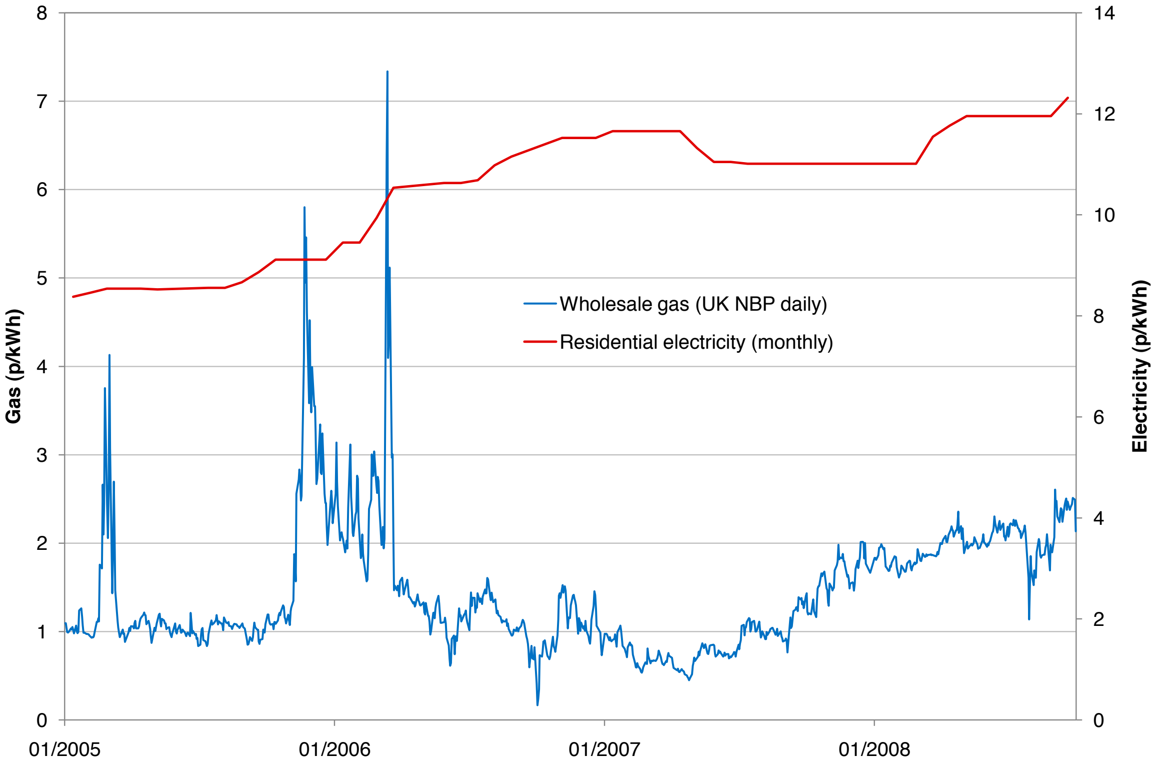
4 In principle there may be questions over the volatility of the uranium price, and indeed this has moved markedly in 2007 and 2008. But the cost of the raw uranium is such a small proportion of total nuclear generation costs that movement in its price has little impact on overall nuclear costs.

- **Individual consumers:** Here the impact of energy efficiency improvements is straightforward; the impact of new non-fossil fuel based energy sources is complex and likely to change over time.
  - Retail consumers will directly benefit from energy efficiency improvements (whether in houses or in transport) since, for any given price, this reduces the percentage of their income devoted to energy purchase, and thus the volatility of their standard of living in the face of oil and gas price oscillations.
  - And retail consumers may also benefit from less volatile electricity prices, with any such benefit offsetting to a degree the disadvantage of slightly higher average energy costs which decarbonised electricity is likely to entail.
  - Hour by hour wholesale electricity prices will not become less volatile: indeed as suggested above they could become more volatile as intermittent capacity enters the system.
  - But retail consumers do not face hour by hour, day by day, or week by week price volatility: the retail supply price averages out those variations (Figure 13.14).
  - On a year by year timescale retail prices tend to adjust to fully reflect gas price movements. This pattern is likely to continue over the medium term, but over the long term (decades rather than years) might break down if and when fossil fuel based generation becomes a significantly lower percentage of total supply.
  - The best judgment therefore is that any economic benefits from less volatile average costs are unlikely to be reflected in less volatile retail electricity prices in the short term but may do so over the long term.

- **The macro economy:** Even if retail consumers do not directly enjoy all the benefits of energy sources whose cost is less volatile, a macroeconomic benefit would result.
  - The energy efficiency benefits accruing to consumers have a macro consequence: the less volatile is consumer expenditure in the face of volatile fossil fuel prices, the easier the macro management of the economy.
  - And at the macroeconomic level, diversifying away from gas-fired generation would reduce the extent to which the rents accruing at times of high gas prices flow to companies outside the UK economy. These would instead accrue to UK-based shareholders of energy companies, and would generate additional tax revenues.
  - At the national income level therefore, measures which reduce energy system reliance on imported fossil fuels subject to high price volatility will tend to help dampen oscillations in GDP and to facilitate macroeconomic management.

Overall our assessment is that there exists a significant economic rationale for reducing future reliance on imported oil and gas, given the oligopolistic nature of the supply markets, and the inherent and unpredictable price volatility. This rationale therefore adds to climate change related arguments for pursuing energy efficiency and for seeking alternative sources of energy. Those alternative sources of energy could be either renewable or nuclear or coal with CCS.

Figure 13.14 Residential electricity and wholesale gas prices, 2005-2007



Source: Residential electricity price from Ofgem; Wholesale gas price from Platts (all prices nominal).

CHAPTER 14:

DIFFERENCES IN NATIONAL CIRCUMSTANCES

The Climate Change Act requires that when advising on carbon budgets the Committee should take into account 'differences in circumstances between England, Wales, Scotland and Northern Ireland'. This chapter responds to the requirement under the Act, and sets out our analysis of carbon budgets as these relate to the national authorities within the UK[1]. It therefore covers Wales, Scotland and Northern Ireland. It does not focus on England or regions within England[2].

We focus on two aspects of carbon budgets:

- Firstly, we provide a high level assessment of potential for reducing emissions in Wales, Scotland and Northern Ireland. This assessment covers emissions relating to buildings and industry, road transport, power generation and non-CO_2 greenhouse gases.

- Secondly, we consider wider impacts of carbon budgets, particularly as these relate to competitiveness and fuel poverty, and how these impacts are likely to vary by nation.

The main messages in the chapter are as follows:

- Allowing for differences in circumstances, there are significant opportunities for abatement in Wales, Scotland and Northern Ireland.

- National authorities have an important role to play in unlocking the abatement potential, given the balance of devolved and reserved powers.

- Though there are potentially adverse impacts of carbon budgets (e.g. an increase in fuel poverty), these can and should be mitigated by appropriate policy design.

The Committee has carried out an initial analysis, which does not at this stage involve developing indicative carbon budgets for Wales, Scotland and Northern Ireland. Further work would be required to underpin any national carbon budgets and climate strategies.

We set out the analysis that underpins these messages in five sections:

1. Emissions trends and projections

2. Opportunities for emissions reductions

3. Economic impacts of carbon budgets

4. Fuel poverty impacts of carbon budgets

5. Next steps in developing the evidence base.

1 In the Climate Change Act, national authorities are: the Secretary of State, Scottish Ministers, Welsh Ministers and the relevant department in Northern Ireland.
2 Hereafter we use 'nations' and 'national' when referring collectively to England, Wales, Scotland and Northern Ireland.

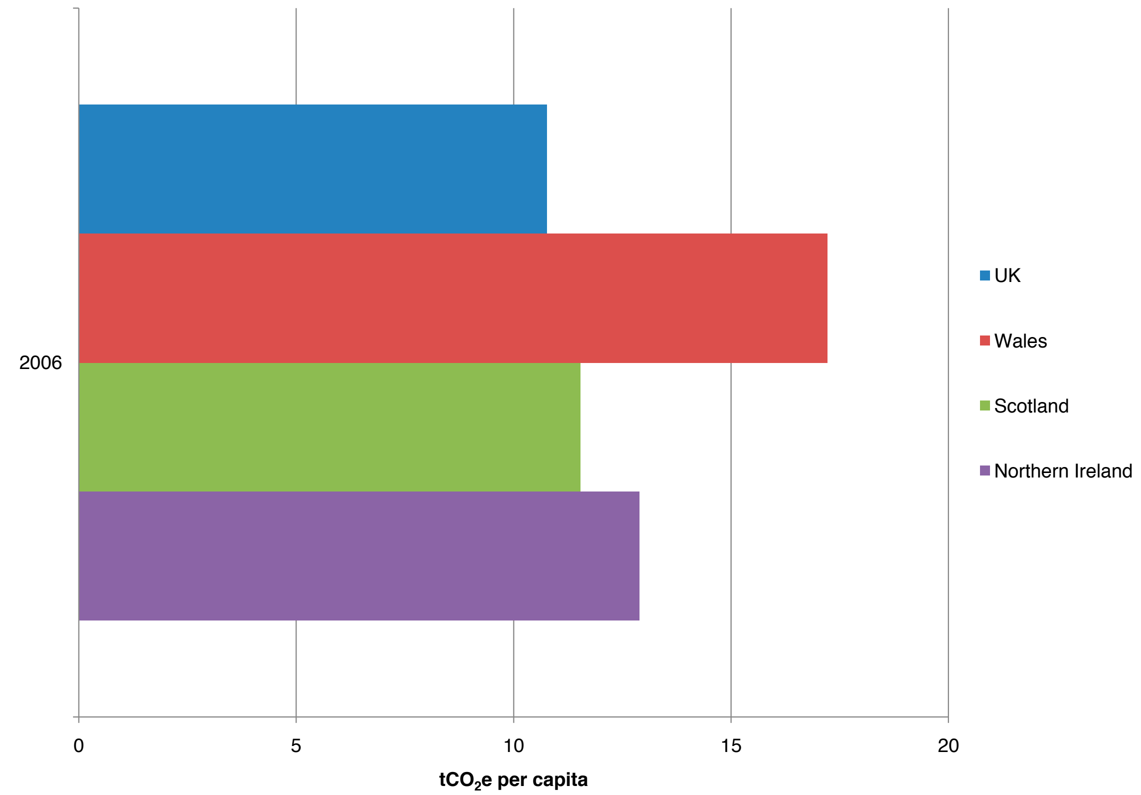
1. EMISSIONS TRENDS AND PROJECTIONS IN WALES, SCOTLAND AND NORTHERN IRELAND

Emissions shares and per capita emissions: The UK's greenhouse gas (GHG) inventory is disaggregated to the level of England, Wales, Scotland and Northern Ireland. In 2006, emissions shares of Wales, Scotland and Northern Ireland were higher than population shares; this was most pronounced in Wales, but each of the three nations has relatively high GHG emissions per capita (Figure 14.1).

Part of this variation can be explained in terms of the power sector: for example, if power generation emissions are excluded, Scotland's per capita emissions fall below the UK average (Figure 14.2). Power does not, however, explain all of the difference in national per capita emissions, which is driven in part by other sectors (Figure 14.3):

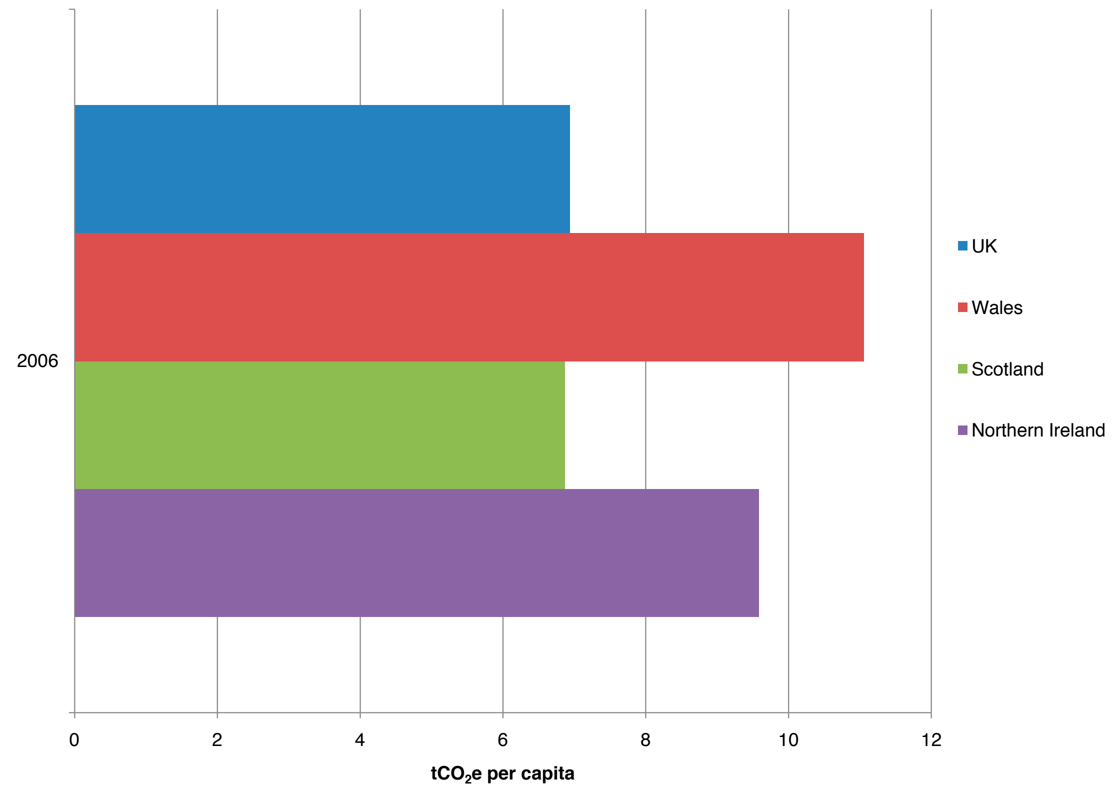
- Transport, where Northern Ireland in particular has relatively high transport emissions due to high levels of rural driving.
- Business, where emissions are relatively high in Wales given the energy-intensive industries (e.g. iron and steel, refining) located there.
- Residential, where emissions are higher than the UK average in Wales, Scotland and Northern Ireland due to a greater proportion of homes being off the mains gas grid and therefore reliant on more carbon-intensive fuels for heating.
- Agriculture, where emissions are relatively high in Wales, Scotland and Northern Ireland due to the sector's relatively large contribution to their economies.
- Land use, land use change and forestry (LULUCF), where sink impacts are greatest in Scotland.

Figure 14.1 Per capita GHG emissions – UK, Wales, Scotland and Northern Ireland, 2006



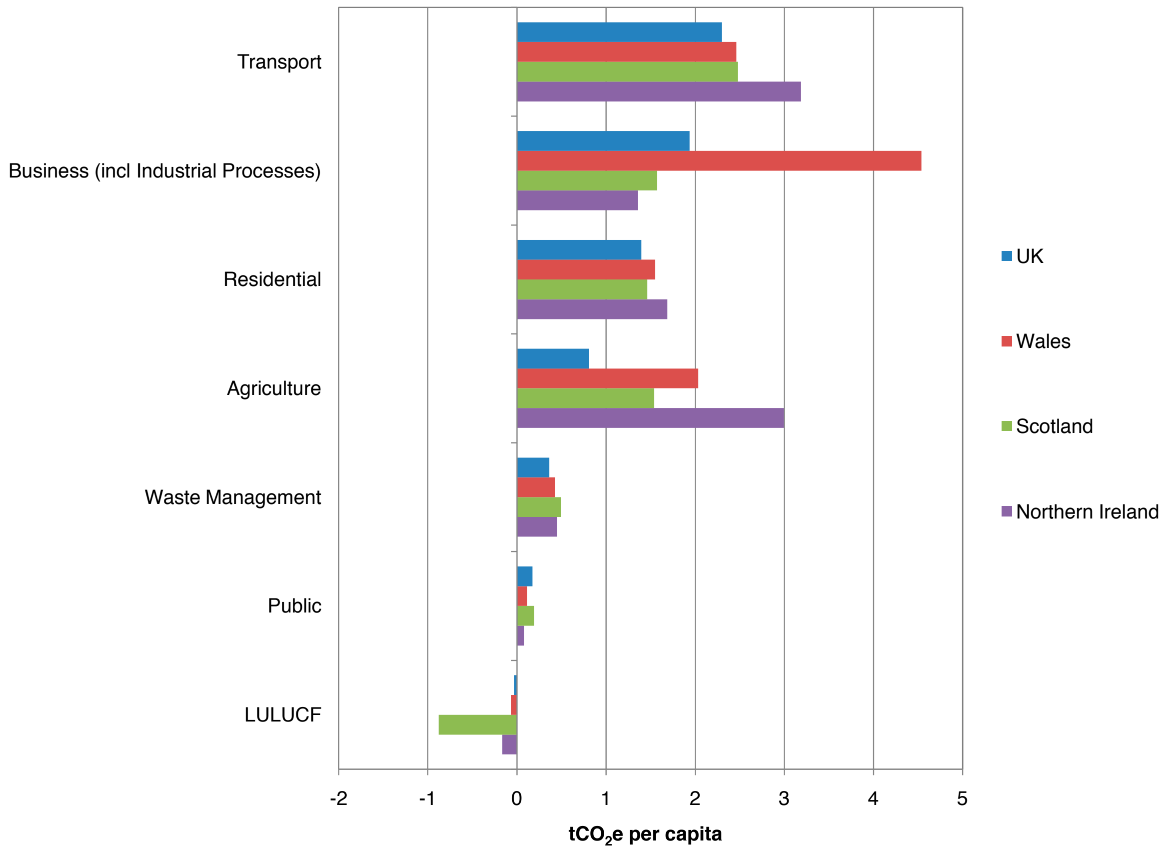
Source: National Atmospheric Emissions Inventory (NAEI) (2008) and Government Actuary's Department (GAD)

Figure 14.2 Per capita GHG emissions, excluding power – UK, Wales, Scotland and Northern Ireland, 2006



Source: NAEI (2008) and GAD

Figure 14.3 Per capita GHG emissions, by sector – UK, Wales, Scotland and Northern Ireland, 2006



Source: NAEI (2008) and GAD

Emissions trends: Each of the nations has contributed to the UK's 16% GHG emissions reduction over the period 1990-2006 (Figure 14.4):

- Wales, Scotland and Northern Ireland have each reduced GHG emissions from agriculture, waste management, business, industrial processes, residential and public sectors. In agriculture, emissions reductions were achieved due to reduced livestock numbers (except in Northern Ireland where they have increased) and more efficient fertiliser application. Emissions reductions were also achieved due to energy efficiency improvements in buildings and industry, and the changing composition of industrial output (e.g. closure of a large steelworks in Scotland).

- Emissions from transport have increased in Wales, Scotland and Northern Ireland as they have done for the UK as a whole, due to increased demand for road and air travel. This trend is particularly marked in Northern Ireland where emissions from transport have increased by almost 50% between 1990 and 2006.

- Emissions from power generation in Wales, Scotland and Northern Ireland have increased over the period, whereas for the UK as a whole they have fallen by 15%. This is in part due to the fuel mix used to generate electricity in each nation (e.g. one or two coal plants dominate power emissions), and also because each of the nations exports electricity.

Figure 14.4 Contribution to total GHG emissions, by sector – UK, Wales, Scotland and Northern Ireland, 1990 and 2006 (relative to 1990)

Source: NAEI (2008)
Note: Total net GHG emissions appear in bold ($MtCO_2e$)

Reference emissions projections: We now set out our reference projections for Wales, Scotland and Northern Ireland. These are based on the same assumptions as the UK reference emissions projections as set out in Chapter 3: *The first three budgets*. However, it should be noted there is greater uncertainty in the disaggregated emissions projections and it has not been possible to achieve complete coverage of all emissions sources[3].

In order to project CO_2 emissions from energy at the national level, we have used a number of models:

- For residential and industry and services CO_2 emissions, we have used the Department for Energy and Climate Change (DECC) Energy Model. In disaggregating the DECC Energy Model outputs, we have assumed that national emissions projections follow the UK trend, and applied this to nation-specific data on fuel consumption, whilst accounting for forecast trends in the number of households and economic circumstances in each nation.

- For road transport CO_2 emissions, we have used the Department for Transport (DfT) National Transport Model (NTM), which provides road transport projections for Wales and Scotland[4].

- For non-energy CO_2 emissions due to LULUCF, we have used nation-specific projections published by the Centre for Ecology and Hydrology (CEH).

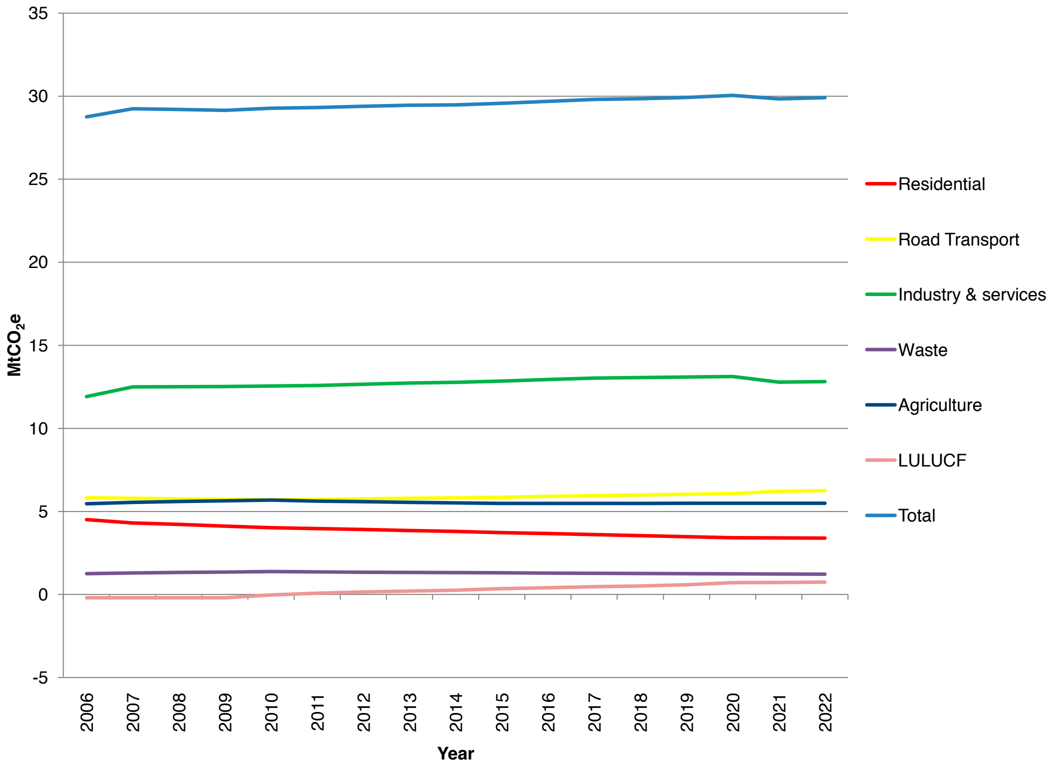
- For non-CO_2 gases, we have used Defra's projections (see Chapter 9: *Non-CO_2 greenhouse gases*), which are produced for Wales, Scotland and Northern Ireland.

Our indicative reference emissions projections (using the DECC Energy model and NTM outputs) for the period 2006-2022 suggest that GHG emissions from these source sectors in Wales, Scotland and Northern Ireland are forecast to rise by 4%, 7% and 1% respectively (Figures 14.5.a-c).

3 Reference emissions projections include industry and services, road transport, residential, waste (non-CO_2 only), agriculture and LULUCF sectors. They do not cover emissions from power generation, industrial processes, refineries, offshore and air, water and rail transport sectors.

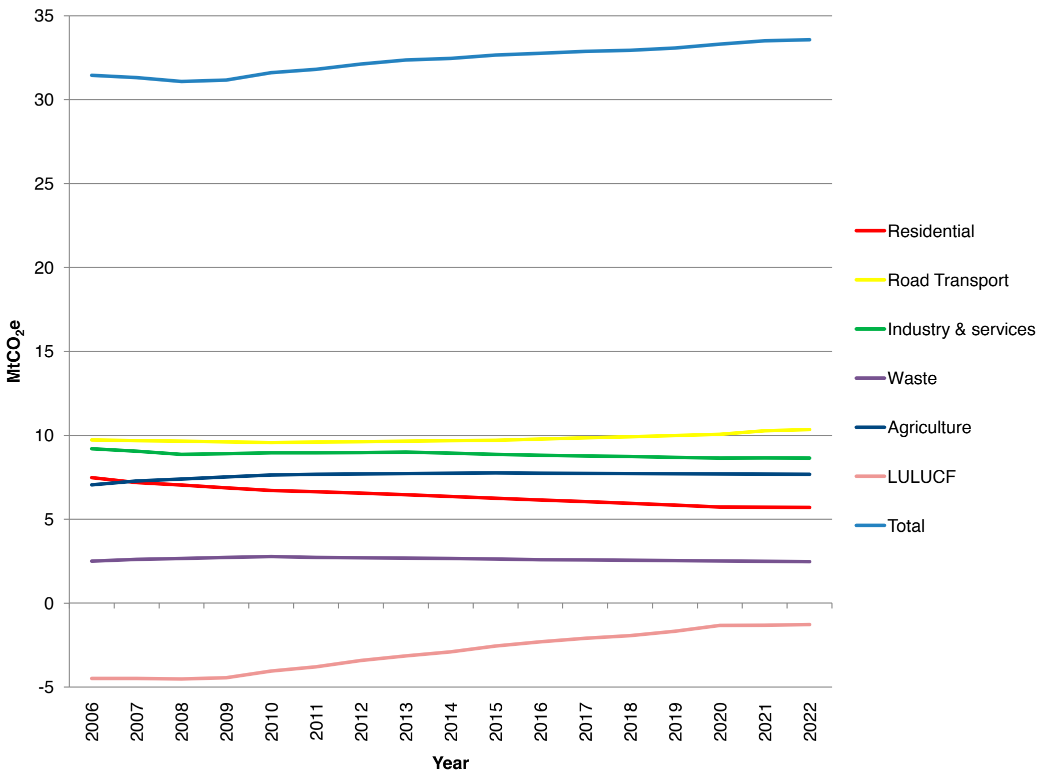
4 An estimate has been derived for Northern Ireland, in line with current road transport fuel consumption. We have assumed that Northern Ireland road transport emissions follow the same trend as the average for Great Britain.

Figure 14.5.a Reference GHG emissions projections – Wales, 2006-2022



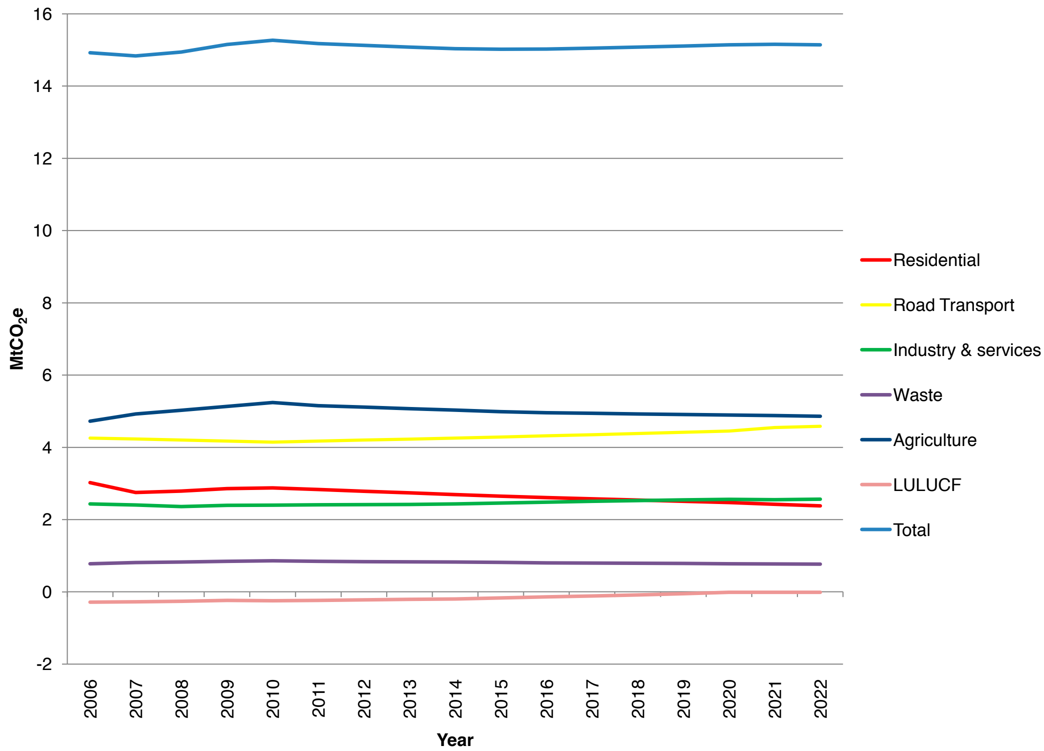
Source: CCC Calculations, DECC, DfT, CEH (2008) and Defra

Figure 14.5.b Reference GHG emissions projections – Scotland, 2006-2022



Source: CCC calculations, DECC, DfT, CEH (2008) and Defra

Figure 14.5.c Reference GHG emissions projections – Northern Ireland, 2006-2022

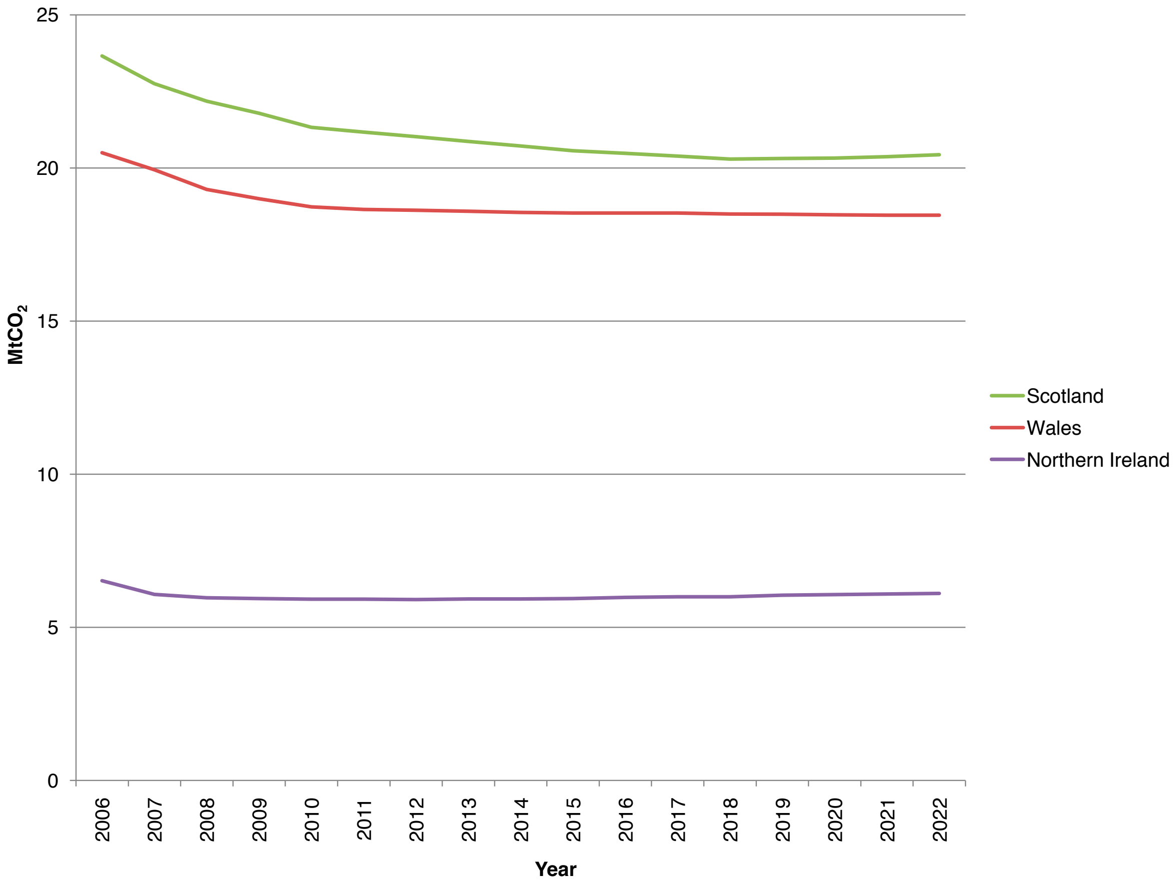


Source: CCC calculations, DECC, DfT, CEH (2008) and Defra
Note (Figures 14.5a-c): Total includes only those sectors listed and excludes emissions from power generation, refineries, offshore, industrial processes and rail, water and air transport.

- Total CO_2 emissions from energy sources (industry and services, road transport and residential) are projected to fall in both Scotland (–7%) and Northern Ireland (–3%), whilst emissions in Wales are projected to rise by 1%:
  - Emissions from residential buildings are expected to fall in each nation, driven by energy efficiency improvements, yet emissions in industry and service sectors rise in Wales and Northern Ireland due to forecast emissions growth in certain industries located there.
  - Road transport emissions are projected to grow in all nations due to sustained growth in demand for road transport.
- Net emissions from land use, land use change and forestry are projected to increase in each nation but especially in Scotland, due in part to the slower rate of forest planting in recent years.
- Total non-CO_2 emissions are projected to grow by between 1% and 7% in the period to 2022, driven by increased emissions in non-CO_2 greenhouse gases in industry and services, road transport and agriculture.

We have also analysed national outputs from the Cambridge Econometrics MDM-E3 model (see Chapter 3). For a set of the energy sectors considered above (industry, services, road transport and residential), these projections show different trends to the DECC/NTM results in some cases; overall CO_2 emissions projections fall in each nation by 6% to 14% between 2006 and 2022 (Figure 14.6). This highlights the sensitivity of nation-level projections to precise assumptions in the modelling approach.

Figure 14.6 Reference CO_2 emissions projections from Cambridge Econometrics – Wales, Scotland and Northern Ireland, 2006-2022



Source: Cambridge Econometrics modelling for CCC

2. OPPORTUNITIES FOR EMISSIONS REDUCTIONS IN WALES, SCOTLAND AND NORTHERN IRELAND

Reference emissions projections above do not include the full range of abatement options across the national economies. Whilst it has not been possible to undertake a thorough bottom-up analysis of abatement potential in each nation, we have carried out a high level disaggregation of the UK Marginal Abatement Cost Curve (MACC) analysis. To complement this approach, we have identified a number of factors that might further influence the scope and scale of abatement potential that have not been taken into account in the disaggregation, which will require further investigation. In addition, we discuss the capacity of national authorities to take action to deliver emissions savings.

The analysis in this section relates to four key areas of abatement potential:

(i) Power sector decarbonisation

(ii) Energy efficiency and new energy sources in buildings and industry

(iii) More efficient vehicles and new transport fuels

(iv) Emissions reductions in non-CO_2 greenhouse gases.

(i) Power sector decarbonisation

We set out scenarios for UK power sector decarbonisation over the first three budget periods in Chapter 5: *Decarbonising electricity generation*. These scenarios included moving away from a reference case with capacity additions based on conventional coal-fired generation. Instead, investment was assumed to flow to renewable generation backed up by gas-fired plant. Depending on the scenario, we also assumed some investment in nuclear new build. Finally, we assumed that there will be one coal-fired carbon capture and storage (CCS) demonstration plant, and that conventional coal-fired capacity could be added only on the expectation that this would be retrofitted with CCS in the 2020s.

We have not undertaken an analysis of where capacity might be added in the UK. Given our scenario-based approach at the UK level, it would not be appropriate to try to be definitive at the national level. At a high level, however, it is reasonable to assume that there will be opportunities for investment in low-carbon technologies in each of the nations of the UK, both because existing capacity is due to be retired, and because of renewable resource endowments, for example:

- There are planned capacity retirements in Scotland and Northern Ireland under the Large Combustion Plant Directive. In Scotland the capacity of the coal plant due to be retired (1,200 MW) is likely to have a significant impact on Scotland's emissions profile. Nuclear plant in Wales is also due to be decommissioned in 2010.

- Around 30% of Britain's onshore wind potential lies in Scotland, and around 10% of both onshore and offshore potential lies in Wales[5]. There is also potential for both on and offshore wind in Northern Ireland. There is significant potential for marine and tidal technologies in Wales (Severn Estuary), Scotland (Pentland Firth) and to a lesser extent in Northern Ireland.

5 Source: SKM (2008) *Growth scenarios for UK renewables generation and implications for future developments and operation of electricity networks*

In Chapter 5, we argued that a key step in significantly increasing the level of renewable electricity generation in the UK would be to address a range of constraints related to the planning system and the transmission network. There will be a particularly important role for the national authorities in addressing these constraints given the balance of reserved and devolved powers in this area, which include:

- Each national authority has responsibilities for planning in relation to energy infrastructure. In Northern Ireland, the national authority is responsible for approving onshore electricity generation capacity and offshore capacity in adjacent territorial waters. In Scotland and Wales, local planning authorities grant permission for onshore capacity up to and including 50 MW. Scottish Ministers have responsibility for approving investments in plant of greater than 50 MW capacity and offshore capacity (wind and water driven) above 1 MW in adjacent territorial waters. In Wales, offshore projects over 1 MW may be approved by the Welsh Assembly Government under the Transport and Works Act where navigation routes are affected.

- Overhead electric lines above 20 kV are subject to consent by the UK Secretary of State in the case of Wales, and the relevant national authorities in the case of Scotland and Northern Ireland.

- National authorities in Northern Ireland and Scotland are also responsible for financing mechanisms (e.g. renewable obligations, see Chapter 5) to support investment in renewable generation.

Given these powers, the national authorities will have key roles to play in delivering our scenarios in Chapter 5 and those set out in the UK Government's draft Renewable Energy Strategy. In Chapter 3 we showed how successful delivery would contribute to the UK meeting the traded sector budget that we have proposed. Successful delivery would also have significant benefits in the context of national emissions reduction programmes, which we believe should include strategies for supporting a significant increase in the level of investment in renewable generation.

(ii) Energy efficiency and new energy sources in buildings and industry

Emission reduction in existing buildings: Estimates of emissions reduction potential in existing residential and non-residential buildings in Chapter 6: *Energy use in buildings and industry* were based on a range of measures including:

- Measures to reduce the energy needed to heat buildings through improved insulation and more efficient and lower carbon ways to generate heat.

- Measures to improve boiler efficiency and reduce gas demand

- The use of more efficient appliances and lighting, resulting in electricity demand reductions

- Investment in (electricity and heat) microgeneration technologies, reducing demand for gas, electricity and other fossil fuels.

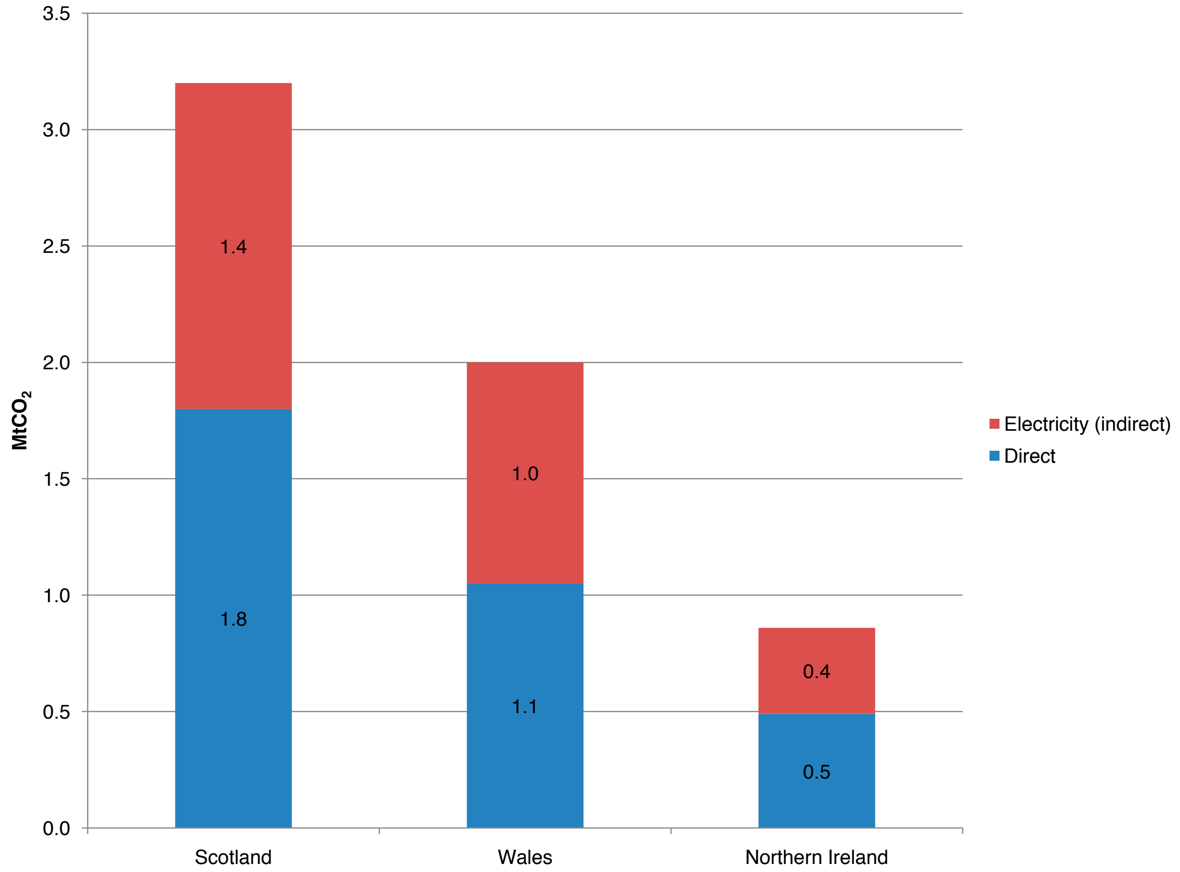
- Lifestyle and energy management measures (e.g. turning down heating thermostats, using economy washing programmes)

We estimated that the total technical potential for emissions reductions across the UK for these measures in 2020 is up to 134 $MtCO_2$. Taking account of emissions reduction constraints, we estimated that there is up to 35 $MtCO_2$[6] of realistically achievable emissions reduction potential in our Extended Ambition scenario.

6 This number excludes savings from Zero Carbon Homes as this policy covers England and Wales only and has not been disaggregated. The Sullivan Report: *A low-carbon buildings strategy for Scotland* has recommended similar measures to zero carbon homes for Scotland.

We have allocated this UK figure across nations according to current energy share (e.g. where Wales consumes 5% of total UK energy, we have assumed that it has 5% of the emissions reduction potential). Based on this methodology, we estimate that in 2020 there is up to 2 $MtCO_2$ feasible emissions reduction in Wales (1.1 $MtCO_2$ of which are direct savings), 3.2 $MtCO_2$ in Scotland (1.8 $MtCO_2$ of which are direct savings), and 0.9 $MtCO_2$ in Northern Ireland (0.4 $MtCO_2$ of which are direct[7] savings) (Figure 14.7).

Figure 14.7 Direct and indirect abatement in buildings – Wales, Scotland and Northern Ireland, 2020



Source: CCC analysis

We recognise that this methodology does not account for national differences in key aspects related to fuel use and energy efficiency of existing buildings which will impact on emissions reduction potential, as shown for the housing stock in Table 14.1:

- Lower levels of gas central heating, particularly in Northern Ireland, may provide opportunities for additional emissions reduction, for example, through switching from current carbon-intensive sources of heat (e.g. domestic fuel oil and coal) to renewable heat technologies (e.g. biomass, combined heat and power (CHP), heat pumps, etc.). On the other hand, scope for boiler efficiency improvement may be lower in Wales, Scotland and Northern Ireland.

- There may be greater scope for cavity wall insulation in Wales and Scotland relative to England, given that a higher proportion of cavity walls in these nations are not currently insulated. Conversely, there is relatively less opportunity in Northern Ireland as a smaller proportion of cavity walls are un-insulated.

7 Direct savings are reductions in emissions relating to consumption of fossil fuels in buildings (i.e. not electricity).

Given the need to account for these considerations, we stress that our estimates of national emissions reduction potential should be regarded as indicative; further work would be required before these could form part of national emissions reduction strategies or national carbon budgets.

Table 14.1 House Condition Survey statistics – England, Wales, Scotland and Northern Ireland, 2004

	England	Wales	Scotland	Northern Ireland
Number of households (000s)	21,620	1,209	2,269	680
Households with mains gas central heating	88%	78%	73%	8%
Households with un-insulated cavity walls	42%	44%	47%	17%

Source: English House Condition Survey 2004, Living In Wales 2004, Northern Ireland Interim House Condition Survey 2004, Scottish House Condition Survey 2003-04

Notwithstanding the need for further work on the level of abatement potential that is available, we have made a preliminary assessment of national authorities' ability to implement policies to reduce emissions. In doing this, we have considered the balance of control between the UK Government and national authorities over the main policy levers for reducing emissions (Table 14.2):

- National authorities in Wales, Scotland and Northern Ireland are responsible for promoting energy efficiency improvements, policy regarding microgeneration technologies, and public estate management.

- National authorities in Northern Ireland and Scotland have devolved control over setting building standards.

Table 14.2 Current balance of powers relating to emissions reductions in buildings

Reserved powers and UK/GB-wide policies			
Carbon Reduction Commitment (UK-wide)			
EEC/CERT and the Supplier Obligation (GB-wide)			
Devolved powers			
	Wales	**Scotland**	**Northern Ireland**
Promotion of energy efficiency	✓	✓	✓
Public sector estate management	✓	✓	✓
Microgeneration policy	✓	✓	✓
Building standards	x	✓	✓
Energy efficiency levy on power companies	x	x	✓

Source: CCC analysis

It is our conclusion that the national authorities have control over some key policy levers, and that devlolved action will be required in order to realise emissions reductions in buildings in Wales, Scotland and Northern Ireland.

Emissions reduction in industry: Estimates of potential for industrial emissions reductions in Chapter 6 were based on a range of measures such as improved energy management, insulation and heat recovery and building new more energy efficient plant. We estimated maximum technical emissions reduction potential of 7 $MtCO_2$ in 2020, and argued that this should largely be regarded as realistically achievable given that much of industry in the UK is covered by emissions caps/trading.

We have allocated this potential across nations using national share of gross value added (GVA) by industrial sector (Table 14.3). On the basis of this methodology, nations with an estimated share of UK abatement potential comparable to their population share are:

- Scotland, where there may be significant scope for emissions reductions in electrical engineering and food and drink.
- Wales, where there may be significant scope for emissions reduction in basic metals.

Table 14.3 Share of UK GVA, by sector, and overall share of abatement potential – Wales, Scotland and Northern Ireland, 2005

Sector	Wales	Scotland	Northern Ireland
Chemicals	4%	5%	1%
Construction	4%	9%	4%
Electrical Engineering	7%	14%	3%
Food and Drink	4%	11%	2%
Mechanical Engineering	4%	7%	2%
Non-metallic mineral products	4%	6%	5%
Other Industries	6%	8%	2%
Paper and Printing	3%	5%	1%
Rubber and Plastics	5%	6%	5%
Basic metals	11%	5%	1%
Textiles and Clothing	3%	8%	2%
Vehicle Engineering	5%	5%	3%
Water	6%	9%	3%
Total share of abatement potential	**5%**	**7%**	**1%**

Source: AEA based on Annual Business Inquiry (ABI) data

More generally, we estimate that there may be up to 0.4 $MtCO_2$ emissions reduction in industry in Wales (0.1 $MtCO_2$ of which are direct savings), 0.5 $MtCO_2$ in Scotland (0.1 $MtCO_2$ of which are direct savings) and 0.1 $MtCO_2$ in Northern Ireland (0.02 $MtCO_2$ of which are direct savings).

Delivery of these reductions will largely be driven by UK-wide initiatives such as the European Union Emissions Trading Scheme (EU ETS), the Carbon Reduction Commitment and Climate Change Agreements (see Chapter 6). There is an important role however for national authorities both in contributing to the design and implementation of these policies, and in helping to address emissions reduction constraints in sectors comprising small non energy-intensive firms, for which the policy framework is currently limited.

(iii) More efficient vehicles and new transport fuels

At the UK level, we noted that the large majority of UK transport emissions relate to road transport, and we identified potential for emissions reductions of up to 19 $MtCO_2$ in 2020 from supply-side measures in the Extended Ambition scenario (see Chapter 7: *Reducing domestic transport emissions*). We based this estimate on a model of the existing vehicle (cars, vans and HGVs) stock with assumptions about the rate of turnover and a range of opportunities for reducing emissions including increased use of biofuels and improved fuel-efficiency of new cars and vans.

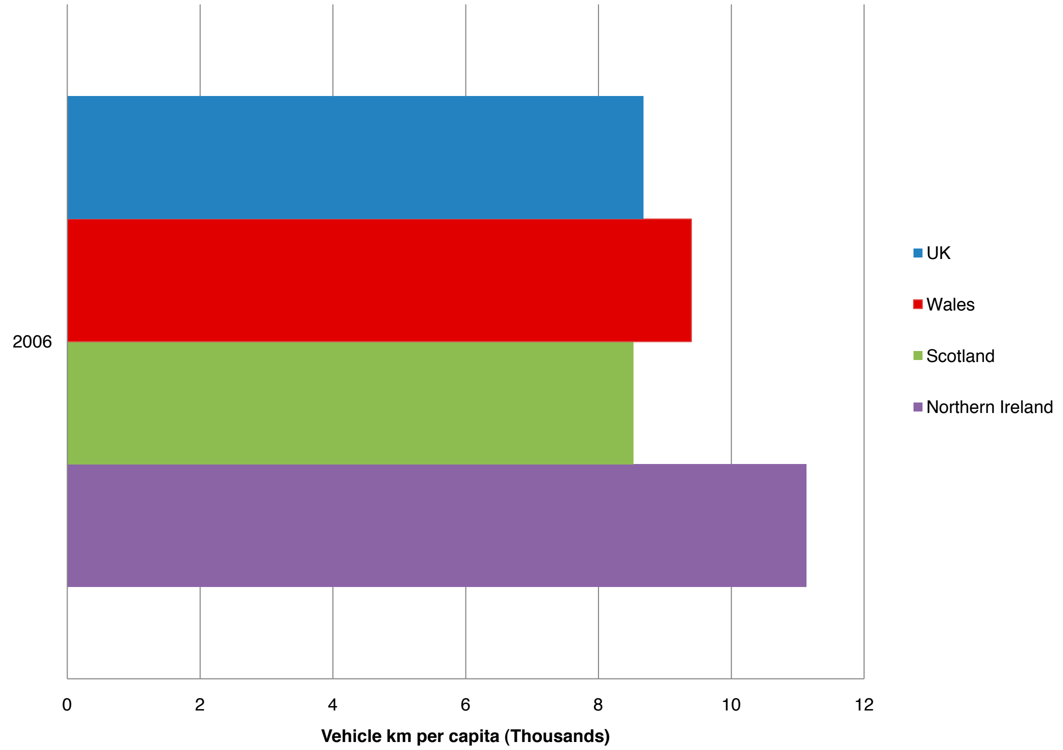
We have allocated our estimate of UK emissions reductions across nations on the basis of share in vehicle kilometres. In doing this we have assumed that the existing car stock is of similar composition across nations, both as regards vehicle size and fuel efficiency. We have also assumed a similar rate of stock turnover and technology options across nations. Under these assumptions, we estimate that in 2020 there is 1 $MtCO_2$ emissions reduction potential in Wales, 1.5 $MtCO_2$ in Scotland, and 0.7 $MtCO_2$ in Northern Ireland.

The delivery mechanism for these emissions reductions will be an EU-wide framework based around legally binding targets for car fuel efficiency and possibly for van fuel efficiency. To the extent that delivering these targets will require strengthening of fiscal incentives, this will be a matter for the UK Government rather than national authorities, given that fiscal matters (e.g. vehicle excise duty) are reserved.

There is a role, however, for national authorities to support delivery of transport demand-side emissions reduction. We suggested, for example, that there may be up to around 3 $MtCO_2$ of emissions reduction available at the UK level through implementation of Smarter Choices measures (e.g. modal shift, car sharing, etc.).

Whether this can be achieved equally across nations will depend to an extent on geography. For example, it may be the case that the higher vehicle kilometres per capita in Northern Ireland (Figure 14.8) reflects higher levels of rural travel for which it would not be economic to substitute public transport. Conversely, there may be scope for more modal switch in areas where public transport networks are currently either underdeveloped or underutilised.

Figure 14.8 Vehicle kilometres per capita – UK, Wales, Scotland and Northern Ireland, 2006



Source: DfT, Department for Rural Development in Northern Ireland and GAD

It is our view that there is worthwhile opportunity for reducing emissions through modal shift, better journey planning and other demand-side measures in each nation. The emissions reductions available may not be large in absolute terms, but could form a useful part of wider national emissions reduction programmes. National authorities have a key role unlocking emissions reduction potential here given that powers to support modal shift are devolved.

(iv) Emissions reduction in non-CO_2 greenhouse gases

Abatement potential in agriculture, land use and forestry: We set out our analysis of emissions reduction potential in agriculture and forestry in Chapter 9: *Non-CO_2 greenhouse gases*, where we considered a range of options including:

- Measures to reduce N_2O emissions from crops and soils
- Measures to reduce methane emissions from livestock
- Peatland restoration[8]
- Increasing the number of trees

Our conclusion was that there is 7 $MtCO_2e$ of realistically achievable emissions reduction potential in 2020, under the central feasible scenario.

8 In Chapter 9, we suggested that the research has not identified significant abatement potential from peatland restoration and other land use measures and therefore savings from this option have not been disaggregated here. However, if peatland restoration were to be identified as a cost-effective measure, it is likely that a significant share of the savings would occur in Scotland.

We have disaggregated this potential[9] across nations on the basis of the following methodologies:

- For measures to reduce N_2O emissions from crops and soils, we have used the proportion of land currently used for each type of crop to determine the share of savings
- For livestock measures, we have estimated the share of savings based on the number of livestock in each nation
- For reforestation/avoided deforestation, we have estimated the share of savings based on Centre for Ecology and Hydrology's nation-specific modelling work of different rates of tree planting.

Applying these methodologies suggests that there are significant opportunities for emissions reduction from agriculture and forestry across the nations:

- In Wales, reductions in emissions from livestock could be up to 0.1 $MtCO_2e$ and from crops and soils measures 0.4 $MtCO_2e$. Forestry measures could deliver 0.06 $MtCO_2$ of savings.
- In Scotland, reductions in emissions from livestock could be 0.1 $MtCO_2e$ and from crops and soils measures 0.6 $MtCO_2e$. Forestry measures could deliver 0.3 $MtCO_2$ of savings.
- In Northern Ireland, reductions in emissions from livestock could be 0.1 $MtCO_2e$ and from crops and soils measures 0.3 $MtCO_2e$. Forestry measures could deliver 0.04 $MtCO_2$ of savings.

Our conclusion in Chapter 9 was that the policy framework for unlocking emissions reduction potential is currently not developed, and that there should be serious consideration of the alternative policy options available. There is an important role for the national authorities in this context, given the balance of reserved and devolved powers. Specifically, though the influence of EU policy is strong, this is largely a devolved policy area, with each national authority having responsibility for its rural development plan and having its own forestry service.

Given the significant emissions reduction potential and the policy levers available to national authorities, therefore, it will be important going forward that national climate change strategies include measures to reduce emissions from agriculture, land use and forestry.

Non-CO_2 emissions reduction in waste management: In Chapter 9 we identified feasible abatement potential of up to 6 $MtCO_2e$ as a result of directing waste away from landfill to energy-producing processes. The MACC model for waste constructed for the CCC included an initial analysis of how the abatement would be distributed across the nations. This analysis estimated that of this potential, 0.3 $MtCO_2e$ could be saved in Wales, 0.7 $MtCO_2e$ in Scotland and 0.1 $MtCO_2e$ in Northern Ireland. Waste management policy is devolved to each of the national authorities, however, some of the key mechanisms for delivering emissions reductions are set at EU level (the landfill directive) or UK level (the landfill tax).

Non-CO_2 emissions reduction in industrial processes: Half of the 3 $MtCO_2e$ of abatement potential identified for industrial process and energy-related non-CO_2 emissions (Chapter 9) largely relates to upgraded recovery and utilisation of methane from coal mines. Whilst we have not undertaken a detailed analysis of the distribution of these savings, given that current activity resulting in coal mining emissions is located in England (84%), Wales (13%) and Scotland (3%), the savings identified are likely to be distributed accordingly.

9 This figure includes savings from anaerobic digestion measures, however due to data constraints, it has not been possible to disaggregate the potential between England, Wales, Scotland and Northern Ireland.

3. ECONOMIC IMPACTS OF CARBON BUDGETS IN WALES, SCOTLAND AND NORTHERN IRELAND

At the UK level, we have undertaken an analysis of the wider economic costs of carbon budgets (Chapter 11: *Economic costs and fiscal implications*). We have not, however, attempted to estimate the GDP impact at the level of the national authorities. Rather, our focus has been on the potential competitiveness impacts of carbon budgets and consequences for employment and output in Wales, Scotland and Northern Ireland.

In Chapter 10: *Competitiveness challenges and opportunities*, we argued that potential competitiveness impacts relate to a small number of energy-intensive sectors. In particular, sectors regarded as being at risk would have to meet two criteria:

- Energy costs should be a significant proportion of production costs and/or gross value added (GVA), such that energy cost increases due to carbon prices would significantly impact output prices.

- Products should be tradable or potentially tradable, implying that transport costs and other trade barriers should not be prohibitive

Our conclusion was that a number of sectors may potentially be at risk, which may include iron and steel, lime, cement and aluminium.

National output and employment impacts: We have developed the analysis in Chapter 10 to understand possible national implications for output and employment as consumers and firms respond to increased production costs and possible competitiveness impacts. At the UK level, we have argued that these impacts are likely to be small. But at the national level, impacts are potentially significant given geographical concentration of energy-intensive sectors.

Our starting point was to group the sectors shown in Chapter 10 into three categories according to their production cost increase:

- Category 1 comprises sectors with cost increase as a share of GVA of more than 25%, plus aluminium[10]

- In Category 2 are sectors with cost increase as a share of GVA of between 15% and 25%

- Category 3 includes sectors that have cost increase as a share of GVA of between 5% and 15%.

10 Aluminium is expected to have <25% increase in production costs as a proportion of GVA but is most highly exposed to electricity cost increases. Its inclusion also negates disclosure issues with the ABI data. Other sectors in this category in fact have >50% increase in production cost as a proportion of GVA.

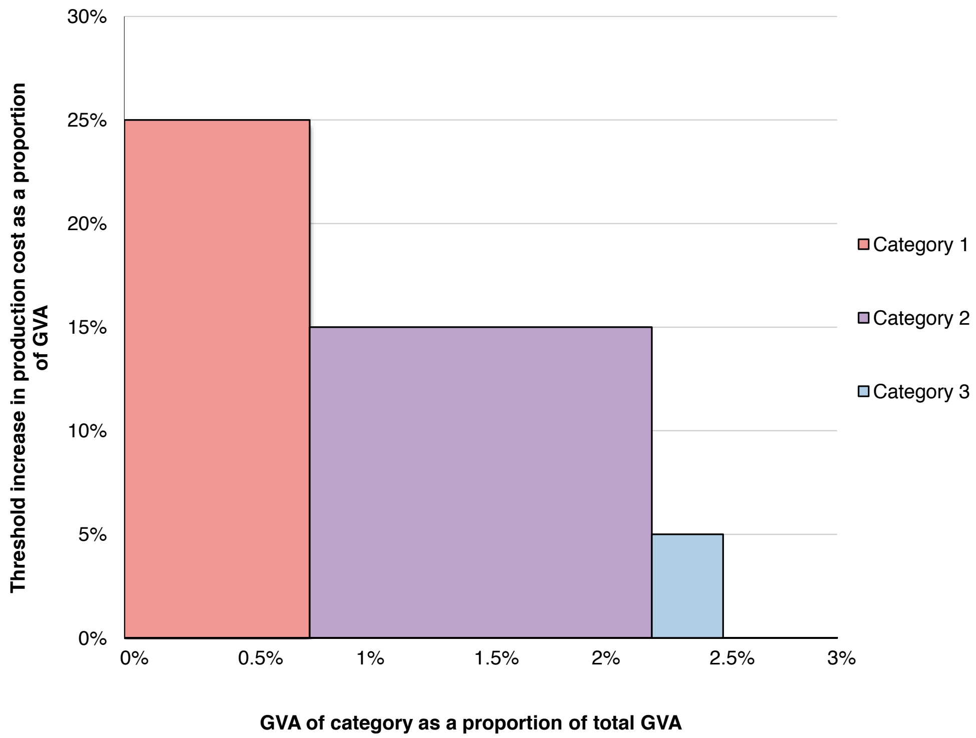
Table 14.4 Industrial sectors at risk by category

Category 1	Category 2	Category 3
Most GVA at risk	**Moderate GVA at risk**	**Some GVA at risk**
Basic iron & steel	Refined petroleum products	Malt
Cement	Starches & starch products	Coke oven products
Lime	Fertilisers & nitrogen compounds	Industrial gases
Aluminium	Other inorganic basic chemicals	Non-wovens
	Pulp, paper & paperboard	Household & sanitary goods
		Finishing of textiles
		Hollow glass
		Rubber tyres & tubes
		Retreading & rebuilding of rubber tyres
		Veneer sheets, plywood, etc.
		Flat glass
		Other textile weaving
		Copper
		Silk & filament yarn
		Casting of iron

Mapping these categories to national production suggests that sectors at risk account for only a small proportion of national GVA (Figures 14.9.a-c). Category 1 sectors accounted for 0.8% of 2005 GVA in Wales but only 0.1% in Northern Ireland and 0.07% in Scotland.

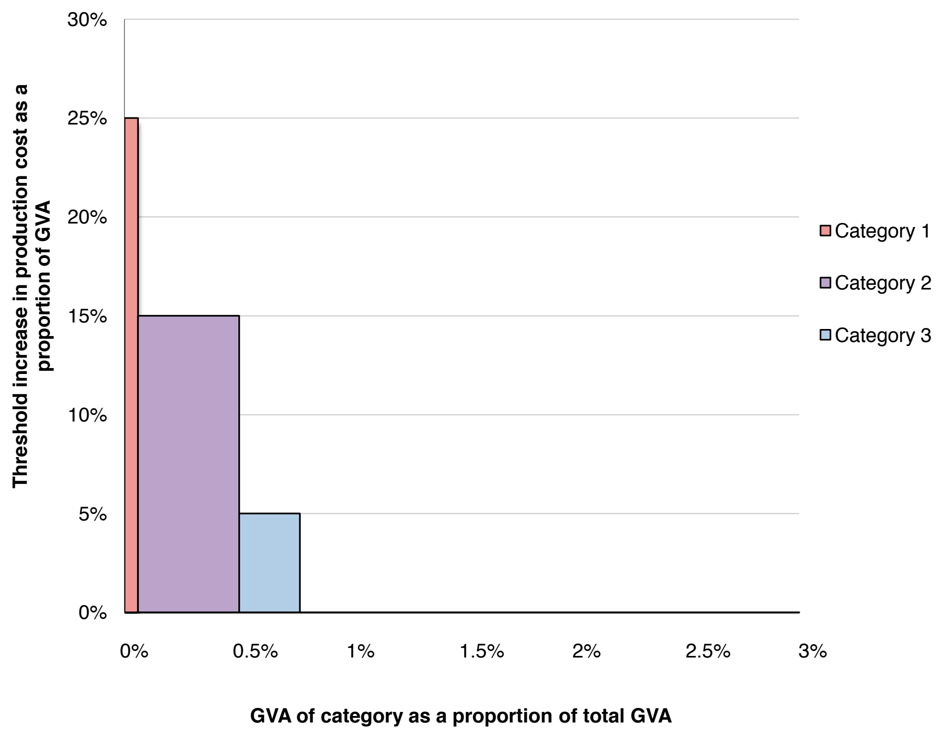
Mapping the same categories to employment suggests that sectors at risk account for only a small proportion of national jobs, and no more than 1.4% in any nation in 2005 (Figures 14.10.a-c). We note, however, that local impacts within nations may be significant (Table 14.5). In particular, around half of the 16,000 jobs in at risk sectors in Wales relate to two industries around which form important parts of local economies.

Figure 14.9.a Proportion of GVA represented by category 1, 2 and 3 sectors – Wales, 2005



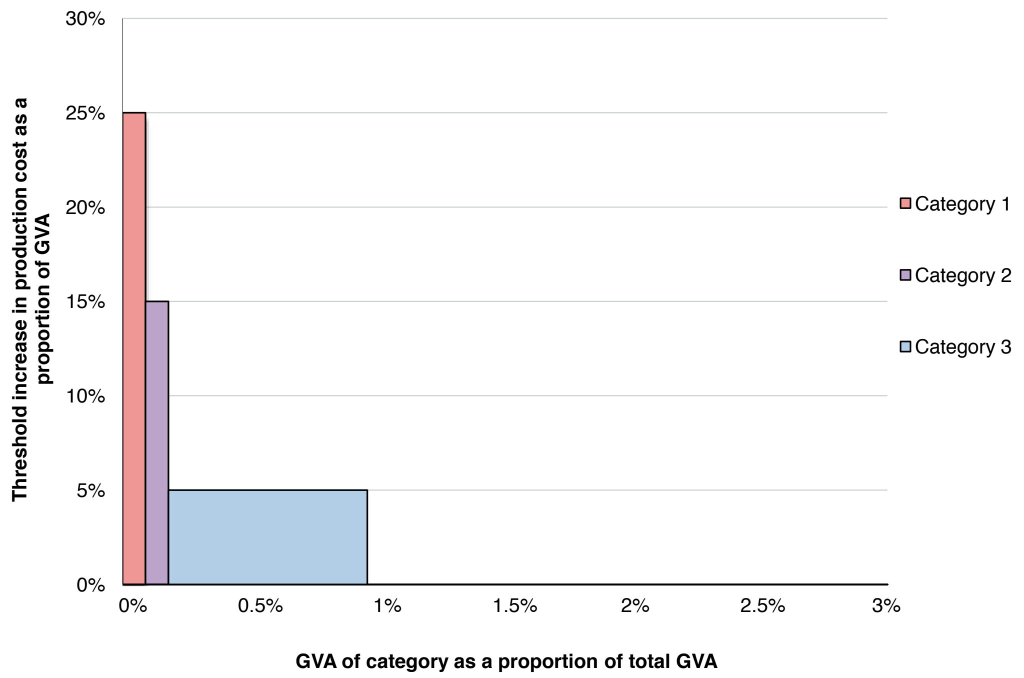
Source: CCC calculations based on ABI data

Figure 14.9.b Proportion of GVA represented by category 1, 2 and 3 sectors – Scotland, 2005



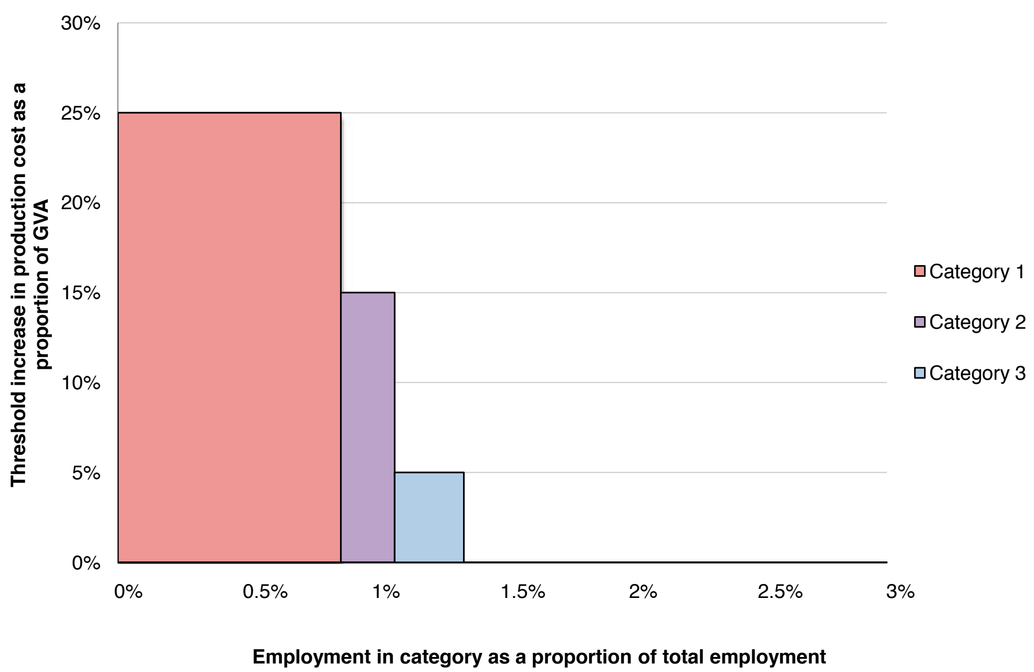
Source: CCC calculations based on ABI data

Figure 14.9.c Proportion of GVA represented by category 1, 2 and 3 sectors – Northern Irealand, 2005



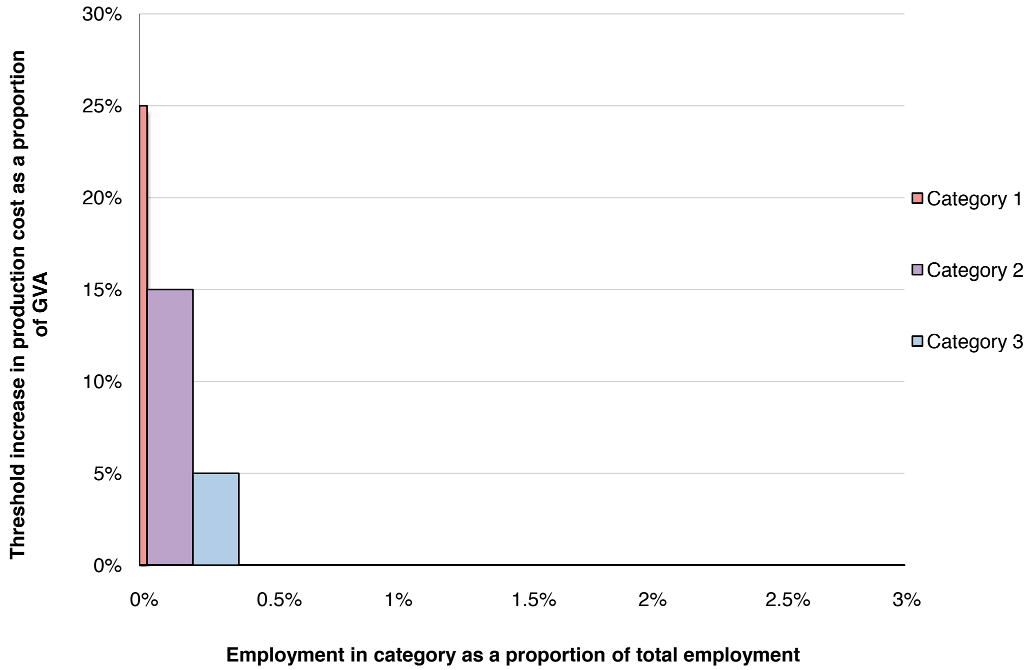
Source: CCC calculations based on ABI data

Figure 14.10.a Proportion of employment represented by category 1, 2 and 3 sectors – Wales, 2005



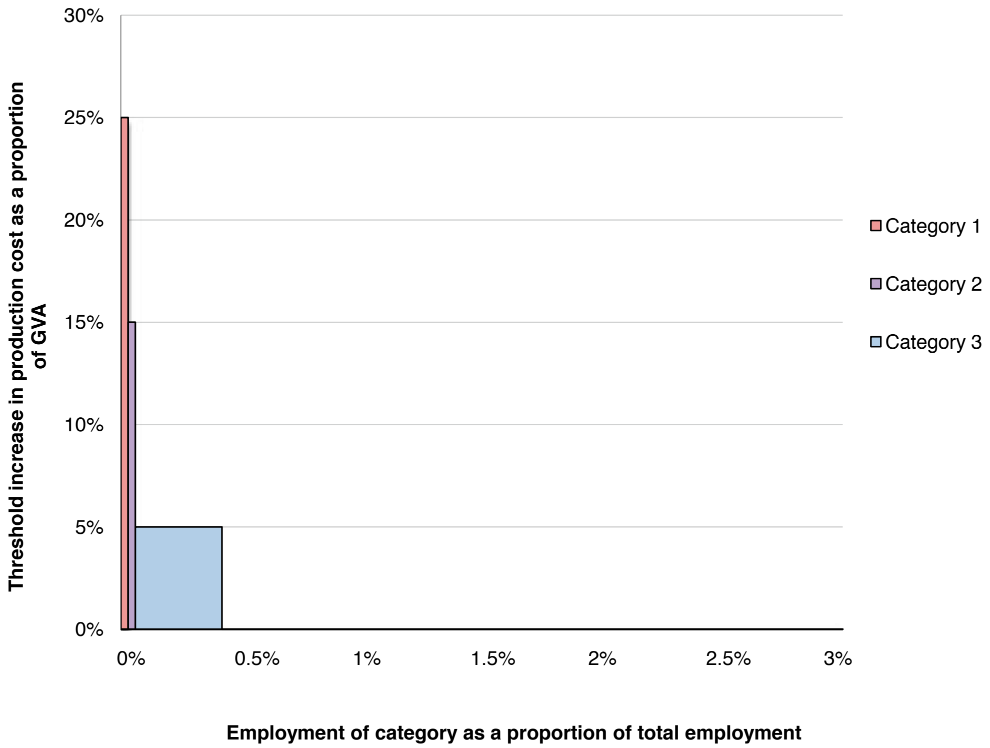
Source: CCC calculations based on ABI data

Figure 14.10.b Proportion of employment represented by category 1, 2 and 3 sectors – Scotland, 2005



Source: CCC calculations based on ABI data

Figure 14.10.c Proportion of employment represented by category 1, 2 and 3 sectors – Northern Ireland, 2005



Source: CCC calculations based on ABI data

Table 14.5 Location of main plant in category 1 in Wales, Scotland and Northern Ireland

Sector	Nation	Location
Aluminium	Wales	Anglesey
Cement	Wales	Flintshire
	Scotland	East Lothian
	Northern Ireland	Co. Fermanagh, Co. Tyrone
Iron and Steel	Wales	Cardiff, Carmarthenshire, Newport, Port Talbot

Source: Defra, EU ETS UK National Allocation Plan

Risk mitigating measures: It is important to stress that whilst there are risks for energy-intensive sectors, there are also risk-mitigating mechanisms (e.g. issuing free carbon allowances to sectors at risk, see Chapter 10). Moreover, these mechanisms are and will be an integral part of the EU ETS framework. Whilst competitiveness impacts may therefore be an issue in principle, in practice we do not expect the localised output and employment impacts identified above to ensue.

Opportunities: We feel more confident in this conclusion recognising that over time dynamic labour markets will facilitate growth in other sectors to offset any output reduction in energy-intensive industry, and to take advantage of specific opportunities related to building a low-carbon economy. The location and scale of these opportunities are difficult to predict, but key growth sectors are likely to include offshore wind energy, wave and tidal, and auto-engines (see Chapter 10).

4. FUEL POVERTY IMPACTS OF CARBON BUDGETS

Fuel poverty is already a significant issue across the nations of the UK, this in the absence of major carbon impacts on energy prices. In 2006, the range for the number of households in fuel poverty in the national authorities was 20%-34%, up from 11%-23% in 2004 (Table 14.6). Given increasing international oil and gas prices which have been reflected in domestic energy prices, we would expect these numbers to have increased further in the last two years.

Table 14.6 Proportion of fuel poor households in Wales, Scotland and Northern Ireland, 2004 and 2006

Year	Scotland (1)	Wales	Northern Ireland
2004	15%	11%	23%
2006	24%	20%	34%

(1) Scottish Fuel poverty estimates relate to survey years 2003-04 and 2005-06 respectively.

Source: Fuel Poverty In Wales 2004, Northern Ireland House Condition Survey 2006, Scottish House Condition Survey 2005-06

Chapter 12: *Fuel poverty implications*, sets out our analysis of incremental fuel poverty impacts due to carbon budgets. This analysis suggested that up to 600,000 UK households could be pushed into fuel poverty through carbon budget impacts on the electricity price in 2022, rising to 1.7 million households through possible gas price impacts. Offsetting these impacts, we estimated that energy efficiency improvement could potentially reduce the number of households in fuel poverty by up to 400,000.

Our analysis is based on a model developed for us by the Buildings Research Establishment (BRE). We have built on the model, which relates to households in England only, to draw indicative implications for fuel poverty in Wales, Scotland and Northern Ireland. To do this, we consider three key potential differences across nations:

- Income, which varies across regions in the UK, with average household disposable income in Northern Ireland, Wales and Scotland being lower than the UK average[11]. For given energy consumption and carbon cost, more households will enter fuel poverty where incomes are lower.

- Demographic changes, including the growth in the number of households, changes in type of household as well as the age structure of the population. For example, the projected number of households in 2022 is expected to be around 19% higher than in 2006 in Northern Ireland and 13% higher in Scotland and Wales[12].

- Differences in opportunities for energy efficiency improvements across nations given differences in the building stock (see Section 2 above).

11 Source: ONS (2005) Gross Disposable Household Income.
12 Source: General Registrar Scotland (2006-based), Northern Ireland Statistics and Research Agency (2006-based) and Welsh Assembly Government (2003-based).

The results of this analysis suggest that up to around 250,000 households in the three national authorities could enter fuel poverty due to electricity and gas price impacts net of energy efficiency improvements:

- In the reference scenario, there are estimated to be 130,000 households in fuel poverty in 2022 in Wales (Table 14.7.a). Electricity price impacts in Wales could result in an additional 40,000 households entering fuel poverty, rising by 90,000 households due to possible gas price impacts. Energy efficiency improvements could take 30,000 households back out of fuel poverty.

- In the reference scenario, there are estimated to be 290,000 households in fuel poverty in 2022 in Scotland[13] (Table 14.7.b). Electricity price impacts in Scotland could result in an additional 40,000 households entering fuel poverty, rising by 90,000 households due to possible gas price impacts. Energy efficiency improvements could take 30,000 households back out of fuel poverty.

- In the reference scenario, there are estimated to be 120,000 households in fuel poverty in 2022 in Northern Ireland (Table 14.7.c). Electricity impacts in Northern Ireland could result in an additional 20,000 households entering fuel poverty. Possible gas price impacts should be less important in the case of Northern Ireland, given the low level of gas penetration. However, an additional 50,000 households could enter fuel poverty in Northern Ireland if a renewable heat levy were applied to all heating fuels. Energy efficiency improvements could take 20,000 households back out of fuel poverty.

We argued in Chapter 12 that emissions reduction effort should not be lowered given possible implications for fuel poverty. Rather, fuel poverty impacts should be addressed. The balance of reserved and devolved responsibilities is such that there will be an important role for the UK Government in addressing fuel poverty impacts, through income transfers and/or through possible introduction of social tariffs. There will also be an important role for national authorities, however, particularly as regards supporting and facilitating energy efficiency improvements which our analysis suggests has significant potential to reduce, if not fully offset, fuel poverty impacts of carbon budgets.

13 This figure does not include demographic changes in Scotland as the base year data were not available. Supplementary analysis suggests the number of households in fuel poverty in 2022 in Scotland could be 17% higher (up to 340,000 households) in the reference case, based on the impact of demographic changes in England.

Table 14.7.a Fuel poverty impacts in Wales

Year	Number of households in fuel poverty (thousands) under:				
	Reference projection	Electricity price increases	Electricity price increases and energy efficiency measures	Electricity and gas price increases	Electricity and gas price increases and energy efficiency measures
2006	240				
2012	190	210	200	220	210
2017	150	180	170	240	220
2022	130	170	150	260	230

Source: BRE modelling, based on CCC assumptions

Table 14.7.b Fuel poverty impacts in Scotland

Year	Number of households in fuel poverty (thousands) under:				
	Reference projection	Electricity price increases	Electricity price increases and energy efficiency measures	Electricity and gas price increases	Electricity and gas price increases and energy efficiency measures
2006	540				
2012	410	430	420	440	420
2017	330	370	350	420	390
2022	290	330	300	420	390

Source: BRE, based on CCC assumptions

Table 14.7.c Fuel poverty impacts in Northern Ireland

Year	Number of households in fuel poverty (thousands) under:				
	Reference projection	Electricity price increases	Electricity price increases and energy efficiency measures	Electricity and gas price increases	Electricity and gas price increases and energy efficiency measures
2006	230				
2012	170	190	180	190	180
2017	140	160	140	180	170
2022	120	140	120	190	170

Source: BRE modelling, based on CCC assumptions

5. NEXT STEPS IN DEVELOPING THE EVIDENCE BASE

Each of the national authorities has adopted emissions reduction targets:

- Wales is targeting a 3% annual emissions reduction from 2011 in areas of devolved competence. Current renewable electricity targets are to produce 4 TWh by 2010 and 7 TWh by 2020.

- Scotland is targeting a 50% GHG emissions reduction by 2030 relative to 1990, rising to 80% in 2050. In addition, Scotland is aiming to generate half of its electricity from renewable sources by 2020.

- Northern Ireland will aim to reduce GHG emissions by 25% in 2025 relative to 1990, and to have 12% of its electricity coming from renewable sources by 2012.

The analysis in this chapter and the accompanying technical paper, together with analysis being carried out by the national authorities, could be used to inform how these targets might be met. It would not, however, form the basis for design of climate strategies in the national authorities. Given the indicative nature of our analysis, we have avoided moving from our estimates of emissions reduction potential to indicative national budgets. To the extent that it would be desirable to design national budgets, either to embody and help deliver national targets, or to set out national contributions to UK budgets, further work would be required. We have highlighted some of the areas where we see a need for further work in this chapter. Going forward, it is our intention to work with the national authorities to build on existing analysis and provide more detailed consideration of key national differences that should be accounted for when designing carbon budgets and climate strategies.

PART V:

SYNTHESIS AND RECOMMENDATIONS

Our recommendations relating to the level and coverage of budgets fall into three categories:

(viii) The 2050 target

(ix) The first three budgets

(x) International aviation and shipping

(i) The 2050 target

We recommend that the UK should aim to reduce emissions by 80% in 2050 relative to 1990. This target should apply to all greenhouse gases and all sectors of the economy. It is an appropriate contribution by the UK to a global emissions reduction of 50-60% which will be required if the likelihood of dangerous climate change is to be kept to acceptable levels.

Meeting this target is feasible and affordable at a cost of 1-2% of GDP in 2050. The Committee believes this cost should be accepted given the costs and consequences of not acting to tackle climate change.

(ii) The first three budgets

We recommend that the UK should legislate budgets in greenhouse gases (GHGs) rather than CO_2.

We propose an Interim budget to apply before a post 2012 global deal, and an Intended budget to apply after a global deal has been agreed. Our Interim and Intended budget proposals are shown in Table V.1 below.

Table V.1 Interim and Intended GHG budgets for the UK for 2008-2022

		Budget 1 (2008-2012)	Budget 2 (2013-2017)	Budget 3 (2018-2022)
Interim budget ($MtCO_2e$)	Traded sector	1233	1114	1011
	Non-traded sector	1785	1704	1559
	Non-traded sector CO_2	1304	1235	1103
	Non-traded sector non-CO_2	481	469	456
	Total	3018	2819	2570
Intended budget ($MtCO_2e$)	Traded sector	1233	1009	800
	Non-traded sector	1785	1671	1445
	Non-traded sector CO_2	1304	1201	989
	Non-traded sector non-CO_2	481	469	456
	Total	3018	2679	2245

Source: CCC
Note: The traded sector comprises energy-intensive firms in the European Union Emissions Trading Scheme (EU ETS). The non-traded sector comprises residential, commercial, small industrial and transport sectors. Non-CO_2 gases are Kyoto greenhouse gases apart from carbon.

Intended budget. Our Intended budget proposals are characterised by:

- Total GHG emissions reductions of 42% in 2020 relative to 1990 (i.e. 31% relative to 2005)
- Split in emissions reduction effort between traded and non-traded sectors in the proportion 68% to 32%.
- Purchase of up to 23 $MtCO_2$ of offset credits annually by 2020 to meet the required non-traded sector emissions reductions.

Interim budget. Our Interim budget proposals are characterised by:

- Total GHG emissions reductions of 34% in 2020 relative to 1990 (i.e. 21% relative to 2005)
- Split in emissions reduction effort between traded and non-traded sectors in the proportion 65% to 35%.
- All non-traded sector emissions reduction to be achieved through domestic effort rather than purchase of offset credits.

These proposed budgets:

- Include an appropriate level of ambition in the context of the 2050 target, the UK's contribution to global emissions reduction required in 2020, and commitments to the EU.
- Are feasible through improving energy efficiency, using lower carbon energy sources and changing lifestyle, and under a strengthened policy framework.
- Are affordable at a cost of less than 1% of GDP in 2020.

(iii) International aviation and shipping

We recommend that international aviation and shipping should be part of the UK's climate strategy, and that these sectors should be included in the 80% target for 2050. There are however practical complexities which currently argue against including international aviation and shipping in the UK's legally defined budgets. To the extent that percentage emissions reductions in international aviation and shipping are likely to fall short of overall targets, it will therefore be essential that budgets for other sectors require a higher level of ambition. And it is essential that emissions reductions in international aviation and shipping are driven by appropriate policies even if they are not included in the legal budget framework. We recommend that the Committee will report annually on trends in international aviation and shipping emissions, development of the policy framework, and progress in reducing emissions.

GLOSSARY AND ABBREVIATIONS

GLOSSARY

Adaptation	Adjustment of behaviour to limit harm, or exploit beneficial opportunities, arising from climate change.
Advanced Supercritical (ASC) or Ultra Supercritical (USC)	New coal combustion systems that operate at increasingly higher temperatures and pressures. Achieve higher efficiencies and CO_2 intensities than conventional pulverised fuel (PF) units.
Amsterdam-Rotterdam-Antwerp (ARA)	A measure of the wholesale price of coal in the UK (measured in $/tonne, calorific value of 6000 kCal per tonne).
Anaerobic Digestion (AD)	A treatment process breaking down biodegradable, particularly waste, material in the absence of oxygen. Produces a methane-rich biogas that can substitute for fossil fuels.
Biofuel	A fuel derived from recently dead biological material and used to power vehicles (can be liquid or gas). Biofuels are commonly derived from cereal crops but can also be derived from dead animals, trees and even algae. Blended with petrol and diesel biofuels it can be used in conventional vehicles.
Biomass	Biological material that can be used as fuel or for industrial production. Includes solid biomass such as wood and plant and animal products, gases and liquids derived from biomass, industrial waste and municipal waste.
Bunker Fuels (International)	Fuels consumed for international marine and air transportation.
Cap and trade schemes	Cap and trade schemes establish binding controls on the overall amount of emissions from participants. Within this quantity ceiling, entities covered by the scheme are then free to choose where best to deliver emission reductions within the scheme by trading units which correspond to quantities of abatement.
Capacity credit	A measure of the proportion of the maximum potential output from an electricity generation plant that will be statistically available during times of peak demand.
Carbon Cycle	The global flow of carbon (in various chemical forms such as carbon dioxide) through the atmosphere, ocean, terrestrial biosphere and lithosphere.
Carbon dioxide equivalent (CO_2e) concentration	The concentration of carbon dioxide that would give rise to the same level of radiative forcing as a given mixture of greenhouse gases.
Carbon dioxide equivalent (CO_2e) emission	The amount of carbon dioxide emission that would give rise to the same level of radiative forcing, integrated over a given time period, as a given amount of well-mixed greenhouse gas emission. For an individual greenhouse gas species, carbon dioxide equivalent emission is calculated by multiplying the mass emitted by the Global Warming Potential over the given time period for that species. Standard international reporting processes use a time period of 100 years.

Carbon leakage	Carbon leakage occurs when there is an increase in emissions in one country/region as a result of emissions reduction by a second country/region with a strict climate policy.
Carbon sink	An absorber of carbon (usually in the form of carbon dioxide). Natural carbon sinks include forests and oceans.
Carbon Capture and Storage (CCS)	Technology which involves capturing the carbon dioxide emitted from burning fossil fuels, transporting it and storing it in secure spaces such as geological formations, including old oil and gas fields and aquifers under the seabed.
Clean Development Mechanism (CDM)	UN-regulated scheme which allows credits to be issued from projects reducing GHG gases in Kyoto non-Annex 1 countries (developing countries).
Carbon Emissions Reductions Target (CERT)	See Supplier Obligation.
Cirrus	High, thin clouds composed of mainly ice particles.
Climate	The climate can be described simply as the 'average weather', typically taken over a period of 30 years. More rigorously, it is the statistical description of variables such as temperature, rainfall, snow cover, or any other property of the climate system.
Climate sensitivity	The response of global mean temperatures to increased concentrations of carbon dioxide in the atmosphere. It is typically defined as the temperature increase that would occur at equilibrium after a doubling of carbon dioxide concentration above pre-industrial levels.
Combined Cycle Gas Turbine (CCGT)	A gas turbine generator that generates electricity. Waste heat is used to make steam to generate additional electricity via a steam turbine, thereby increasing the efficiency of the plant.
Combined Heat and Power (CHP)	A technology which generates electricity at the same time as useable heat. Technologies range from small units similar to domestic gas boilers which generate electricity whilst heating homes through to large-scale CCGT plants which supply surplus heat for major industrial processes.
CONSAVE	CONSAVE 2050 was an EC Accompanying Measure Project that developed scenarios on aviation and emissions, with a particular focus on 2050.
Contrail	Condensation trail (i.e., white line-cloud often visible behind aircraft).
Derated capacity	Electricity plant capacities expressed in terms of their average plant availability during peak demand (rather than in terms of their maximum potential output).
Devolved powers	Policy areas governed by the relevant national authority, as defined by the relevant devolution agreement(s) and legislation.

Discount rate	The rate at which the valuation of future costs and benefits decline. It reflects a number of factors including a person's preference for consumption now over having to wait, the value of an extra £1 at different income levels (given future incomes are likely to be higher) and the risk of catastrophe which means that future benefits are never enjoyed. For example the Social Discount Rate (3.5%) suggests future consumption of £1.035 *next year* is equivalent in value to £1 today. Discount rates in the private sector generally reflect the real cost of raising capital, or the real interest rate at which consumers can borrow.
Eco-driving	Eco-driving involves driving in a more efficient way in order to improve fuel economy. Examples of eco-driving techniques include driving at an appropriate speed, not over-revving, ensuring tyres are correctly inflated, removing roof racks and reducing unnecessary weight.
Energy Efficiency Commitment (EEC)	The predecessor of the CERT, and a type of Supplier Obligation.
Enusim	A model used to consider energy use and opportunities to reduce consumption and emissions in industry.
Electric vehicle	Vehicle capable of full electric operation (i.e. without an internal combustion engine) fuelled by battery power.
Electricity production	The total amount of electricity generated by a power plant. It includes own-use electricity and transmission and distribution losses.
Energy intensity	A measure of total primary energy use per unit of gross domestic product.
European Union Emissions Trading Scheme (EU ETS)	Cap and trade system covering the power sector and energy-intensive industry in the EU.
European Union Allowance (EUA)	Units corresponding to one tonne of CO_2 which can be traded in the EU ETS.
Feed-in-tariffs	A type of support scheme for renewable generation, whereby renewable generators obtain a long-term guaranteed price for the output they deliver to the grid.
Fischer- Tropsch (FT) process	Catalytic production process for the production of synthetic fuels. Natural gas, coal and biomass feedstocks can be used.
Fluorinated Gases (F-gases)	Family of greenhouse gases containing fluorine. Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) are used in industrial processes, refrigeration and air conditioning. They have a high global warming potential.
Fuel cell	A device that can be used to convert hydrogen or natural gas into electricity. Various types exist that can be operated at temperatures ranging from 80 degrees Celsius to 1,000 degrees Celsius. Their efficiency ranges from 40% to 60%. For the time being, their application is limited to niche markets and demonstration projects due to their high cost and the immature status of the technology, but their use is growing fast.

Fuel Duty	A tax on petrol and diesel. In May 2008, the UK tax was £0.55 per litre for diesel and £0.52 for unleaded petrol.
Fuel Poverty	A fuel poor household is one that needs to spend in excess of 10% of household income on all fuel use in order to maintain a satisfactory heating regime.
Full hybrid	Vehicle engine plus electric motor(s) of significant power; capable of some electric vehicle operation. E.g. Toyota Prius.
GAINS	The GAINS model quantifies the cost and potential of reducing the six greenhouse gases (CO_2, CH_4, N_2O, HFC, PCF and SF_6) in 43 European regions. It is based in the International Institute for Applied Systems Analysis, Austria.
Gas to liquids (GTL)	The production of synthetic crude from natural gas using a Fischer-Tropsch process.
Global Warming Potential (GWP)	A metric for comparing the climate effect of different greenhouse gases, all of which have differing lifetimes in the atmosphere and differing abilities to absorb radiation. The GWP is calculated as the integrated radiative forcing of a given gas over a given time period, relative to that of carbon dioxide. Standard international reporting processes use a time period of 100 years.
GLOCAF	The Global Carbon Finance model was developed by the Office of Climate Change to looks at the costs to different countries of moving to a low-carbon global economy, and the kind of international financial flows this might generate.
Greenhouse Gas (GHG)	Any atmospheric gas (either natural or anthropogenic in origin) which absorbs thermal radiation emitted by the Earth's surface. This traps heat in the atmosphere and keeps the surface at a warmer temperature than would otherwise be possible, hence it is commonly called the Greenhouse Effect.
Gross Domestic Product (GDP)	A measure of the total economic activity occurring in the UK.
Gross Value Added (GVA)	The difference between output and *intermediate consumption* for any given sector/industry.
Gt	A gigatonne or 1000 million tonnes.
GWh (Gigawatt hour)	A measure of energy equal to 1000 MWh.
Heat pumps	A form of heating for buildings. Working like a 'fridge in reverse', heat pumps use compression and expansion of gases or liquid to draw heat from the natural energy stored in the ground or air.
Heavy Good Vehicle (HGV)	A truck over 3.5 tonnes (articulated or rigid).
Integrated Assessment Models (IAM)	IAMs model the relationship between GHG emissions, GHG concentrations, temperature rise and economic and other impacts. They are used to measure the costs and benefits of action to mitigate climate change.

Integrated gasification combined-cycle (IGCC)	A technology in which a solid or liquid fuel (coal, heavy oil or biomass) is gasified, followed by use for electricity generation in a combined-cycle power plant. It is widely considered a promising electricity generation technology, due to its potential to achieve high efficiencies and low emissions.
Intergovernmental Panel on Climate Change (IPCC)	The IPCC was formed in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). It is designed to assess the latest scientific, technical and socio-economic literature on climate change in an open and transparent way which is neutral with respect to policy. This is done through publishing a range of special reports and assessment reports, the most recent of which (the Fourth Assessment Report, or AR4) was produced in 2007.
Ionophores	Feed additives that can improve the performance of cattle. They are currently banned in the EU.
Joint Implementation (JI)	UN-regulated scheme which allows credits to be issued from projects that reduce emissions of GHGs in Kyoto Annex 1 countries.
Kerosene	Hydrocarbon fuel for jet aircraft.
kWh (Kilowatt hour)	A measure of energy equal to 1000 Watt hours. A convenient unit for consumption at the household level.
kWp (Kilowatt peak)	A measure of the peak output of a photovoltaic system under test conditions.
Kyoto gas	A greenhouse gas covered by the Kyoto Protocol.
Kyoto Protocol	Adopted in 1997 as a protocol to the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol makes a legally binding commitment on participating countries to reduce their greenhouse gas emissions by 5% relative to 1990 levels, during the period 2008-2012. Gases covered by the Kyoto Protocol are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).
Large Combustion Plant Directive (LCPD)	A European Commission Directive that aims to control emissions of sulphur dioxide (SO_2), oxides of nitrogen (NOx) and dust (particulate matter (PM) from large power plants in Europe (>50MW) from 2008. Affected plants (mainly coal and oil) can chose to opt in or out of the requirement. Opted out plant is limited to 20,000 hours of operation and must either close before 2016 or re-open as "new" plant satisfying the emissions criteria.
Levelised cost	Cost estimates which allow comparison between different electricity generation technologies. Lifetime costs and output are discounted back to their present values to produce estimates of cost per unit of output (e.g. p/kWh).

Life-cycle	Life-cycle assessment tracks emissions generated and materials consumed for a product system over its entire life-cycle, from cradle to grave, including material production, product manufacture, product use, product maintenance and disposal at end of life. This includes biomass, where the CO_2 released on combustion was absorbed by the plant matter during its growing lifetime.
Light Goods Vehicle (LGV)	A van (weight up to 3.5 tonnes; classification N1 vehicle).
Liquefied natural gas (LNG)	Natural gas that has been liquefied by reducing its temperature to -162 degrees Celsius at atmospheric pressure. In this way, the space requirements for storage and transport are reduced by a factor of over 600.
Lithium-ion batteries	Modern batteries with relatively high energy storage density. Presently used widely in mobile phones and laptops and likely to be the dominant battery technology in the new generation of plug-in hybrid and battery electric vehicles.
Marginal Abatement Cost Curve	Graph showing costs and potential for emissions reduction from different measures or technologies, ranking these from the cheapest to most expensive to represent the costs of achieving incremental levels of emissions reduction.
MARKAL	Optimisation model that can provide insights into the least-cost path to meeting national emissions targets over the long-term.
Mechanical biological treatment (MBT)	Waste treatment technology for dealing with mixed waste, involving a mechanical sorting process and a biological process, typically composting or anaerobic digestion producing biogas.
Micro hybrid	Vehicle engine with stop start and capable of regenerative braking.
Millennium Development Goals (MDGs)	Adopted in 2000 by the 191 states that make up the UN General Assembly, the MDGs are a list of 10 goals that have been generally accepted as a framework for measuring progress in development. They include ensuring environmental sustainability, improving maternal health and eradicating extreme poverty and hunger.
Mitigation	Action to reduce the sources (or enhance the sinks) of factors causing climate change, such as greenhouse gases.
$MtCO_2$	Million tonnes of Carbon Dioxide (CO_2).
MWh (Megawatt hour)	A measure of energy equal to 1000 KWh.
National Atmospheric Emissions Inventory (NAEI)	Data source compiling estimates of the UK's emissions to the atmosphere of various (particularly greenhouse) gases.
National authority	In the Climate Change Act, "national authority" means any of the following: the Secretary of State; the Scottish Ministers; the Welsh Ministers; the relevant Northern Ireland department.
National Balancing Point (NBP)	A measure of the wholesale price of gas in the UK (measured in p/therm or p/kWh).

NOx	Oxides of nitrogen, defined as the sum of the amounts of nitric oxide (NO) and nitrogen dioxide (NO_2).
OECD member countries	Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Republic of Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States.
Offset credits	Credits corresponding to units of abatement from projects, such as those generated under the Kyoto treaty's project based flexibility mechanisms, Joint Implementation (JI) and Clean Development Mechanism (CDM).
Ofgem (Office of Gas and Electricity Markets)	The regulator for electricity and downstream gas markets.
Other transformation, own use and losses	The use of energy by transformation industries including the energy losses in converting primary energy into a form that can be used in the final consuming sectors. It includes energy use and loss by gas works, petroleum refineries, coal and gas transformation and liquefaction. It also includes energy used in coal mines, in oil and gas extraction and in electricity and heat production. Transfers and statistical differences are also includes in this category.
Ozone	A gas that is formed naturally in the stratosphere by the action of ultraviolet radiation on oxygen molecules. A molecule of ozone is made up of three atoms of oxygen.
Percentile	A percentile is a value on a scale of one hundred that indicates the percentage of the data set values that is equal to or below it. The percentile is often used to estimate the extremes of a distribution. For example, the 90th (10th) percentile may be used to refer to the threshold for the upper (lower) extremes.
Plug-in Hybrid	Vehicle capable of electric operation; chargeable by plugging into the electric grid.
Pre-Industrial	The period before rapid industrial growth led to increasing use of fossil fuels around the world. For the purposes of measuring radiative forcing and global mean temperature increases, 'pre-industrial' is often defined as before 1750.
PRIMES	The PRIMES model simulates a market equilibrium solution for energy supply and demand in the EU Member States. The model was developed with the support of the EU and is based at the National Technical University of Athens.
Pumped storage	A technology which stores energy in the form of water, pumped from a lower elevation reservoir to a higher elevation. Lower cost off-peak electric power is generally used to run the pumps. During periods of high electrical demand, the stored water is released through turbines.
Purchasing power parity (PPP)	The rate of currency conversion that equalises the purchasing power of different currencies. It makes allowance for the differences in price levels and spending patterns between different countries.

Radiative forcing	The change in total (downward minus upward) radiation passing through the atmosphere due to a change in some external driver such as solar irradiance, increasing greenhouse gas concentrations, or volcanic activity. Radiative forcing is expressed in units of Watts per square metre (Wm^{-2}) and is usually taken as a global average value relative to the balance of atmospheric radiation during pre-Industrial times.
Renewables	Energy resources, where energy is derived from natural processes that are replenished constantly. They include geothermal, solar, wind, tide, wave, hydropower, biomass and biofuels.
Renewable Energy Strategy (RES)	Published in 2008 by DECC.
Reserved powers	Policy areas governed by the UK Government. Also refers to 'excepted' matters in the case of Northern Ireland.
Renewables Obligation Certificate (ROC)	A certificate issued to an accredited electricity generator for eligible renewable electricity generated within the UK. One ROC is issued for each megawatt hour (MWh) of eligible renewable output generated.
Segmentation	Segmentation involves subdividing the public up into more manageable groups based on the attributes they possess (e.g. attributes held, or behaviours undertaken). Segmentation is a pragmatic technique that allows the user to target priority audience groups and then ensure any interventions are tailored to people's needs.
Sequestration	The process of removing CO_2 from the atmosphere and capturing it, particularly in biomass and soils.
Smart meters	Technology which can provide information on energy use directly to energy consumers (for example through display units or through the internet) with the potential to provide gas and electricity customers with accurate bills as well as information that could help them use less energy.
Smarter Choices	Smarter Choices are techniques to influence people's travel behaviour towards less carbon intensive alternatives to the car such as public transport, cycling and walking by providing targeted information and opportunities to consider alternative modes.
Social Tariff	An energy tariff where vulnerable or poorer customers pay a lower rate.
Solar photovoltaics (PV)	Solar technology which use the sun's energy to create electricity.
Solar water heating	Solar technology which uses the warmth of the sun to heat water to supply hot water in buildings.
Solid Recoverable Fuel (SRF)	Fuel that can be produced from waste using particular processes, especially MBT, and can substitute for fossil fuels, e.g. coal use in cement kilns.
Stop start	Vehicle engine with automated starter motor.

Supplier Obligation	An obligation that the Government places on energy suppliers, to help householders reduce their carbon footprint. The current policy is the Carbon Emissions Reductions Commitment (CERT) running from April 2008 to 2011.
Technical potential	The theoretical maximum amount of emissions reduction that is possible from a particular technology (e.g. What would be achieved if every cavity wall were filled). This measure ignores constraints on delivery and barriers to firms and consumers that may prevent up take.
Tidal range	A form of renewable electricity generation which uses the difference in water height between low and high tide by impounding water at high tide in barrages or lagoons, and then releasing it through turbines at lower tide levels.
Tidal stream	A form of renewable electricity generation which harnesses the energy contained in fast-flowing tidal currents.
Total final consumption	The sum of consumption by the different end use-sectors.TFC is broken down into energy demand in the following sectors: industry, transport, other (includes agriculture, residential, commercial and public services) and non-energy uses. Industry includes manufacturing, construction and mining industries. In final consumption, petrochemical feedstocks appear under industry use. Other non-energy uses are shown under non-energy use.
Total primary energy supply	Total primary energy supply is equivalent to total primary energy demand. This represents inland demand only and, except for world energy demand, excludes international marine bunkers.
Traditional biomass	Refers mainly to non-commercial biomass use.
TWh (Terawatt hour)	A measure of energy equal to 1000 GWh or 1 billion kWh. Suitable for measuring very large quantities of energy – e.g. annual UK electricity generation.
United Nations Framework Convention on Climate Change (UNFCCC)	Signed at the Earth Summit in Rio de Janeiro in 1992 by over 150 countries and the European Community, the UNFCCC has an ultimate aim of ‘stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.’
Vehicle Excise Duty (VED)	Commonly known as road tax, an annual duty which has to be paid to acquire a vehicle licence for most types of motor vehicle. VED rates for private cars have been linked to emissions since 2001, with a zero charge for the least emitting vehicles (under 100 gCO_2/km).
Vulnerable household	A household containing someone aged 60 or over or under 16, or someone who is disabled or has a long-term illness.
Wave electricity generation	A form of renewable electricity generation which converts the energy contained in the movement of the waves into electricity.

ABBREVIATIONS

Abbreviation	Full form
AAU	Assigned Amount Unit
ACARE	Advisory Council for Aeronautics Research in Europe
AD	Anaerobic Digestion
ADCs	Advanced Developing Countries
AGR	Advanced gas-cooled reactor
AR4	IPCC Fourth Assessment Report
ARA	Amsterdam- Rotterdam- Antwerp
ASC	Advanced Supercritical
ATOC	Association of Train Operating Companies
BERR	Department for Business Enterprise and Regulatory Reform
BETTA	British Electricity Trading and Transmission Arrangements
BMRB	British Market Research Bureau
BRE	Buildings Research Establishment
BtL	Biomass-to-liquid
CAIT	Climate Analysis Indicators Tool
CAP	Common Agricultural Policy
CCA	Climate Change Agreement
CCC	Committee on Climate Change
CCGT	Combined-Cycle Gas Turbine
CCP	Climate Change Programme
CCS	Carbon capture and storage
CDC	Common but Differentiated Convergence
CDM	Clean Development Mechanism
CEH	Centre for Ecology and Hydrology
CER	Certified Emission Reduction
CERT	Carbon Emissions Reduction Target
CGE	Computable General Equilibrium (HMRC model)
CHP	Combined heat and power
CLG	Dept for Communities And Local Government
CRC	Carbon Reduction Commitment
CSP	Concentrated Solar Power
DECC	Department for Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs

Abbreviation	Full form
DfT	Department for Transport
DG TREN PRIMES / GAINS	Directorate General Energy and Transport
DTLR	Department for Transport, Local Government and the Regions
DUKES	Digest of UK Energy Statistics
E&Y	Ernst & Young
EC	European Commission
EDGAR	Emission Database for Global Atmospheric Research
EEC	Energy Efficiency Commitment
EIA	Energy Information Administration
ENUISM	(A DECC model)
EPC	Energy Performance Certificate
ESRL	Earth System Research Laboratory
EU ETS	European Union Emissions Trading Scheme
EUA	European Union Allowance
EWP	Energy White Paper
FBP	Freight Best Practice (DfT programme)
FIT	Feed-in Tariff
GAD	Government Actuary's Department
GHG	Greenhouse gas
GIS	Green Investment Scheme
GLOCAF	Global Carbon Finance Model
GVA	Gross value added
GWP	Global Warming Potential
IAM	Integrated assessment model
IAS	International Aviation and Shipping
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
ICs	Industrialised Countries
ICT	Information and communications technologies
IEA	International Energy Agency
IEEP	Institute for European Environmental Policy
IMO	International Maritime Organisation
IMO MEPC	International Maritime Organisation – Marine Environment Protection Committee

Abbreviation	Full form
IPCC	Intergovernmental Panel on Climate Change
IPPC	Integrated Pollution Prevention and Control (directive)
ISL	Institute of Shipping Economics and Logistics
JI	Joint Implementation (mechanism)
LDCs	Less Developed Countries
LDV	Light duty vehicle
LULUCF	Land Use, Land Use Change and Forestry
MACC	Marginal Abatement Cost Curve
MAGICC	Model for the Assessment of Greenhouse-gas Induced Climate Change
MBT	Mechanical Biological Treatment
MMP	Major Power Producer
MS	Member State
MTOE	Million Tonnes of Oil Equivalent
NAEI	National Atmospheric Emissions Inventory
NBP	National Balancing Point
NG	National Grid
NOAA	National Oceanic and Atmospheric Administration
NTM	National Transport Model (DfT)
NTS	Non-Traded Sector
OECD	Organisation for Economic Co-operation and Development
ONS	Office for National Statistics
OPEC	Organisation of Petroleum Exporting Countries.
PNAS	Proceedings of the National Academy of Sciences
POLES	Prospective Outlook on Long-Term Energy Systems
PV	Photovoltaic
RCEP	Royal Commission on Environmental Pollution
RFA	Renewable Fuels Agency
RO	Renewable Obligation
ROC	Renewable Obligations Certificate
RP	Redpoint
RTFO	Renewable Transport Fuel Obligation
SAFED	Safe and Fuel Efficient Driving
SBSTA	(the UNFCCC) Subsidiary Body for Scientific and Technological Advice

Abbreviation	Full form
SMMT	Society of Motor Manufacturers and Traders
SO	Supplier Obligation
SRES	Special Report on Emissions Scenarios (IPCC report)
SRF	Solid Recovered Fuel
TAR	Third Assessment Report
UEP	Updated Energy Projections
UKERC	UK Energy Research Centre
UNFCCC	United Nations Framework Convention on Climate Change
VA	Voluntary Agreement
VED	Vehicle Excise Duty
WRAP	Waste and Resources Action Programme

TSO
information & publishing solutions

www.tso.co.uk

75% recycled
This book is printed
on 75% recycled paper

ISBN 978-0-11-703929-2

9 780117 039292