

The Fourth Carbon Budget

Reducing emissions through the 2020s



Committee on Climate Change
December 2010

Preface

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

Setting carbon budgets

In December 2008 we published our first report, *'Building a low-carbon economy – the UK's contribution to tackling climate change'*, containing our advice on the level of the first three carbon budgets and the 2050 target; this advice was accepted by the Government and legislated by Parliament.

Progress towards meeting carbon budgets

The Climate Change Act requires that we report annually to Parliament on progress meeting carbon budgets; to date we have published two progress reports (October 2009, June 2010) and will publish our third report in June 2011.

Advice requested by Government

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

Advice on the fourth carbon budget

This report sets out our advice on the fourth carbon budget, covering the period 2023-2027, as required under Section 4 of the Climate Change Act; the Government will propose draft legislation for the fourth budget in Spring 2011.

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Foreword

The Climate Change Act requires that Parliament sets ‘carbon budgets’ which define the maximum level of greenhouse gases which the UK will emit in a series of five-year periods to 2050. The Committee on Climate Change is required to recommend the level of these budgets to government, which in turn must lay a proposed budget before Parliament.

In our first report in 2008, we recommended the level of the first three budgets, covering periods 2008-12, 2013-17, and 2018-22. Parliament subsequently legislated budgets in line with our recommendations. We are now required to make recommendations for the fourth budget, covering the years 2023-27. This report sets out those recommendations.

In setting the first three budgets, the feasible pace of emissions reduction was constrained by two factors: first because the budget was set eighteen months after the first budget period had already begun, second because reductions attainable in any year are dependent on technologies available and policies in place many years before.

The further ahead we look, the greater the potential to achieve rapid reductions. Our fourth budget proposals therefore represent an acceleration of the pace of reduction above that required in the first three budgets. But not only is this acceleration possible, it is also essential: the pace of reduction in the first three budgets would not be sufficient to achieve the target which Parliament has set for 2050 – an emissions reduction of 80% from 1990 levels.

A crucial feature of this report is therefore that we place our fourth budget recommendations in the context of the required path to 2050. To ensure that this path is feasible, we consider what emissions will need to be in 2030, halfway between now and 2050. We have then designed our fourth budget recommendations to be consistent both with emissions in the third budget period, and with the required 2030 level.

Despite accelerated emissions reductions in the 2020s, further acceleration will be required after 2030, with a total reduction of 62% between 2030 and 2050, versus 46% between now and 2030. This ‘back-ending’ of the reduction path is unavoidable given constraints on faster early progress, and acceptable given the wider range of technology options likely to become available over time. But it means that our fourth budget recommendations must be seen as the minimum reductions necessary if the 2050 target is to be attainable. If further analysis suggests that more rapid progress is possible, a subsequent tightening of the fourth budget would be appropriate.

We describe in this report specific sectoral actions which would make the budget attainable. However, it is important not to see this sectoral description as defining necessary sector specific paths: the UK's carbon targets are appropriately set at national aggregate rather than sectoral level, reflecting the fact that unforeseen developments could result in faster reductions than anticipated in some sectors, offset by slower reductions in others.

But the Committee has to satisfy itself that there exists a range of feasible emissions reduction opportunities which, in some combination, are capable of delivering the recommended budget. We are confident that these opportunities exist.

The pace of reductions which we describe varies significantly by sector. Very significant decarbonisation of electricity generation plays a crucial role over the next twenty years, enabling the use of low-carbon electricity in a wider set of applications – in particular surface transport and residential heat.

Conversely there are sectors where rapid early progress seems more difficult to achieve. In addition to aviation (on which we reported in December 2009) we identify direct emissions from industry and agricultural emissions as particularly difficult challenges. Shipping may also prove difficult: we will explore this further in our review of shipping emissions in 2011.

In the industrial sector, we have identified more scope for reduction than in our 2008 report, but further work is needed to ensure that all opportunities, in particular in relation to CCS technology, radical production processes such as steel electrolysis and alternative cement technologies, product substitution and material efficiency are identified and pursued.

In agriculture, our current abatement scenarios do not include several potentially controversial measures, nor the use of more forceful policy levers which go beyond the current voluntarist approach. In agriculture as well as in industry, however, further significant progress beyond our current assumptions will be essential if emissions from these sectors, along with those of aviation, are not to make the 2050 target unattainable even if other sectors are almost entirely decarbonised.

These 'difficult to reduce' sectors are therefore key areas for future analytical focus and policy development. Industry and agriculture are moreover, the two sectors where we need to ensure that policy measures used do not produce 'carbon leakage' – the transfer of production abroad with no benefit to the global environment even when the UK's recorded emissions fall. The policy levers required to offset this danger are also a key area for future focus. And the related issue of whether policy should focus solely on a production-based definition of emissions or also on the UK's consumption of carbon-intensive imports, is one which we believe it would be useful for the Committee to investigate in detail.

This report extends the horizon of budgets for five years, but comes only two years after the 2008 report, which recommended the first three budgets. This reflects the startup timetable required by the Act . From now on, budget recommendation reports will be delivered every five years: the next one, covering the fifth budget period will be due in December 2015.

Given the short space of time since our first report, this has inevitably limited our ability but also the need to conduct fundamentally new analysis in some areas. Particularly in relation to the wider social and economic implications we are required to consider – the impact of carbon budgets on fiscal revenue, competitiveness, fuel poverty and devolved administration circumstances – much of the analysis set out in the 2008 report is still relevant. We have not therefore repeated the basic analysis relevant to these considerations, but refer back to the 2008 report findings, highlighting areas where considerations or conclusions will change as we move into the fourth budget period.

Since our first report in 2008, the Committee has also been required to produce two annual monitoring reports and a number of specific subject reports (on aviation, the Carbon Reduction Commitment, the Scottish emissions targets, and research and development); this has placed huge demands on the Secretariat staff. On behalf of the Committee I would like to thank them for their excellent hard work in producing this and the other reports.



Lord Adair Turner

Chair

Acknowledgements

The Committee would like to thank:

The team that prepared the analysis for the report. This was led by David Kennedy and included: Owen Bellamy, Russell Bishop, Ute Collier, Aaron Collins, Ben Combes, Kristofer Davies, Amelia Doughty, Adrian Gault, Neil Golborne, Philip Hall, Jonathan Haynes, David Joffe, Alex Kazaglis, Swati Khare-Zodgekar, Anna Leatherdale, Eric Ling, Nina Meddings, Laura McNaught, Sarah Naghi, Stephen Smith, Kavita Srinivasan, Jonathan Stern, Indra Thillainathan, Mike Thompson, Claire Thornhill, Emily Towers and Jo Wilson.

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A wide range of stakeholders who engaged with us, attended our expert workshops, or met with the Committee bilaterally.

The Committee



Lord Adair Turner, Chair

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 of the Confederation of British Industry (CBI).



David Kennedy, Chief Executive

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



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



Professor Michael Grubb

Professor Michael Grubb is Chair of the international research network Climate Strategies. He is a 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, and Professor of Climate Change and Energy Policy at Imperial College.



Sir Brian Hoskins

Professor Sir Brian Hoskins, CBE, FRS is the Director of the Grantham Institute for Climate Change at Imperial College 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

Professor Julia King CBE FREng is Vice-Chancellor of Aston University. She led the 'King Review' for HM Treasury in 2007/8 on decarbonising road transport. She was formerly Director of Advanced Engineering for the Rolls-Royce industrial businesses. Julia is one of the UK's Business Ambassadors, supporting UK companies and inward investment in low-carbon technologies.



Lord John Krebs

Professor Lord Krebs Kt FRS, is currently Principal of Jesus College Oxford. Previously, he held posts at the University of British Columbia, the University of Wales, and Oxford, where he was lecturer in Zoology, 1976-88, and Royal Society Research Professor, 1988-2005. From 1994-1999, he was Chief Executive of the Natural Environment Research Council and, from 2000-2005, Chairman of the Food Standards Agency. He is a member of the U.S. National Academy of Sciences. He is chairman of the House of Lords Science & Technology Select Committee.



Lord Robert May

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



Professor Jim Skea

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

Executive summary

In our first report in 2008 we recommended that the UK should set a 2050 target to reduce emissions of all Kyoto greenhouse gases by 80% relative to 1990 levels. This would be appropriate as a minimum contribution to a global deal required to limit risks of dangerous climate change, and would be technically feasible at a cost of 1-2% of GDP.

We also recommended the first three carbon budgets, setting a ceiling on emissions of greenhouse gases in the UK for the three periods 2008-2012, 2013-2017 and 2018-2022.

We considered feasible emissions reductions, the path to the 2050 target, and the EU framework. We recommended that Interim budgets based on a 2020 emissions reduction of 34% relative to 1990 levels should be legislated in the first instance. We also recommended that Intended budgets based on a 42% emissions reduction in 2020 should subsequently be enacted if and when there was progress towards a deal to reduce global emissions.

The 2050 target was included in the Climate Change Act, and our recommended carbon budgets were enacted in secondary legislation in May 2009.

In this report we set out our advice on the fourth carbon budget, covering the period 2023-2027. This advice is required under the Climate Change Act prior to the Government proposing and Parliament legislating the fourth budget before June 2011. In line with the required timetable, this report comes only two years after our first report. However, from now on budget advice reports will be delivered every five years (i.e. advice on the fifth carbon budget, covering the period 2028-2032, will be provided in 2015).

In developing advice we have started by considering an appropriate and feasible target for UK emissions in 2030 – half way between now and the 2050 target in the Climate Change Act. This 2030 indicative target needs to reflect likely emissions in the early 2020s, feasible and cost-effective emissions reductions in the 2020s, and feasible pathways to further reductions between 2030 and 2050.

This report therefore joins up the detailed analysis that we have previously published on the path to 2020, with longer-term analysis of the path to 2050.

Our advice is based on consideration of the latest climate science, the evolving international framework, feasible and cost-effective emissions reductions in the UK through the 2020s, and plausible paths to the 2050 target. It comprises recommended budgets with associated costs and investment requirements. It also includes implications for Government policies required to ensure emissions reductions in the 2020s can be achieved (e.g. the need for electricity market reform and support for technology development).

Box 1: Key recommendations and findings

- An **Indicative 2030 target** to reduce emissions by 60% relative to 1990 levels (46% relative to 2009 levels).
- A **Domestic Action** fourth carbon budget of 1950 MtCO₂e to be legislated in the first instance and to be achieved on a gross basis (i.e. without credit purchase).
- A **Global Offer** budget of 1800 MtCO₂e indicating a minimum UK contribution to a future global deal to be legislated when a global deal for the 2020s is agreed.
- The **second and third budgets** should be adjusted to reflect the level of ambition in the Intended budget for the non-traded sector, giving an economy-wide reduction of 37% in 2020 relative to 1990.
- **International aviation and shipping** should in future be included in carbon budgets.
- The **cost** of meeting the Domestic Action and Global Offer budgets is under 1% of GDP.
- Annual **investment** requirements through the 2020s are around £16bn.
- New **policies** will be required, including fundamental reform of the electricity market.

The key messages in the report are (Box 1):

- **Global emissions pathways.** We have assessed the latest climate science and the international context. Our conclusion is that the climate objective and the global emissions pathway underpinning our first report recommendations remain appropriate. Our advice on the fourth carbon budget is therefore based on the need for the UK to be on a pathway to 80% cuts in greenhouse gases below 1990 levels by 2050, with maximum 2050 emissions of 160 MtCO₂e. It also reflects the need for deep emissions cuts at global and therefore UK levels through the 2020s, and the rising carbon price (e.g. to £70/tCO₂, real terms £2009, by 2030) that this implies.
- **2030 emissions reductions.** By 2030, the UK should aim to have reduced total greenhouse gas emissions from today's level of 574 MtCO₂e to around 310 MtCO₂e (a 60% reduction relative to 1990); this 46% reduction over the next twenty years will require a subsequent 62% reduction between 2030 and 2050 to meet the 2050 target. We believe that this 'back-ending' is justifiable given the feasibility of accelerated emissions reductions in the 2030s and 40s if key enabling technologies and conditions (e.g. a largely decarbonised power sector) are in place by 2030. But any less ambitious target for 2030 would endanger the feasibility of the path to 2050.
- **The fourth carbon budget for the period 2023-2027.** We recommend that Parliament legislates a 'Domestic Action' budget for 2023-2027 which will place the UK on a feasible and cost-effective path towards the indicative 2030 and legislated 2050 targets, but that the Government should be prepared to commit to a more ambitious 'Global Offer' budget, if and when a global deal covering action in the 2020s is agreed:
 - **Domestic Action budget.** This budget reflects our assessment of feasible and cost-effective emissions reductions in the UK through the 2020s, consistent with the path to the 2050 target. It limits emissions over the period 2023-2027 to 1950 MtCO₂e (average

390 MtCO₂e a year). It embodies an emissions cut of 50% in 2025 below 1990 levels (32% below 2009 levels). This budget should be legislated in the first instance, with the aim to achieve it through domestic emissions reductions only (i.e. without recourse to purchase of credits in international carbon markets, including through the EU ETS). The level of ambition in this budget should be regarded as an absolute minimum, and more may be both feasible and required as current uncertainties over emissions projections and abatement opportunities are resolved.

- **Global Offer budget.** This budget represents our assessment of a minimum UK contribution likely to be appropriate to a future global deal covering the 2020s. It limits emissions over the period 2023-2027 to 1800 MtCO₂e. The Global Offer budget should be legislated in the context of a global deal covering the 2020s. The aim should be that this budget would be met largely through domestic emissions reductions (e.g. consistent with reductions in the Domestic Action budget or more), together with possible purchase of credits at the margin.
- **The first three carbon budgets: Interim and Intended.** The Domestic Action budget recommended for 2023-2027, and the indicative 2030 target, will be difficult to achieve unless the UK enters the 2020s at a level of emissions consistent with the Intended budgets for the non-traded sector, rather than with the less ambitious Interim budgets. Our latest emissions projections which include the impacts of the recession suggest that in the non-traded sector the UK will meet the Intended first, second and third budgets as long as it implements public policy measures to which the Government is already broadly committed at a high level, and which are required to make the path to the 2050 target feasible. We therefore recommend that Parliament should now legislate to adjust the first three budgets to reflect non-traded sector emissions under the Intended budgets. The UK should also argue for a tightening of the EU ETS cap which constrains traded sector emissions: if and when such tightening is agreed, the UK should then adjust its traded sector budgets onto the Intended path.
- **International aviation and shipping.** The UK's legislative framework does not currently include international aviation and shipping (IA&S) emissions in carbon budgets. But it is clear that the UK's contribution to IA&S emissions should be reflected in carbon targets, and the Committee has been asked to consider how and when they can be incorporated within the budgeting approach. We recommend that the Government accepts the principle that IA&S emissions in future be included in carbon budgets, and we intend to make specific recommendations on how to adjust the second, third and fourth budgets to allow inclusion following our review of international shipping emissions, to be published in autumn 2011. In the meantime, the recommended Domestic Action and Global Offer budgets for the fourth period do not include IA&S, but have been set so as to be compatible with meeting a 2050 total emissions target of 160 MtCO₂e with IA&S included.
- **Costs and investment requirements.** We estimate the cost of meeting the Domestic Action budget is under 1% of GDP in 2025. Meeting the Global Offer budget would require an additional cost of 0.1% of GDP based on credit purchase at projected carbon prices.

Annual investment requirements include £10 billion for power sector decarbonisation, £1 billion for reducing emissions in industry and £3 billion (over and above business as usual expenditure) for reducing emissions from heating buildings.

- **Implications for Government policies.** New policies are required to ensure that the emissions path through the 2020s can be achieved, and to lay the foundations for further progress in the 2030s and 2040s. These include:
 - **Electricity market reform.** Our analysis suggests the need to decarbonise the power sector through the 2020s by adding 30-40 GW of low-carbon plant. This would reduce average emissions from current levels around 500 gCO₂/kWh to around 50 gCO₂/kWh by 2030. Existing electricity market arrangements are not well designed to ensure this progress occurs in a cost-effective fashion. Therefore we recommend that new arrangements are introduced entailing competitive tendering of long-term contracts for investment in low-carbon capacity.
 - **Carbon price underpin.** Given carbon price volatility and the current low carbon price, a carbon price underpin would complement electricity market reforms. It could also strengthen incentives for investment in low-carbon technologies in other sectors, subject to competitiveness and affordability concerns being addressed. A carbon price underpin which reached at least £27/tCO₂ (i.e. 30 euros per tonne) in 2020 and rising through the 2020s would provide appropriate signals.
 - **Funding and policies to support development of technologies and new markets.** Key technologies which should be demonstrated now for deployment in the 2020s include CCS in power generation and industry, electric cars and vans, and electric heat pumps. Comprehensive programmes in each of these areas should be developed as a matter of urgency to ensure timely disbursement of funds committed in the 2010 Spending Review, with further funding committed as appropriate (e.g. electric cars) and as fiscal constraints ease.
 - **New policies to deliver the first three budgets.** As explained above, our recommended fourth budget will be difficult to achieve unless the UK enters the 2020s with non-traded sector emissions in line with the Intended budget. This Intended budget looks attainable in light of latest projections which include the impacts of the recession, but only if new policy measures recommended in our reports to Parliament are effectively implemented. As we highlighted in our June 2010 progress report to Parliament, progress in reducing emissions during the first budget period has so far primarily reflected the recessionary effect, and it remains essential to achieve the step change in the pace of underlying emissions reductions that we called for in both the October 2009 and June 2010 progress reports. New policies to drive the step change include approaches to energy efficiency improvement in residential and non-residential buildings, roll-out of smart meters, consumer behaviour change in transport, and more widespread use of carbon-efficient practices on farms.

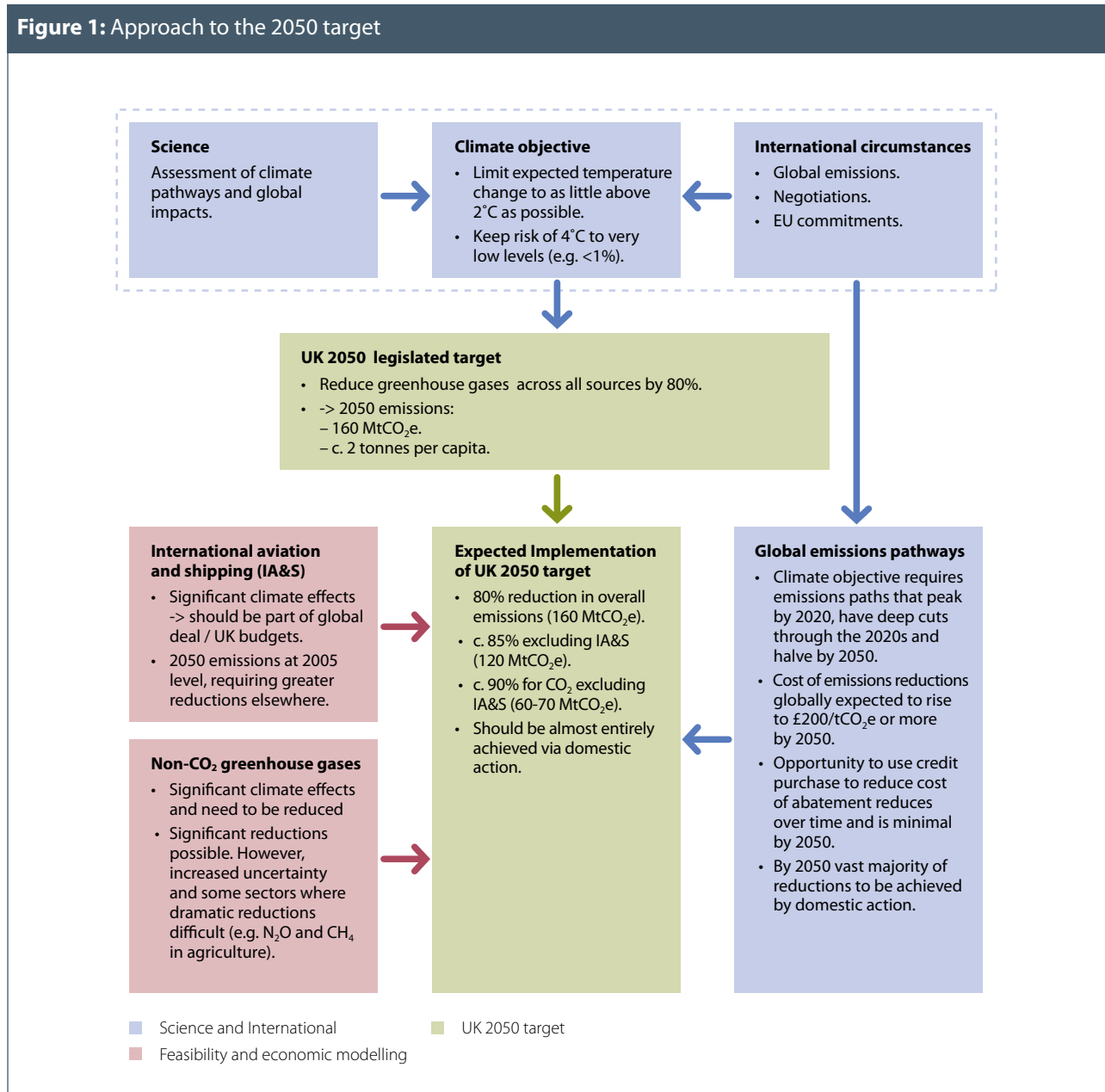
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- **Further evidence to resolve uncertainties.** There are a number of promising but uncertain options for cutting emissions in the 2020s. These include district heating, and abatement options in agriculture and industry. The evidence base should be developed in these areas, with new policies introduced as appropriate.
 - **Implications for EU policies and measures.** There is a set of policies that the UK Government should push for to set the EU on a cost-effective and credible path to its 2050 target, and which would reinforce UK action to meet the fourth carbon budget, including:
 - Supporting the move to an EU 30% emissions reduction target in 2020 relative to 1990 levels.
 - Agreeing an appropriate emissions reduction target for 2030 (e.g. around a 55% reduction relative to 1990).
 - Tightening of the EU ETS emissions cap, both in 2020 and through the 2020s.
 - Setting 2030 targets for new car and van emissions (e.g. around 50gCO₂/km for cars and 80gCO₂/km for vans).
 - Reforming the EU Common Agricultural Policy, which is due for revision in 2013, so that it links subsidies and incentives to climate change mitigation objectives.
 - Supporting technology development, particularly for CCS in industry.

We set out our summary in 6 sections:

1. Global emissions pathways and the 2050 target: climate science and the international context.
2. The fourth carbon budget (2023-2027)
3. The path from 2030 to 2050
4. The first three carbon budgets (2008-2022): Interim versus Intended, and the treatment of international aviation and shipping (IA&S)
5. Developing options for meeting the fourth budget: policy implications
6. Wider economic and social considerations and differences in national circumstances.

1. Global emissions pathways and the 2050 target: climate science and the international context

In advising on carbon budgets, we are required under the Climate Change Act to consider climate science and the international context. In our 2008 report we set out why these considerations led us to recommend that the UK should set a 2050 target to reduce total greenhouse gas emissions by 80% relative to 1990 levels: this implies maximum 2050 emissions of 160 MtCO₂e. This section sets out why we believe that target remains appropriate; it highlights the fact that achieving 80% overall reductions will entail still higher reductions in some sectors of the economy. It considers required global emissions pathways, which also carry implications for the UK's appropriate contribution to global emissions reductions between now and 2050, and for the likely evolution of carbon prices. These aspects – the 2050 target, global pathways and implications for UK pathways – inform our specific fourth carbon budget recommendations (see Section 2 below). Figure 1 illustrates the key steps in our analysis.



Assessment of the latest climate science

Recent controversies concerning the University of East Anglia and the IPCC have raised some concerns about transparency and IPCC process which are now being addressed.

However, our assessment of the latest climate science, including a review that we commissioned covering over five hundred recently published peer-reviewed papers, confirms that the fundamental science remains robust:

- Global climate change is already happening.
- It is very likely that this is largely a result of human activity.
- Without action, there is a high risk of global warming well beyond 2°C, with potentially very significant changes in regional climate.
- This would have damaging consequences for human welfare and ecological systems over the course of this century and beyond. If anything, our assessment is that risks have worsened since we advised on the 2050 target in 2008, but not sufficiently to change our climate objective.

Therefore the climate objective and the global emissions pathway underpinning the Climate Change Act remain appropriate.

- The climate objective is to limit central estimates of global mean temperature change by 2100 to as little above 2 degrees as possible, and to limit the likelihood of temperature change above 4 degrees to very low levels (e.g. to below 1% probability).
- Global emissions pathways that deliver this objective are characterised by peaking of global emissions around 2020, followed by deep cuts in the 2020s and a halving of emissions by 2050, with further cuts thereafter.

The international context

Whether this global emissions pathway remains feasible depends on the international context. Of particular importance is agreement on and delivery of pledges under the Copenhagen Accord:

- Our assessment of the Copenhagen Accord is that peaking of global emissions by 2020 is still feasible if the most ambitious pledges can be delivered, but with important issues to be resolved relating to land-use change, and to the sale of excess rights to emit under the Kyoto Protocol (the so called “hot air” issue).
- Delivering these pledges will be difficult, however, particularly given the current political situation in the US.
- But slow progress in agreeing a global deal should not and will not preclude action to reduce emissions. In parallel to negotiations on a global deal, there is significant action at the country level (e.g. in China, India, EU member states, and states within the US). These and other countries acting early will be well-placed in a carbon-constrained world.

The UK's 2050 target and contributions to global emissions reduction

Overall therefore, while developments in science since our 2008 report have marginally increased the strength of the case for forceful global action to reduce emissions, the likelihood of getting early global agreement has decreased. This cannot be taken, however, as a reason for reducing the UK's 2050 target since:

- Radical cuts in global emissions by 2050 – to around 20-24 GtCO₂e annually – remain essential if the world is to reduce significantly the risks of seriously harmful climate change.
- The logic which led to the UK's specific 160 MtCO₂e target remains robust: it is difficult to imagine a global deal emerging that does not require developed countries to reduce per capita emissions to a level broadly in line with that which can be sustained globally.
- A key objective of the Climate Change Act was to set a target which would not vary with the ups and downs of global negotiations, but would provide certainty within which policies and technologies could be developed.

In addition, our assessment remains that deep cuts in global emissions are both required and possible through the 2020s. This implies the need for deep cuts in UK emissions, and via its implications for the global carbon price, informs the appropriate level of domestic emissions reduction effort in the UK.

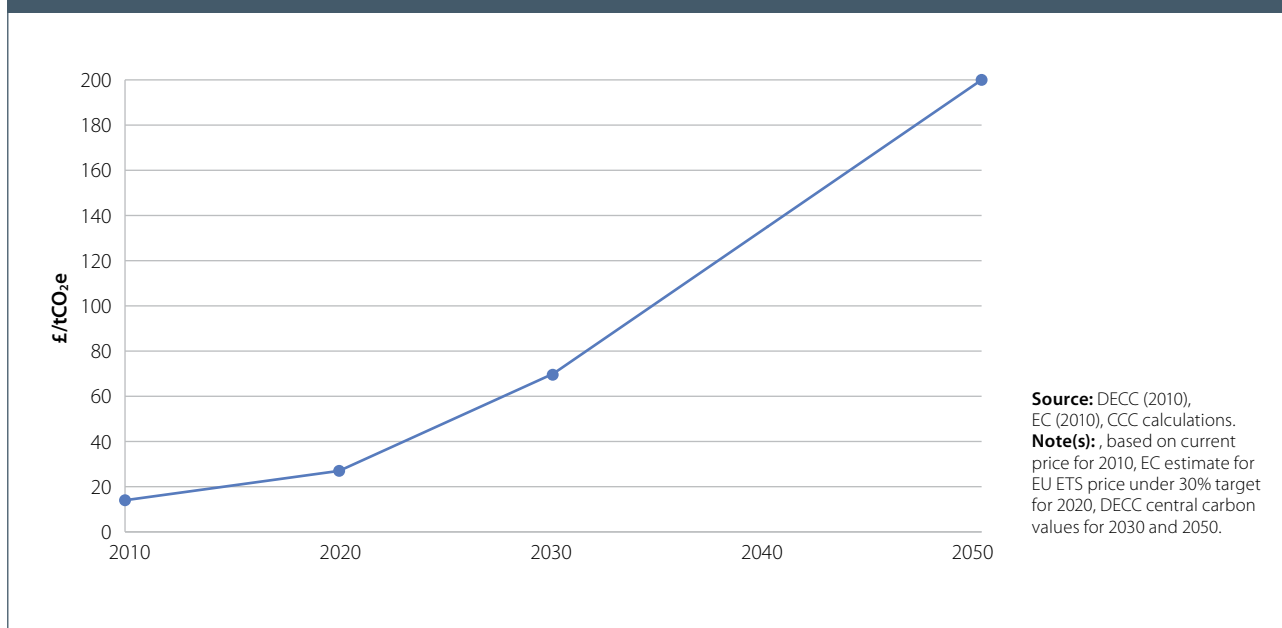
Our recommendations for the fourth carbon budget are therefore designed to be compatible with progress towards achieving an 80% cut in the UK's total greenhouse gas emissions by 2050, implying maximum emissions in 2050 of 160 MtCO₂e (including IA&S), and the need for deep cuts in emissions through the 2020s at global and UK levels.

Implications of the 80% target: specific sectors and the domestic action/credit purchase split

It is important to note, however, that an overall target of 80% reduction by 2050 will require still higher percentage reductions in some sectors of the economy. This is because there are some sectors where feasible reductions are likely to be considerably less. In particular:

- It is vital that the UK's target includes the UK's contribution to international aviation and shipping (IA&S) emissions (and as described in Section 4 below these should in future be included in the legally binding carbon budgets). The UK is now committed to ensure that 2050 aviation emissions do not exceed 2005 levels, and it is essential that this target is met. But it is unlikely to be optimal to reduce aviation emissions by 80%, since, unlike in other sectors (e.g. power generation), alternative technologies which could make radical reductions feasible without major economic cost are less likely to be available. If we assume that IA&S emissions in 2050 are at 2005 levels, other sectors of the economy will need to cut by 85% in 2050.

Figure 2: Carbon price projections (2010-2050)



- Similarly, the attainment of radical reductions in agricultural non-CO₂ emissions poses significant challenges. Large reductions from today's level of around 45 MtCO₂e will be essential if the overall 80% reduction target is to be attained, and a more robust policy framework to drive emissions reductions is likely to be required. But even with such a framework, cuts as high as 80% in agriculture itself may not be feasible. If agricultural and other non-CO₂ emissions are reduced by 70% by 2050 (relative to 1990), while IA&S emissions are held flat at 2005 levels, emissions of CO₂ in other sectors of the economy will have to fall by around 90%.

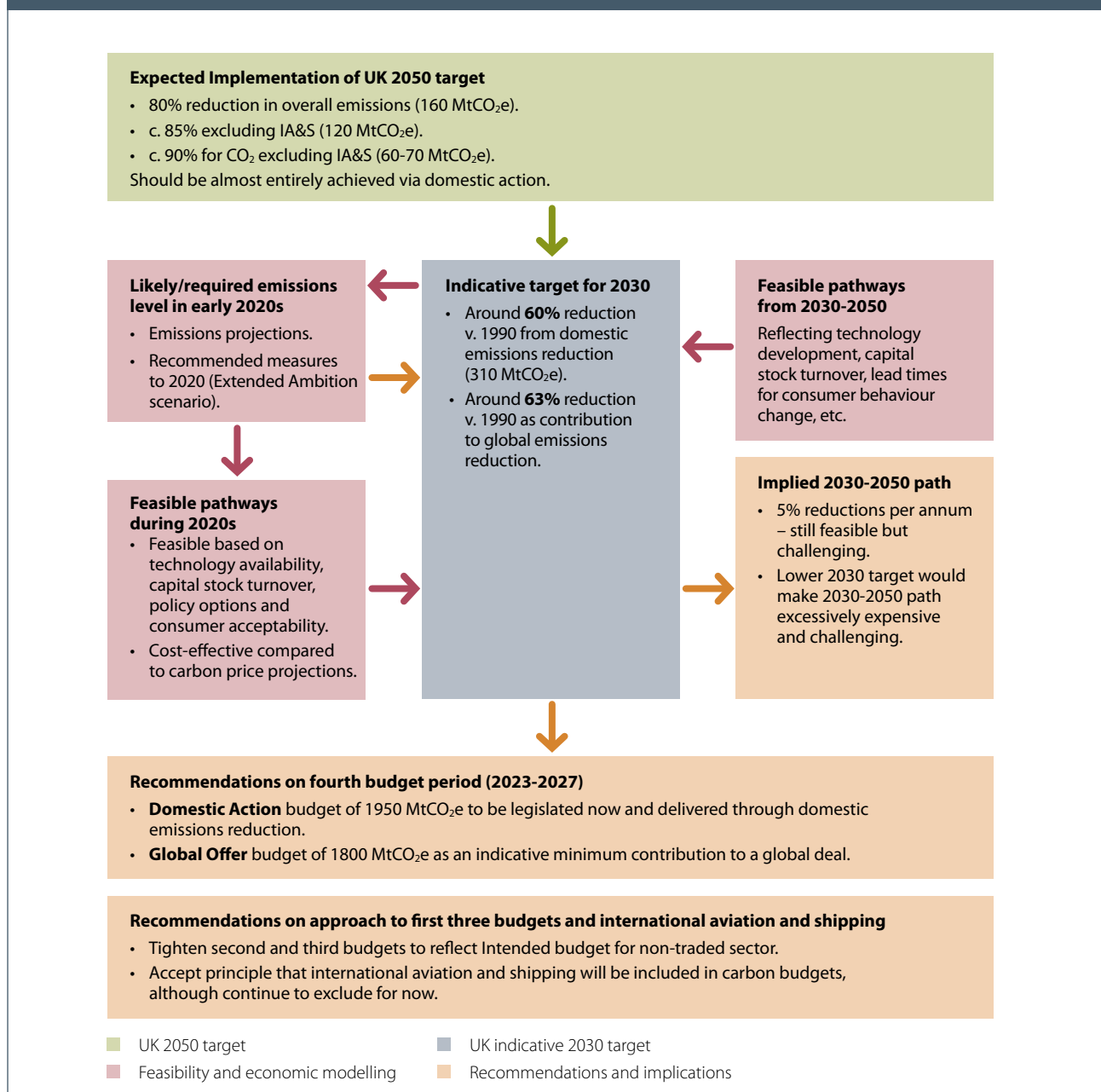
In addition, we need to face the reality that in the long term, reductions in emissions will need to be achieved almost entirely through domestic action. Whereas at present and for the foreseeable future, there may exist opportunities to buy carbon credits internationally at a price below the marginal cost of emissions reduction in the UK, by mid-century global prices will need to have reached several hundred £s per tonne if climate objectives are to be achieved (see Figure 2), and some current sellers of emissions credits (e.g. China) are as likely to be buying credits from the UK as vice versa. By mid-century, a UK target of 160 MtCO₂e is likely to require that our domestic emissions are close to this level.

Our budget recommendations therefore assume that the UK needs to reduce total greenhouse gas emissions to 80% below 1990 levels, non-IA&S emissions by 85%, and non-IA&S CO₂ emissions by around 90%, and that these emissions reductions will need to be achieved entirely domestically. This has implications for the progress needed in decarbonising the economy to 2030, and for the Domestic Action budget for 2023-2027.

2. The fourth carbon budget: 2023-2027

Figure 3 sets out the considerations which have informed our recommendations for the fourth carbon budget. A key objective has been to create a clear link between near- and medium-term budgets out to 2027, and the overall required pathway to 2050. To create this link we have considered what an appropriate indicative target would be for 2030 – halfway between now and 2050.

Figure 3: From the 2050 target to an indicative 2030 target and a 2023-2027 budget



The key building blocks in the analysis are:

- We accept as a given the overall 2050 80% target, and the need to achieve still larger reductions in non-IA&S sectors and in CO₂ (as against other greenhouse gases).
- We therefore define a range of possible indicative targets for 2030, based on:
 - The level of emissions with which we are likely to enter the 2020s, and/or could enter the 2020s with appropriate intensity of policy effort over the first three budget periods.
 - The feasible and cost-effective pace of emissions reductions through the 2020s.
 - The feasible pace of emissions reductions from 2030 to 2050.
- The indicative targets for 2030, together with the pace of emissions reductions in the 2020s, then inform our recommendations for the fourth budget period. They also inform our recommendations for the adjustment of the first three budgets; these, together with our recommendations on the budget treatment of IA&S, are set out in Section 4 below.

In setting out our recommendations for the fourth budget, we have distinguished between the path which makes sense for UK domestic action, and the path that the UK should be willing to offer as part of a global deal:

- **Domestic Action indicative 2030 target and fourth budget.** These reflect a bottom-up assessment of abatement opportunities during the 2020s, and include abatement measures which will either be cost-effective at projected carbon prices or which will be necessary to ensure a feasible path from 2030 to 2050. We recommend that the Domestic Action budget for 2023-2027 is legislated now, with the aim to meet it through domestic emissions reduction (i.e. without recourse to credits purchased in international carbon markets including the EU ETS).
- **Global Offer indicative 2030 target and fourth budget.** These are intended to illustrate a possible UK contribution to the overall global emissions reductions required to achieve the climate objective discussed in Section 1 above. They are slightly more ambitious than the Domestic Action target and budget: the additional ambition could be achieved either via the purchase of emission reduction credits in international carbon markets, or via accelerated domestic abatement. The Global Offer budget is intended to be indicative of a minimum contribution to a global deal. It would only be legislated in the context of a global deal covering the 2020s, with a precise level of ambition to reflect the deal achieved.

We now consider in turn:

- (i) Possible emissions levels in the early 2020s.
- (ii) Feasible emissions reductions in the 2020s and an appropriate Domestic Action 2030 target and fourth carbon budget.
- (iii) The indicative Global Offer budget.

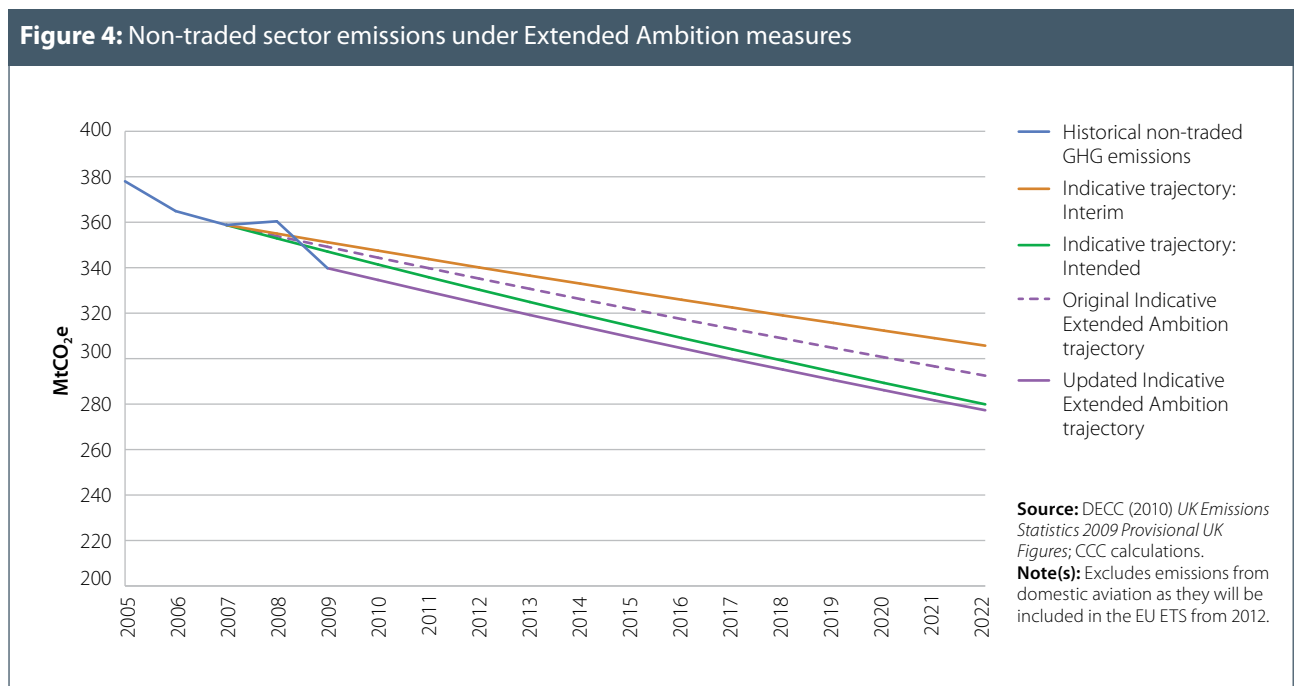
The feasible pathway between 2030 and 2050 is considered in Section 3. Recommendations for the approach to carbon budgets in the first three periods, and to international aviation and shipping, are covered in Section 4.

(i) Possible emissions levels in the early 2020s

Following the Committee’s advice in our 2008 report, and Parliament’s decision in June 2009, the UK is currently legally committed to the Interim budgets, which entail emissions falling from 3018 MtCO₂e in the first five-year budget to 2544 MtCO₂e in the third. It was hoped that progress to the Intended budgets, in which emissions reduce to 2245 MtCO₂e in the third budget period, would become possible after a global deal at Copenhagen, and an EU commitment to a 30% (rather than 20%) emissions reduction target for 2020.

Since the decision to proceed with the Interim budget, however, UK emissions have fallen significantly due to the recession. 2009 emissions were 8.6% below 2008 levels: at 574 MtCO₂e they are significantly below the average 604 MtCO₂e per annum allowed in the first budget period. Our latest projections moreover suggest that if the UK successfully implements measures which we had previously thought necessary to meet the Interim budget (the “Extended Ambition” scenario described in our 2008 report) we will enter the early 2020s with emissions levels in line with the Intended rather than the Interim budget in the non-traded sector (Figure 4).

We therefore design the fourth budget around the assumption that the Intended third budget is achieved in the non-traded sector. Indeed, this will be essential for progress through the 2020s, and we discuss the implications for appropriate policy adjustments to the second and third budgets in Section 4 below.



(ii) The Domestic Action budget

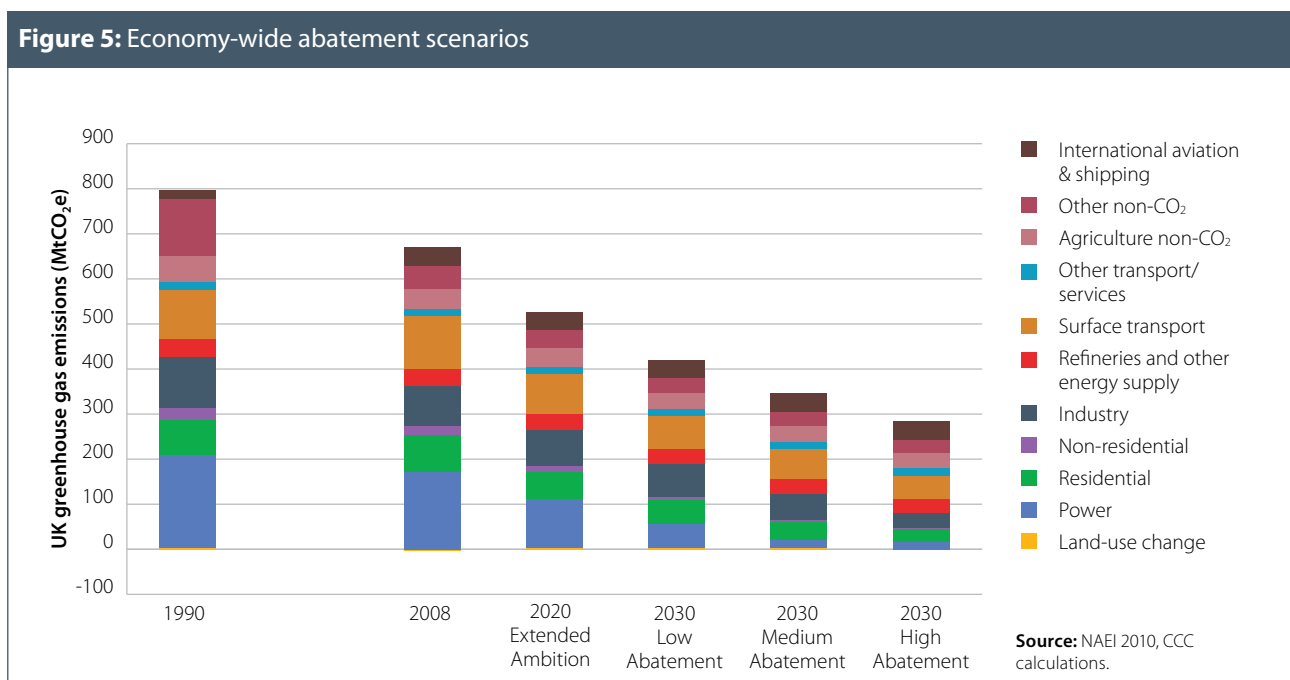
Scenarios for UK emissions through the 2020s

Future technological developments and costs are uncertain. It is not the role of the Committee to predict what precise mix of different technologies will be used to deliver future carbon budgets.

But our budget recommendations need to be based on confidence that there exists a range of technological options which are likely to make the budgets attainable; and we need to identify if there are policies required to increase the likelihood that potentially important options will be available for deployment. As in our 2008 report, we therefore set out a range of emissions scenarios based on a bottom-up analysis of abatement opportunities in each sector of the economy.

We have developed scenarios for UK emissions through the 2020s based on assessment against four criteria:

- **Feasibility** given current technology readiness and possible innovation, capital stock turnover, build rates, consumer acceptability and new policies to support uptake.
- **Sustainability** of bioenergy in particular given tensions between use of land for growth of bioenergy feedstocks versus food, and possible air quality impacts from burning biomass.
- **Cost-effectiveness** relative to our projected carbon prices through asset lives; we follow DECC in assuming a carbon price rising to £70/tCO₂ in 2030 and £135/tCO₂ in 2040.
- **Consistency with the 2050 target** given the long lives of assets, limits on the pace of emissions reduction beyond 2020, and the need to achieve the 2050 target largely through domestic abatement.



We construct three scenarios (Low, Medium, High abatement) which meet the four criteria above to differing extents, and which deliver emissions reductions of 51%, 60% and 69% in 2030 relative to 1990 levels (Figure 5).

The Medium abatement scenario (Box 2) forms the basis of what we should plan for in the 2020s as it prepares sufficiently for 2050 whilst being feasible, sustainable and cost-effective:

- It reflects significant uptake of abatement potential that currently appears to be cost-effective for different assumptions on key cost drivers and carbon prices.
- It balances the risks of under-achievement versus risks of excessive costs during the 2020s.
 - It keeps other scenarios in play and therefore maximises flexibility (e.g. if deeper cuts are required, depending on the outcome of a future global deal covering the 2020s, it could be possible to move to the High abatement scenario; or the Medium abatement scenario could be delivered through a different technology mix).
 - Planning for higher ambition currently appears to entail significant further costs, but could become desirable in the future (e.g. depending on low-carbon technology innovation, and/or in the context of a global deal).
 - Planning for a lower level of ambition would carry three risks. It could result in investment in carbon-intensive assets in the period to 2020 which, while compatible with meeting the first three budgets, would impede further progress in the 2020s. It could fail to develop adequately technologies that will be required in the 2020s. It could also fail to put appropriate policies in place far enough in advance of the fourth budget, resulting in limited investments with long lead times and limited supply chain expansion. It could therefore necessitate scrapping of high-carbon assets and/or the purchase of high-cost carbon credits in the 2020s.
- It implies a feasible path to 2050 in terms of required annual emissions reductions and abatement options beyond 2030. Lower cuts through the 2020s would not sufficiently develop abatement options required in subsequent periods, and would leave a need for very challenging and expensive emissions reductions beyond 2030, whilst higher cuts are not necessary and would involve additional costs on the path to 2050 (see Section 3 below on the path from 2030 to 2050).

Given these properties, we use the Medium abatement scenario as the basis for our Domestic Action budget.

Box 2: The Medium abatement scenario

The Medium abatement scenario includes the following measures:

- **Power:** Addition of 30-40 GW¹ low-carbon capacity to the system through the 2020s. This results in a reduction in carbon intensity from around 300 gCO₂/kWh in 2020 to around 50 gCO₂/kWh in 2030. The scenario includes a 30% demand increase from 2020 to 2030, reflecting increased uptake of electric vehicles and heat. The scenario could be delivered through a mix of technologies including renewable (e.g. wind, marine), coal and gas CCS, and nuclear. This scenario also includes investments in smart meters and increased interconnection with Europe to provide greater system flexibility, therefore addressing potential problems associated with intermittency.
- **Buildings:** Ongoing energy efficiency improvement through the 2020s, including insulation of 3.5m solid walls in the residential sector. The key option for supply-side decarbonisation in this scenario is heat pumps. These reach a penetration rate of 25% in the residential sector, and around 60% in the non-residential sector by 2030. There is a limited assumed role for district heating, reflecting uncertainties around technical and economic aspects of this option, with the possibility of deeper penetration as uncertainties are resolved. There is some use of biomass and biogas, although the majority of these energy sources is used in the industrial sector, given the lack of low-carbon alternatives for industry decarbonisation.
- **Industry:** Use of biomass and biogas, which together account for around 25% of total heat demand by industry in 2030. There is a growing role for CCS in industry through the 2020s, which by 2030 reduces emissions by around 5 MtCO₂.
- **Transport:** Ongoing improvement of conventional vehicle efficiency, to 80 gCO₂/km for conventional cars and 120 gCO₂/km for conventional vans in 2030. There is 60% penetration of electric vehicles in new sales by 2030, the majority of which are assumed to be plug-in hybrids rather than pure electric, reflecting ongoing concerns around range constraints. There is a role for hydrogen vehicles in niche sectors (e.g. 50% of new buses in 2030 are hydrogen), with the possibility of broader penetration. We take a cautious approach to sustainable biofuels, with these remaining at levels recommended for 2020 in the Gallagher Review through the 2020s.
- **Agriculture non-CO₂:** Continuation of progress over the next decade implementing soils and livestock measures. The scenario recognises the possibility of, but does not require, consumer behaviour change, both as regards reducing waste and rebalancing diet to less carbon-intensive foods. It includes emissions reduction potential from increasing afforestation in the 2020s. The overall emissions reduction to 35 MtCO₂e in 2030 is low relative to abatement potential from all these measures, and could therefore be delivered in different ways.

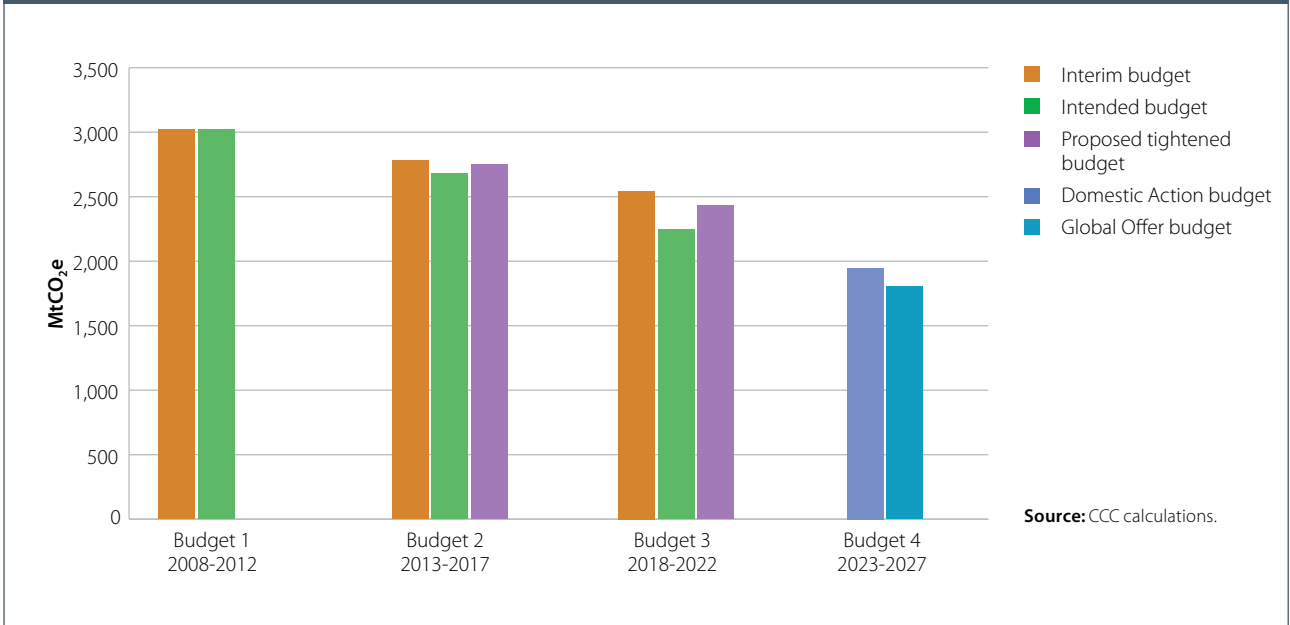
The Domestic Action indicative 2030 target and fourth budget

The Domestic Action budget follows the trajectory for the Medium abatement scenario through the relevant part of the 2020s, and limits greenhouse gas emissions (excluding IA&S) to 1950 MtCO₂e over 2023-2027, an annual average of 390 MtCO₂e (Figure 6). It embodies an emissions cut of 50% in 2025 below 1990 levels (32% below 2009 levels), on the path to an indicative 2030 target of a 60% cut in emissions relative to 1990 levels (46% relative to 2009 levels).

We recommend that the Domestic Action budget is now enacted. Under the Climate Change Act this budget will legally commit the UK to keeping net emissions (i.e. emissions adjusted for any net credit purchase in EU ETS or in global carbon markets) below the defined level. But the Domestic Action budget will only be a feasible stepping stone to the 2030 and 2050 targets if it is met on a gross basis (i.e. if the UK's domestic emissions are at or below this level). We therefore recommend that, alongside legislating this budget, the Government commits to bring forward policy measures which will make it attainable without the purchase of credits (additional reductions under the Global Offer budget could be delivered via credit purchase, see below).

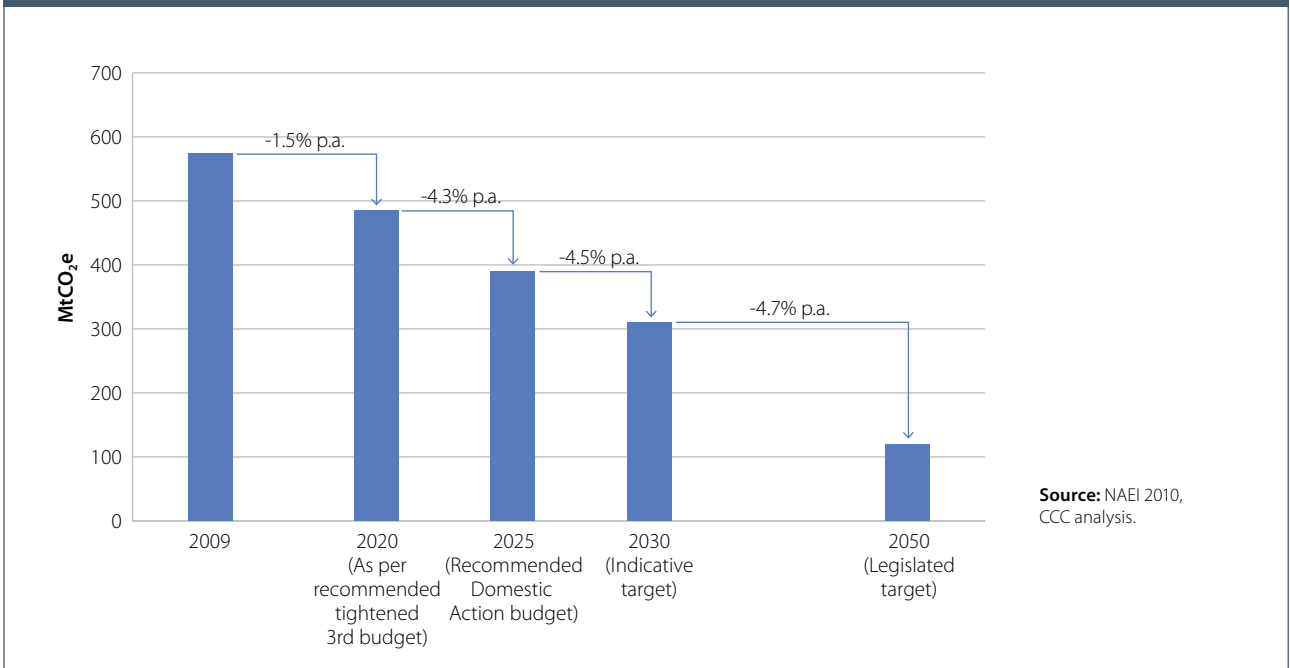
¹ Capacity is adjusted to reflect annual availability – these figures are for baseload-equivalent GW.

Figure 6: First four UK five-year carbon budgets (2008-2027)



It is important to recognise that the recommended budget requires steady acceleration of progress over time. Our proposed pace of progress through the 2020s is significantly faster than that required to meet carbon budgets in the 2010s, and faster still in the late 2020s and between 2030 and 2050 (Figure 7), as reflected in total required emissions reductions of 46% between 2009 and 2030 and 62% between 2030-2050. This is acceptable given the range of available technologies likely to be available through the 2020s and from 2030 to 2050. But the Committee judges any further 'back-ending' of the reduction path (i.e. a less ambitious budget, requiring further acceleration towards the end of the 2020s) would risk making the indicative 2030 target unattainable, which would in turn put the 2050 target at risk (see Section 3 below).

Figure 7: Rate of reduction of greenhouse gas emissions, excluding international aviation and shipping (2009-2050)



In addition, our recommended budget is based on uncertain reference emissions projections from the DECC Energy Model. The Committee has concerns that this model may underestimate the future extent of decoupling of energy demand from GDP growth, for example concerning industrial energy and materials demand. Therefore our reference emissions projections may be too high, in which case a tighter budget would be appropriate. We will work with DECC in 2011 to try to resolve this issue.

Therefore for these two reasons – back-ending and uncertainty over emissions projections – the recommended budget should be regarded as an absolute minimum level of ambition. This could be adjusted over time, and the precise mix of abatement options determined if and as uncertainties over emissions projections and abatement opportunities are resolved. One specific opportunity to implement such an adjustment would be in the context of moving from the Domestic Action budget to the Global Offer budget, to which we now turn.

(iii) Fourth budget based on a UK Global Offer

Our top-down approach derives a fourth carbon budget from the global pathway described in Section 1 above (i.e. peaking of emissions by 2020, deep cuts through the 2020s and a halving of emissions by 2050).

- At a minimum the UK contribution to global effort should track the global pathway (e.g. broadly characterised by equal annual percentage reductions from the early 2020s towards 2 tonnes per capita by 2050).
- It is hard to envisage a situation where the UK is less ambitious than the global average, which would require that other countries are more ambitious.
- Beyond this minimum, more is likely to be required, depending on financing agreed under a future global deal (e.g. depending on the burden share methodology)².

A UK path tracking the global pathway (i.e. equal annual percentage cuts from the Intended budget in 2020 to the 2050 target) gives an indicative Global Offer budget of 1800 MtCO₂e, an annual average of 360 MtCO₂e (i.e. 8% lower than the Domestic Action budget), on the path to an indicative 2030 target of a 63% reduction relative to 1990.

We recommend that this budget is legislated in the context of a global deal for the 2020s, once specific global emissions pathways and financing arrangements are more certain. The aim should be to meet this budget largely through domestic abatement given cost-effective abatement opportunities in the UK and on the path to the 2050 target, with possible purchase of credits at the margin (e.g. depending on technology costs and carbon prices, and on the role of financial flows as part of a future global deal).

² At the country level equal annual percentage reductions to emissions of 2 tCO₂e per capita in 2050 would vary by country according to their 2020 entry point and would imply greater reductions on a per capita basis given rising population.

3. The path from 2030 to 2050

The challenge from 2030

In the previous section, we considered the feasible path of emissions reduction in the 2020s, and defined a Domestic Action indicative 2030 target and a Domestic Action recommended fourth budget for 2023-2027 which are likely to be attainable at acceptable macroeconomic cost (see Section 6 below on costs). We need to check, however, if this target and budget are sufficiently ambitious to make achieving the 2050 target feasible, given the further reductions that would be required between 2030 and 2050.

Given delivery of the Medium abatement scenario to meet the Domestic Action budget without purchase of credits, remaining UK emissions in 2030 would still be 310 MtCO₂e (excluding IA&S). Further reductions of around 200 MtCO₂e would then be required to meet the 2050 emissions target through domestic action (Figure 8).

To understand the scale and sectoral mix of further reductions required beyond 2030, it is useful to be clear about how emissions scenarios for progress vary by sector (Figure 9). Reductions achieved by 2030 in our Medium abatement scenario vary from over 90% below 2008 levels in power generation, to 56% in buildings and 43% in surface transport, to only 28% in industry (including refineries and other energy supply) and just 19% in agriculture.

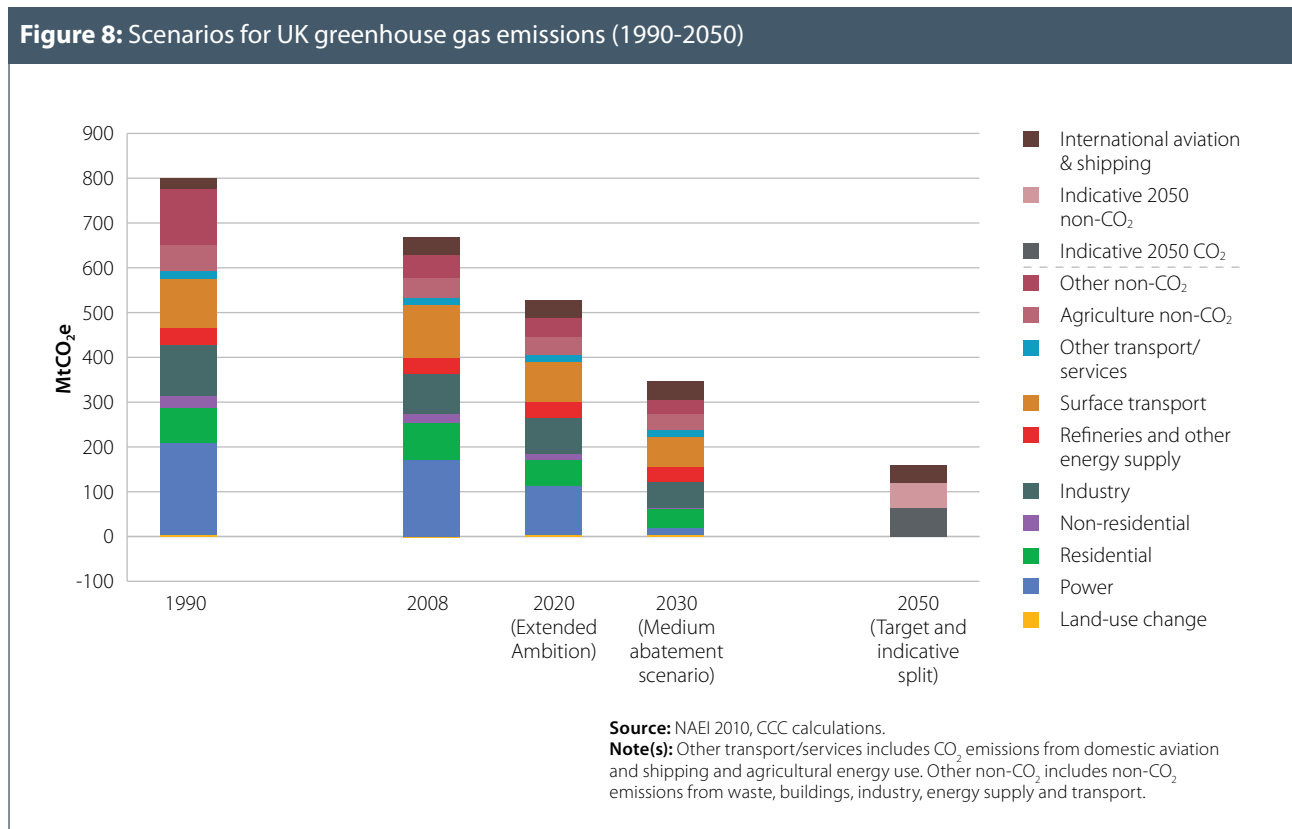
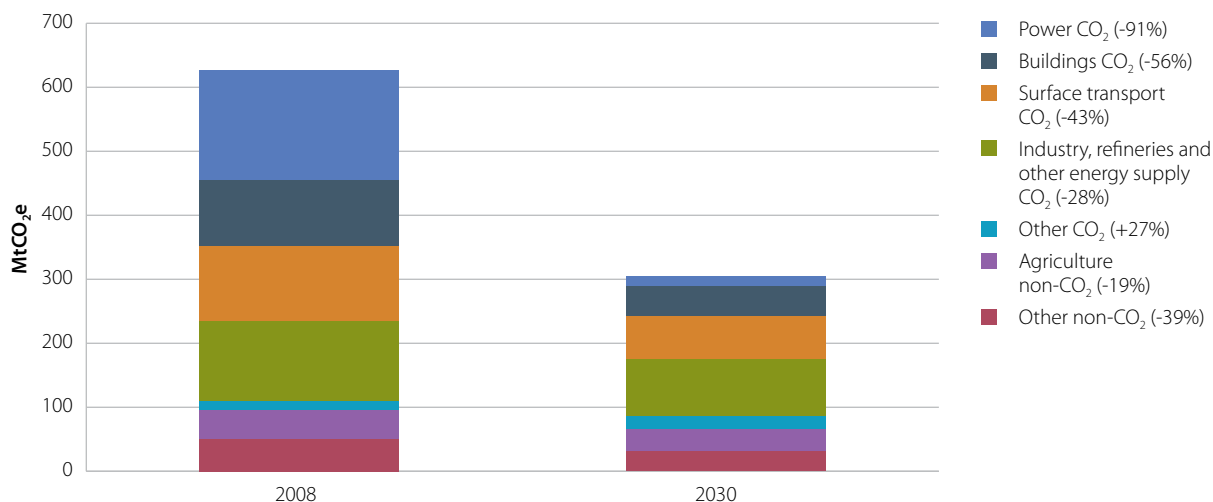


Figure 9: Possible sectoral emissions reductions achieved by 2030



Source: NAEI 2010, CCC calculations.

Note(s): Other CO₂ includes CO₂ emissions from domestic aviation and shipping, agricultural energy use and land-use change. Other non-CO₂ includes non-CO₂ emissions from waste, buildings, industry, energy supply and transport.

Options from 2030 to 2050

Reductions beyond 2030 will require both a move to near full decarbonisation of those sectors where this is technologically possible, and significant emissions reductions in industry and agriculture, two sectors where radical reductions pre-2030 may prove more difficult to achieve. While it is not possible or necessary to specify what mix of technologies and/or consumer behaviour change will provide the optimal path to reductions over the 2030-50 period, the following review of potential options suggests that the 2050 target of 160 MtCO₂e (around 120 MtCO₂e excluding IA&S) could be attained from the 2030 starting point defined by our indicative target:

- Power sector.** Power sector emissions are reduced to low levels in 2030 under the Medium abatement scenario. Further reductions will be required to 2050, such that the sector is close to zero emissions (or even negative emissions if biomass generation with CCS features significantly). At the same time, demand is likely to increase considerably in line with increased penetration of electric vehicles and heat (e.g. from around 425 TWh in 2030 to well over 500 TWh total annual consumption in 2050)³. Continued investment in new power generation between 2030 and 2050 (e.g. at the rate assumed for the 2020s, 3-4 GW per annum) would be necessary to complete the decarbonisation of the power system and to meet likely increasing demand.

³ MARKAL modelling by University College London for the CCC suggests that power generation may need to increase to around 515 TWh per year by 2050, compared with today's 372 TWh per year, an increase of around 40%. DECC's 2050 Pathways work includes six indicative scenarios that meet the 2050 target, with power generation ranging from 744 (Scenario C) to 972 (Scenario F) TWh per year in 2050, i.e. an increase of 100-160% on today's system.

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- **Buildings.** Direct emissions from heat in buildings are reduced significantly by 2030, as a result of major improvements in energy efficiency and roll-out of low-carbon heat, especially heat pumps. Beyond 2030, further reductions are required, through energy efficiency improvement, further deployment of heat pumps where suitable, possibly combined with conventional electric heat and a potentially important role for district heating in those built-up urban areas for which heat pumps are not suitable. A feasible pace of deployment could almost fully decarbonise heat in buildings by 2050.
 - **Surface transport.** Emissions from this sector remain a large share (22%) of total emissions in 2030 under the Medium abatement scenario. However, this would fall through the 2030s and 2040s with increasing penetration of electric cars and vans (e.g. with 100% penetration of pure electric vehicles in new sales by 2035, there would be no emissions from these vehicles in 2050). Alternatively, if the experience to 2030 suggests limits to penetration of electric vehicles, there could be scope for increased penetration of hydrogen cars and vans. HGVs could be decarbonised through hydrogen produced from low-carbon sources (e.g. electrolysis using low-carbon electricity, pre-combustion CCS or bioenergy). Biofuels could meet any residual demand for liquid fuels, for example, from plug-in hybrid vehicles or those HGVs not using hydrogen, but should not be relied upon as the main decarbonisation strategy given sustainability concerns.
 - **Industry.** By 2050 we would expect available biomass and biogas to be used in industry rather than residential and commercial buildings, where electrification would dominate. In addition, there should be scope for reducing industry emissions through deployment of CCS in the 2030s. Together these options could reduce industry emissions to close to 40 MtCO₂ in 2050. Further abatement potential may be available through electrification, product substitution, and restructuring of the refinery sector as downstream demand is reduced.
 - **Agriculture.** With no further emissions reductions beyond 2030, non-CO₂ emissions from agriculture would be around 35 MtCO₂e. Emissions at this level, combined with those from other difficult to reduce sectors (e.g. IA&S, industry), would make the overall target of 160 MtCO₂e extremely difficult to attain. A long-term plan to achieve more radical agricultural emissions reductions will therefore be needed. Further work is required to identify the options for additional reductions, and the policy levers needed to ensure implementation, but these options may need to include radical and controversial measures on both the supply side (e.g. the use of GM organisms) and in consumer behaviour (e.g. waste reduction or rebalancing of diet).
 - **Other non-CO₂ emissions.** Residual emissions of other non-CO₂ gases in 2030 (i.e. from waste, buildings, industry, energy supply and transport) would be around 30 MtCO₂e. Options to reduce emissions further to 2050 include further diversion of waste from landfill, reduction of energy supply and transport non-CO₂ emissions as fossil fuel use is reduced, and phasing out use of F-gases.

In addition it is important to remember that while the UK is now committed to keep aviation emissions in 2050 no higher than 2005 levels, and while we have assumed that the same is true for the UK's international shipping emissions, strong policy action and significant technological development is required to meet these targets. The policies and technologies required in aviation are set out in our December 2009 report *Meeting the UK aviation target*; those required in shipping will be set out in our review of international shipping emissions in 2011.

Domestic Action indicative 2030 target as a minimum ambition on the path to 2050

As noted above, the recommended budget and the indicative 2030 target imply accelerated progress from 2020, with further acceleration in the late 2020s, and from 2030 to 2050. This can be justified given abatement opportunities from 2030, provided key enabling technologies and conditions (in particular a largely decarbonised power sector) are by then in place.

But setting a lower level of ambition to 2030 and for 2023-2027 would require a very challenging pace of annual emissions reduction from 2030, given rates of capital stock turnover, feasible investment levels, and new technology deployment:

- At the economy-wide level, the Stern report suggested that annual emissions reductions beyond even 3% would be very challenging⁴.
- Lower ambition on key abatement options would be incompatible with meeting the 2050 target, based on current understanding of sectoral opportunities:
 - As noted above, decarbonisation of surface transport requires that all new vehicles beyond 2035 should be ultra low-carbon; this implies the need for very significant penetration of ultra low-carbon vehicles by 2030.
 - A similar point applies to low-carbon heat, given a fifteen-year period for turnover of the boiler stock.
 - Deep decarbonisation of the power sector is required through investment in low-carbon technologies through the 2020s, given asset lives of forty years or longer.
 - Some progress in less well understood areas (e.g. agriculture and industry) will be required to lay the foundations for potentially more radical options beyond 2030.
- The DECC 2050 pathways scenarios reflect the need for deep cuts in emissions by 2030 on the path to 2050, and actually include more aggressive emissions reductions to 2030 than in our Medium abatement scenario (e.g. the range for emissions excluding international aviation and shipping in 2030 in the DECC scenarios is 248-297 MtCO₂e, compared to our indicative Domestic Action target for 2030 of 310 MtCO₂e).

Overall therefore, our conclusion is that there is a feasible pathway from our 2030 indicative target of 310 MtCO₂e (excluding IA&S) to the required 2050 target (160 MtCO₂e in total, but around 120 MtCO₂e excluding IA&S). But any less stretching target for 2030 risks making the 2050 goal unachievable over the subsequent 20 years.

⁴ The Stern Review, *The Economics of Climate Change*, chapter 8 'The Challenge of Stabilisation'

4. The first three carbon budgets (2008-2022): Interim versus Intended and the treatment of international aviation and shipping

(i) Interim versus Intended budgets

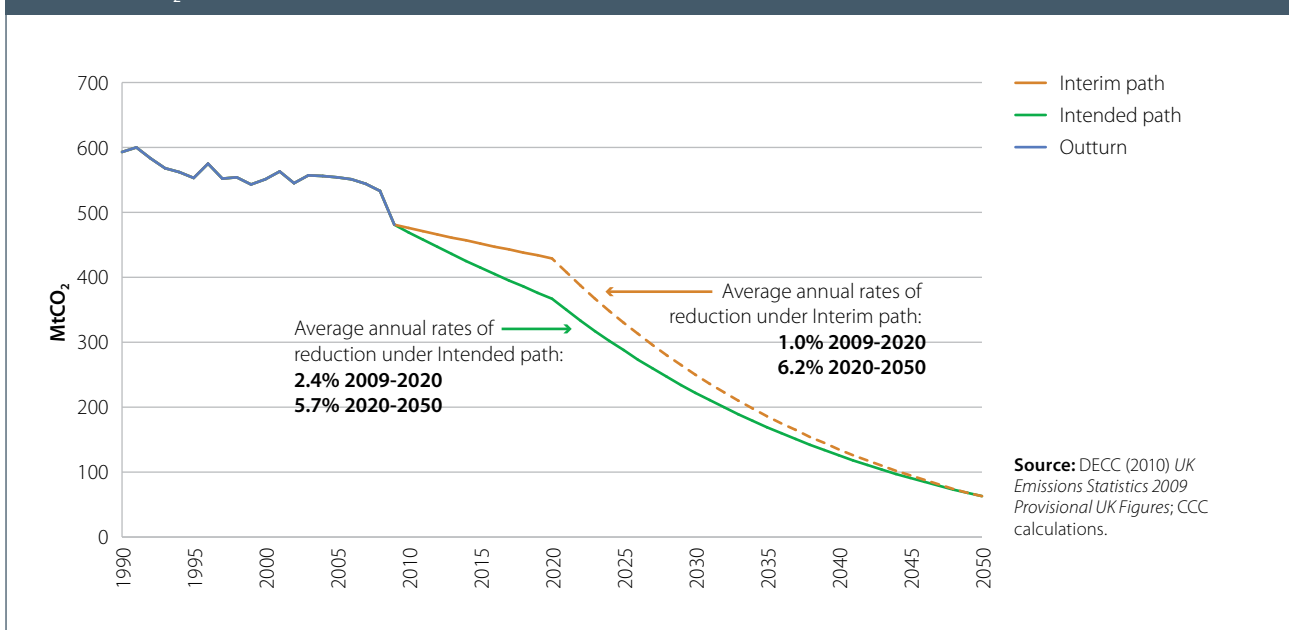
In Section 2 above we described how emissions trends have been influenced by the recession, and the fact that on our current projections the UK is well placed to enter the early 2020s with emissions in line with the Intended third budget for the non-traded sector, rather than the Interim budget legislated by Parliament in June 2009. We have therefore assumed that the Intended budget emissions levels in the non-traded sector are the starting point for our consideration of feasible emissions paths in the 2020s.

It is important to note, however, that this is not just an assumption but necessary to mitigate risks of meeting the fourth budget, as is clear from Figure 10. From the third Intended budget to the fourth Domestic Action budget would entail a feasible reduction of 13% over a five-year period: from the third Interim budget to the fourth Domestic Action budget would require a much more challenging 23% reduction.

We therefore recommend that government policy should be designed to ensure that emissions in the third budget period are in line with the Intended rather than Interim budget.

Ideally we would reflect this policy commitment in an immediate move to legislate the Intended budget. However, in practice, this could not be delivered without a tightening of the EU ETS cap (because this defines the net carbon account for the traded sector under the Climate Change Act). And it would in any case be highly desirable that any UK commitment to tighten the traded sector budget should be made in combination with similar tightening across Europe.

Figure 10: CO₂ emissions reduction to 2050 under Interim and Intended budgets



Therefore we recommend the following approach (Table 1):

- The Government should commit not to bank outperformance of the first carbon budget through to the second budget period.
- The Government and Parliament should adjust the second and third carbon budgets to reflect allowed non-traded sector emissions under the Intended budgets. With this adjustment the third carbon budget would require a 37% emissions reduction in 2020 relative to 1990 (versus 42% under the Intended budget for both the traded and non-traded sectors and 34% under the legislated Interim budget).
- A full move from the Interim to the Intended budget should be legislated in line with a tightening of the EU ETS cap, as and when this occurs.
- The Government should aim to deliver the Intended budget through domestic abatement in the non-traded sector, and through domestic abatement together with limited purchase of credits in the traded sector.

We reflect this approach in our fourth budget advice, which takes as its starting point a 37% emissions cut in 2020 consistent with delivery of our proposed tightened budget with no net credit purchase.

Table 1: Proposed tightening of second and third budgets to include Intended budget for non-traded sector

	Budget 1 (2008-2012)	Budget 2 (2013-2017)	Budget 3 (2018-2022)
Interim budget	3018	2782	2544
Interim traded	1233	1078	985
Interim non-traded	1785	1704	1559
Intended budget	3018	2679	2245
Intended traded	1233	1009	800
Intended non-traded	1785	1671	1445
Proposed tightened budget	3018	2749	2430
Interim traded	1233	1078	985
Intended non-traded	1785	1671	1445

Source: CCC analysis.

(ii) International aviation and shipping (IA&S)

We are required under the Climate Change Act to advise on inclusion of IA&S in the context of our advice on the fourth carbon budget.

As already discussed in Section 1, it is clear that these sectors need to be included within the overall UK target framework, and our recommendations for the fourth budget have been designed to be compatible with the UK achieving by 2050 a maximum emissions level of 160 MtCO₂e including the UK's contribution to IA&S emissions.

Our previous advice was however that these sectors should not be explicitly included in the first three carbon budgets. This was because of complexities around methodologies for inclusion and lack of progress towards an international deal in the case of shipping.

Since 2008 there has been progress in resolving methodological complexities (e.g. as regards accounting for international aviation in the EU ETS). However, further analysis is required to determine specific UK emissions projections for these sectors.

We therefore recommend that Government should accept the principle that IA&S emissions of CO₂ will be included in carbon budgets; further assessment is required in order to determine the appropriate approach to potentially significant non-CO₂ emissions and effects.

The Committee intends to make specific recommendations for limits on emissions from these sectors following completion of our shipping review in Autumn 2011. The second, third and fourth budgets recommended would then be adjusted to include IA&S by adding in emissions limits for these sectors to economy-wide budgets.

This is within the schedule set out in the Climate Change Act, which requires the Government to take a decision on inclusion before the end of 2012.

In this report we allow for IA&S by including these in the 2050 target; given limited scope for abatement in these sectors, this implies the need for deeper cuts in other sectors than would otherwise be the case.

5. Developing options for meeting the fourth budget: policy implications

A number of new policy approaches are required to develop options for meeting the fourth budget. These include power market reform, a carbon price underpin, support for technology development, and policies to drive emissions reductions through the first three carbon budgets (e.g. to encourage energy efficiency improvement). In some key areas, improvements to the evidence base are needed to inform design of new policies. We also draw out implications for EU policies and measures.

Reform of power market arrangements

To meet the indicative 2030 target, putting the UK on the path to 2050, it is essential radically to decarbonise power generation, cutting emissions intensity from today's level of around 500 gCO₂/kWh to around 50 gCO₂/kWh in 2030. This will require the addition of up to 40 GW of (baseload-equivalent) low-carbon plant during the 2020s, on top of the 30 GW (on a nameplate basis) needed over the decade 2010-2020.

Current market arrangements are unlikely to deliver required investments in low-carbon capacity on this scale and/or are likely to result in unnecessarily high electricity prices.

Tendering of long-term contracts (e.g. through low-carbon Contracts for Differences or Power Purchase Agreements) would provide confidence that required investments will be

forthcoming at least cost to the consumer, since they mitigate risks which energy companies are not well placed to manage.

Other mechanisms (e.g. reliance on a carbon price alone or extension of the current Renewables Obligation) would not provide confidence around delivery of required investments, and would involve unnecessarily high costs and electricity prices.

Given the need to decarbonise the power sector and the long lead times for low-carbon investments, reform of the current market arrangements to introduce a system of tendered long-term contracts is an urgent priority.

Our recommendations on power market reform are set out in more detail in Box 3.

Underpinning the carbon price

We have previously highlighted the importance of a robust carbon price in encouraging low-carbon investments. However, we have argued that the low and volatile carbon price generated in the EU ETS does not provide such a signal.

Our analysis in this report suggests that unless the EU ETS cap is tightened significantly, the carbon price in 2020 is likely to remain low relative to expectations before the recession. Latest estimates suggest a possible price of 30 euros per tonne in 2020 versus the 55 euros per tonne which we assumed for a 30% reduction target in the 2008 report.

To provide a stronger signal, there should ideally be a carbon price underpin (i.e. a guaranteed minimum price) at the EU level consistent with the required pathway to 2050 (e.g. reaching at least the EC's projected price of 30 euros, or around £27/tCO₂, in 2020 and rising through the 2020s to £70/tCO₂ in 2030).

In the absence of an EU underpin, a UK underpin (e.g. in the form of a carbon tax or a contract for difference) would strengthen incentives for low-carbon investments in power generation and more generally. It should be introduced subject to addressing competitiveness concerns in the energy-intensive sectors and affordability/fuel poverty concerns in the residential sector.

Box 3: Recommendations on power market reform

We recommend that tendering of long-term contracts for low-carbon capacity would provide most confidence about delivery of required investments, at least cost to the consumer. Other mechanisms (such as reliance on a higher carbon price alone or extension of the current Renewables Obligation) would not provide confidence about delivery of investments, and would involve unnecessarily high costs and electricity prices, delivering economic rents to some generators. These other mechanisms seek to compensate for high risk by providing subsidy; the optimal policy would instead reduce the risks which private operators currently face but are not well placed to manage relative to government or consumers.

There are five arguments underpinning this conclusion:

- **Rapid power sector decarbonisation will be needed to meet the fourth carbon budget.** A feasible path to 2050 requires early power sector decarbonisation and the large-scale deployment of low-carbon electricity in transport and heat sectors during the 2020s.
- **Risks under current arrangements are likely to limit investment in and increase the cost of low-carbon generating capacity.**
- **Faced with these adverse impacts, government policy can either seek to reduce risks, or subsidise to offset risks; the former strategy is the optimal one.**
 - Reducing risks is the optimal public strategy given that the private risks faced by investors do not correspond to the social risks of the investments, and can therefore be removed from the private sector by the Government at limited cost to itself or consumers. Lower electricity prices than in the subsidy strategy will result.
 - Analysis conducted for the Committee by Redpoint suggests that a strategy of reducing risks could lower the weighted average cost of capital up to 3 percentage points and could reduce the cost of decarbonising the power sector by around £5 billion annually by 2030.
- **Tendering of long-term contracts for low-carbon generation would allocate risks appropriately while providing the discipline of price competition, including allowing new players to enter the market. It would provide most confidence that required investments will be delivered at least cost to the consumer.**
 - The long-term contracts tendered could take a number of forms, including: (i) low-carbon Contracts for Differences around the fluctuating electricity wholesale price, which could preserve positive aspects of the existing market arrangements (e.g. providing incentives for appropriate location of wind farms and investment in system flexibility, and ensuring efficient dispatch), or (ii) Power Purchase Agreements/low-carbon tariffs in a separate low-carbon market.
- **Other mechanisms that rely on subsidy rather than risk reduction would not ensure a required scale of investment and would be unnecessarily expensive:**
 - Carbon price strengthening without long-term contracts would result in escalating electricity prices in line with the increasing cost of unabated gas-fired generation. Relying on carbon price strengthening alone could result in continued investment in unabated gas generation, and would deliver economic rents to low-carbon generators.
 - Extension of the current Renewables Obligation to cover all low-carbon generation may work, but at an unnecessary cost to electricity consumers, since the premium price paid to low-carbon generators would need to be high enough to compensate for the risks they would still face.
 - Capacity mechanisms applicable to all types of generation (whether high- or low-carbon) may have a useful complementary role to play in securing balancing and peaking capacity, but will not ensure a shift to low-carbon generation alone, and could result in inappropriately high levels of unabated gas generation in the system.

We therefore strongly recommend that a system of tendering for some form of long-term contract for low-carbon capacity is introduced. Relying on other mechanisms would reduce the likelihood of meeting carbon budgets and/or increase the net cost to society of meeting them.

Support for development of new technologies and markets

Feasibility and cost risks in meeting the fourth budget would be mitigated through Government support for development of key technology options including, but not restricted to:

- **CCS in power generation.** The current proposal to support four CCS power generation projects (in the Coalition Agreement, reconfirmed in the 2010 Spending Review), would result in a critical mass for potential roll-out from the early 2020s. It is important that a funding mechanism for the four projects is finalised and that these are tendered in 2011 to facilitate early deployment. Given the extent of decarbonisation required by 2030, and the possibility that future gas prices may be lower than seemed likely at the time of our 2008 report, CCS for gas as well as coal generation will be a crucial set of technologies. The Government's recent announcement that gas CCS will be included in the demonstration projects is therefore welcome.
- **Offshore wind.** Given the vast UK resource, this is a valuable option for power sector decarbonisation. Deployment in the 2020s could play a significant role in power decarbonisation; the appropriate scale will depend on cost reductions achieved in the period to 2020 and the pace of development and deployment of other technologies. We will consider offshore wind in detail in our renewable energy review, to be published in Spring 2011.
- **Electric vehicles.** We have previously estimated that government financial support of around £800 million will be required to fund purchase of electric cars in the period to 2020, with possible additional costs for funding investment in a battery charging network. Analysis in this report suggests that government funding of these initial costs is clearly justified since early development of the electric car option will reduce the costs of meeting later budgets (e.g. the present value cost saving through supporting early-stage market development for electric vehicles is over £5 billion in the period to 2050). Announced Government support of £400 million for ultra low-carbon vehicles over the Spending Review period could provide useful support for development of electric vehicles. Further funding is also likely to be required in the period to 2020 to ensure that this key technology option is developed and deployed. In addition further funding for hydrogen technology and infrastructure development is likely to be required.
- **Low-carbon heat.** Electric heat pumps and heat from bioenergy are potentially major contributors to required emissions cuts through the 2020s. In both cases, technologies are mature but not demonstrated in all relevant sectors in the UK context. Financial support and other policies to encourage take-up will therefore be required. The Renewable Heat Incentive (RHI) announced in the 2010 Spending Review could provide the required financial support. However, it is not clear whether this policy will provide appropriate incentives for energy efficiency improvement, or will address non-financial barriers to deployment; we will consider the RHI in detail in our renewable energy review, to be published in Spring 2011.

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- **CCS in industry.** This is a major option for cutting emissions in heavy industry, especially in those applications where significant emissions result from chemical reactions as well as from fossil fuel combustion (e.g. iron and steel, cement). Without CCS, required cuts in industry emissions to 2050 will be very challenging. To ensure that this technology is available for deployment from the 2020s, a policy approach is required which either funds demonstration, or ensures that demonstration elsewhere (e.g. under the EU's CCS demonstration programme) will provide scope for timely deployment in the UK.
 - **Aviation.** There is a need to develop new aviation technologies in order to help limit emissions in 2050 at 2005 levels. These include evolutionary innovations such as narrow body aircraft and open rotor engines, and more radical options such as blended wing aircraft. As set out in our July 2010 report *Building a low-carbon economy – the UK's innovation challenge*, the UK has strong capabilities in these areas, and public support for more radical options in cooperation with EU partners should be seriously considered.

New policies to deliver the first three carbon budgets

Achieving the fourth budget will only be feasible if the UK enters the 2020s with non-traded sector emissions in line with the Intended rather than Interim third budget. This will require the implementation of the emissions reduction measures which our 2008 report included within our 'Extended Ambition' scenario, achieving a step change in the underlying pace of reduction. New policies are required to drive this step change:

- **Energy efficiency improvement.** New approaches are required to address financial and non-financial barriers to energy efficiency improvement. The focus should be strengthening incentives in residential and SME sectors, and ensuring a coherent approach across all sectors given the current multiplicity of policy instruments (EU ETS, Climate Change Levy, Climate Change Agreements, Carbon Reduction Commitment, etc.).
- **Roll-out of smart meters.** This is planned for the period to 2020 and will be crucial in providing flexibility to respond to volatile power demand and intermittent supply. For example, smart meters together with time of day pricing would allow charging of electric vehicle batteries when there is spare power capacity on the system, and possibly allow these also to act as extra capacity at times of low system reserve margin.
- **Transport consumer behaviour change.** There is a low-cost opportunity for significant emissions reductions through roll-out of Smarter Choices policies which encourage rationalisation of car trips (e.g. through switching to public transport, car pooling). The £560 million announced in the 2010 Spending Review for a Sustainable Travel Fund should be designed in a way that would allow national roll-out of Smarter Choices, given its carbon and wider economic benefits.

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- **Changing agricultural practices.** New approaches are required to support wider uptake of low-cost measures to reduce soils and livestock based emissions. The current industry-led approach, supported by action from retailers, and EU policies (e.g. the Nitrates Directive) should strengthen incentives for action. However, stronger levers may be required, particularly to deliver more expensive measures. The Government has committed to a review of the policy framework in 2012. This should include a full range of options to buttress the current voluntary approach.
 - **Afforestation.** There is potential for significant emissions reduction over the next decades through afforestation. This is likely to require a planned rather than reactive approach. There are a range of options to implement a planned approach which should be considered now given the long lead time for afforestation.

Areas where further evidence is required

There are a number of abatement options in our scenarios where further evidence is required to inform policy development. Major areas include:

- **District heating.** Our analysis suggests that district heating using waste heat from low-carbon power generation could be very cost-effective and suitable for houses not well-suited to fitting heat pumps. The option to roll out district heating would be useful, but significant uncertainties over technical and economic aspects of this technology still need to be resolved.
- **Implications of vehicle battery charging for power networks.** Slow charging of electric vehicle batteries off-peak is attractive given that this uses spare low-carbon capacity, and minimises implications for investment in power networks. Analysis of trip data suggests that slow off-peak charging should be feasible for most drivers, given smart meters and time of day tariffs. However, precise implications of battery charging for power networks are uncertain, particularly as regards implications of a fast charging network to complement slow off-peak charging. As implications are better understood, these can be reflected in the regulatory regime for power networks (e.g. through license requirements to install fast charging points, and allowing investments to upgrade networks in the regulatory asset base).
- **Radical abatement options in industry.** Our high-level assessment has identified key options for decarbonising industry emissions including use of biomass, biogas and CCS. However, there are other promising options which we have not yet considered in detail including electrification, resource efficiency and product substitution (e.g. use of low-carbon construction materials such as wood rather than carbon-intensive cement and steel); such additional options are likely to be required in the context of the 2050 target, and may have a role to 2030.

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- **Abatement options in agriculture.** There is considerable uncertainty around emissions and abatement potential in agriculture: this derives partly from incomplete scientific understanding, and partly from a lack of good information over current farming practice. This means that it is difficult to evaluate abatement opportunities as they relate to soils and livestock measures to be pursued over the next two decades, and to more radical options such as the use of genetically modified organisms (GM). Uncertainties should be resolved given that currently identified potential for reducing agriculture emissions is unlikely to be compatible with meeting the 2050 target.
 - **Biofuels.** We have adopted a cautious approach to use of biofuels through the 2020s to reflect sustainability concerns, mainly relating to tensions between use of land for growth of biofuels feedstocks versus growth of food for a significantly increasing global population. There is a high degree of uncertainty over future levels of sustainable biofuels, which we will consider further in our bioenergy review in 2011.

These areas are priorities for development of the evidence base. We will work with Government to address them, drawing out any implications for design of new policies.

Implications for EU policies and measures

There is a set of policies that the UK Government should push for in Europe to set the EU on a cost-effective and credible path to its 2050 target, and which would reinforce UK action to meet the fourth carbon budget, including:

- Supporting the move to an EU 30% emissions reduction target in 2020 relative to 1990 levels.
- Agreeing an appropriate emissions reduction target for 2030 (e.g. around a 55% reduction relative to 1990).
- Tightening of the EU ETS emissions cap, both in 2020 and through the 2020s.
- Setting 2030 targets for new car and van emissions (e.g. around 50gCO₂/km for cars and 80gCO₂/km for vans).
- Reforming the EU Common Agricultural Policy, which is due for revision in 2013, so that it links subsidies and incentives to climate change mitigation objectives.
- Supporting technology development, particularly for CCS in industry.

6. Wider economic and social considerations and differences in national circumstances

The Climate Change Act requires that our budget advice includes consideration of six sets of wider economic and social issues:

- Macroeconomic impacts (e.g. costs and investment requirements),
- Fiscal impacts,
- Competitiveness impacts,
- Affordability/fuel poverty,
- Security of supply,
- National circumstances.

We considered these impacts in detail in our 2008 report, where we concluded that the various risks (e.g. for competitiveness, fuel poverty, security of supply) could be mitigated through available policy levers.

In this report, we update our earlier analysis, and consider high-level incremental impacts through the 2020s. We reach a similar set of conclusions to those in our first report: the budget can be achieved at a manageable economic cost; to the extent there are risks of adverse impacts, these can and should be mitigated through appropriate policy.

Macroeconomic impacts: costs and investment requirements

Based on detailed assessment of specific abatement options, we estimate that meeting the Domestic Action budget will cost under 1% of GDP in 2025 (i.e. the mid-year of the budget period), with additional costs of the order 0.1% of GDP for meeting the Global Offer budget.

The additional cost of meeting the Global Offer budget is the projected carbon price (£45/tCO₂) multiplied by possible credit purchase (around 30 MtCO₂); costs would be lower if credit purchase were to be substituted by lower-cost domestic abatement, but could be greater if the carbon price were higher than £45 per tonne, or if the Government chose to make a more ambitious commitment within global negotiations.

The main investment costs associated with delivering the Domestic Action budget relate to the power and heat sectors. These are larger than recent investment costs in the energy sector, but small relative to the investment ratio for the economy as a whole:

- The largest investment costs in the Medium abatement scenario relate to low-carbon power generation with, for example, average annual capital spend of around £10 billion over the period 2021 to 2030.
- Average annual investments in abatement technology in the industry sector would be around £1 billion.

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- There will also be significant up-front costs in the buildings sector, which if financed via energy companies may also be considered as investment costs. These costs are around £6 billion annually in our Medium abatement scenario.
 - There may be additional investment costs related to this scenario for rolling out a charging network for electric cars, and associated power distribution and transmission network strengthening.
 - Total investment requirements are under 1% relative to GDP through the 2020s, relative to an investment ratio for the economy as a whole which was at around 19% of GDP before the recession.

New policies will be required to improve the investment climate for development and deployment of low-carbon technologies in power, heat and other sectors. In addition, a Green Investment Bank would provide focus and could address market failures in the financial sector, potentially mobilising new sources of funds for required investments.

Fiscal impacts

In our 2008 report we identified key fiscal impacts of meeting carbon budgets to 2020 as being increased auction revenues from the EU ETS, offset by decreasing revenues from fuel duty and Vehicle Excise Duty (VED). We concluded that to the extent there could be net negative impacts, these would be small enough to be manageable.

In this report we have extended the analysis to cover emission scenarios for the 2020s:

- The UK's EU ETS auction revenues should increase through the 2020s, potentially reaching £3 billion to £8.5 billion in 2030 depending on the level of allowance auctioning.
- Under the current structure of taxes, receipts from road fuel duty would fall, by around £3 billion in 2030 relative to our reference emissions projection, reflecting reduced fuel use from more efficient conventional vehicles and as more electric vehicles penetrate the fleet.
- With no change in duty categories, VED revenues (of up to £7 billion) would be virtually eliminated by 2030, reflecting the lower rates of duty currently attached to more efficient vehicles. This indicates the need to tighten VED banding in line with improving average efficiency to maintain incentives to purchase more efficient vehicles.

The order of magnitude of any fiscal impacts through the 2020s is likely to be small, and with adjusted VED banding and full auctioning of EU ETS allowances could be broadly neutral or even positive. To the extent that further rebalancing is necessary or desirable, there is a long lead time for this, with key options for raising revenue including introduction of new green taxes (e.g. a carbon price underpin, aviation taxes) and other taxes (e.g. congestion charging would have both environmental and economic benefits).

Competitiveness impacts

The assessment of competitiveness impacts in our 2008 report showed that there were risks of leakage for a limited number of sectors subject to a combination of high energy costs and significant exposure to international competition, accounting for less than 1% of GDP nationally, but significantly more at the local level. We argued that it would be important to address these impacts, as recognised by the EU in granting free allowances to firms in the EU ETS in sectors potentially subject to competitiveness risks.

If a global deal for the 2020s were to result in carbon constraints for some but not all countries, there would be the risk of leakage, particularly as regards energy-intensive industries. This could be addressed either through sectoral agreements or through the imposition of border carbon price levies, with the specific policy instrument to be determined as any competitiveness risks are better understood.

In the particular case of agriculture, whilst measures required over the next ten years are generally cost saving, some more expensive measures required through the 2020s and beyond could potentially have competitiveness impacts. Options to mitigate any impacts include EU-level policies, or unilateral UK downstream carbon taxes; these should be considered further as part of broader policy development for the agriculture sector.

Affordability/fuel poverty

In our 2008 report we suggested that meeting carbon budgets need not increase the number of households in fuel poverty, because the impact of higher energy prices in 2020 could be broadly offset by energy efficiency improvements.

Recent increases in energy prices have substantially added to the number of fuel poor and the Government's latest estimate is that there were 4.5 million fuel poor households in 2008, with a projection that this could rise further to 5.4 million in 2010. Therefore in 2020, it is likely that there would be significantly more households in fuel poverty than previously envisaged, although not as a consequence of meeting carbon budgets.

The range of policy levers for addressing fuel poverty to 2020 and beyond includes targeted installation of energy efficiency measures and some low-carbon heat options, and social tariffs/income transfers (e.g. winter heating allowance). In addition, introduction of new electricity market arrangements will have an important role, since electricity costs and prices will be higher without this.

With appropriate policies in place, meeting carbon budgets is compatible with significantly reducing the number of households in fuel poverty.

Security of supply

In our 2008 report we noted that carbon budgets will have an impact on two aspects of security of supply:

- **Technical security of supply (or reliability).** Potential issues related to increasing levels of intermittent power generation can be addressed through a range of flexibility options (e.g. demand response, interconnection, flexible generation) and the package of electricity market reforms (e.g. to incentivise back-up capacity).
- **Geopolitical and economic security of supply.** Increased low-carbon power generation and extension to other sectors will increase the diversity of energy supply and reduce vulnerability to supply interruption and price volatility.

On balance, therefore, negative security of supply impacts can be addressed, with net positive impacts ensuing through reduced exposure to the risk of supply interruption and price volatility associated with imported fuels.

National circumstances

There are significant opportunities for emissions reductions in each of the UK nations, with an important role for the devolved administrations in planning for and delivering deep emissions cuts through the 2020s:

- Much of the UK renewable electricity resource lies in the devolved administrations, with significant targets in place in Scotland, Wales and Northern Ireland to develop this potential.
- Agriculture forms a larger share of emissions in Scotland, Wales and Northern Ireland than the UK as a whole. Our analysis finds abatement potential in line with these shares for a range of soils and livestock measures.
- We also find significant abatement potential from low-carbon heat, insulation and energy efficiency measures, other options in carbon-intensive industries and transport (from both more efficient and ultra low-carbon vehicles and demand-side measures).

Combining these opportunities with our reference emissions projections for the devolved administrations suggests potential to reduce direct emissions by 48%, 36% and 49% respectively in Scotland, Wales and Northern Ireland by 2030 (relative to 2008). Achieving these reductions will require active policy support from the UK and devolved governments, given the balance of reserved and devolved powers.

The emissions path through the 2020s is of crucial importance in building a low-carbon economy. During this period there is scope for widespread deployment of low-carbon technologies including clean power generation, electric vehicles and low-carbon heat generation. Therefore there is an opportunity to build on the progress required under the first three carbon budgets, and accelerate the pace of emissions reduction from 2020 to 2030. The need for such an acceleration is reflected in our recommended budget. This is stretching but feasible, and can be delivered at a cost of under 1% of GDP. It will bring economic benefits to the UK and, with similar action in other developed countries, will mitigate risks of dangerous climate change. Given these benefits, we urge the Government and Parliament to legislate the proposed Domestic Action budget, and to put in place the policies required to ensure that that budget can be delivered.

7. Key findings



Reduction in UK greenhouse gas emissions by 2050 (relative to 1990 levels) required to limit the risks of dangerous climate change.

80%
by 2050

Emissions reduction in 2020 (relative to 1990) under our proposed tightening of second and third carbon budgets.

37%

Our proposed fourth budget for 2023-2027 – to be delivered through Domestic Action.

1950
MtCO₂e

Required reduction in emissions from today to 2030.

46%

Further required reduction in emissions from 2030-2050.

62%

The cost of meeting the fourth carbon budget and the 2030 target.

Under
1%
GDP



Chapter

1



Introduction

1. The basic science of climate change
2. Appropriate climate objectives and global emissions pathways: recap on our 2008 approach
3. Recent inquiries relating to climate science
4. Recent scientific developments
5. Remaining uncertainties and implications for our approach to mitigation
6. Key findings

Chapter 1: Revisiting the science of climate change

Introduction

In our 2008 report 'Building a low carbon economy – the UK's contribution to tackling climate change' we reviewed the scientific evidence on future climate risks. Based on that evidence we proposed a climate objective: to limit central estimates of global temperature increase by 2100 to as little above 2°C over pre-industrial levels as possible, and limit the likelihood of a 4°C increase to very low levels (e.g. less than 1%¹). We assessed emissions pathways to meet this objective and concluded that global emissions of Kyoto greenhouse gases must peak by 2020, then decline rapidly so that they are halved by 2050, and continue to decline thereafter.

From these global pathways we assessed an appropriate contribution for the UK, and recommended that the aim should be to reduce emissions by 80% in 2050 relative to 1990 levels. The resulting UK emissions in 2050 of around 2 tCO₂e per person would, if replicated around the world, deliver a 50% cut in global emissions, consistent with our climate objective.

In this chapter we do three things:

- We review the basic science of climate change.
- We consider recent inquiries, notably concerning the Climatic Research Unit (CRU) at the University of East Anglia and the Intergovernmental Panel on Climate Change (IPCC).
- We consider developments in climate research since our 2008 report was published, assessing their implications for our climate objective and the global emissions pathways required to meet it.

Our aim is to set out the science which underpins our advice on carbon budgets. We do not present a comprehensive review; more detailed introductions are available from specialist science groups². There are five key messages in the chapter:

- There is a robust scientific case for human-induced climate change, supported by a vast body of theory and observation developed over many years. Although gaps and uncertainties in understanding remain, the case for action remains strong:
 - Global climate change is already happening.
 - It is very likely that this is largely a result of human activity.
 - Without action, there is a high risk of global warming well beyond 2°C, with significant consequences for human welfare and ecological systems over the course of this century and beyond.

¹ 'less than 1%' should be taken as indicative in the context of limiting extreme warming. We set 1% as the maximum allowable likelihood of 4°C arising from the modelling methods used in our 2008 report. Alternative modelling methods may give slightly different odds of 4°C for the global emissions paths we use, because of uncertainties in quantifying the upper tail of the distribution of possible outcomes.

² See for instance Royal Society (2010) Climate Change: a summary of the science, <http://royalsociety.org/climate-change-summary-of-science/>; Geological Society (2010) Climate change: evidence from the geological record, <http://www.geolsoc.org.uk/climatechange>; The Science of Climate Change, <http://www.bis.gov.uk/go-science/climatescience>; IPCC (2007) WG1-AR4 Frequently Asked Questions, http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faqs.html; Weart (2008) The discovery of global warming (2nd ed.), <http://www.aip.org/history/climate/index.htm>

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- Recent public controversies have sparked several independent inquiries into the activities of climate scientists. As a result there have been recommendations for reinforcing the IPCC assessment process and increasing the transparency of research data and methods, which are being addressed. A small number of minor factual errors have been found in the IPCC's reporting of climate change impacts in its Fourth Assessment Report. However, no new findings have emerged that call into question the robustness of the fundamental science.
 - We have reviewed developments in research on the impacts of climate change since 2008. We find no major change in the picture of future damage, although some risks may have increased slightly (e.g. the effect of climate change on food production). Based on this review, we judge that the climate objective we set in 2008 remains appropriate (i.e. to limit central estimates of global average temperature change by 2100 to as little above 2°C over pre-industrial levels as possible, and limit the likelihood of a 4°C increase to a level around 1%).
 - Our review of developments in projecting future climate change for a given global emissions path provides more confidence in the conclusions of our 2008 report: early peaking of global emissions, followed by cuts throughout the century consistent with a halving of emissions by 2050, should meet our climate objective.
 - The precise consequences of climate change remain uncertain in a number of areas. Periodic review of our climate objective and emissions targets is required to understand any implications as information improves.

Our evidence and analysis underpinning these conclusions is set out in five sections:

1. The basic science of climate change
2. Appropriate climate objectives and global emissions pathways: recap on our 2008 approach
3. Recent inquiries relating to climate science
4. Recent scientific developments
5. Remaining uncertainties and implications for our approach to mitigation

We use this chapter as a benchmark for assessing international progress towards mitigating climate change (Chapter 2), and also to underpin UK emissions trajectories through the 2020s consistent with required global trajectories (Chapter 3).

1. The basic science of climate change

It is important when drawing on the science of climate change to distinguish those things which we know with near certainty from those where our understanding is less certain. Overall however the evidence provides strong reasons for believing that human emissions are producing global warming, and that the resulting climate change is likely to cause adverse consequences for human welfare and ecosystems.

(I) The greenhouse effect

Greenhouse gases (GHGs) warm the Earth's surface, which is around 33°C warmer than it would otherwise be in the absence of the greenhouse effect:

- The primary source of the Earth's heat is the Sun, but simple calculations show that solar heating alone (without an atmosphere) cannot explain the temperatures we observe on Earth; average surface temperatures are about 33°C warmer than would be expected for a planet of Earth's reflectivity and distance from the Sun.
- There is now a large and very well established evidence base showing that atmospheric GHGs create the extra warmth by trapping heat. This natural 'greenhouse effect' was first deduced by Joseph Fourier in the 1820s, with significant contributions to understanding during the 19th Century by John Tyndall and Svante Arrhenius.
- Since then, repeated and varied measurements from laboratories, aircraft and satellites have all confirmed that atmospheric GHGs trap heat.

Status: the fact that the Earth's surface is warmer than it would otherwise be without atmospheric GHGs is as close to certain as any scientific finding, based on fundamental laws of physics.

(II) Non-GHG drivers of climate change

Several factors other than changes in atmospheric concentrations of GHGs can lead to global climate change:

- **Changes in incoming solar radiation.**
 - **Solar output.** The Sun undergoes a characteristic cycle in output every 11 years or so, but has also shown some variability over longer timescales which may be linked to historic variations in Earth's temperature (e.g. there was an extended period of low solar activity which could have caused some cooling particularly in the European region during the 17th Century).
 - **Earth's orbit.** Gradual cycles in Earth's orbit cause regular, alternating patterns in the distribution of solar radiation over the Earth, occurring over timescales of many thousands of years.

- **Changes in the atmosphere.**

- **Clouds.** These exert large and complex effects on Earth's energy balance. Cloud patterns can be influenced either directly (e.g. by contrail formation from aircraft) or indirectly (e.g. in response to warming or cooling).
- **Aerosols.** In addition to GHGs, other particles or droplets suspended in air cause complex climate effects, some cooling and some warming. They are emitted by human activity but also by natural volcanic explosions. For instance, in 1991 Mt Pinatubo ejected enough sulphate aerosol to cause measurable global cooling over the following year or so.

- **Changes in the reflectivity of Earth's surface.** Surface change (e.g. clearing of forest, development of urban areas and melting of ice & snow) can alter the amount of sunlight absorbed by the Earth, causing potentially strong, local effects on climate.

- **Natural variability.** Even in the absence of the above drivers, Earth's average temperature shows some natural variability. Complex interactions between the atmosphere, land surface and oceans cause the daily fluctuations we know as weather, but also give rise to variability over years or decades. For instance, the El Niño phenomenon occurs every three to seven years, whereby a warm pool of water is formed for a season or more in the Tropical Pacific, altering weather patterns around the Pacific and beyond.

Status: the fact that there are other potential drivers of global climate change is well understood. A key challenge in climate science is to identify the extent to which these different GHG and non-GHG drivers are responsible for observed changes, recognising that initial changes produced by one factor can be enhanced or reduced by feedback responses from other factors.

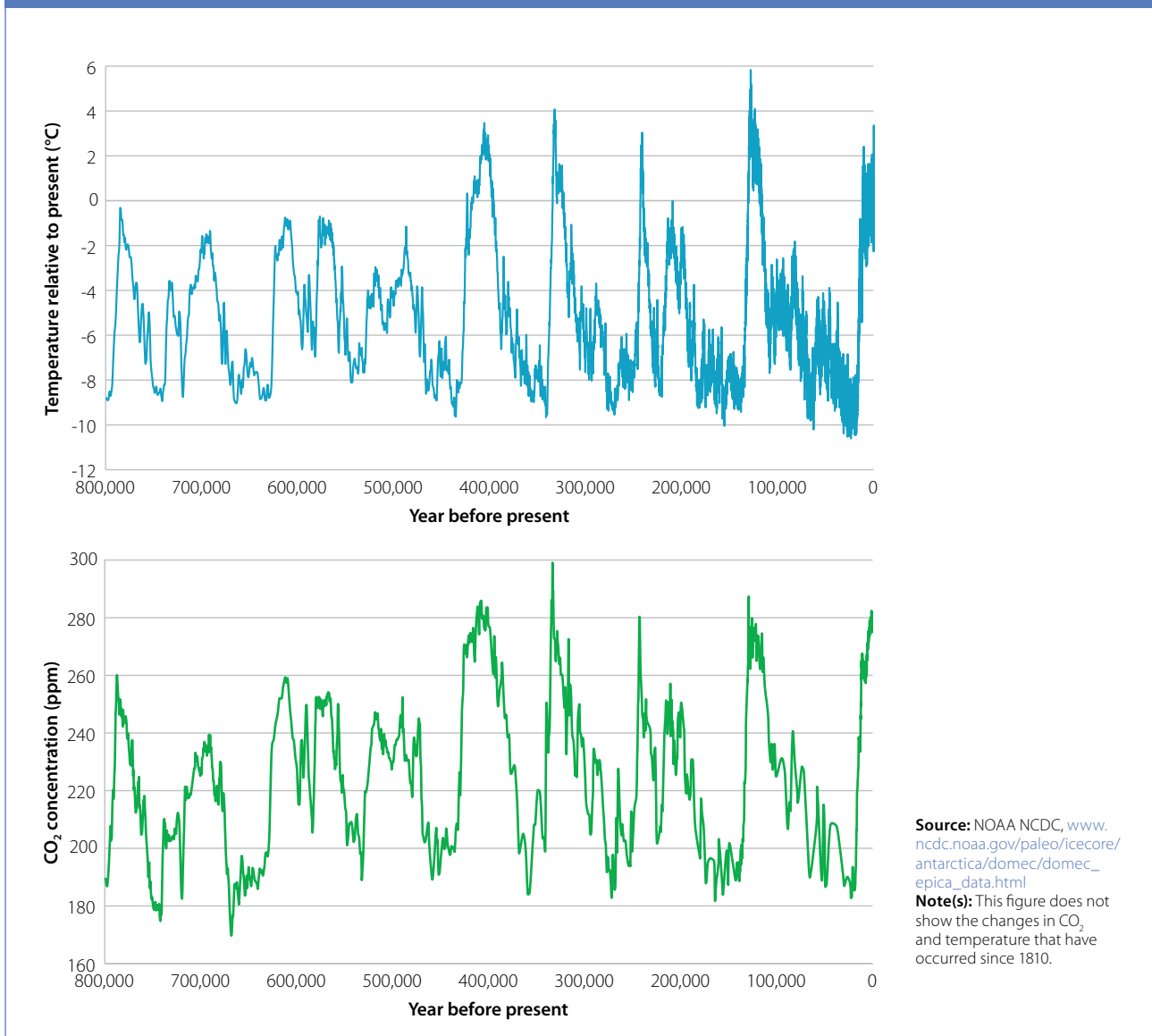
(III) Long-term climate history before human effects

The climate of the Earth has varied greatly over very long timescales. Past changes have been caused by various drivers, but it is clear throughout that CO₂ and other GHGs have played an important role either as an initial trigger of change or as an amplifying feedback.

- **The last 50 million years.** Geological records suggest that the Earth was around 6-7°C warmer 50 million years ago. CO₂ concentrations were also high, and there were no major ice sheets (such as those currently over Greenland and Antarctica). Since then there has been a slow, long-term decline in both CO₂ concentration and global temperature.
- **The last million years.** Earth's climate over the last million years or so has been cooler than today on average, characterised by a natural cycle between ice ages and warmer interglacial periods:
 - Records from ice cores spanning the last 800,000 years show a series of ice ages and interglacials (Figure 1.1). Transitions between the two have taken around 5,000 years and are estimated to have led to an eventual 4-7°C of global temperature change³.

³ See for example Schneider von Deimling et al. (2006) How cold was the Last Glacial Maximum? *Geophysical Research Letters*.

Figure 1.1: Measurements of local temperature (top) and atmospheric CO₂ concentration (bottom) over the last 800,000 years, taken from Antarctic ice cores



Atmospheric CO₂ is directly measurable over this time from air bubbles trapped in the ice cores.

- There is strong evidence that these climate shifts were triggered by regular cycles in Earth's orbit which altered the distribution of sunlight over the Earth.
- But while orbital cycles acted as the initial driver, other factors then amplified the change. For example, cooling causes snow and ice to advance, reflecting more sunlight away from the Earth's surface, and CO₂ concentrations also decrease, amplifying the cooling effect further.
- This record provides direct evidence that altered CO₂ concentrations exert a significant influence on global temperature, whether acting in response to an initial change or as an initial driver. It also shows that additional feedback processes are an important consideration when understanding past and future climate change.

- **The last 10,000 years.** Since the end of the last ice age we have lived in a relatively warm period with stable CO₂ concentrations and global temperatures. Some regional changes have occurred in this time, affecting local societies and ecosystems. For instance, persistent droughts have occurred in Africa and North America, and both El Niño and the Asian monsoon have undergone changes in frequency and intensity. These have not however been part of a coherent global change.

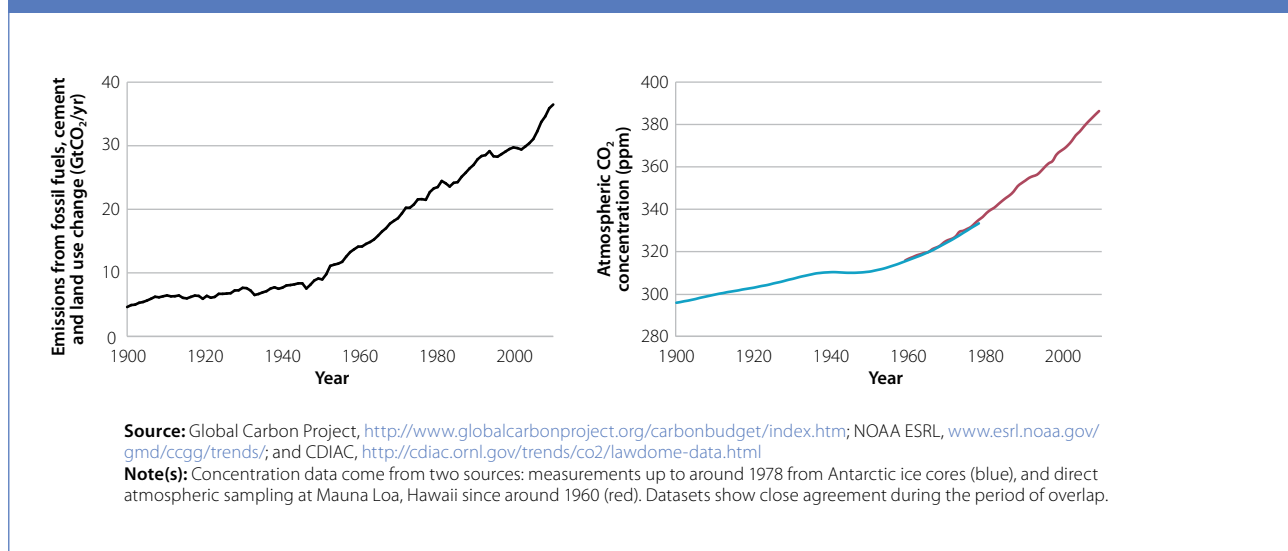
Status: there is a high degree of confidence that temperature changes over the last one million years have been amplified by closely-linked changes in atmospheric CO₂ concentration.

(IV) Human emissions as an additional factor

Human-caused emissions of GHGs have now driven atmospheric concentrations well outside the natural cycle of the last million years:

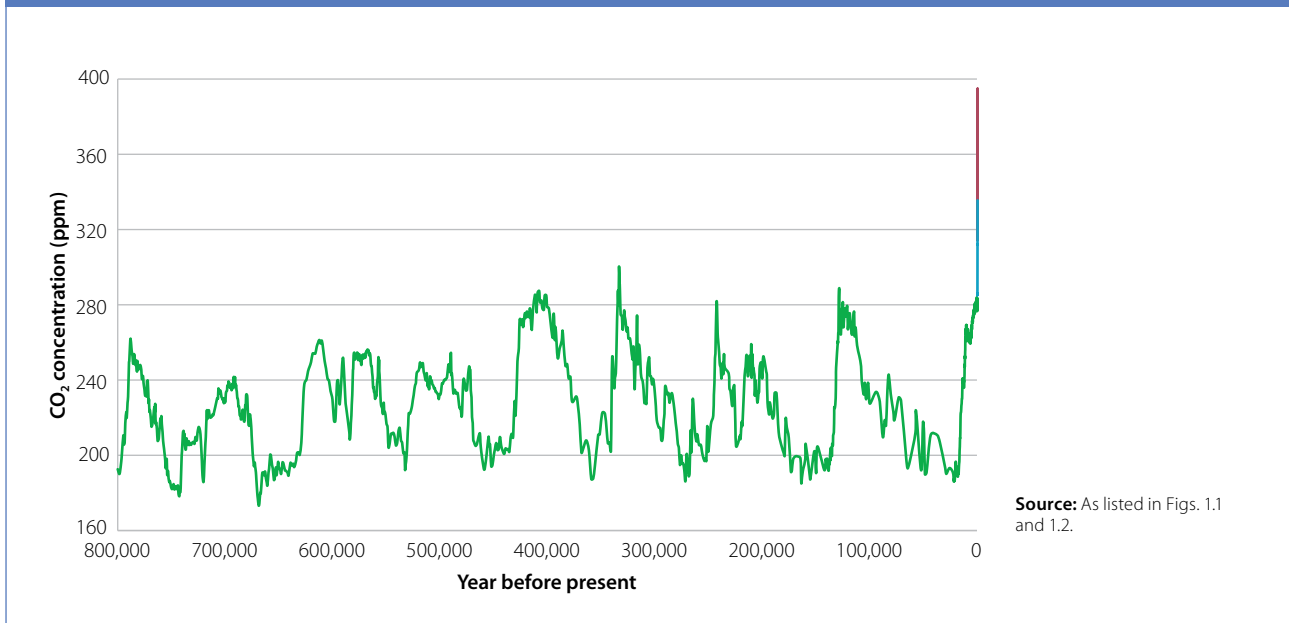
- Data from the Global Carbon Project suggest that total global CO₂ emissions rose six-fold over the 20th Century (Figure 1.2); this is largely a result of fossil fuel burning, with additional contributions from deforestation and cement production.
- The concentration of CO₂ in the atmosphere is now nearly 390 parts per million by volume (ppm) and rising, compared to around 280ppm in pre-industrial times (Figure 1.2). This increase is clearly due to CO₂ emissions from human activity, as underlined by several sources of evidence (e.g. the balance of different carbon atom isotopes in the atmosphere⁴).

Figure 1.2: Global CO₂ emissions (left) and annual average atmospheric CO₂ concentration (right) since 1900



⁴ CDIAC <http://cdiac.ornl.gov/trends/co2/iso-sio/iso-sio>

Figure 1.3: Increases in atmospheric CO₂ concentration since the Industrial Revolution (blue and red) in the context of changes over the last 800,000 years (green)

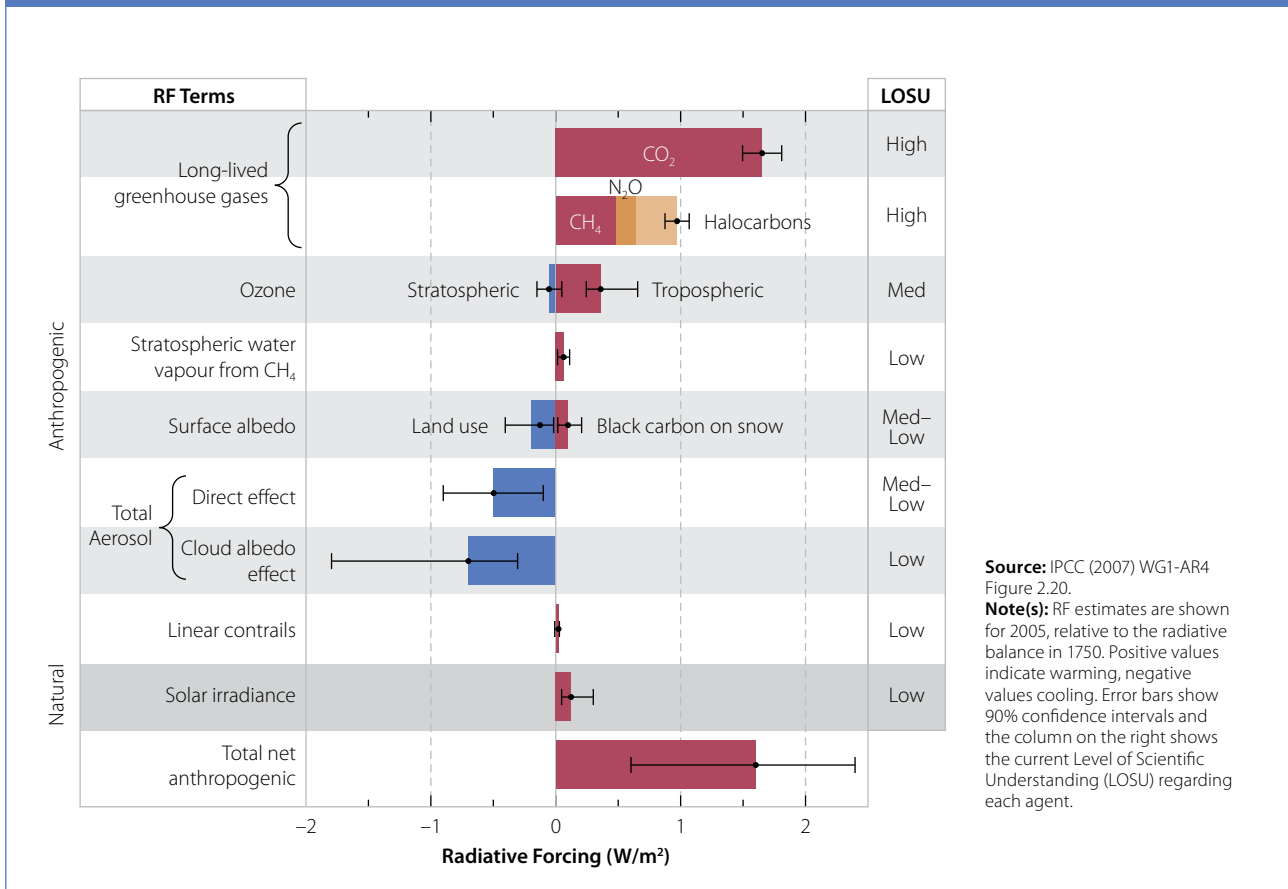


- The magnitude and rate of CO₂ increase in recent decades are far greater than anything seen in the ice core record (Figure 1.3).
- Similar trends in other long-lived GHGs are taking place⁵:
 - Methane (CH₄) concentrations have increased to nearly 1,800 parts per billion (ppb) from pre-industrial levels of around 700ppb, as a result of emissions from agriculture, waste and fossil fuel use.
 - Emissions of nitrous oxide (N₂O), primarily from intensive agriculture, have led to concentrations exceeding 320ppb, up from a pre-industrial level of around 270ppb.
 - A range of halocarbons (artificial compounds such as CFCs and HFCs which did not exist in pre-industrial times) are now present in the atmosphere.
- Fossil fuel combustion gives rise to additional short-lived gases, particles and aerosols which cause both warming and cooling. Amongst these:
 - Sulphate aerosol concentrations have increased. These cause local cooling and have partially offset the global warming trend, however estimates suggest emissions flattened during 1980-2000 following steps taken to improve air quality.
 - Ground level ozone (O₃) concentrations have increased, causing further local warming.
- The influence of different climate change drivers is measured by their radiative forcing⁶. There is high confidence that current overall forcing from human activity is strongly positive (leading to warming), and it is most likely about an order of magnitude larger than the forcing from changes in the Sun (Figure 1.4).

⁵ NOAA ESRL www.esrl.noaa.gov/gmd/aggi/

⁶ Radiative forcing is a standard measure of the energy imbalance in the atmosphere at a given point in time.

Figure 1.4: Global average radiative forcing (RF) for various agents measured in Watts per square metre (W/m²)



Status: it is close to certain that increasing atmospheric concentrations of GHGs since the industrial revolution are due to human activity.

The implication of sections I, III and IV above is that, even if we did not yet have strong evidence of warming, we should be extremely concerned about the possible consequences of our GHG emissions, since:

- We face a rapid increase in the presence of key chemicals which, from basic physics, are bound to have significant effects on climate.
- The geological record shows that fluctuations in GHG concentrations have been correlated with major changes in global climate in the past, playing an amplifying role even in cases where they did not drive the initial temperature change.
- We have moved far beyond the range of concentrations which has applied throughout the whole period during which human civilisation has evolved.

(V) Evidence of warming so far

In fact, we do already see unequivocal evidence that warming is occurring:

- Ten major, global indicators measured by various independent groups all demonstrate that the climate is warming (Figure 1.5).

-
- Near-surface air temperatures over land are increasing.
 - Near-surface air temperatures over the oceans are increasing.
 - Sea surface temperatures are increasing.
 - Ocean heat content is increasing.
 - Sea level is rising (water expands as it warms, and there are additional contributions to sea level through melting of ice and snow on land).
 - Atmospheric humidity is increasing (warmer air is able to hold more moisture).
 - The temperature of the lower atmosphere (troposphere) is increasing.
 - Northern hemisphere snow cover during March-April is decreasing.
 - Total glacier mass is decreasing.
 - Arctic sea ice extent in September is decreasing (Arctic sea ice changes cyclically over the year, usually reaching a minimum in September).
 - The last decade showed the warmest global average surface temperatures since records began, about 0.8°C above pre-industrial levels. Although there is variability between years and regions, the long-term trend still shows warming:
 - Data from three separate research groups, all based on direct thermometer measurements from land and sea around the world, agree that 2000-2010 was the warmest decade on record (Figure 1.6).
 - This is true even though 1998 was the hottest year so far, according to one record (HadCRUT, produced by the Met Office and the Climatic Research Unit). 1998 temperatures were exacerbated by a particularly strong El Niño event, however the NOAA GISS and NASA NCDC records calculate that 2005 was hotter than 1998, and 2010 is on course to be hotter still⁷.
 - And while the 2009-2010 winter in the UK was around 2°C colder than average, with the cold snap extending into Europe and parts of the US, many other regions experienced unusual warmth (Figure 1.7). Global temperature during this period was well above the recent average.
 - It is known that natural variability can offset (or enhance) the surface warming trend from GHG emissions for periods of up to a decade or so^{8,9}. Scientists therefore tend to use 20-30 year periods in order to identify climate trends over the noise of short-term variability. From this perspective it is clear that temperatures are on a long-term rising trend.

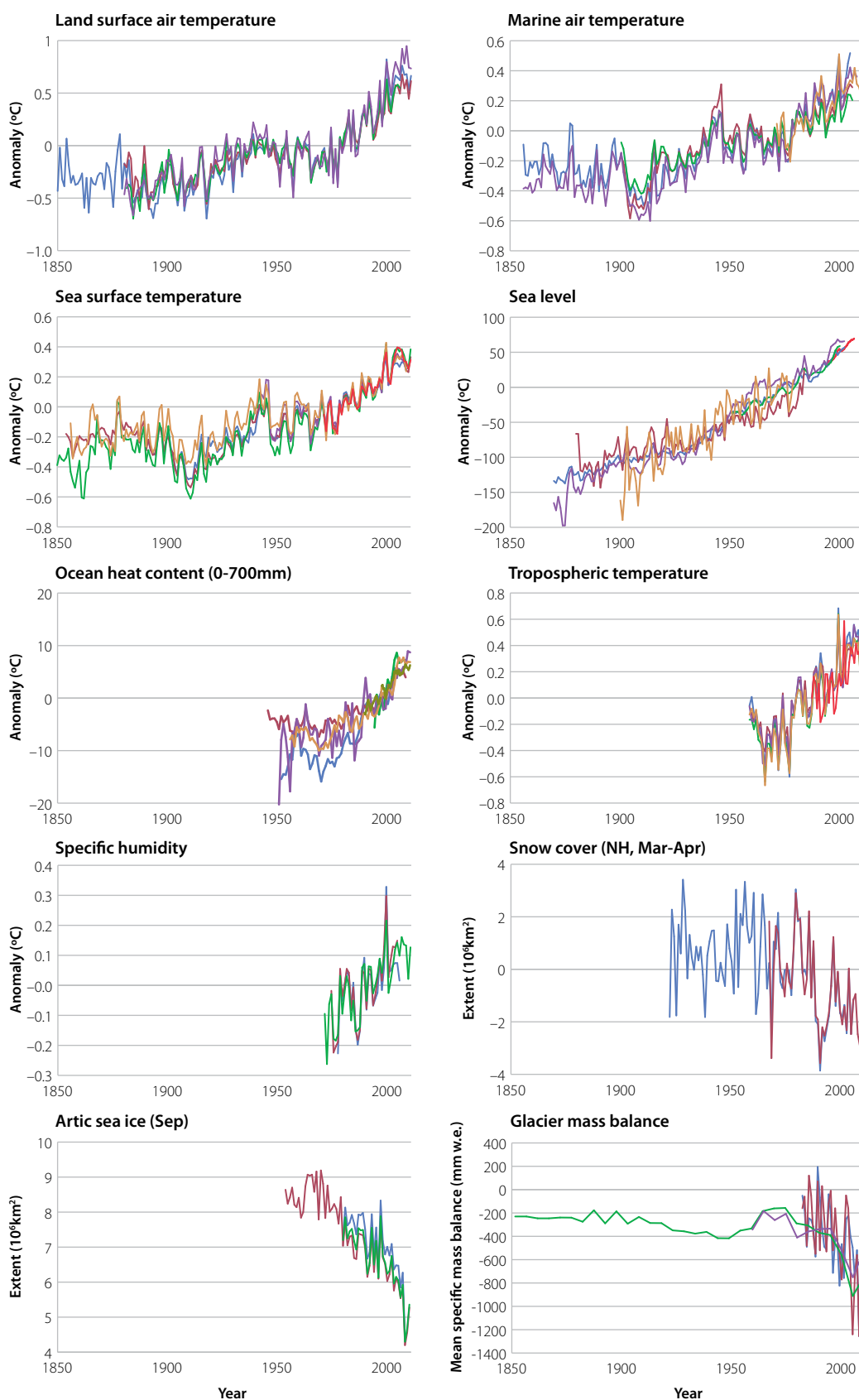
Status: it is close to certain that the planet has warmed since the late 19th Century.

⁷ See sources listed in Fig. 1.6.

⁸ Easterling and Wehner (2009) Is the climate warming or cooling? *Geophysical Research Letters*.

⁹ Knight et al. (2009) Do global temperature trends over the last decade falsify climate predictions? In 'State of the Climate in 2008'. *Bulletin of the American Meteorological Society*.

Figure 1.5: Time series of ten climate parameters which would be expected to correlate strongly with global surface temperature change. All show changes over the last decades consistent with a warming world



Source: Arndt et al. (2010) State of the Climate in 2009, *Bulletin of the American Meteorological Society*, www.ncdc.noaa.gov/bams-state-of-the-climate/2009.php

Note(s): Each coloured line denotes a dataset calculated by a different research group and/or using a different method.

Figure 1.6: Global average surface temperatures since 1880 as calculated by three different research centres

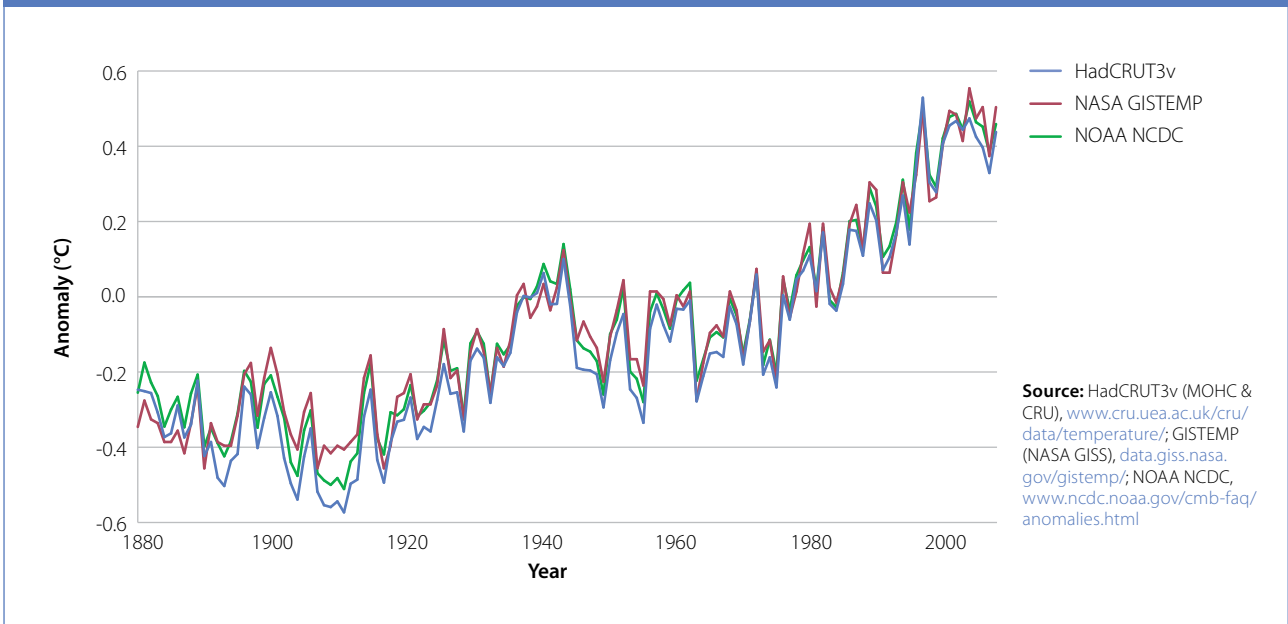


Figure 1.7: Map of surface temperatures for the period December 2009 to February 2010, relative to the 1968-1996 average

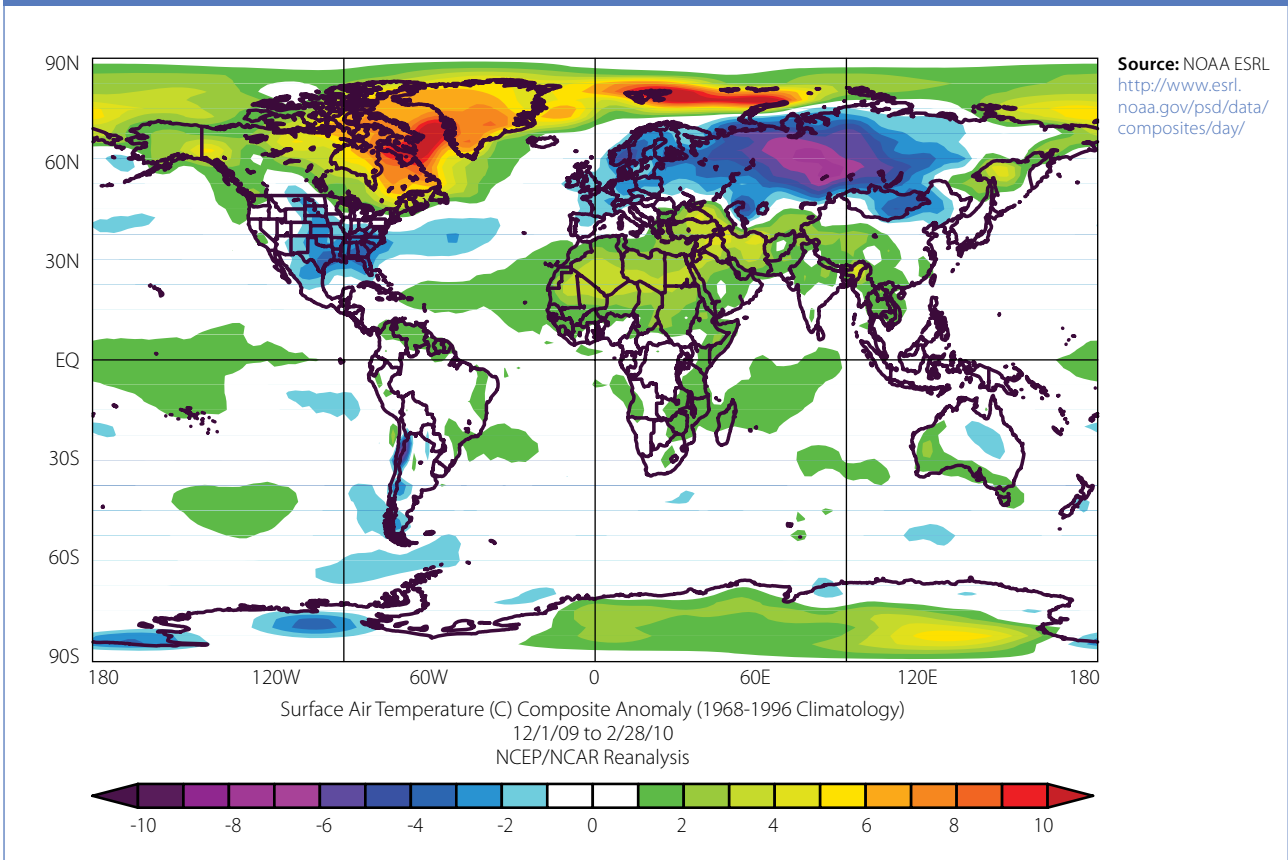
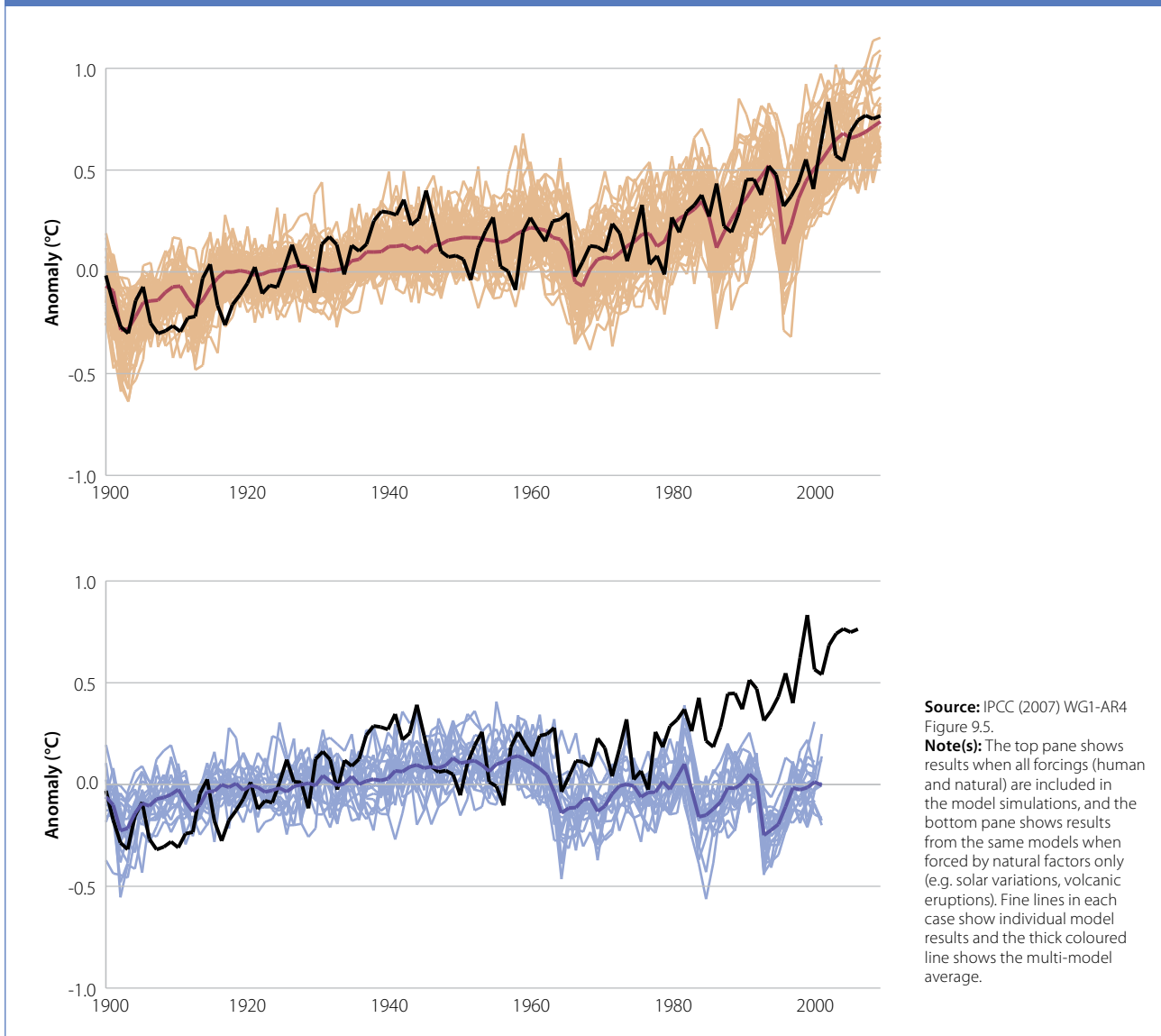


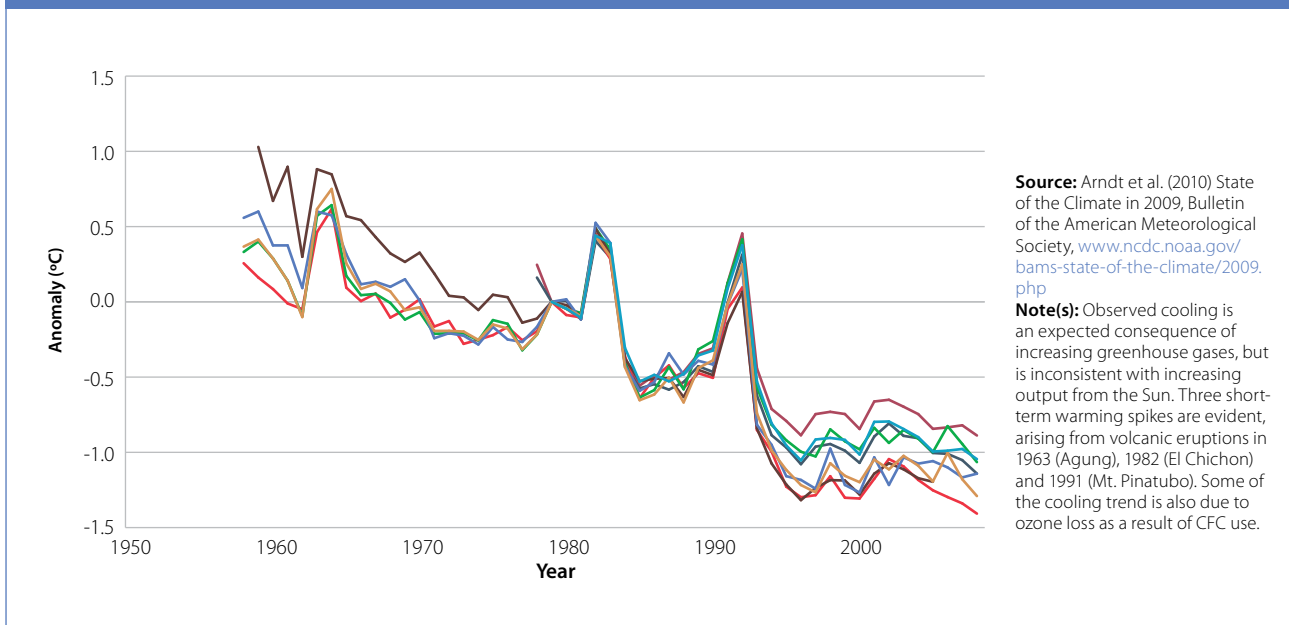
Figure 1.8: 20th Century global average surface temperature anomalies, as observed (black line) and as obtained from multiple simulations by several different climate models



(VI) Linking warming with human activity

The combination of climate observations, measured GHG emissions and a fundamental scientific understanding of the greenhouse effect provides a strong chain of logic linking human activities to current global warming. Furthermore, the observed warming is consistent with GHG emissions being the main driver and is not explainable by other (natural) drivers alone, as demonstrated by the world's leading climate models (Figure 1.8).

Figure 1.9: Trends in stratospheric temperature since systematic measurements began, from eight different datasets



While natural variability and other factors continue to play a role in climate, the pattern of warming also suggests they are not the primary drivers of change in the last few decades:

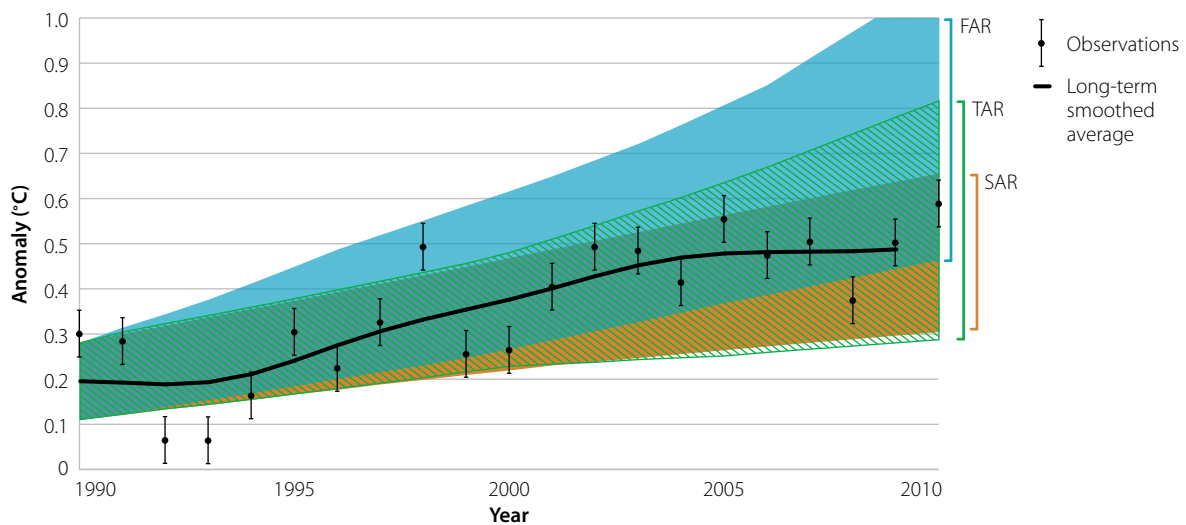
- **Natural variability** within the climate system is unlikely to explain such a large worldwide increase, sustained for so long. Although we cannot rule out some form of large internal variation, as yet poorly understood, studies of climate in earlier centuries suggest that the current trend is unusual in the context of natural variation. Those long-term modes of variability that we do know about (such as El Niño) cause distinct regional patterns of warming, partially offset by cooling in some regions. Furthermore, surface warming caused by heat transfer from another part of the climate system, such as the oceans or the cryosphere, would leave a cooling signal in those parts. In fact, however, warming is seen in both the oceans and in the melting of global snow and ice (Figure 1.5), consistent with the influence of an external source such as the Sun or GHGs.
- Satellite measurements of **solar output** since the late 1970s show changes of about $\pm 0.08\%$ over the Sun's regular 11-year cycle¹⁰, and there is still more to learn about the influence of solar variability on climate. However, there is no clear increasing trend in solar output over recent decades. Furthermore, increasing solar output would warm all parts of the atmosphere, including the lowest few kilometres (the troposphere) and the layer above (the stratosphere). Although measurements of global atmospheric temperature are more uncertain than surface measurements, results suggest that the stratosphere is in fact cooling (Figure 1.9) while the troposphere warms (Figure 1.5), which is consistent with forcing from GHGs¹¹.

Status: there is a high degree of confidence that human emissions have caused most of the observed warming since the mid-20th century.

¹⁰ NOAA NGDC <http://www.ngdc.noaa.gov/stp/solar/solarirrad.html#composite>

¹¹ U.S. Climate Change Science Program (2006) Temperature trends in the lower atmosphere <http://www.climatechange.gov/Library/sap/sap1-1/finalreport/>

Figure 1.10: Comparison of global average surface temperature trends since 1990 with projections from the IPCC First (FAR), Second (SAR) and Third (TAR) Assessment Reports



Source: after IPCC (2007) WG1-AR4 Figure 1.1; observations from NASA GISS, data.giss.nasa.gov/gistemp/

Note(s): Dots show observations for each year along with 95% confidence intervals for year-on-year differences (a preliminary 2010 result is shown based on observations to September). Thick black line shows long-term variations obtained by smoothing the series using a 19-point filter. IPCC projections show long-term predicted trends in temperature from 1990 due to GHG forcing, with an additional range of $\pm 0.09^{\circ}\text{C}$ added to represent the natural variability in the observations. FAR projected a higher warming rate than SAR & TAR partly because these later assessments used lower emission scenarios and included the cooling effect of sulphate aerosols.

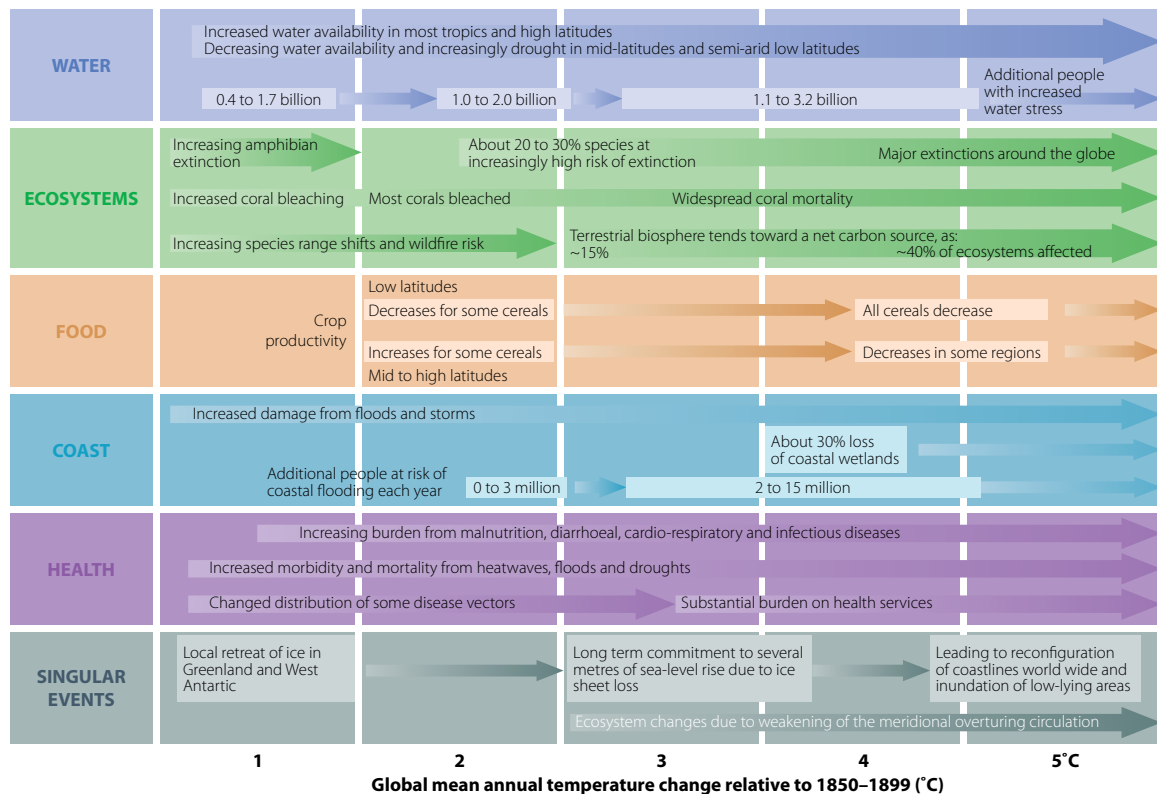
(VII) Projections for the future

Despite this high level of certainty that warming is occurring due to human activity, projections about the exact future level of warming and its consequences are inherently uncertain. This uncertainty derives from the complexities involved in modelling the whole Earth system (including the strength of feedbacks from clouds, etc.) and also from predicting the future path of human activities. Scientists have developed models as best possible to capture these effects and produce projections. These are continually improving and provide us with the best estimate of the range on which we need to base policy.

- For several different scenarios of 'business as usual' emissions growth over the next century, IPCC AR4 gave a likely range of 1.8-7.1°C warming above pre-industrial levels by 2100¹² (i.e. two to nine times greater than has been experienced so far). This range comes both from the different possible future paths of global emissions, and from imprecise knowledge of the climate system (e.g. the strength of possible feedbacks from clouds and the natural carbon cycle).
- Projections of trends in surface temperature from the IPCC's earlier assessments appear to be in broad agreement with observations since 1990, although the noise of year-to-year variability makes this a relatively short time period for comparison (Figure 1.10). This gives us some confidence in the range of global average projections for the 21st century.

¹² IPCC (2007) WG1-AR4 Summary for Policymakers, Table SPM.3.

Figure 1.11: Examples of global impacts projected for climate change associated with global average surface temperature increases in the 21st Century



Source: Adapted from IPCC (2007) WG2-AR4 Figure 20.8.

Note(s): Effects of adaptation are not included in these estimates. Entries for water stress and flooding show impacts attributable to climate change across the range of IPCC scenarios. Current average temperature is around 0.7°C above 1850-1899 levels.

- Uncertainty increases when translating these temperature changes into impacts on human welfare and ecological systems. Impacts will depend crucially on climate changes at local scales (including shifts not only in temperature but also precipitation, sea level, extreme weather events, etc.) and the level to which human and ecological systems can adapt, which are more difficult to predict than future global average temperature. However, there are likely to be significant consequences for human and ecological systems, as set out in IPCC AR4 (Figure 1.11):
 - **Water.** Climate change is likely to amplify precipitation patterns around the world, so that wet regions will generally get wetter and dry regions drier. Precipitation is also projected to shift towards heavier rainfall events interspersed with longer droughts. Warming will lead to retreating glaciers and reduced snow cover, which are important freshwater resources for over one-sixth of the world's population.

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- **Ecosystems.** Extinctions of species are of particular concern because they are irreversible. Many ecosystems are in any case facing a range of pressures due to human activity, however, 20-30% of plant and animal species assessed so far would face a commitment to extinction¹³ as a direct result of 2-3°C of global warming. Further change could lead to major species loss.
 - **Food.** The impacts of climate change on crop production are projected to differ markedly by region and crop. Positive impacts could be experienced in temperate zones for 1-3°C local warming (which would correspond to a lower increase in global average temperature) and increased CO₂ levels, but in low latitudes, where a high fraction of GDP depends on agriculture, falling productivity is likely even for low levels of warming. World food production is projected to fall beyond a 3°C global increase.
 - **Coasts.** Some of the largest cities are situated on coasts, such as those on the US Eastern seaboard or the mega-deltas of Bangladesh and Eastern China. Many small islands are also very exposed to sea level rise. This would lead to heightened risk of inundation during storms, and freshwater supplies becoming increasingly contaminated with salt.
 - **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, fires and droughts are predicted, as well as problems associated with poorer urban air quality. Overall impacts will be critically dependent on socio-economic factors such as education and healthcare.
 - **Singular events.** Strong warming leads to the possibility of large, irreversible shifts in the Earth system. For example, complete melting of the Greenland and West Antarctic Ice Sheets could result in an additional 12m of sea level rise over several centuries. In addition, strong warming could accelerate release of CO₂ and CH₄ from large natural reserves in wetlands, permafrost and oceans, resulting in increased GHG concentrations and therefore further warming.

Status: precise scientific projections are uncertain, but they are the best evidence on which to base policy. Current evidence points to major potential impacts on human welfare and ecological systems if efforts are not made to curb emissions.

Overall conclusion: policy needs to reflect the clear scientific conclusion that warming is occurring and is being induced by human activity, while recognising the inevitably wide range of uncertainty over the precise scale and timing of future impacts. This uncertainty on precise scale should not however be confused with uncertainty on direction, and provides a strong case for action rather than for inaction.

¹³ '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.

2. Appropriate climate objectives and global emissions pathways: recap on our 2008 approach

Global climate objective

In our 2008 report we set out an approach to assessing what level of future climate change should be seen as dangerous and hence avoided, given the scientific evidence and uncertainties set out above.

- We considered the range of climate impacts in the IPCC AR4, along with some subsequent published research papers, and concluded that there is highly likely to be a range of increasingly harmful effects, unevenly distributed around the world and quickly becoming severe in some regions:
 - Risks from a relatively small temperature increase (e.g. 1°C) are likely to be manageable in many regions with adaptation efforts, and there may be some benefits in temperate areas.
 - Benefits are likely to disappear and scope for adapting likely to decline for more significant increases.
 - The impact of temperature change on human welfare is highly likely to be non-linear (e.g. a 4°C rise is highly likely to be more than twice as harmful as a 2°C rise).
 - Damage would be more pronounced in certain regions (such as polar, mountain, Mediterranean regions and coral reefs), and disproportionately impact the world's poor.
- Despite this complex picture, the IPCC drew some general conclusions which we cited in 2008 as relevant in setting our objectives¹⁴:
 - 'Global mean temperature changes of up to 2°C above 1990-2000 levels would exacerbate current key impacts, 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.'

¹⁴ IPCC (2007) WG2-AR4 Chapter 19, p781. Note: pre-industrial global average temperatures were 0.6°C below 1990-2000 level.

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- Ideally the world should therefore aim to limit temperature increase to very low levels. In practice, high current concentrations of GHGs that will remain in the atmosphere for many years commit the world to further warming, and continued emissions make it impossible to be certain that warming less than 2°C can be avoided.

Our climate objective reflected both the potential damage from further climate change and the difficulty in aiming for a very low temperature target, given current GHG concentrations and emissions. We recommended that the aim should be to keep central estimates of global mean temperature change by 2100 to as little above 2°C over pre-industrial levels as possible, and limit the likelihood of extremely dangerous climate change above 4°C to very low levels (e.g. less than 1%).

Global emissions pathways¹⁵

We developed a set of global emissions pathways and tested them against our climate objective in collaboration with the Met Office Hadley Centre (Box 1.1). We concluded that credible pathways to deliver our climate objective broadly require early peaking of global emissions, and deep cuts beyond this peak, consistent with halving or more by 2050:

- We constructed global pathways out to the year 2200, covering all Kyoto GHGs (plus many other relevant emissions such as sulphate aerosols and oxides of nitrogen) from all major sources (including CO₂ emissions from land-use and international aviation & shipping), and with two sets of peaking years (2016 and around 2030).
- In each case CO₂ emissions were reduced after peaking at 1.5%, 2%, 3% or per year until they reached a minimum 'floor' beyond which they could not be reduced further, with non-CO₂ emissions reduced at consistent rates.
- The pathways delivering the climate objective were characterised by early peaking with subsequent annual emissions reduction of 3% or more; no late peaking pathways delivered the objective (i.e. peaking after about 2025) irrespective of the rate of cuts after the peak.
- Early peaking followed by annual cuts of 3% or more would result in at least a halving of global emissions by 2050.
- In order for the UK to have emissions per person equal to the global average in 2050, a global halving of emissions requires an 80% UK reduction on 1990 levels.

¹⁵ For further details on this section, see Chapter 1 of the 2008 report and accompanying technical appendix *Projecting global emissions, concentrations and temperatures* <http://www.theccc.org.uk/reports/building-a-low-carbon-economy/technical-appendices>

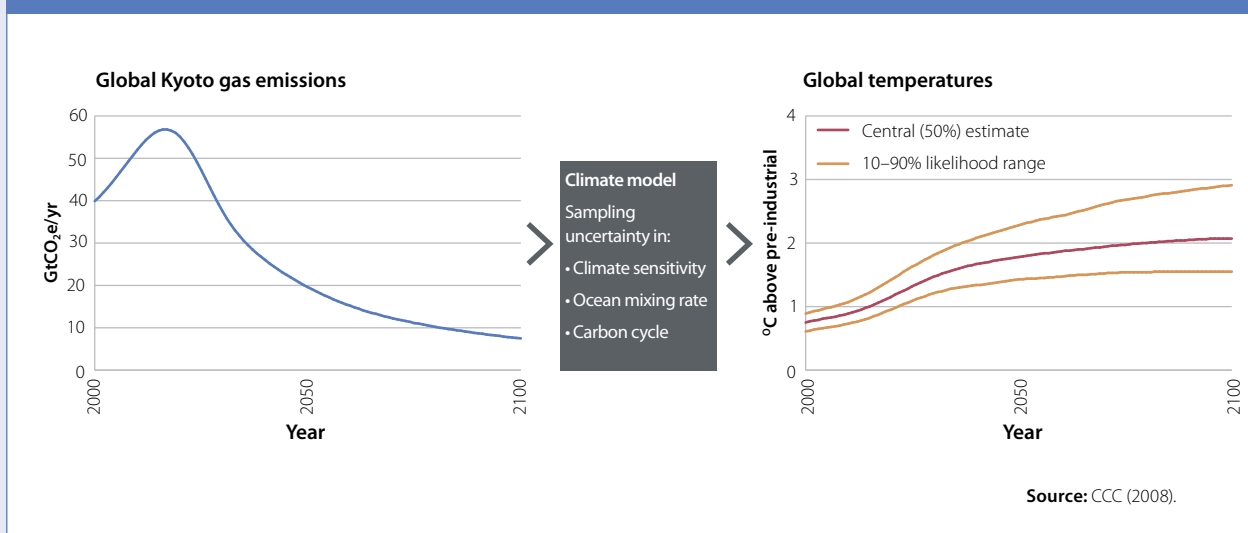
Box 1.1: Modelling climate change arising from future global emissions pathways

Researchers use a range of climate models to understand and predict climate change, from relatively simple to highly complex. The most complex models split the atmosphere and ocean into a three-dimensional grid and solve the equations of fluid motion, thermodynamics and various other processes at each point on the grid. They typically have more than 100 parameters and take weeks on a supercomputer to produce a single 200-year simulation. Several such models have been built by research groups around the world. Each produces a slightly different outcome for a given future scenario because of differences in their construction and uncertainties in some of the parameter values used.

Simpler climate models are able to emulate the large-scale features of the more complex models, such as global average temperature. A key benefit of these simpler models is that they are faster to run, and by varying a small number of parameters they can explore the full range of uncertainty across the more complex models.

With the Met Office Hadley Centre, we used a modified version of a simple model known as MAGICC 4.11¹⁶, which has been used extensively in IPCC assessments. For each emissions pathway the model was run several hundred times, each with a different combination of values for key climate parameters (Figure B1.1). In this way we accounted for a broad range of climate system uncertainties. By weighting these runs according to the likelihood of each parameter combination, an overall likelihood distribution of global temperature increase was built for each pathway.

Figure B1.1: Schematic of the modelling process for relating emissions pathways to climate objectives



These results comprehensively cover the range of possible global temperature outcomes from the leading complex models covered in IPCC AR4. They do not, however, account for other possible processes which may affect global temperature but are not included in those complex models, such as additional release of carbon from large natural reserves in wetlands, permafrost and oceans.

3. Recent inquiries relating to climate science

Climatic Research Unit (CRU), University of East Anglia

CRU is known primarily for its work in reconstructing past surface temperatures, extensively cited by the IPCC. These reconstructions fall into two types:

- A dataset of land surface temperature based on direct thermometer measurements going back to 1850, which is in close agreement with at least three other records (Figure 1.5, top left panel).
- Estimates going further back (up to around 1,000 years) based on tree rings as a 'proxy' measure of temperature. Proxy measures are much more uncertain, but several records using different methods (boreholes, glacier lengths, corals, sediments and other tree ring analyses) all suggest that the rate of warming over recent decades has been unusual in the context of the last few centuries¹⁷. It should be noted however that the scientific argument presented in the first part of this chapter does not rest on evidence from these proxy measures.

Based on a set of CRU emails leaked in 2009, scientists were accused of malpractice:

- Over 1,000 selected CRU emails were leaked, drawn from the period 1996-2009, containing conversations between climate scientists at CRU and other institutions around the world.
- The emails were used to accuse scientists of using inadequate data analysis methods, deliberately withholding or deleting data that should have been made available and conspiring to block competing conclusions being published in journals and IPCC assessments, all with the intention of overstating recent warming.

Three separate inquiries were launched following the email controversy:

- A group chaired by **Sir Muir Russell** was convened by the University of East Anglia to review the emails and assess whether or not CRU scientists had acted with due honesty, rigour and openness¹⁸. It did not specifically address the validity of their published scientific work.
- The University of East Anglia also convened a **Science Assessment Panel** chaired by Lord Oxburgh to look at 11 pre-selected research papers written by CRU scientists¹⁹. The aim of the panel was to establish whether the conclusions reached in these papers were 'honest and scientifically justified' rather than correct or incorrect.

¹⁷ National Research Council (2006) Surface Temperature Reconstructions for the Last 2,000 Years http://www.nap.edu/catalog.php?record_id=11676

¹⁸ Russell (2010) The Independent Climate Change E-mails Review <http://www.cce-review.org/>

¹⁹ Oxburgh (2010) Report of the International Panel set up by the University of East Anglia to examine the research of the Climatic Research Unit <http://www.uea.ac.uk/mac/comm/media/press/CRUstatements/SAP>

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- The **House of Commons Science and Technology Committee** carried out an inquiry into the accuracy and availability of CRU's data and methods, the issue of withholding these data in light of the Freedom of Information Act, and the suitability of the reviews set up by the University of East Anglia²⁰. Its conclusions were published in advance of the other reviews and before the recent General Election.

All three inquiries concluded that there was no evidence of scientific malpractice and none found anything to question the fundamental science, but they did make suggestions to support increased transparency of the data and methods used by the researchers:

- The Muir Russell review found no evidence that might undermine the conclusions of IPCC assessments, and no evidence that scientists subverted the peer review processes in order to suppress other studies.
- The Science Assessment Panel found that CRU work included suitable discussion of uncertainties and showed no hint of tailoring results to a particular agenda.
- The Science and Technology Committee stated that researchers should be more transparent by publishing raw data and methodologies given the importance of decisions being made in light of the scientific evidence.

There has been some controversy about the inquiries themselves, with allegations that critical views were not listened to and the veracity of the science was not directly addressed. The new Science and Technology Committee, appointed after the General Election, followed up on the earlier reviews in subsequent evidence sessions involving the University of East Anglia, Sir Muir Russell and Lord Oxburgh²¹.

Intergovernmental Panel on Climate Change (IPCC)

The IPCC was established to help inform climate change decision makers by producing comprehensive assessments that are accurate, balanced and impartial with respect to policy; its most recent assessment (AR4) was published in 2007.

The assessment process involves three working groups, covering the physical science basis (Working Group 1), impacts, adaptation and vulnerability (Working Group 2) and mitigation (Working Group 3). In addition to providing in-depth reports in each area, all three groups contribute to a single synthesis report.

²⁰ House of Commons Science and Technology Committee (2010) The disclosure of climate data from the Climatic Research Unit at the University of East Anglia
<http://www.publications.parliament.uk/pa/cm200910/cmselect/cmsctech/387/3871.pdf>

²¹ <http://www.parliament.uk/business/committees/committees-a-z/commons-select/science-and-technology-committee/inquiries/100831-new-inquiry---reviews-into-crus-e-mails/>

In early 2010 a number of claimed errors in the IPCC AR4 were widely reported, and IPCC responses criticised:

- Two specific errors in the most recent Working Group 2 assessment were highlighted by experts:
 - Overstatement of the likely future rate of retreat for Himalayan glaciers²².
 - Overstatement of the area of Dutch land lying below sea level²³.
- While the IPCC has published official corrections to both these errors, it has been criticised for responding slowly and handling the issue badly.
- Furthermore, some critics have voiced concerns over aspects of the IPCC assessment process, such as the use of 'grey' literature²⁴ and the handling of dissenting views.

Three independent inquiries were launched in 2010:

- Responding to the claimed errors, the **Netherlands Environmental Assessment Agency** (PBL) carried out a detailed review of the extent to which the IPCC impact summaries accurately presented the state of scientific knowledge²⁵.
- The **US Environmental Protection Agency** (EPA) reviewed its use of IPCC evidence after petitions were raised by various energy companies and sceptical groups²⁶. These petitions cited the inaccuracy of the Himalayan glacier statement and improper review of IPCC chapters as reasons for the EPA to reconsider its finding that GHG emissions are a danger to health.
- The IPCC itself, along with the UN Secretary General, invited the **InterAcademy Council** (an umbrella body of science academies, including the UK's Royal Society) to review its structure and processes²⁷.

These reviews confirmed a small number of minor errors in the Working Group 2 report:

- The PBL review confirmed the two errors already found, and identified an additional error (regarding impacts on African anchovy fisheries²⁸). It also made minor comments on several other details and references. However, these errors were small in number relative to the evidence base in the 1,000 page Working Group 2 report, and no significant errors were found in the summary conclusions.

²² IPCC (2007) WG2-AR4 Chapter 10, p493.

²³ IPCC (2007) WG2-AR4 Chapter 12, p547.

²⁴ 'Grey literature' often refers to studies which contain original results but have not been published in research journals. Examples include technical reports by government agencies and research institutes.

²⁵ PBL (2010) Assessing an IPCC Assessment: an analysis of statements made on projected regional impacts in the 2007 report http://www.pbl.nl/images/500216002_tcm61-48119.pdf

²⁶ EPA (2010) EPA's Response to the Petitions to Reconsider the Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act. Volume 2: Issues Raised by Petitioners on EPA's Use of IPCC <http://epa.gov/climatechange/endangerment/petitions/volume2.html>

²⁷ InterAcademy Council (2010) Climate Change Assessments: review of the processes and procedures of the IPCC <http://reviewipcc.interacademycouncil.net/report.html>

²⁸ IPCC (2007) WG2-AR4 Chapter 9, p448.

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- A greater emphasis on climate change damages rather than benefits was found by PBL in the Working Group 2 summary. This was a deliberate, 'risk-oriented' approach taken by the IPCC authors, and was implicitly endorsed by governments involved in drafting the document, but it means that the summary document may present a different balance of evidence to that in the full Working Group 2 report.

The various reviews made recommendations to improve the process of assessing the range of literature and views:

- The InterAcademy Council made a number of recommendations, including review editors fully exercising their authority to ensure genuine controversies are reflected, and the three Working Groups being more consistent and rigorous in communicating levels of understanding and uncertainty.
- Similarly, the PBL review stated that the provenance of summary statements needed to become more transparent.

The IPCC has agreed to implement the InterAcademy Council's recommendations on procedures, communications policy and conflicts of interest. It will review further the recommendations on governance²⁹.

More generally, no new evidence has emerged to question the overall conclusions of IPCC AR4:

- The InterAcademy Council found that the IPCC has been successful in following its remit of accuracy, balance and impartiality.
- The EPA found that most, if not all, of the petitions it received about the IPCC were unsupported, not relevant or inconsequential to the EPA's policymaking on GHG emissions.

In summary, these inquiries have identified important issues of process in climate research and assessment, and have made recommendations for improvement. However, the findings of the CRU researchers have been found honest and balanced, supported by evidence from other lines of research, and the conclusions of IPCC AR4 have been upheld. Therefore the fundamental climate science reviewed in this chapter remains robust.

²⁹ http://www.ipcc.ch/meetings/session32/ipcc_IACreview_decisions.pdf

4. Recent scientific developments

Given the rapidly growing research base, we highlighted in our 2008 report a need to monitor developments in climate science, understanding any implications for our recommended emissions pathways.

We have followed this up by commissioning the AVOID consortium³⁰ to review recent publications in relevant fields. This review³¹ suggests no major changes in the overall picture of future damage (although some risks may have worsened since our 2008 report) and provides more confidence in our approach to modelling the range of possible temperature increases from future global emissions pathways.

New evidence on climate impacts

The AVOID review classifies impacts following broadly similar conventions to the IPCC AR4 and the Committee's 2008 report: coastal systems, ocean acidification, ecosystems & biodiversity, water resources & desertification, agriculture & food security and human health.

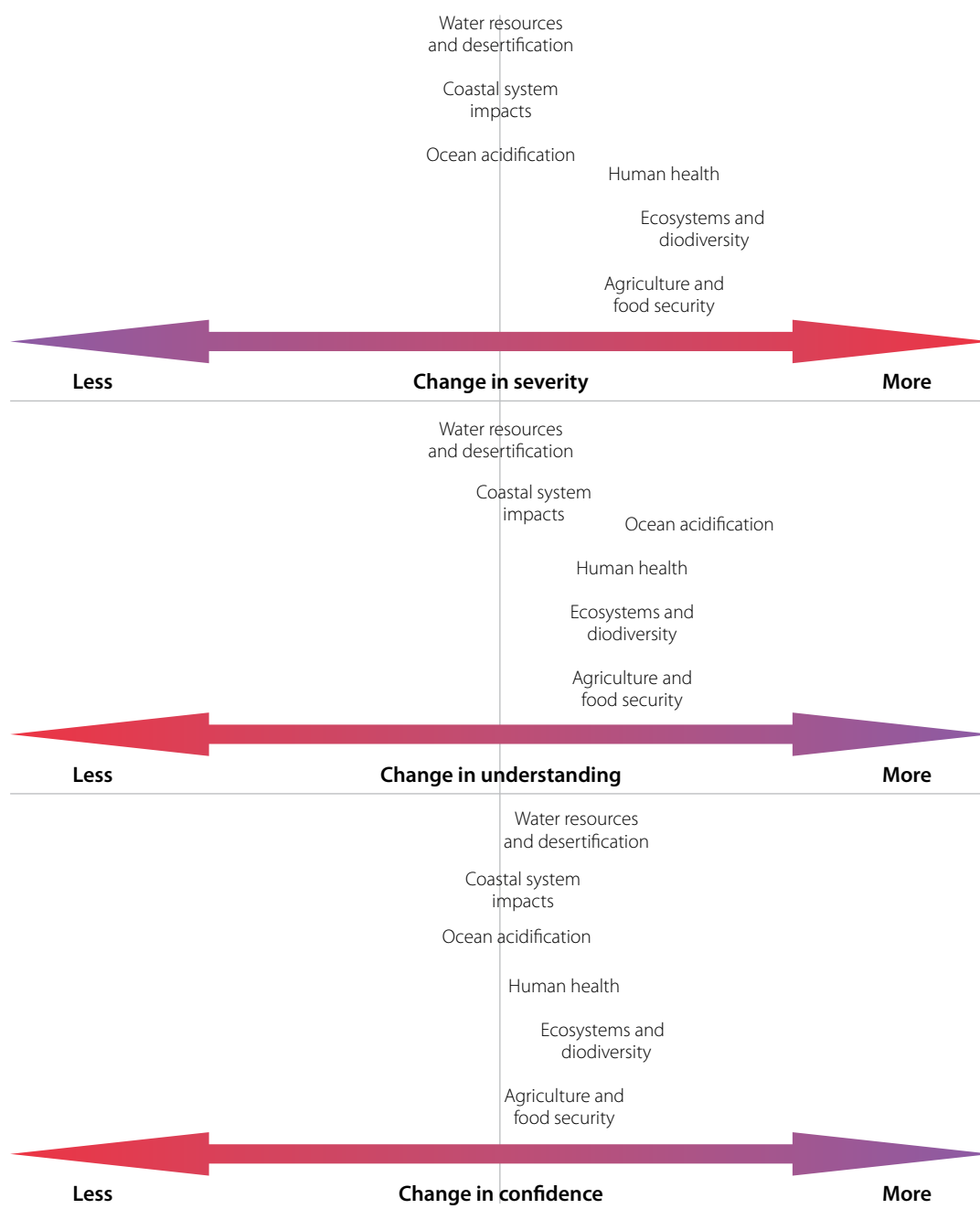
Key conclusions are that many sectors show little new evidence for a change in risk, while some developments have occurred in projections for Arctic sea ice, ecosystems & biodiversity, agriculture & food security and human health (Figure 1.12):

- In **ecosystems & biodiversity**, tropical ecosystems have now been added to the list of those most vulnerable alongside polar, mountain, Mediterranean and coral reef systems. There is also increasing evidence to support the IPCC AR4 conclusion that 20-30% of plant and animal species are at increasingly high risk of extinction as global warming exceeds 2-3°C.
- In **agriculture & food security**, assessments which better capture the uncertainties in model projections of future climate are yielding less optimistic results than those presented by IPCC AR4. New research since IPCC AR4 also suggests a smaller fertilisation effect from raised CO₂ concentrations on crop productivity.
- In **human health**, there is evidence that previous projections of heat-related deaths are underestimates because they do not consider the role of temperature variability as well as average temperature. The role of recent climate change in incidences of malaria may also be greater than previously expected. This has implications for future malaria exposure. However, it should be noted that malaria incidence (as with many other vector-borne diseases) is affected by numerous factors other than climate.

³⁰ AVOID is a research programme led by the Met Office in a consortium with the Walker Institute, Tyndall Centre and Grantham Institute. <http://www.avoid.uk.net/>

³¹ The review is available on the CCC website as a technical appendix to this chapter: AVOID (2010) An updated review of developments in climate science research since the IPCC Fourth Assessment Report.

Figure 1.12: Post-IPCC AR4 changes in severity, understanding and confidence for projections of impacts across five major sectors



Source: AVOID (2010) An updated review of developments in climate science research since the IPCC Fourth Assessment Report. Available on the CCC website.

Note(s): This figure is subjective and represents the views of the AVOID authors. It compares pre- and post-AR4 estimates for similar degrees of global warming (top), evaluates what new research has added to current knowledge (middle), and considers the degree of consensus across current studies (bottom). Positions on the chart represent change relative to AR4, rather than an absolute positive/negative state.

Furthermore, impacts could be affected significantly by some processes that we highlighted in our 2008 report, but are still not captured well by climate models:

- Some large-scale elements of the climate system continue to show potential for nonlinear and irreversible change that is not well captured in current impact assessments. We cited in 2008 the possible dieback of tropical forests, and the likely deglaciation of Greenland and West Antarctica beyond some level of warming, leading to further sea level rise. These continue to be the subject of research, but the last two years have seen few advances in narrowing the uncertainties involved.
- In our 2008 report we highlighted loss of Arctic sea ice occurring more rapidly than model projections. Although partial recovery since then has reduced concerns about imminent collapse, it is still likely that the Arctic will be routinely ice-free in summer before the end of the century.

In summary, the scientific evidence now provides at least as strong a case for action as it did in 2008. Some projections indicate greater reason for concern than they did in 2008 (e.g. agriculture & food security) whereas a few others may show a slight reduction (e.g. Arctic summer sea ice).

New evidence on global pathways to deliver climate objectives

The AVOID review highlights the consistency of the Committee's modelling approach and pathways with other, more recent studies:

- Recent independent studies add confidence to our results in 2008, emphasising the role of cumulative emissions and reaching similar conclusions on the emissions limits required to keep central temperature estimates close to 2°C.
- A review of the latest evidence regarding climate sensitivity (a key uncertain parameter in climate projections) concluded that estimates are still consistent with the likely range given in IPCC AR4. Hence the distribution of climate sensitivity values we used in our climate modelling work remains appropriate.
- There is increasing evidence that even if CO₂ emissions are eventually reduced to zero, atmospheric concentrations will fall only very slowly indeed. Temperatures will remain high for even longer, as the oceans continue to absorb heat. Therefore, without significant negative emissions, temperature targets are likely to be very difficult to return to once they are exceeded.
- Some potentially important processes which we cited in 2008 are known still to be missing from leading model projections. In particular, there is greater confidence that there is a risk of additional CO₂ and CH₄ release from large natural reserves in wetlands, permafrost and oceans. Early results suggest these sources may add additional warming of the order of several percent, but large uncertainties remain.

5. Remaining uncertainties and implications for our approach to mitigation

The overall case for human induced climate change is underpinned by a vast body of theory and observation which forms a coherent picture, and where we can be confident about several basic tenets:

- Climate has varied regionally and globally throughout Earth's history, in response to a variety of factors.
- Among these, CO₂ and other gases in the atmosphere give rise to natural warming. Increasing the concentrations of these gases enhances the warming effect.
- Atmospheric concentrations of GHGs have increased during the 20th Century and are still rising as a direct result of emissions from human activity.
- Over the last decades the climate system has warmed, with rising temperatures, ocean heat content and sea levels, and melting glaciers, snow and ice.
- A continued rise in emissions is likely to cause sustained global heating of a magnitude and rate unprecedented in the course of human civilisation.

There are also still some areas where large uncertainties remain:

- Some key processes affecting climate are not yet understood well enough to have complete confidence in their characterisation, but new measurements and theories may improve our understanding. Hence, over time, we could well have better information on the strength of effects from short-lived gases and particles, the size and types of natural climate variability in earlier centuries, the future role of clouds (and other potential feedbacks) and the likely nature and consequences of climate change at a local scale.
- In other areas the limits to our knowledge are more fundamental, meaning uncertainties are unlikely to ever be completely resolved:
 - The exact forecasting of individual weather events is limited by the chaotic nature of the climate system.
 - Furthermore, the exact impacts of future climate on people will depend on social factors: where they are living, what they are doing, and the resources they have to cope and adapt. Scenarios can be used to explore these factors, but forecasts of socio-economic impacts are even more uncertain than forecasts of weather.

Given both our confidence in the fundamental science and current uncertainties, we continue to recommend a two step approach:

- Carbon budgets and targets should be based on the climate objective and pathways in our 2008 report:
 - Central estimates of global temperature increase by 2100 should be limited to as little above 2°C over pre-industrial levels as possible, and the likelihood of a 4°C increase should be kept to very low levels (e.g. less than 1%).
 - To meet this objective, global emissions should peak by 2020 and be halved or more by 2050; the UK should therefore aim to achieve at least an 80% emissions reduction in 2050 relative to 1990 levels.
- Significant research effort is aimed at resolving current uncertainties; we will continue to monitor scientific developments and periodically review implications for carbon targets and budgets.

We therefore use the pathways from the 2008 report as a benchmark for understanding progress and challenges in moving to a new global deal in Chapter 2, and the targets for the UK implied by these pathways in recommending the fourth carbon budget in Chapter 3. Our advice on the fifth carbon budget (scheduled for 2015) will provide an opportunity to revisit these pathways following the publication of the IPCC's Fifth Assessment Report.

6. Key findings



Global average temperatures from 2000-2009 were around 0.75°C above pre-industrial levels.

0.75°C

Limiting central estimates of global warming by 2100 close to 2°C will reduce (but not avoid) the risks from climate change.

2°C

Many societies and ecosystems will not be able to adapt to 4°C of warming. The risk of reaching this should be kept to very low levels.

4°C

The number of climate research papers reviewed by the Committee this year, providing us with the latest understanding of climate science.

500

Global CO₂ emissions increased 6-fold over the 20th Century.

6x

CO₂ concentration has not been as high as today for at least the last million years, possibly much longer.

1
million
years

The last decade has been the hottest since records began.

2000 to
2010

Chapter 2



1. The impact of the recession on global emissions
2. Global emissions to 2020 and beyond
3. EU ambition to 2020 and beyond
4. Carbon price projections and policy implications
5. Next steps in developing international and EU frameworks
6. How we use the international context in this report
7. Key findings

Chapter 2: The international context – implications for the fourth carbon budget

Introduction and key messages

In the previous chapter we showed that the climate objective in our 2008 Report remains appropriate. This is to limit central estimates of global temperature increase by 2100 to as close to 2°C as possible and limit the likelihood of a temperature increase above 4°C to very low levels. It could be delivered by peaking of global emissions before 2020, with a halving of emissions by 2050, and further cuts thereafter.

In this chapter we consider key global and EU developments since 2008, including:

- The impact of the recession on the achievement of our climate objective; our analysis in 2008 did not include this impact.
- The extent to which pledges under the Copenhagen Accord are consistent with global pathways that achieve our climate objective.
- The appropriate level of EU effort to 2020 and 2030 given the climate goal we wish to achieve.
- The implications of EU and global emissions reductions for the carbon price.

The key messages in the chapter are:

- The global recession will make short-term targets easier to meet (i.e. to 2020), but is unlikely to have a significant impact on cumulative GHG emissions reduction required to deliver the climate objective in the period to 2100.
- *If* high-end ambition pledges are delivered by 2020, pledges under the Copenhagen Accord *could* result in peaking of GHG emissions by 2020 and therefore keep the long-term climate objective within reach.
- Even if high-end ambition pledges can be delivered, however, agreement on deep cuts through the 2020s is required to provide confidence that a cost-effective and credible emissions pathway to meet the climate objective will be delivered.
- A move by the EU from the current 20% GHG emissions reduction target for 2020 (relative to 1990) to a 30% target, combined with a new 2030 target to cut emissions by around 55%, would put it on a cost-effective and credible pathway to deliver a cumulative budget consistent with the climate objective.

These conclusions and the analysis in this chapter are used to underpin our advice on the UK's fourth carbon budget (2023-27):

-
- EU action to 2020 is one relevant factor in considering whether the UK should move from the currently legislated Interim budget (i.e. based on a 34% cut in 2020 GHG emissions relative to 1990 levels) to the Intended budget (i.e. based on a 42% cut), thus defining the entry point for the UK to the 2020s.
 - The cost-effective and credible global emissions pathway, building on the Copenhagen Accord pledges and based on strong action beyond 2020, implies that the UK's 2050 target to reduce GHG emissions by 80% relative to 1990 levels continues to be appropriate. The shape of the global pathway also informs the UK's pathway towards the 2050 target.
 - Carbon price projections, based on EU effort and global pathways, inform the appropriate balance between domestic effort and purchase of credits in delivering a UK emissions pathway through the 2020s.

We set out our analysis of global and EU pathways, and implications for the carbon price, in six sections:

1. The impact of the recession on global emissions
2. Global emissions to 2020 and beyond
3. EU ambition to 2020 and beyond
4. Carbon price projections and policy implications
5. Next steps in developing international and EU frameworks
6. How we use the international context in this report

1. The impact of the recession on global emissions

In the decade to 2008 the global economy grew by an average annual 3% while emissions grew at around 2%. Prior to the global recession continued growth was envisaged. This is reflected in the scenarios which underpinned our advice in 2008 on the 80% target (these assumed annualised global GDP growth rates of around 4% to 2020 with emissions growing at an annualised 2% from 2008 to their envisaged peak in 2016).

In practice, the assumptions underpinning these scenarios have not been borne out in the near-term due to the global recession and impacts in terms of reduced energy demand and emissions. However, long-term impacts are likely to be limited:

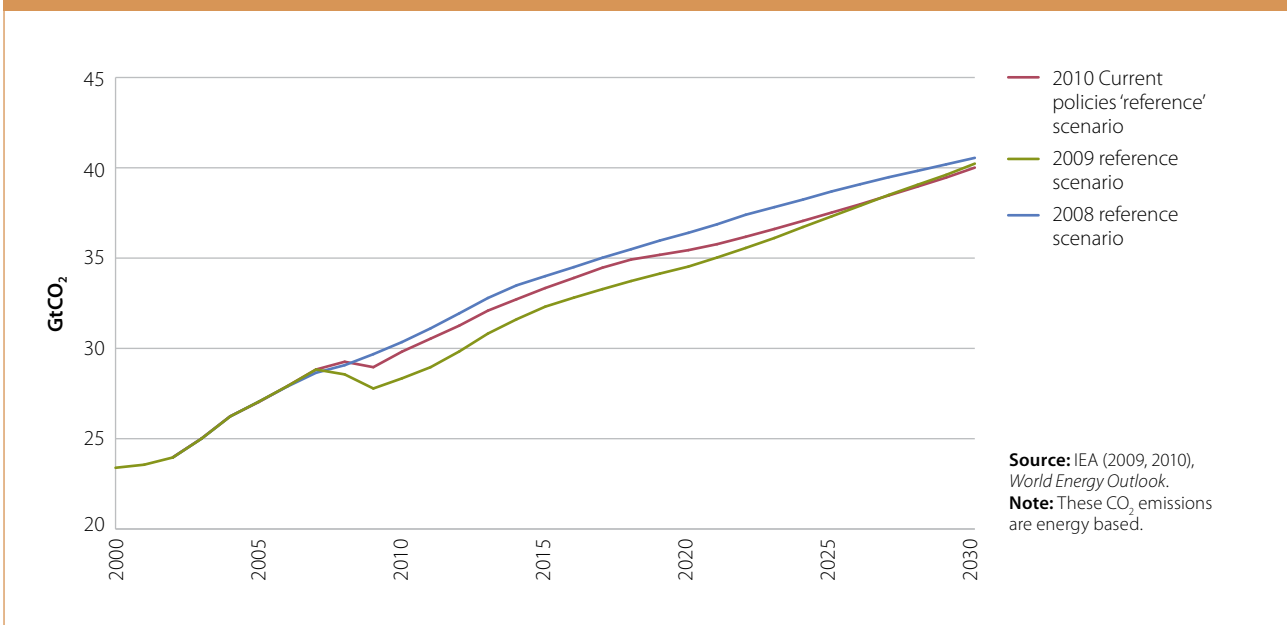
- Evidence at the global, EU and UK levels suggests that the emissions reduction in 2009 and 2010 was largely due to the recession:
 - The International Energy Agency (IEA) estimates¹ that global energy based CO₂ emissions in 2009 were around 3% below their 2008 pre-recession forecast.

¹ International Energy Agency (2009 & 2010), *World Energy Outlook*.

- Stern estimates² that global GHG emissions in 2010 could be around 6% below where they would have been if the recession had not occurred.
- The European Environment Agency estimates³ that EU emissions fell by just under 7% in 2009 compared to 2008 with the recession affecting all sectors in the EU.
- Our 2010 Progress Report⁴ showed that UK emissions fell by around 9% in 2009, largely due to the recession.
- In the longer term, the latest IEA analysis suggests that once the global economy returns to trend growth CO₂ emissions will grow without additional mitigation effort by around 1.5% p.a. to 2030. The latest IEA analysis suggests that the lasting impact of the recession is likely to be no more than a 20 Gt reduction in cumulative CO₂ emissions (Figure 2.1). This is only around 0.5% of the total abatement that is required across the whole of the 21st Century, relative to the global 'business as usual' scenario we considered in 2008.

Therefore whilst short-term impacts of the recession may persist and make 2020 targets easier to meet, this does not fundamentally change the level of international effort required to deliver a cumulative emissions budget to 2050 and 2100 consistent with the climate objective; achieving a new and ambitious international deal under which there is early peaking of emissions followed by deep cuts, in the period to 2050 (and beyond), remains key.

Figure 2.1: IEA reference scenarios for global CO₂ emissions



² Stern and Taylor (2010), *What do the Appendices to the Copenhagen Accord tell us about global greenhouse gas emissions and the prospects for avoiding a rise in global average temperature of more than 2°C?*

³ See <http://www.eea.europa.eu/highlights/recession-accelerates-the-decline-in>

⁴ See <http://www.theccc.org.uk/reports/2nd-progress-report>

2. Global emissions to 2020 and beyond

Assessment of the Copenhagen Accord

In the lead up to the Copenhagen Conference of the Parties (COP15) in 2009, the G8 agreed an aim to reduce global emissions by at least 50% by 2050. It was hoped that this agreement would underpin an ambitious global deal which would result in a peaking of emissions by 2020.

Although the Copenhagen meeting failed to deliver a legally binding global emissions reduction agreement, it did result in the Copenhagen Accord⁵, which included at least four positive aspects:

- Agreement that the **climate objective** should be to constrain global temperature increase to 2°C. The Copenhagen Accord does not specify the baseline from which to measure this increase, nor the level of confidence in avoiding 2°C. If however it is interpreted as requiring around a 50% likelihood of avoiding 2°C above pre-industrial levels, then it is consistent with the objective recommended by the Committee.
- Agreement that developed countries would submit commitments for **emissions reduction** in 2020 and for developing countries to submit **intended mitigation actions** that are quantifiable.
- Commitments to provide **finance** for developing countries, approaching US\$ 30 billion for the period 2010-2012 and US\$ 100 billion a year by 2020. The high-level advisory group on climate change financing concluded that raising US\$ 100 billion a year was 'challenging but feasible' in a report to the UN Secretary-General⁶ in November 2010.
- Commitment to support **avoided deforestation** by establishing a mechanism to mobilise financial resources from developed countries.

Peaking of global emission by 2020

Under the Copenhagen Accord, 85 countries including all the major emitters have come forward with pledges for 2020 in terms of either emissions reduction (developed countries), or intended mitigation actions (developing countries) – see Tables 2.1a & 2.1b.

Table 2.1a: Copenhagen Accord: selected developed country (Annex 1) pledges

Annex 1 party	Emissions reduction in 2020	Base year	Emissions relative to 1990	Abbreviated notes
Australia	5/15/25%	2000	+13% to -11%	Unilateral 5% below 2000 levels by 2020. 15% to 25% depending on scope of global agreement.
Canada	17%	2005	+3%	To be aligned with the final legislated economy-wide emissions target of the United States.
EU	20/30%	1990	-20/-30%	Move from 20% to 30% reduction if global agreement.

⁵ <http://unfccc.int/home/items/5262.php>

⁶ http://www.un.org/wcm/webdav/site/climatechange/shared/Documents/AGF_reports/AGF_Final_Report.pdf

Table 2.1a: Copenhagen Accord: selected developed country (Annex 1) pledges

Annex 1 party	Emissions reduction in 2020	Base year	Emissions relative to 1990	Abbreviated notes
Japan	25%	1990	-25%	If all major economies participate with ambitious targets.
Russia	15 – 25%	1990	-15 to -25%	If legally binding agreement covering all major emitters, with appropriate accounting of forestry abatement.
United States of America	17%	2005	-3%	In line with anticipated domestic legislation – final target to be reported in light of enacted legislation.

Source: www.unfccc.net

Table 2.1b: Copenhagen Accord: selected developing country (Non-Annex 1) pledges

Non-Annex 1 party	Action	Pledge	Reference year
Brazil	36-39%	Emissions reduction	2020 BAU
China	40-45%	Carbon intensity reduction	2005
India	20-25%	Carbon intensity reduction	2005
Indonesia	26%	Emissions reduction	2020 BAU
Mexico	30%	Emissions reduction	2020 BAU
South Africa	34%	Emissions reduction	2020 BAU
South Korea	30%	Emissions reduction	2020 BAU

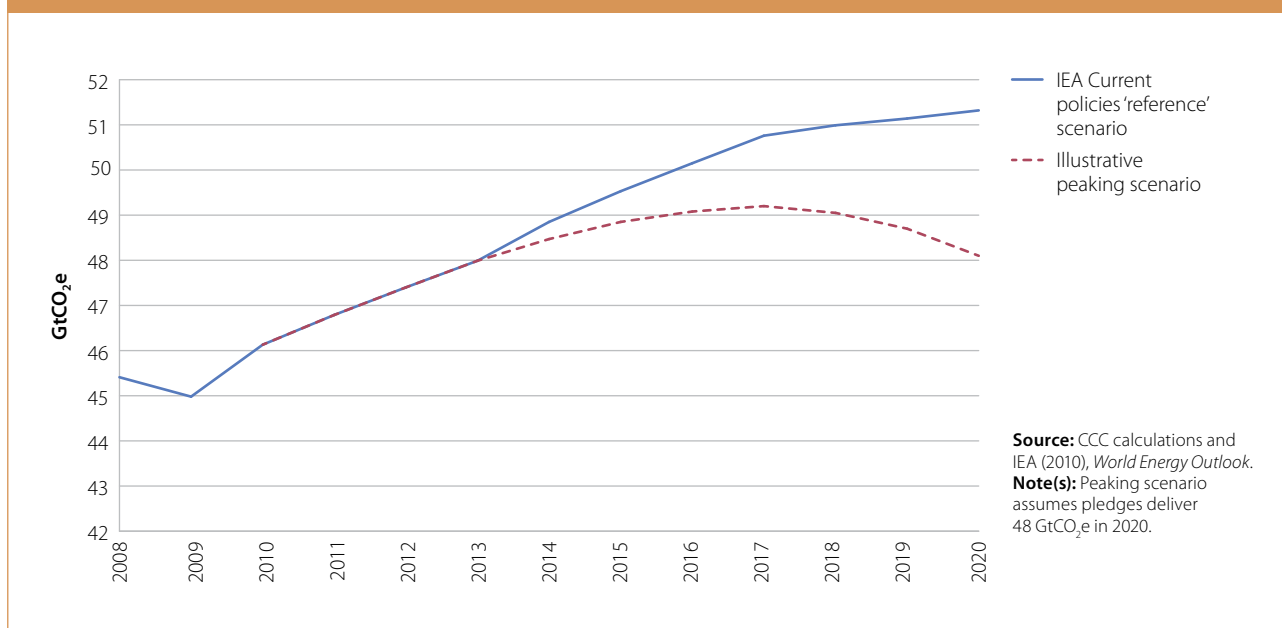
Source: www.unfccc.net

Taken together, these pledges *could* deliver peaking of global emissions by 2020, but significant challenges remain:

- Studies⁷ suggest that delivery of the pledges at the high-end of ambition could result in global GHG emissions of around 48 GtCO₂e in 2020:
 - If the high-end ambition pledges are delivered (e.g. EU 30%) *and* if no surplus against earlier Kyoto targets ('hot air') is banked *and* land-use change rules are addressed, global emissions would be around 48 GtCO₂e in 2020.
 - If the low-end pledges are delivered (e.g. EU 20%) global emissions would be higher at around 50 GtCO₂e in 2020, provided again that 'hot air' is not banked and land-use change rules are addressed.
 - If the low-end pledges are delivered, 'hot air' is banked, and land-use change rules are *not* addressed emissions could be up to 54 GtCO₂e in 2020.

⁷ For example: AVOID (2010), *Are the emission pledges in the Copenhagen Accord compatible with a global aspiration to avoid more than 2°C of global warming?*; Stern and Taylor (2010), *What do the Appendices to the Copenhagen Accord tell us about global greenhouse gas emissions and the prospects for avoiding a rise in global average temperature of more than 2°C?*; Rogelj and Meinshausen (2010), *Nature opinion article Copenhagen Accord pledges are paltry.*

Figure 2.2: Copenhagen Pledges – Illustrative peaking by 2020



- Global GHG emissions are estimated by the IEA to be around 46 GtCO₂e in 2010 and to reach 50 GtCO₂e in 2015 in their Current Policies 'reference' Scenario. Therefore achievement of the high-end of ambition (i.e. around 48 GtCO₂e in 2020) *could* be consistent with a peak if 'hot air' is not banked and land-use change rules are addressed (Figure 2.2).
- It will be very challenging to achieve the high-end of ambition:
 - Moving from pledges to agreed targets may be more difficult to achieve now considering that the US energy and climate legislation anticipated at the time of the Copenhagen Accord has not been forthcoming in 2010.
 - Even if targets are in place, experience in the UK suggests that delivering targets and driving the transition to a low-carbon economy remains a significant challenge (see our 2009 and 2010 Progress Reports to Parliament).
- In the meantime, slower progress than previously envisaged towards a global deal does not preclude country/regional action, of which there are many positive examples. In addition to UK and EU actions: **China** is making significant investments in energy efficiency and low-carbon technologies (e.g. nuclear and renewables); **India** has brought in measures to encourage investment in renewable energy and energy efficiency; **California** recently voted to retain their climate legislation to cut emissions to 1990 levels by 2020. Such action will leave these countries/regions well placed in terms of preparing for a carbon constrained world; it will also underpin agreement on, and delivery of, emissions reduction required under a future international deal.

The implication of this is that the aim should be to deliver the high-end ambition pledges under the Copenhagen Accord, and to address accounting issues, in order that global emissions peak by 2020.

Global emissions after 2020 to deliver the climate objective

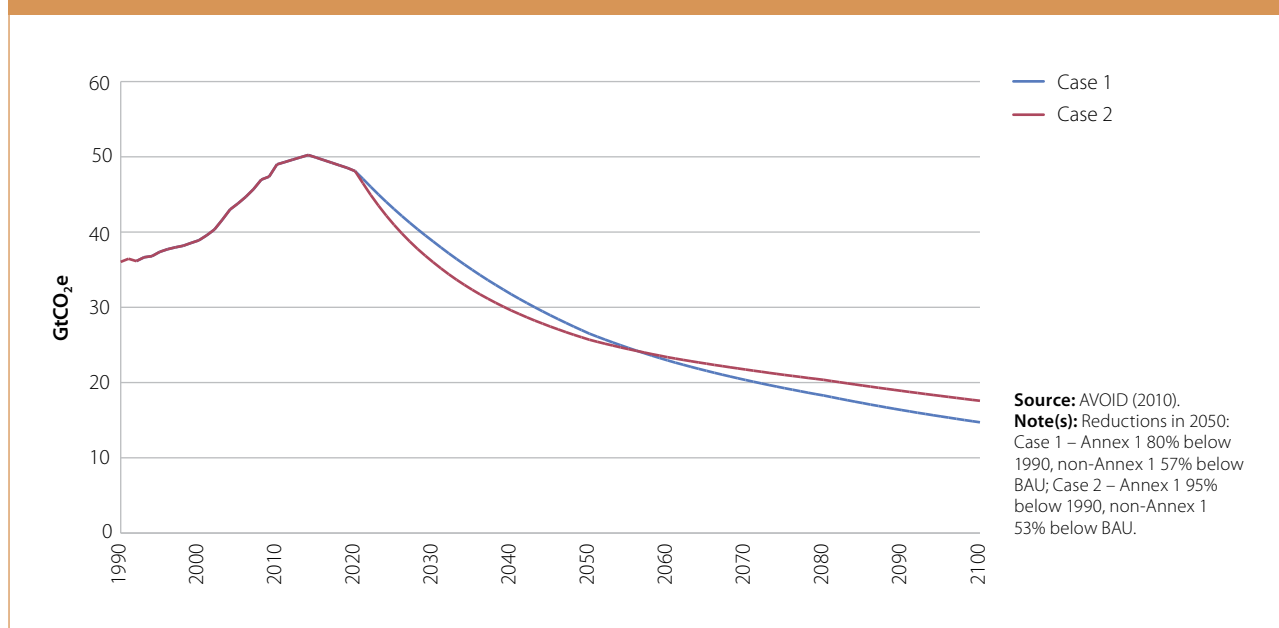
Early peaking of global emissions is a necessary but not sufficient condition for delivery of our climate objective, which also requires deep cuts in emissions such that global emissions are halved by 2050 with further cuts in the period to 2100.

A number of studies have assessed consistency of Copenhagen Accord pledges and possible paths beyond 2020 with climate objectives:

- Post-Copenhagen analysis by the AVOID consortium⁸, using a similar modelling approach to that in our 2008 Report, suggests that the Copenhagen Accord's 2°C limit could be avoided with 50% likelihood if the pledges are followed by average annual emissions cuts of 2% to 2050 and beyond (Figure 2.3).
- Other studies suggest that the required post-2020 emissions reductions to meet the Copenhagen Accord's 2°C target are only possible if emissions in 2020 are already lower than even the most ambitious pledges under the Copenhagen Accord (Box 2.1). Most of this difference in conclusions can be attributed to a requirement of higher probabilities for limiting temperature increase to 2°C, and/or a lower estimation of the maximum rate at which global emissions can feasibly fall after 2020.

Based on the AVOID analysis, our climate objective – as opposed to a more stringent objective that would give a higher probability of limiting temperature increase to 2°C – remains feasible if the more ambitious pledges under the Copenhagen Accord are delivered, followed by deep emissions cuts after 2020 (consistent with roughly halved global emissions by 2050).

Figure 2.3: AVOID's post-Copenhagen 2°C trajectories



⁸ AVOID (2010), *Are the emission pledges in the Copenhagen Accord compatible with a global aspiration to avoid more than 2°C of global warming?*

Box 2.1: Consistency of Copenhagen Accord pledges and the climate objective

Studies have shown that, if the high-end ambition pledges are delivered, emissions could be around 48 GtCO₂e in 2020. In February 2010, the Chief Scientist's Office of the United Nations Environment Programme (UNEP) published a note⁹ attempting to answer the key question as to whether the emissions reduction commitments and mitigation actions for 2020 are consistent with the 2°C limit.

According to the UN, the emissions targets in 2020 in line with the 2°C limit from four studies¹⁰ are in a range from 40 GtCO₂e to 48 GtCO₂e.

Not all of these studies were aiming to keep central estimates of global mean temperature increase close to 2°C, consistent with the Committee's climate objective. The lowest mid-range estimate of 40 GtCO₂e from Meinshausen et al. has a 44% to 71% chance of keeping temperature increase to below 2°C. Bowen and Ranger, however, who used a similar climate objective to the Committee, suggest mid-range values of 44 GtCO₂e and 47 GtCO₂e depending on how rapidly global emissions can feasibly fall per annum.

The case for deep cuts in the 2020s

Our emissions pathways, and those in the AVOID analysis, define a cumulative budget consistent with our climate objective. Given a cumulative budget, there is a question over the precise pathway for delivering this budget, with relevant considerations including projected technology costs, discount rates and risk management.

We have considered arguments for delivery of a cumulative budget based on delayed action (i.e. later peaking of emissions followed by more rapid reductions), but concluded that this would increase both costs and risks of missing our climate objective:

- The contention is that later action would allow abatement at lower costs as new technologies are developed, and because the present value of abatement costs fall further into the future due to discounting.
- However, a fundamental objection to this contention is that the cumulative budget to deliver our climate objective provides very limited scope for delaying action; the area under the curve on an early action trajectory is such that it is not clear where any delays could be compensated, given that emissions in later periods already need to be very low (Box 2.2).
- In addition, it is not clear that new low-carbon technologies would be developed without the pressure of early action and the important role of research, development and demonstration in pulling through abatement options.
- Various analyses suggest that early action is also cost-effective:
 - IEA estimate in their World Energy Outlook (2010) that delayed action, as a result of slow progress agreeing a global deal at Copenhagen, has already added US\$ 1 trillion to the cost of required decarbonisation to 2030.

⁹ UNEP (2010), *How close are we to the two degree limit?*

¹⁰ Van Vuuren et al. (2009), Bowen and Ranger (2009), Meinshausen et al. (2009) and Lowe et al. (2010).

- DECC’s GLOCAF model and recommended carbon values – see Section 4 below – suggest that the present value of future marginal costs rises over time; the implication is that – if anything – costs of delivering a cumulative budget could be reduced by accelerating, not delaying, action.
- Modelling at the UK level suggests that when given a cumulative budget the MARKAL model chooses an early action path that is consistent with a path based on equal annual percentage cuts (see Chapter 3).
- In terms of delivery risk, delayed action would increase the possibility that reducing emissions at the rate required to avoid dangerous climate change will not be achieved.
- Finally, delayed action would limit options for tightening long-term targets if the science were to suggest that this is appropriate (e.g. as new evidence emerges about the relationship between emissions and climate damage, see Chapter 1).

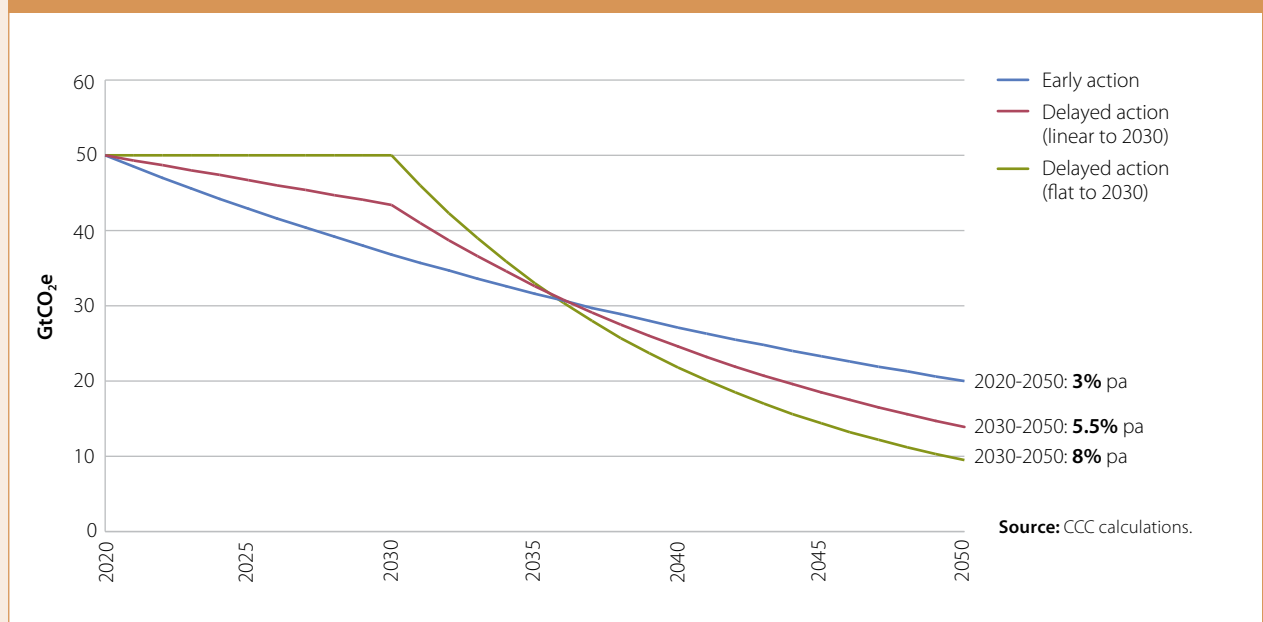
Therefore a path based on early action (e.g. equal annual percentage reductions) is likely to be cost-effective and credible in terms of risk management to deliver our climate objective – alternative paths do not meet these criteria. We reflect such a global pathway in our analysis of the appropriate action at the UK level in the 2020s in Chapter 3, whilst recognising uncertainties and ensuring robustness to alternative pathways consistent with delivering the climate objective.

Box 2.2: Why delayed action makes a cumulative budget harder to meet

Cumulative emissions are the main driver in determining the climate outcome; slow progress in early years would have to be offset by faster progress in later years to achieve a given target.

This is illustrated in Figure B2.2, which shows global emissions trajectories to 2050 consistent with cumulative emissions of 1,017 GtCO₂e. It is clear that slow progress to 2030 would significantly increase the required rate of change after 2030 and could also require a much larger reduction in 2050.

Figure B2.2: Early vs. late action to meet a global cumulative budget



3. EU ambition to 2020 and beyond

In October 2009, the European Council set out an EU objective to reduce emissions by 80% to 95% by 2050 compared to 1990 levels. The bottom end of the range is consistent with the UK's 2050 target to reduce emissions by 80% compared to 1990 levels. However, the extent to which this would deliver our climate objective depends on the path of emissions to 2050, which we now consider in two parts: the path to 2020 and the path beyond 2020.

The EU's 2020 emissions reduction targets

The EU agreed, in December 2008, to a 20% GHG emissions reduction target in 2020 relative to 1990, rising to a 30% target conditional upon international emissions reduction effort. A package of legislation was put in place to support these targets, including renewable energy targets and caps for the traded and non-traded sectors.

The targets and the supporting package informed our 2008 advice on the level of the first three carbon budgets:

- Our **Interim** budgets – based on a 34% cut in greenhouse gas emissions in 2020 relative to 1990 – reflected UK obligations under the EU's 20% target.
- Our **Intended** budgets – based on a 42% cut in greenhouse gas emissions in 2020 – reflected likely obligations under a 30% target.

Since we gave our advice on the first three budgets, the EU has reiterated its commitment to move to a 30% target in its submission to the Copenhagen Accord, conditional upon other developed countries committing themselves to comparable reductions, and developing countries contributing adequately according to their responsibilities and capabilities.

More recently, in May 2010 the European Commission set out the case for moving to a 30% target¹¹. This is based on the benefits in terms of meeting climate objectives in the most cost-effective manner, strengthening the carbon price, and building a green economy:

- The European Commission paper argues that moving to a 30% target would reduce longer term delivery risks around an appropriate EU contribution to its 2°C climate objective. Conversely, the annual emissions reduction required to move from a 20% target in 2020 to a 2050 target of up to a 95% reduction in 2050 would go beyond the limits of plausibility.
- It argues that a 30% reduction is on the cost-effective pathway to reductions required in the period to 2050.
- It notes the currently low carbon price of around €15/tCO₂e, which provides only limited incentives for fuel switching in power generation, energy efficiency improvement in energy intensive industries, and development of and/or investment in low-carbon technologies. In addition, the forecast price of around €17/tCO₂e for 2020 (under the 20% target) suggests that the carbon price signal will remain muted throughout the 2010s.

¹¹ European Commission (2010), *Analysis of options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage*.

-
- Increasing the level of EU ambition and tightening the EU ETS cap, reflecting a 30% target, would strengthen the carbon price signal (e.g. to €30/tCO₂e in 2020) and the incentives that this provides for emissions reduction in the energy-intensive sectors.
 - It also highlights the benefits of early action in the EU. This would give first mover advantage in a global market for low-carbon goods and services which is forecast to triple over the next decade to over US\$ 2 trillion by 2020¹².

The European Commission considered the costs of meeting a 30% target, and showed that these are only slightly higher than the costs previously envisaged for meeting a 20% target prior to the recession and still less than 0.6% of GDP in 2020:

- In 2008, the cost of the climate and energy 20% package was estimated at around €70 billion (0.45% of GDP) in 2020.
- Taking into account the recession the cost of the 20% package is now estimated at €48 billion (0.32% of GDP) in 2020 – representing around a 30% reduction on previous estimates.
- The 30% package is now estimated to cost €81 billion (0.54% of GDP) in 2020 – €11 billion (16%) more than the original cost estimate for meeting the 20% target.

Even though the costs of the 30% package are higher than the 20% package in 2020, analysis by Climate Strategies¹³ suggests that moving from a 20% to a 30% target in 2020 will lower the total cost of meeting an 80% emissions reduction in 2050. If the EU retained its 20% target in 2020, more rapid reductions (at higher cost) would be required in the 2040s to achieve an 80% emissions reduction.

Given the potential benefits for the EU and the UK, namely that this would put the EU on a credible and cost-effective path to delivering emissions reduction consistent with the climate objective, the UK Government should urge an early EU move to a 30% target, which will provide stronger incentives for investment in low-carbon technologies.

The EU 2020 target is one relevant factor in considering whether the UK should move to the Intended budget. However, there are uncertainties over the precise timing of any EU move and the implications of a move for the UK in terms of the exact level of emissions reduction required under a revised package.

Our approach therefore frames the UK's 2020 ambition in the context of the 2050 target under the Climate Change Act, subject to these uncertainties and implications at the EU level for the ability to tighten the traded sector budget in the UK (see Chapter 3).

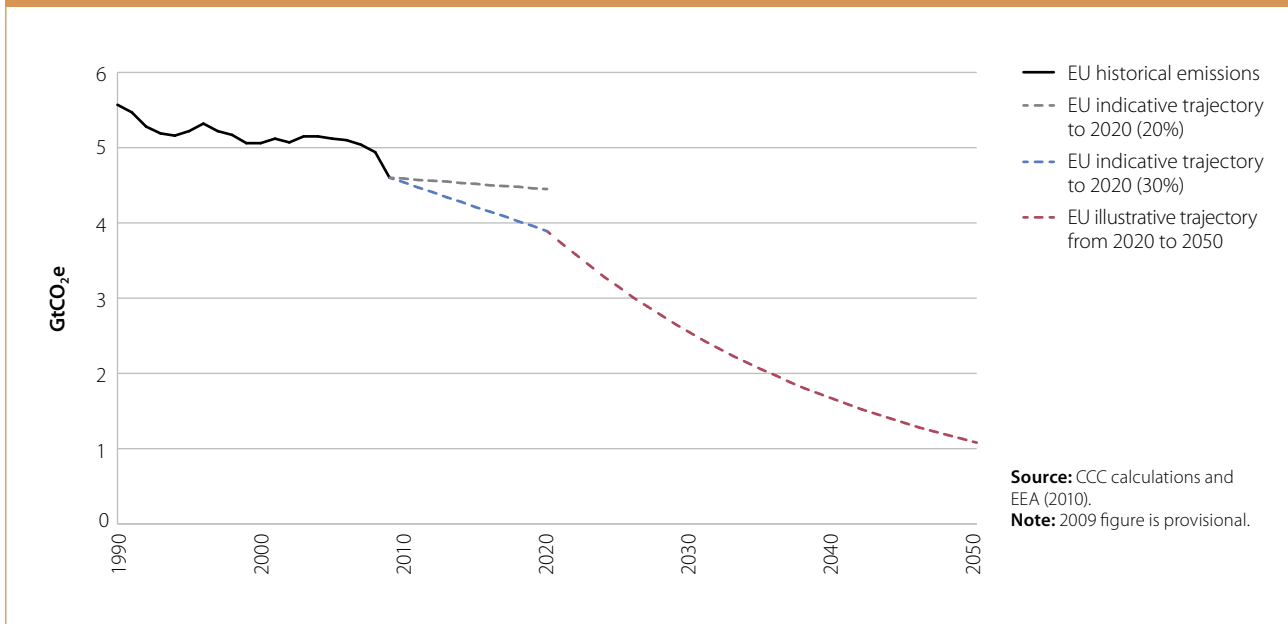
The path for EU emissions beyond 2020

We have argued that a cost-effective and credible pathway to deliver the climate objective is an early action path characterised by equal annual percentage reductions. A global emissions pathway from 2020 based on early action implies pathways for developed countries also based on early action:

¹² HSBC (2010), *Sizing the climate economy*.

¹³ <http://www.climatestrategies.org/our-reports/category/57/271.html>

Figure 2.4: EU pathway to 2050



- A **global** path based on equal annual percentage emissions reductions is likely to require **developed countries** to be responsible for delivery of at least equal annual percentage reductions, with the possibility of further responsibility depending on financing arrangements agreed under any future international deal.
- An equal annual percentage emissions pathway for the **EU** from a 30% target in 2020 to an 80% target in 2050 implies average annual emissions reduction of around 4% from 2020 (compared to 1.5% annual reduction from 2009 levels to meet a 30% target in 2020) and would result in 2030 emissions around 55% below 1990 levels (Figure 2.4).

The current situation is that the EU framework includes a default provision for emissions covered by the EU ETS to fall through the 2020s, although not at a rate implied by equal annual percentage reductions (Box 2.3). More generally, the EU framework does not yet include a target for economy-wide ambition to 2030.

The gap in the framework could be addressed by the EU setting a 2030 target, the rationale for which is the same for that of the UK's fourth carbon budget:

- It would provide clear signals for investment in long-lived assets and development of new technologies.
- It would also ensure that Member States remain in step, and avoids potential competitiveness impacts that might otherwise ensue based on unilateral action.

Therefore we recommend that the UK Government should seek early agreement on an EU emissions reduction target for 2030 which goes beyond the default provision in the current framework (see Chapter 3).

Box 2.3: Tightening the EU ETS to 2020 and beyond

Current plans to 2020

In October 2010 the European Commission (EC) announced the cap for the start of Phase III of the EU ETS in 2013, set at just under 2.04 billion allowances¹⁴. This does not include aviation, which has a separate cap (set at 95% of average EU aviation emissions over 2004-06), expected to be just over 200 million allowances (i.e. making the overall cap around 2.2 billion allowances).

Going forward, the cap (excluding aviation) will decline each year by around 37 million allowances (i.e. 1.74% of the average level of the cap over 2008-12). By 2020 this leads to a cap of around 2 billion allowances (including aviation).

Move to 30%

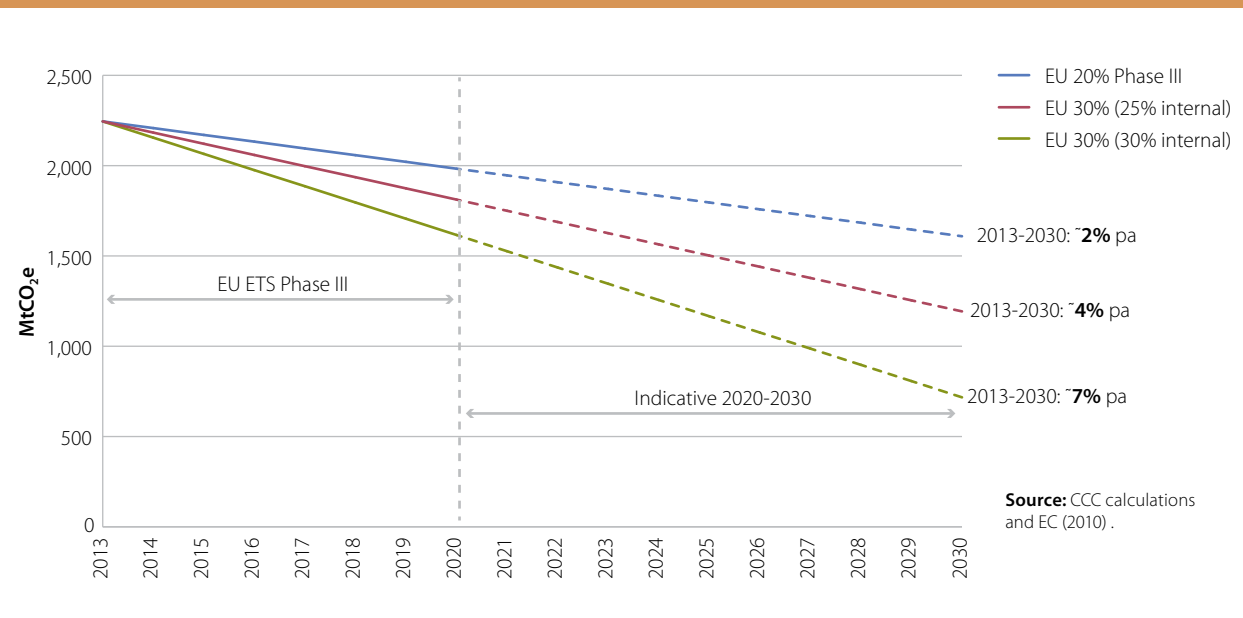
If the EU decided to move to a 30% emissions reduction target for 2020 then the EU ETS cap for Phase III would need to be tightened. The EC have published initial analysis of the implications of a move to 30%¹⁵ which suggests the cap in 2020 could be 1.6 to 1.8 billion allowances (including aviation), depending on the extent to which the additional effort is done internally within the EU or via credit purchase.

Beyond 2020

Beyond 2020 there is uncertainty over how the EU package will evolve. There is a default provision in the directive that the EU ETS cap will continue to decline beyond 2020 at the existing rate in a '20% world' (i.e. 37 million allowances). However, this is likely to be subject to revision particularly as higher rates of reduction are required to put the EU on a credible path to its objective – an 80% to 95% reduction by 2050 (Figure 2.4).

Extrapolating forward the average annual reductions across Phase III suggests the cap in 2030 (including aviation) could be around 1.6 billion allowances in a '20% world', or 0.7 to 1.2 billion allowances in a '30% world' (Figure B2.3).

Figure B2.3: EU ETS caps to 2030



¹⁴ See: http://ec.europa.eu/clima/policies/ets/2012_en.htm Note: 1 allowance = 1 tCO₂e

¹⁵ See: http://ec.europa.eu/clima/documentation/international/future_en.htm

4. Carbon price projections and policy implications

In our 2008 Report we highlighted the importance of a robust carbon price in encouraging low-carbon investments. The pace and scope of emissions reduction at the global and EU levels will have implications for the level of the carbon price in the EU ETS and global carbon markets over the fourth budget period and to 2050.

In this section we discuss the carbon price projections we use in this report and risks and uncertainties in these projections. In addition, we consider potential policy implications to ensure a carbon price that provides strong incentives for investment in low-carbon technologies in the 2010s and beyond.

Carbon price projections

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

We have considered DECC's EU ETS MACC model, their model of the global carbon market ('GLOCAF'), and their recommended carbon values which are benchmarked against a range of models' outputs (Box 2.4).

We have developed a carbon price projection characterised by the following:

- **2020:** we use the European Commission's estimate for the EU ETS price for a 30% target of €30/tCO₂e (i.e. around £27/tCO₂e).
- **2030 & 2050:** we use DECC's recommended central values of £70/tCO₂e in 2030, rising to £200/tCO₂e in 2050, which are peer reviewed and comparable to a range of different models' outputs.

This carbon price projection is broadly consistent with the global pathways set out in this chapter, and is a robust basis for identifying cost-effective abatement options in the UK; see Chapters 3 to 7 for a comparison of sectoral abatement costs to this projection.

Box 2.4: DECC's carbon price modelling

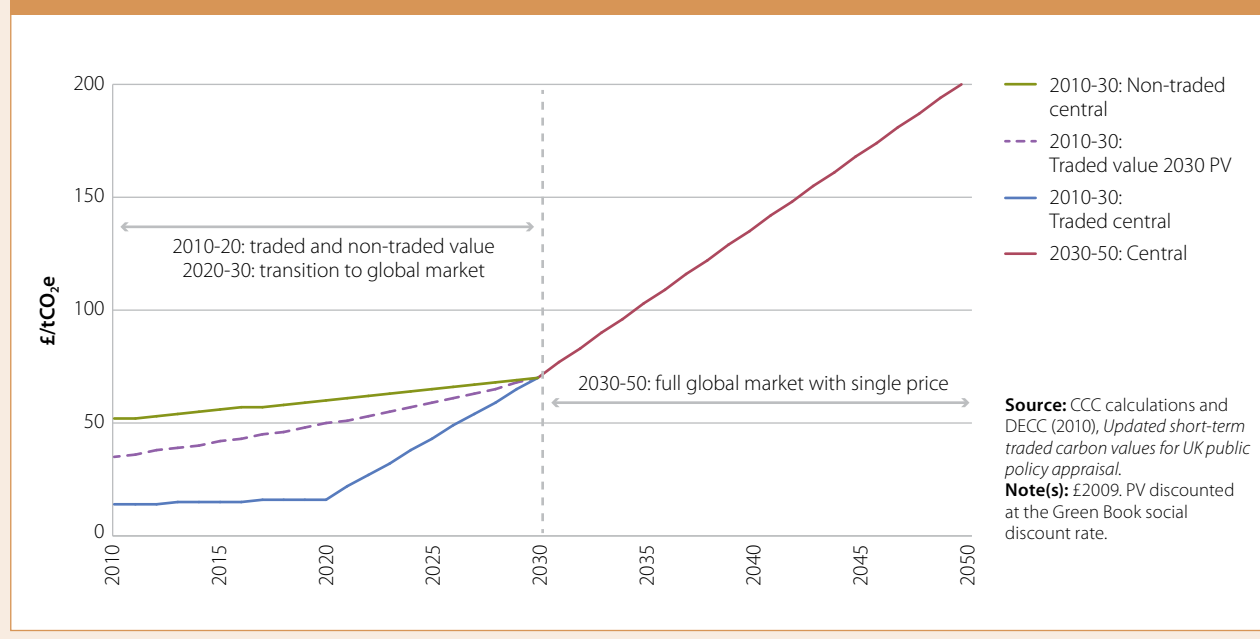
DECC published a revised approach to Carbon Valuation in 2009¹⁶, updated in June 2010¹⁷, where they set out their carbon values for use in UK policy appraisal.

In the period to 2030 DECC have two different carbon prices depending on whether emissions reductions are in the traded or non-traded sectors. The traded sector price is based on estimates of future prices of EUAs, the non-traded price is based on estimates of the marginal abatement cost required to meet emissions targets. These prices converge in 2030 when DECC assume a single traded price of carbon will exist in a comprehensive global carbon market.

The 2030 (and 2050) carbon values were calculated following work carried out using DECC's Global Carbon Finance (GLOCAF) model and reviewing their results against a range of different models. The GLOCAF model uses global abatement cost information to estimate the financial flows and carbon price that result from different climate change agreements, under various scenarios.

Overall, DECC decided that £70/tCO₂e was a reasonable central estimate for 2030 with £35/tCO₂e and £105/tCO₂e presented as the low and high estimates – this range covered most of the relevant modelling results.

Figure B2.4: DECC's carbon values to 2050



¹⁶ DECC (2009), *Carbon Valuation in UK Policy Appraisal: A Revised Approach*.

¹⁷ DECC (2010), *Valuation of energy use and greenhouse gas emissions for appraisal and evaluation*.

Risks and uncertainties in carbon price projections

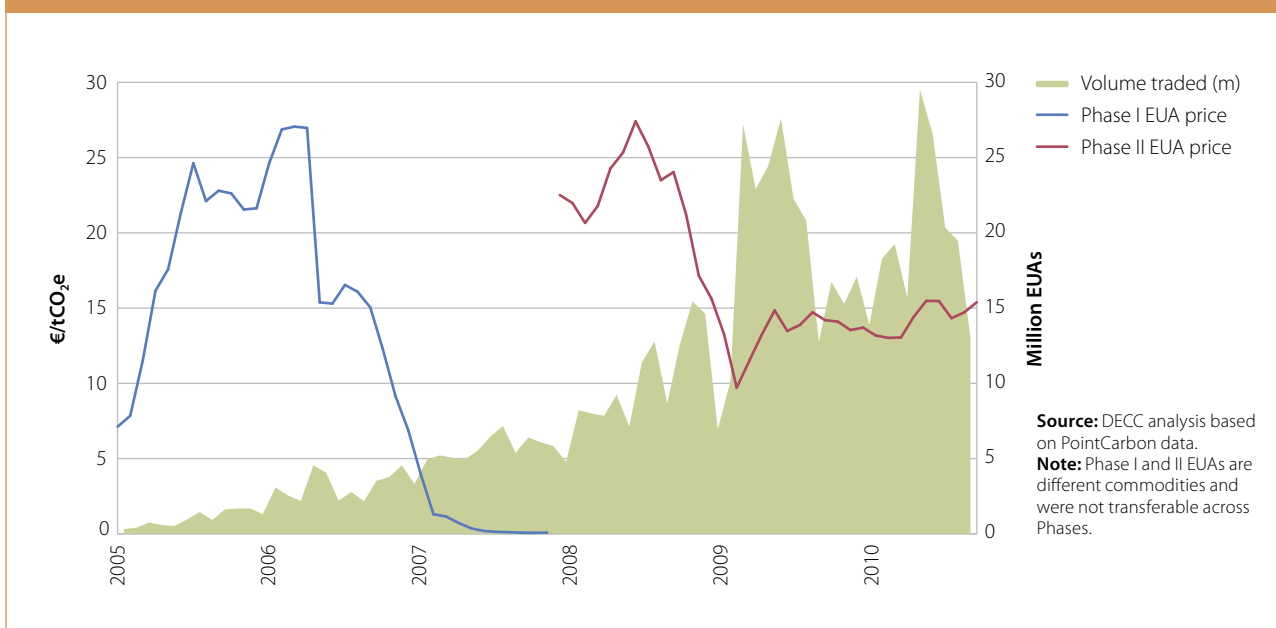
In projecting carbon prices to 2050 there are inherent uncertainties in how the international framework will evolve, the speed at which low-carbon technologies will develop and the price of available substitutes (e.g. fossil fuel prices):

- **Pace of global emissions reduction:** the speed at which countries decarbonise will affect the profile, and level, of carbon prices out to 2050. If action is delayed then the carbon price will remain low, initially, but have to rise more steeply to achieve an equivalent amount of cumulative emissions reduction.
- **Breadth of emission trading:** DECC's recommended 2030 carbon value of £70/tCO₂e assumes a comprehensive and freely-traded global regime. However, if a comprehensive global carbon market does not evolve then abatement costs will be higher – DECC illustrate this with a 'no trade' option, where the resulting weighted average regional carbon price of around £300/tCO₂e¹⁸ is four times greater than their 'central' 2030 estimate.
- **Technology costs:** Carbon price projections are based on expectations about future low-carbon technology costs. To the extent that technology costs are higher than expected, there would be two consequences: the carbon price would be higher than in our projection; abatement costs would also be higher. These effects work in the same direction as regards determining the set of cost-effective technology options to achieve an emissions goal.
- **Fossil fuel prices:** Carbon prices and abatement costs would be higher in a low fossil fuel price world, although not necessarily changing the broad shape of a cost-effective strategy to achieve an emissions goal.

Given these uncertainties over drivers of the carbon price, DECC's central values (£70/tCO₂e in 2030) are a good basis for identifying options likely to be cost-effective across a broad range of states of the world.

¹⁸ DECC (2009), *Carbon Valuation in UK Policy Appraisal: A Revised Approach* pp72 – 73.

Figure 2.5: The EU carbon market from 2005



Policy implications: underpinning the carbon price

Given these risks and uncertainties it is important that policy delivers a robust carbon price to encourage low-carbon investments:

- This could be particularly useful in the case of energy-intensive sectors where energy inputs account for a significant proportion of total costs. 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.
- It could also help in residential and non-residential sectors, reinforcing other policy instruments (e.g. to encourage energy efficiency improvement).

However, the volatile and low carbon price generated in the EU ETS does not provide such a signal:

- Historically the EUA price has been highly volatile ranging from €10/tCO₂e to €27/tCO₂e in Phase II (Figure 2.5).
- Going forward, the EUA price is driven by market expectations of the marginal cost of abatement to 2020 given a cap, which in turn is driven by a range of highly uncertain fundamentals. These include, expectations of the path of fuel prices, economic activity and judgements on future political decisions (e.g. on the cap or the quantities of offsets allowed). Changes in the market expectation of these factors led to a highly volatile EUA price in the past.

-
- In 2008 our projected EUA price for a 30% target was around €55/tCO₂e in 2020, whereas the current analogous projection, which includes the impact of the recession, is for a carbon price of around €30/tCO₂e.

Our analysis above also suggests that the carbon price in 2020 is likely to remain low relative to carbon price projections consistent with a global path that delivers the climate objective; even if the EC's carbon price projection of €30/tCO₂e (£27) for 2020 were to ensue, this is lower than the present value of the projected carbon price for 2030 (i.e. the present value of a £70/tCO₂e carbon price in 2030 is £35/tCO₂e in 2010 at a 3.5% real discount rate). This further limits the ability of the current EU ETS to provide an appropriate signal for long-term investment.

In order to provide a stronger signal, ideally there would be a carbon price underpin (i.e. a guaranteed minimum price) at the EU level consistent with the required pathway to 2050 (e.g. rising to £70/tCO₂e in 2030).

In the absence of an EU underpin, a UK underpin (e.g. in the form of a carbon tax) would strengthen incentives for low-carbon investments (e.g. in power generation, see Chapter 6, and more generally), and could usefully be introduced along the following lines:

- An underpin could reflect the projected EU price in 2020 (e.g. €30/tCO₂e or £27) and rise through the 2020s (e.g. to £70/tCO₂e in 2030).
- A higher price in 2020 would increase Government revenues, which could be used to support low-carbon technology development.
- Risks of leakage from UK energy intensive production to the EU, and affordability impacts from rising heat prices would have to be addressed (see Chapter 8).

Subject to addressing these concerns, the Committee strongly supports in principle the Government's proposed reform of the Climate Change Levy to underpin the carbon price, without having yet considered specific details of the proposals.

5. Next steps in developing international and EU frameworks

The following key actions at the international and EU levels would lay the foundations for cost-effective and credible emissions pathways to deliver climate objectives:

- **International framework**

- Agree credible targets consistent with more ambitious pledges under the Copenhagen Accord, and support these with delivery plans at country levels.
- Once 2020 targets are agreed shift the focus of discussion to, and gain agreement on, deep global emissions cuts after 2020 (e.g. cutting global emissions in 2030 back to 1990 levels/around a 25% cut relative to current levels, see Figure 2.3).

- **EU framework**

- Move to a 30% emissions reduction target for 2020, which is cost-effective and would provide stronger incentives for investment in low-carbon technologies.
- As discussions about the 2020 target are resolved, assess and agree an appropriate 2030 target (e.g. around a 55% emissions reduction relative to 1990 levels/around 45% relative to current levels, see Figure 2.4).

The Government should push for these agreements at EU and global levels, given their crucial importance in delivering the climate objective.

6. How we use the international context in this report

As with our previous advice on carbon budgets and the 2050 target, our approach in advising on the level of the fourth carbon budget is to view this as a UK contribution to required global emissions reduction.

This chapter has set out our analysis of EU actions, global pathways and carbon price implications consistent with the Copenhagen Accord and delivery of our climate objective. We use these blocks of analysis to underpin our advice on the fourth budget in a number of ways:

- EU action to 2020 informs whether the UK should move to the Intended budget or retain the currently legislated Interim budget.
- Global emissions pathways (to meet the climate objective) inform the UK long-term target.
- The shape of the global pathway (e.g. pace of reduction, early vs. late action) informs the broad shape of the UK path to the long-term target.
- Global and EU emissions pathways underpin our carbon price projections to 2050, which we use to identify cost-effective abatement options and develop UK emissions pathways through the 2020s.

The next chapter sets out in detail how we move from this international assessment to develop UK pathways and a fourth carbon budget consistent both with required global pathways and the UK's 2050 target.

7. Key findings



IEA estimate of the additional cost of failing to reach an ambitious global deal at Copenhagen.

\$1,000
billion

Countries made pledges under the Copenhagen Accord.

85

When global emissions could peak, if high-end ambition pledges made under the Copenhagen Accord are met.

2020

By 2030 world should cut current emissions by around 25%.

25%

By 2030 EU should cut emissions by around 55% (relative to 1990 levels).

55%

The carbon price we use in 2030.

£70/
tCO₂e



Chapter 3

1. The entry point to the 2020s
2. The 2050 emissions reduction target
3. Inclusion of international aviation and shipping
4. UK contributions to global emissions in the 2020s
5. Emissions reduction opportunities in the 2020s:
high-level modelling
6. Emissions reduction opportunities: bottom-up analysis
7. Advice on the fourth carbon budget
8. The path from 2030 to 2050
9. Role for purchase of offset credits
10. Costs and investment requirements
11. Implications for the first three budget periods
12. Key findings

Chapter 3: The Fourth Carbon Budget

Introduction and key messages

The analysis in chapters 1 and 2 suggests that the fundamental climate science remains robust, and that the climate objective underpinning the Climate Change Act remains appropriate. Delivering this will require a global deal that builds on the Copenhagen Accord and achieves peaking of global emissions by 2020 followed by deep emissions cuts through the 2020s and beyond.

In this chapter we consider how the UK should plan for the 2020s, including appropriate UK contributions to global emissions pathways, domestic action given projected international carbon prices, and action on the path to the UK's 2050 target (i.e. an 80% cut in emissions relative to 1990 levels). These considerations form the basis of our advice on the level of the fourth carbon budget (2023-27).

The key messages in the chapter are:

- **2030 emissions reductions.** In 2030, the UK should aim to have reduced greenhouse gas emissions from today's level of around 574 MtCO₂e to around 310 MtCO₂e (i.e. 60% below 1990 levels, or 46% below 2009 levels). This 46% reduction over the next twenty years will require a subsequent 62% reduction between 2030 and 2050 to meet the 2050 target. We believe that this 'back-ending' is justifiable given the feasibility of accelerated emissions reductions in the 2030s and 2040s if key enabling technologies and conditions (e.g. a largely decarbonised power sector) are in place by 2030. But any significantly less ambitious target for 2030 would endanger the feasibility of the path to 2050.
- **The fourth carbon budget.** We recommend that the Government legislate a carbon budget for the fourth period reflecting our bottom-up analysis of UK abatement opportunities (the **Domestic Action** budget). Our indicative **Global Offer** budget shows that the Government should be willing to go beyond this as a UK contribution to a global deal.
 - **Domestic Action.** This reflects our assessment of feasible abatement in the UK through the 2020s that is cost-effective and necessary on the path to 2050. The Domestic Action budget is 1950 MtCO₂e from 2023 to 2027. It reflects an emissions reduction of around 50% in 2025 relative to 1990 levels (32% relative to 2009 levels) and on the path to the 2030 reduction of around 60% relative to 1990 levels. The Domestic Action budget should be legislated now, with the aim to deliver it through domestic emissions reduction (i.e. without relying on credits purchased in international carbon markets). The level of ambition in this budget should be regarded as an absolute minimum, and more may be both feasible and required as current uncertainties over emissions projections and abatement opportunities (e.g. particularly in the industry sector) are resolved.

-
- **Global Offer.** This represents an indicative minimum UK contribution to a global pathway consistent with our climate objective. The Global Offer budget would be 1800 MtCO₂e from 2023 to 2027 (i.e. around 30 MtCO₂e per annum tighter than the Domestic Action budget) and on the path to a 2030 reduction of 63% relative to 1990 levels (50% relative to 2009 levels). Extra effort in the Global Offer budget relative to the Domestic Action budget could be achieved through either credit purchase or increased domestic effort.
 - **The first three carbon budgets.** Given these objectives for the 2020s, and the need to prepare for meeting the 2050 target, it will be important to deliver domestic emissions reductions consistent with the Intended budget in 2020. There would be significant risks and increased costs for meeting future carbon budgets if policy ambition is tailored to the lower reductions in the Interim budget, particularly for the non-traded sector. Therefore, the Government should tighten the second and third carbon budgets in line with the Intended budget for the non-traded sector:
 - The Intended budget in 2020 is broadly consistent with required implementation of measures on the path to the 2050 target, together with impacts of the recession, and limited purchase of credits in the traded sector.
 - Ideally the Intended budget would be legislated now, but this is not practical for the traded sector given that it would require a tightening of the EU ETS cap.
 - The Government should therefore tighten the second and third carbon budgets in line with the Intended budget for the non-traded sector; this does not require any corresponding EU action.
 - A full move from the Interim to the Intended budget should be legislated in line with a tightening of the EU ETS cap as and when the EU moves to a 30% emissions reduction target for 2020; it is appropriate for the UK to continue to push for a move to the EU 30% target as soon as possible.
 - The Government should plan to deliver the Intended budget largely through domestic emissions reductions, both to prepare for meeting the Intended budget when it is legislated and in the context of meeting carbon budgets beyond 2020.
 - **Implications for Government policies.** Given the long lead times for investment and technology innovation, it is crucial to plan and put in place new policies to develop options for meeting the legislated budget. We envisage that the Government's response to this advice as required under the Climate Change Act will set out an approach to developing key options for reducing emissions in the 2020s; this will manage costs and risks of meeting the fourth budget on the path to the 2050 target.

-
- **Costs.** We estimate the cost of meeting both the Domestic Action and the Global Offer budget at under 1% of GDP in a central case, including further costs from possible credit purchase to meet the Global Offer budget of around 0.1% of GDP.
 - **International aviation and shipping (IA&S).** We are required under the Climate Change Act to advise on the role of IA&S in carbon budgets. Our advice is that the Government should now accept the principle that emissions from these sectors will be included. In practice, further analysis is required to establish the precise methodologies for future inclusion. We will provide detailed advice on this issue in keeping with the statutory timetable, which requires a full decision by the Government on inclusion before the end of 2012.

Approach to the fourth carbon budget

In setting out the analysis underpinning our key messages, we first consider the entry point to the 2020s. We revisit our recommended scenario for emissions reduction measures in the first three carbon budgets¹. This comprises measures that are cost-effective (e.g. energy efficiency in buildings) and measures required to lay foundations for the path through the 2020s (e.g. electric cars, renewable heat). Together these would deliver around a 37% emissions reduction against 1990.

We next reconsider the UK 2050 target in light of the new analysis in chapters 1 and 2 on climate science and progress towards a global deal. We conclude that it remains appropriate to aim to cut all GHG emissions (including international aviation and shipping) by 80% in 2050 relative to 1990 levels.

Given our assessment of emissions reductions to 2020 and to 2050, setting the fourth budget requires defining a path from emissions in 2020 which are 37% below 1990 levels (excluding IA&S) towards an 80% emissions reduction in 2050 (including IA&S). We define this path in two ways, one top-down and one bottom-up:

- We consider an appropriate UK contribution to global pathways that would meet our climate objective, based on the analysis in chapters 1 and 2. This informs the development of our Global Offer budget.
- We then consider potential for UK emissions reductions reflecting options that are feasible, cost-effective and desirable on the path to meeting the 2050 target. We develop three scenarios out to 2030, reflecting different levels of domestic effort through the 2020s, to inform the development of our Domestic Action budget.

¹ As developed in our 2008 report on the first three carbon budgets *Building a low-carbon economy – the UK's contribution to tackling climate change*, and updated in our 2009 and 2010 progress reports to Parliament – we called this the 'Extended Ambition' scenario.

These two approaches give different levels of emissions for the fourth budget (i.e. the bottom-up analysis of appropriate domestic UK abatement falls short of levels, net of credit purchase, required to deliver an appropriate UK offer to a global deal). We therefore propose a Domestic Action budget that the Government should legislate now and aim to meet through domestic emissions reduction. We also propose a Global Offer budget, which is indicative of a UK contribution (including possible credit purchase) to a future global deal. The remainder of the chapter costs the budgets, puts them in context of emissions reductions required by 2050 and draws implications for actions required in the nearer term.

The blocks of analysis in the chapter are illustrated in Figures 3.1a and 3.1b and set out in the following 11 sections:

1. The entry point to the 2020s
2. The 2050 emissions reduction target
3. Inclusion of international aviation and shipping
4. UK contributions to global emissions in the 2020s
5. Emissions reduction opportunities in the 2020s: high-level modelling
6. Emissions reduction opportunities in the 2020s: bottom-up analysis
7. Advice on the fourth carbon budget
8. The path from 2030 to 2050
9. Role for purchase of offset credits
10. Costs and investment requirements
11. Implications for the first three budget periods

Figure 3.1a: Approach to the 2050 target

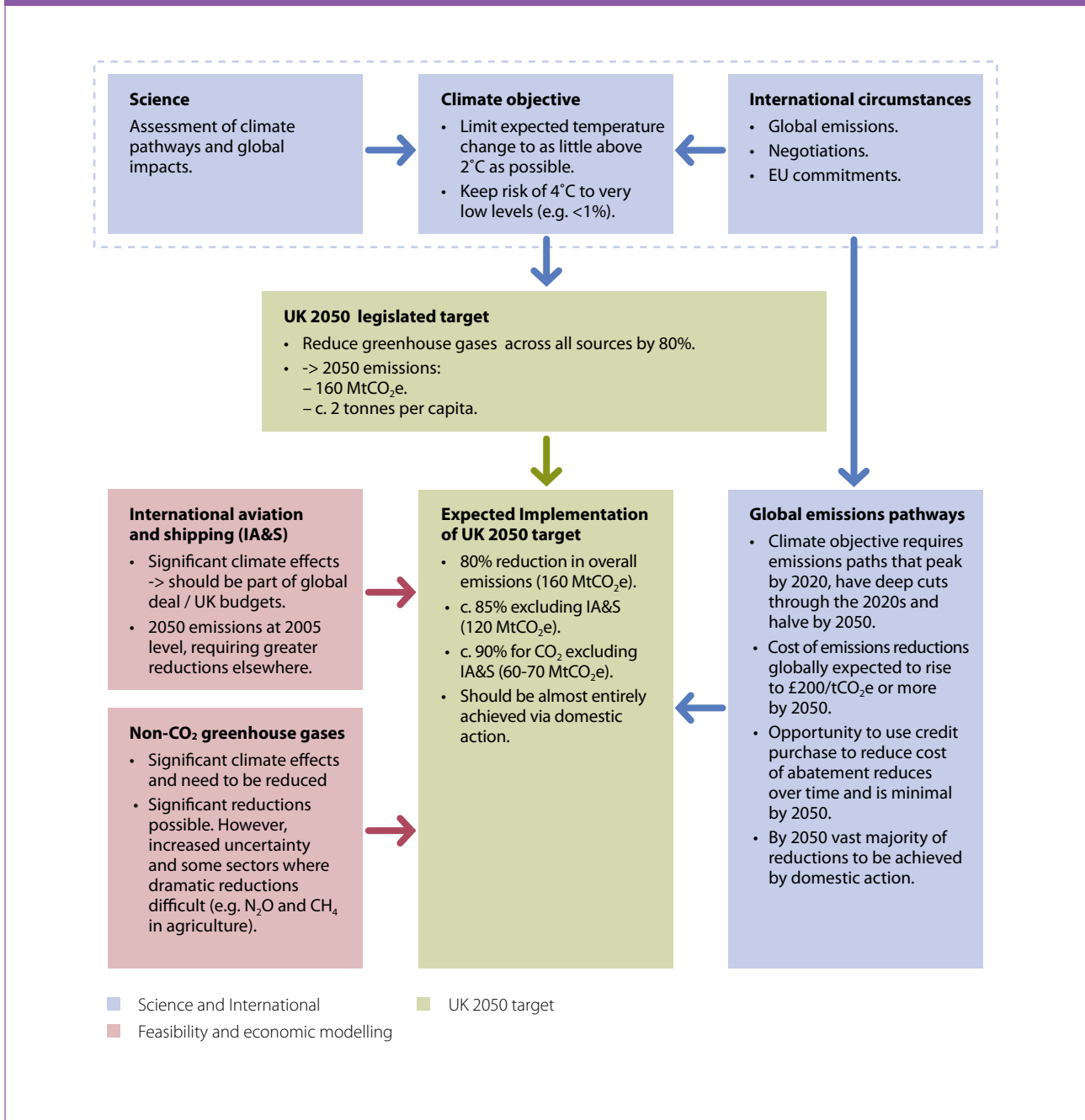
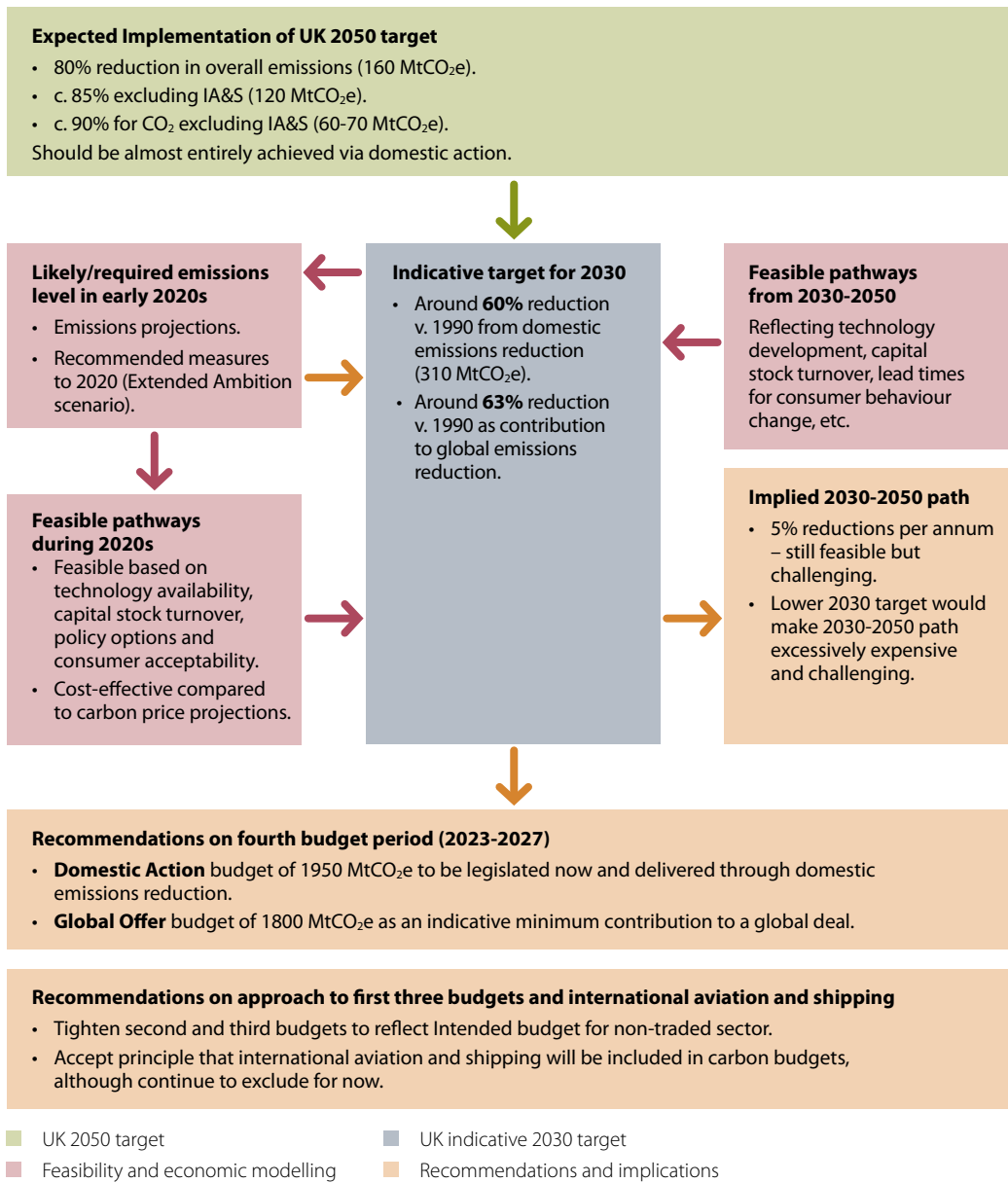


Figure 3.1b: From the 2050 target to a 2030 target and then a 2023-2027 budget



1. The entry point to the 2020s

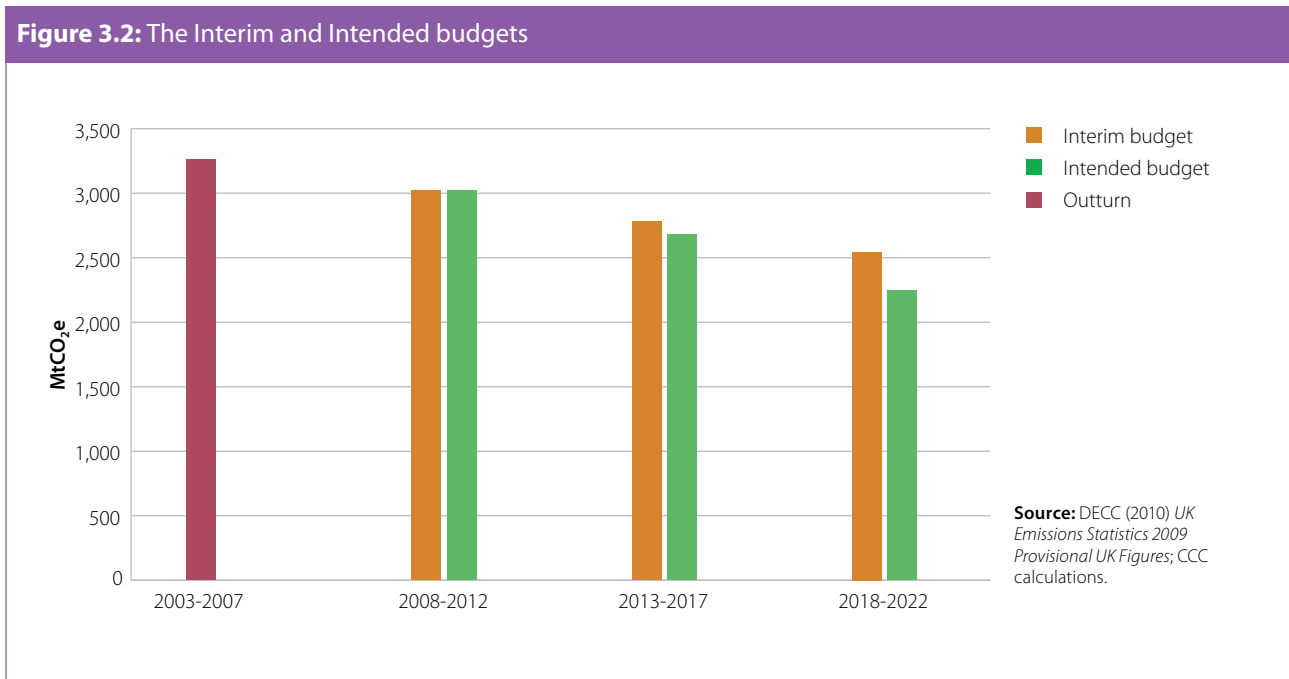
Our recommendations for the fourth carbon budget (2023-2027) reflect a path from emissions in 2020 to the 2050 target. This requires us to make an assumption on the level of emissions in 2020, which forms the starting point for our analysis of feasible emissions reductions through the 2020s.

2020 emissions reductions under Interim versus Intended budgets

In our December 2008 advice under the Climate Change Act, we proposed two sets of carbon budgets to 2020 (Figure 3.2):

- Under the **Interim** budget, 2020 greenhouse gas emissions would be 34% below 1990 levels in 2020 (11% below 2009 levels); this is the currently legislated budget, and corresponds to the UK's share of the EU's target to reduce emissions by 20% in 2020 relative to 1990.
- Under the **Intended** budget, the level of ambition would be higher, with a 42% greenhouse gas emissions reduction in 2020 relative to 1990 (21% below 2009 levels); we recommended that this budget, corresponding to the UK's share of the EU's target to reduce emissions by 30% in 2020, should be enacted in the context of a new global deal to reduce emissions².

We showed that the Interim budget could be achieved through domestic emissions reductions, which would be feasible given new policies (we set out the opportunities for emissions reductions to achieve this in our Extended Ambition scenario³ – see Table 3.1).



² Our Intended budget was based on detailed proposals from the EU on Member State burden shares, which were subsequently excluded from the agreed package. In that sense, the proposed budget was indicative, with the precise numbers to be revisited following finalisation of the EU's 30% package.

³ As developed in our 2008 report Building a low-carbon economy, and updated in our 2009 and 2010 progress reports.

We recommended that this should be the objective for three reasons:

- Many of the feasible emissions reduction measures that we identified would result in net cost reductions, for example through energy efficiency improvement in homes and businesses. Other options for domestic emissions reductions were cost-effective when compared to projected carbon prices over asset lives.
- Some options would be required to bring forward new technologies for deployment in the 2020s (e.g. renewable electricity and heat generation, electric cars – see Chapters 4-6).
- Domestic emissions reductions in the period to 2020 would be required to prepare for deep domestic cuts in the period to 2050, towards achieving the 2050 target with very limited purchase of credits in international carbon markets (we explain why there is likely to be limited scope for credit purchase to meet the 2050 target in section 9).

Table 3.1: Measures to deliver the first three carbon budgets – the Extended Ambition scenario

Measure	Key assumptions	Abatement potential in 2020 (MtCO ₂ e)
Power		*
Renewables	23GW wind and 4GW non-wind added by 2020	
Nuclear	One plant every 18 months from 2018	
Carbon Capture and Storage	Four demonstration units	
Buildings		26
Residential buildings	All lofts and cavity walls where practical by 2015, 2.7m solid walls by 2020, efficient glazing, floor insulation, room thermostats, insulated pipes and cylinders, efficient boilers 33% A++ cold appliances, 50% A+ wet appliances, reduced heating by 1°C, reduced washing machine temperatures, unnecessary lights turned off 'Zero carbon' new-build homes	17
Non-residential buildings	All cost effective measures in buildings covered by the CRC, 90% of cost-effective measures in other non-residential buildings. Includes efficient heating & cooling, efficient lights & appliances, process efficiency, energy management	9
Industry		6
Industry	Cost-effective process energy efficiency measures	6
Low-carbon heat		17
Low-carbon heat	12% penetration of renewable heat (heat pumps, biomass boilers, biogas, solar thermal water heating), plus district heating	17

We set out three options for moving from the Interim to the Intended budgets:

- Increasing the level of ambition in areas covered by the existing policy framework (e.g. solid wall insulation).
- Adopting new policies (e.g. introduction of road pricing).
- Purchase of credits in international carbon markets – European Union Allowances (EUAs) or offset credits.

In May 2009 the Government legislated the Interim budget, committing to enact the Intended budget following a global deal, and to prepare for this by aiming to outperform the Interim budget.

Table 3.1: Measures to deliver the first three carbon budgets – the Extended Ambition scenario

Measure	Key assumptions	Abatement potential in 2020 (MtCO ₂ e)
Surface transport		24
Biofuels	8% by energy	5
Cars and vans – conventional	New ICE car efficiency 110 gCO ₂ /km New ICE van efficiency 157 gCO ₂ /km; now revised to 135 gCO ₂ /km in line with proposed EU target	9
Cars and vans – EV/PHEV	1.7 million cars (5% of fleet, 16% market share) 130,000 vans (4% of fleet, 16% market share)	3
HGVs – conventional	Average 8% reduction	1
Demand	Smarter Choices reduce vehicle kms by 5% 10% of drivers trained in eco-driving by 2020 70 mph speed limit enforced on motorways	5
Rail	Efficiency measures, e.g. energy metering, regenerative braking	1
Non-CO₂		6
Agriculture	Fertiliser efficiency, livestock feeding and breeding, manure management in England; original savings for England have now been scaled up to cover the whole UK	4.5
Waste	Reduced waste to landfill, increased methane capture	1
Total (excluding power sector)		79

Source: CCC analysis.

Note: these are the measures from our 'Extended Ambition' scenario, as defined in our December 2008 report on the first three carbon budgets and revised in our October 2009 and June 2010 Progress reports to Parliament. Numbers may not sum to totals due to rounding.

* Emissions savings for measures in the power sector will depend on the counterfactual assumed for generation displaced.

The impact of the recession

The 2008 emissions projections upon which our carbon budget recommendations were based did not include the impacts of the recession. In our subsequent reports to Parliament – October 2009 and June 2010 – we have highlighted recession impacts, showing that these will make the first three carbon budgets easier to achieve, given that emissions remain a function of economic activity (Box 3.1, Figure 3.3):

- We estimated that the impact of the recession together with implementation of measures would result in outperformance of the first budget by up to 75 MtCO₂e in the non-traded sector. In this context, we have argued that the aim should be still to implement measures in preparation for meeting subsequent budgets. The resulting outperformance of the first budget should therefore not be banked through to the second budget, so as to preserve ongoing incentives for required implementation of measures.
- Emissions in the traded sector have also reduced during the recession. However, this will not affect achievement of the traded sector part of the budget, which is defined by the EU ETS cap.
- Projections from the Office of Budget Responsibility suggest a permanent impact of the recession, such that GDP in 2020 is expected to be around 10% lower than was projected before the recession. Together with our recommended implementation of measures in 2020, this would be sufficient to achieve the Intended budget with no credit purchase in the non-traded sector and limited credit purchase in the traded sector.

Figure 3.3: Non-traded sector emissions under Extended Ambition measures (2005-2022)



Box 3.1: Projected non-traded sector emissions including the impact of the recession

In our 2009 progress report, we projected emissions reductions due to the recession and other exogenous factors of around 3-6% (40-75 MtCO₂) in non-traded sector CO₂ across the first budget:

- Projections from the DECC Energy Model suggested impacts of around 3% (40 MtCO₂).
- Projections from the Cambridge Econometrics model, which assumes more income-responsive energy demand, suggested impacts of around 6% (75 MtCO₂).

Emissions data for 2008 and 2009 confirm a strong reduction during the recession, with new analysis for our 2010 progress report suggesting emissions around 4% (55 MtCO₂) lower than we originally envisaged for the first budget period. Although the economic effects are expected to be permanent, the persistence of the impact on energy use is hard to predict. For example, there are various uncertainties over the permanence of changes in consumer behaviours (e.g. in energy use, purchasing patterns) and over industrial energy use as mothballed plants reopen and as resources released from permanent closures are redeployed elsewhere in the economy.

Notwithstanding these uncertainties, latest projections point to non-traded sector GHG emissions in 2020 being in line with the Intended budget (Figure 3.3):

- We take our new CO₂ projections from the DECC Energy Model, building in outturn emissions in 2009 and the latest projections for GDP (which include some bounce-back in industry GVA as inventories reduced during the recession are restocked), together with savings from measures in our Extended Ambition scenario. Combined with latest projections for non-CO₂ emissions under our Extended Ambition scenario, these give projected non-traded sector GHG emissions in 2020 which are around 5% (15 MtCO₂e) lower than projected pre-recession, at 286 MtCO₂e.
- This compares to the allowable level for non-traded sector emissions in 2020 of 312 MtCO₂e under the Interim budget and 289 MtCO₂e under the Intended budget; our recommended measures are now sufficient to meet the Intended budget in 2020.
- Given that the projections from the DECC model assume a lower impact from the recession than observed in outturn emissions in 2009 and than projected by the Cambridge Econometrics model, the long-term impact of the recession may be larger than we have assumed. This emphasises the risk that the first three budgets could now be achieved with reduced policy effort and without implementation of the required measures to drive the necessary step change in emissions reduction.

Table 3.2: 2020 emissions savings for measures included in the Low Carbon Transition Plan compared to the CCC recommended scenario (Extended Ambition)

Measures	2020 emissions savings in Extended Ambition scenario (MtCO ₂ e)	2020 emissions savings in LCTP (MtCO ₂ e)
Power	*	*
Buildings	26	25
Residential	17	18
Non-residential	9	7
Industry	6	3
Low-carbon heat	17	15
Surface transport	24	18
Biofuels	5	7
Cars and vans	13	10
HGVs and buses	1	1
Demand-side measures	5	<1
Rail	1	<1
Agriculture & Waste	6	4
TOTAL excluding power	79	64

Source: CCC analysis, DECC (2009) The UK Low Carbon Transition Plan.
Note: these are the measures from our 'Extended Ambition' scenario, as defined in our December 2008 report on the first three carbon budgets and revised in our October 2009 and June 2010 Progress reports to Parliament. Savings from renewable heat have subsequently been revised following the RHI consultation and savings from agriculture have been scaled up to cover the whole UK. Numbers may not sum to totals due to rounding.
 * Emissions savings from power sector measures depend on the counterfactual assumed for generation displaced. The Extended Ambition and the LCTP assume similar build rates for low-carbon generation to 2020 (e.g. 23GW of wind).

Faced with these impacts, there is a choice for the Government of whether to maintain policy effort, or to reduce it such that emissions reductions are just enough to meet the Interim budget; given risks for meeting subsequent budgets, the optimal response is to maintain policy effort:

- In its Low Carbon Transition Plan (LCTP) the previous Government committed to a range of measures that would achieve the Interim budget without accounting for the impact of the recession. These measures are broadly comparable in ambition for most sectors to those we previously recommended (Table 3.2).
- Although the new Government has not explicitly committed to measures in the LCTP, specific commitments suggest that the level of ambition will not be reduced (e.g. the new Government has committed to the renewable energy target, will introduce a Green Deal to address energy efficiency potential in residential and non-residential sectors, is reforming electricity market arrangements to support low-carbon investments, see Box 3.2).

Box 3.2: Coalition commitments to emissions reduction measures to 2020

The coalition Government has not yet published a full package of policies (e.g. an update to the Low Carbon Transition Plan). Nevertheless, there are many areas where it is clear that policy intention is in line with our proposed set of measures. For example:

- Some abatement measures are either EU requirements, or have been committed to in that context:
 - New car emission targets, across the EU, of 130 gCO₂/km in 2015 and 95 gCO₂/km in 2020.
 - A target for new vans is currently being negotiated; the EU has proposed 135 gCO₂/km in 2020.
 - Under the EU Renewable Energy Directive, the UK is required to source 15% of its energy in 2020 from renewable sources, and has submitted the National Renewable Energy Action Plan detailing how this might be delivered.
- Some measures have been announced as part of the coalition's Programme for Government, the June 2010 budget, the 2010 Spending Review, and/or other official policy announcements:
 - The Government is committed to providing public funding for four CCS demonstration plants. £1 billion has been allocated for the first commercial-scale CCS demonstration plant at a power station.
 - £860 million funding for the Renewable Heat Incentive is to be introduced from 2011-12.
 - Over £200 million is to be invested in manufacturing facilities at port sites and in technology innovation to support the development of offshore wind power and energy efficiency technology for buildings.
 - Over £400 million has been confirmed for measures to promote the uptake of ultra-low carbon vehicle technologies, to include supporting consumer incentives for electric and other low-emission cars, and continued investment in electric vehicle recharging infrastructure (Plugged In Places).
 - A £560 million Sustainable Transport Fund will enable local authorities to bid for money to support packages of transport interventions that support economic growth and reduce carbon emissions.
 - A Green Investment Bank will be created, initially capitalised with a £1 billion spending allocation with additional proceeds to be made available from the sale of Government-owned assets.

Publication of a government-wide carbon plan to set out policies and deadlines to ensure action, department by department, has been promised.

- Reduced policy effort such that the aim is to just meet the Interim budget would increase risks and costs for meeting future budgets, requiring an expensive acceleration in the annual rate of emissions reduction after 2020 (e.g. from 1% for 2010 to 2020 to 6% for 2020 to 2050 for CO₂), and not sufficiently developing specific options for roll-out in the 2020s (Box 3.3, Figure 3.4).

Box 3.3: Implications of reduced ambition to 2020

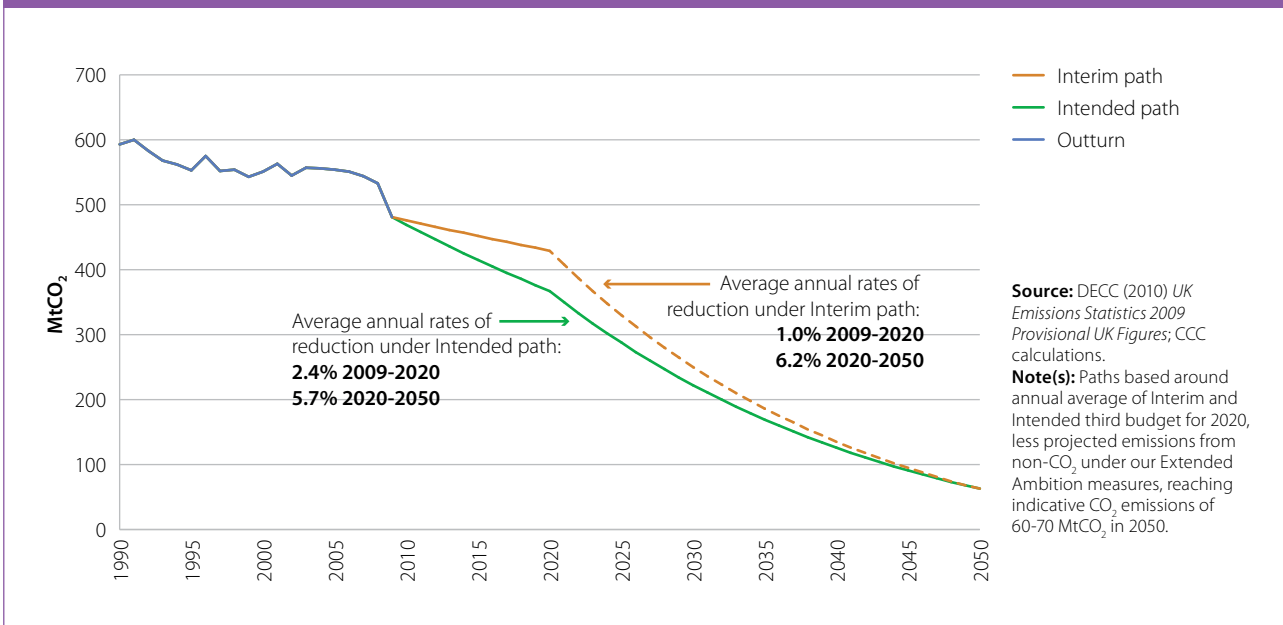
There are several areas in which policy effort is required in the 2010s not only to reduce emissions in the near term, but also to develop options for roll-out in the 2020s and beyond.

Key areas in which to make progress by 2020 include:

- Early deployment of battery and plug-in hybrid **electric vehicles**, in order to develop the market, encourage consumer acceptance and establish the required infrastructure in advance of wider roll-out during the 2020s (see Chapter 4).
- Roll-out of various **renewable electricity** technologies, driving the learning that will bring down costs and developing the supply chain, to put the power sector in a position by 2020 from which the sector can then be virtually decarbonised by 2030.
- Demonstration of a variety of **carbon capture and storage** technologies by around 2016, to enable these technologies to make a significant contribution to decarbonising electricity supply and industry from the early 2020s onwards (see Chapters 5 and 6).
- Early deployment of **heat pumps** and **solid wall insulation**, to drive learning and build supply chains for widespread roll-out in appropriate buildings during the 2020s.

Progress in each of these areas by 2020 will create the options needed to provide confidence that emissions can be reduced at the necessary rate during the 2020s.

Figure 3.4: Required CO₂ emissions reduction to 2050 under Interim and Intended budgets



2020 emissions in the context of the fourth budget

Given the impacts of the recession and the importance of delivering measures on the path to the 2050 target, the ideal response would be now to legislate a move from the Interim to Intended budget. This would reflect consistency in policy effort through the recession.

In practice, there are two complexities related to the fact that the EU has not yet moved from a 20% to a 30% emissions reduction target in 2020 (see Chapter 2):

- It would not be possible to deliver the Intended budget for the traded sector without a tightening of the EU ETS cap, given the definition of the net carbon account⁴ under the Climate Change Act.
- It is not clear how the EU will move from 20% to 30%, and whether the balance of effort between non-traded and traded sectors will be appropriate in a UK context on the path to the 2050 target. For example, if increased EU ambition were to be achieved solely through tightening of the EU ETS cap, required non-traded sector effort from the UK would be low relative to what is required in the context of the 2050 target.

Given these complexities, we make four recommendations:

- The Government should tighten the second and third carbon budgets to reflect the Intended budget for the *non-traded* sector (Table 3.3). This would require policy effort to be maintained and measures required on the path to 2050 to be successfully implemented. It would result in a 37% cut in emissions in 2020 relative to 1990 levels.
- Any outperformance in the first carbon budget period should not be banked through to the second budget period; the current Government have not yet committed to this recommendation, and should now do so.
- The Intended budget should be legislated as the EU moves from a 20% to a 30% target, and should reflect the impact of tightening of the EU ETS cap.
- The Government should plan to deliver the Intended budget only through domestic emissions reductions in the non-traded sector, and largely through domestic emissions reductions in the traded sector (i.e. with limited purchase of credits).

⁴ The net carbon account is the amount of emissions of all greenhouse gases from UK sources (net of any removals, e.g. from forestry), less net purchase of international carbon units. To 2020, this is in effect the amount of UK emissions in the non-traded sector, plus the UK's share of the EU ETS cap, less any additional offset credit purchase outside the EU ETS.

Table 3.3: Proposed tightening of second and third budgets to include the Intended budget for the non-traded sector

	Budget 1 (2008-2012)	Budget 2 (2013-2017)	Budget 3 (2018-2022)
Interim budget	3018	2782	2544
Interim traded	1233	1078	985
Interim non-traded	1785	1704	1559
Intended budget	3018	2679	2245
Intended traded	1233	1009	800
Intended non-traded	1785	1671	1445
Proposed tightened budget	3018	2749	2430
Interim traded	1233	1078	985
Intended non-traded	1785	1671	1445

Source: CCC analysis.

We reflect these recommendations in our scenarios for emissions through the 2020s, the starting point for which is a level of UK gross emissions in line with the proposed tightened budget.

2. The 2050 emissions reduction target

Recap on the 2050 target

The UK's 2050 target to reduce emissions by 80% relative to 1990 was recommended by the Committee as an appropriate contribution to global efforts to keep the risk of dangerous climate change at very low levels:

- Based on an assessment of potential climate impacts and damage costs, we proposed an objective to limit average global temperature change as little above 2 degrees as possible, and to reduce the risk of dangerous climate change to very low levels (e.g. less than a 1% chance of a global temperature increase in excess of 4 degrees).
- Global emissions trajectories consistent with this objective peaked before 2020 with 3% or 4% annual emissions cuts thereafter.
- The resulting global emissions cut in 2050 was 50% to 60% relative to 2005, giving average emissions per capita in 2050 around 2 tCO₂e.
- We assumed that it would not be feasible for UK emissions to be above the global average in 2050. Emissions of 2 tCO₂e/capita in the UK translates to an emissions reduction target of 80% in 2050 relative to 1990, allowing for expected population growth.
- We advised that the UK should aim to deliver the vast majority of the 80% reduction through domestic cuts rather than through international emissions trading. This is because all countries will need to be on a strong downward trajectory by 2050 and therefore any international credits available are likely to have a very high price.

The 80% target remains appropriate

The analysis in Chapters 1 and 2 suggests that the 80% target remains appropriate:

- Chapter 1 suggests that the climate change objective remains valid, and can be delivered by global emissions trajectories similar to those we previously proposed (e.g. because the relationships between temperature and damage, and emissions and temperature, have not changed significantly).
- Given delivery of ambitious commitments in the context of a global deal, the analysis in chapter 2 suggests that peaking of global emissions by 2020 remains feasible with a significant increase in effort internationally.

The UK's 2050 target should therefore continue to be the legislated 80% reduction relative to 1990. We will continue to monitor progress in international climate discussions and consider implications for the long-term target and carbon budgets as appropriate.

3. Inclusion of international aviation and shipping

Inclusion of international aviation and shipping in the 2050 target and the first three carbon budgets – previous advice

Our 2008 report clearly recommended that international aviation and shipping should be included in the 80% 2050 target:

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 sectors⁵.

The rationale was that if unchecked, these sectors will account for an increasing share of total emissions and could have damaging climate effects.

However, we also recommended in our 2008 report (see Chapter 8: International Aviation and Shipping) that it would be premature to include these sectors in the first three carbon budgets:

- **International aviation:** We did not recommend explicit inclusion in the first three carbon budgets, pending resolution of potential discrepancies between current UK emissions estimates (on a bunker fuels basis) and possible EU ETS allocation methodologies.
- **International shipping:** We noted limited progress towards an EU or global deal to reduce international shipping emissions. In combination with questions over appropriate methodology and data availability, there was not a clear basis for including international shipping emissions in the first three carbon budgets.

⁵ CCC (2008) Building a low-carbon economy, page xv.

Future inclusion of international aviation and shipping in carbon budgets

In the context of our fourth budget advice, we are specifically required under the Climate Change Act to advise on whether international aviation and shipping should be included in carbon budgets.

In principle, these sectors should be included in carbon budgets for two reasons:

- The 80% target for 2050 in the Climate Change Act should include international aviation and shipping. A changed definition of the net carbon account to include international aviation and shipping in the 80% target for 2050 under the Climate Change Act would also apply to carbon budgets.
- International aviation and shipping emissions on the path to 2050 have important climate effects, and should therefore be included in the budget framework. For example, if emissions from these sectors were to be off-track on the path to the 2050 target, this would raise a question over remedial action, whether in these or other sectors.

Therefore we recommend that the Government should accept the principle that emissions from international aviation and shipping will be included in carbon budgets.

However, in practice there remain outstanding challenges for including international aviation and shipping emissions in carbon budgets:

- **International aviation:** EU ETS data on international aviation emissions will not be available until 2011; subject to data availability and accuracy, it is likely that there then will be an appropriate basis for inclusion in the net carbon account.
- **International shipping:** The appropriate basis for inclusion of international shipping emissions in carbon budgets remains unclear, given uncertainty over the policy framework and questions relating to methodology (e.g. whether bunker fuels provide an appropriate estimate for emissions). However, we expect progress in resolving policy uncertainty in 2011/12 (e.g. through a global agreement or an EU approach), and will assess alternative methodologies for measuring UK shipping emissions as part of our shipping review to be carried out in 2011.

Given progress in the areas above, we should be in a position to advise on specific methodologies for inclusion in carbon budgets in 2011/12. This is within the timeframe set out in the Climate Change Act whereby the Government must consider whether to change the definition of the net carbon account to include international aviation and shipping before the end of 2012 (Box 3.4).

Box 3.4: Future work on international aviation and shipping

By the end of 2012 the Climate Change Act requires the Government to decide whether to include international aviation and shipping (IA&S) in the UK's net carbon account, or explain why it has not. The Committee will continue to develop its evidence base and make further recommendations on IA&S in 2012, in line with the Government's timetable set out in the Climate Change Act.

The Committee's work in 2011/12 will include consideration of:

- **UK shipping emissions.** To complement its December 2009 review of UK aviation emissions, the Committee has started a review of UK shipping emissions (both domestic and international) which will report in late 2011. The purpose of the review is to enable a much better understanding of UK shipping emissions including demand drivers, allocation methodologies, abatement options, policy levers and emission scenarios to 2050.
- **Allocation methodologies.** Revisiting appropriate methodologies for inclusion of IA&S in carbon budgets, including whether bunker fuels is the best measure.
- **Emission scenarios.** Bringing together gross and net scenarios for IA&S emissions (building on the 2009 aviation report and forthcoming shipping report), including analysis of the implications for credit purchase and/or use of policy levers.
- **Non-CO₂ climate effects.** Monitoring advances in climate science for aviation and shipping, and implications for the appropriate policy response.
- **UK carbon budgets.** Considering the implications of inclusion of IA&S on other sectors, appropriate treatment of non-CO₂ effects, and any required revisions to the net carbon account or the first four budgets (e.g. due to inclusion of IA&S or an EU move to a 30% target for 2020).

We will also continue to monitor recent trends in UK IA&S emissions, and UK and international policy developments in our annual Progress reports to Parliament.

Assumptions on international aviation and shipping in this report

Our approach in this report is to reflect, but not explicitly include, international aviation and shipping emissions. For example, in the context of the 2050 target, lower expected abatement in international aviation and shipping must be made up by higher abatement in other sectors of the economy (Table 3.4):

- Our assessment of UK contributions to global trajectories assumes a 2050 target to reduce greenhouse gas emissions by 85% excluding international aviation and shipping. This equates to an 80% reduction in total greenhouse gas emissions where these sectors are included based on bunker fuels estimates and where their emissions are at 2005 levels in 2050.
- Our assessment of feasible and desirable CO₂ emissions reductions assumes a 2050 target to reduce these by 90% excluding international aviation and shipping. This equates to an 80% reduction in total greenhouse gas emissions where non-CO₂ emissions are assumed to reduce by 70% by 2050 relative to their 1990 level and where international aviation and shipping emissions are at 2005 levels in 2050.

Table 3.4: Implications of 2050 target for emissions reductions under different definitions of coverage

UK Coverage	1990	2050	Reduction
GHG (inc IA&S)	797	159	80%
IA&S	23	41	2005 levels
GHG (exc IA&S)	774	118	85%
Non-CO ₂	183	e.g. 55	70%
CO ₂ (exc IA&S)	591	60-70	~90%

Source: CCC analysis.
Note: Reductions for IA&S and non-CO₂ are working assumptions, to be kept under review pending improved information.

Therefore our advice, which is based on these two approaches, is consistent with the path to a 2050 target which includes international aviation and shipping. These sectors can then be explicitly included in the net carbon account by adding in the appropriate net emissions projections over the next two decades once current methodological and policy uncertainties are resolved.

4. UK contributions to global emissions in the 2020s

One way to determine the path for UK emissions through the 2020s is to consider what would be an appropriate contribution to global emissions reductions. We show in chapter 2 that the cost-effective and credible global path to deliver our climate objective requires early action delivering deep emissions cuts (e.g. broadly equal annual percentage cuts from 2020 on the path to a 50-60% reduction in 2050 emissions). As a starting point we assume that the UK's contribution to the global pathway would entail equal annual percentage reductions:

- As a richer developed nation the UK should as a minimum match global abatement effort. For a global path broadly characterised by equal annual percentage reductions, this would require at least equal annual percentage reductions in the UK from the Intended budget in 2020 to the 2050 target. On this path, UK greenhouse gas emissions in 2030 are 63% below 1990 levels, and CO₂ emissions are 64% below 1990 levels. Together with equal annual percentage reductions in other countries towards 2 tCO₂e per capita emissions in 2050, this would imply a cost-effective and credible global path for emissions reductions to limit the risk of dangerous climate change.
- Financing approaches which put a greater burden on developed countries (e.g. approaches with more emphasis on historical responsibility) would require a larger contribution from the UK in the 2020s.

We now consider whether it would be feasible for the UK to deliver equal annual percentage emissions reductions through the 2020s based on high-level MARKAL modelling (Section 5).

We then set out detailed bottom-up analysis of abatement opportunities. Our aim is to determine the set of opportunities that are both feasible and desirable given the possibility of purchasing emissions reductions in the global carbon market and the need to prepare for deeper reductions to 2050 (Section 6).

Our budget advice draws together these blocks of analysis and reflects both our assessment of appropriate contributions to a global deal, and our assessment of feasible and desirable emissions reductions (Section 7).

5. Emissions reduction opportunities in the 2020s: high-level modelling

Alternative modelling approaches

We have used two modelling approaches to understand feasible emissions reduction pathways through the 2020s:

- We have undertaken high-level analysis, using the MARKAL model (Box 3.5) to identify the broad shape of emissions reduction paths for the UK CO₂ emitting sectors (excluding international aviation and shipping).
- We have also developed bottom-up scenarios based on detailed analysis of scope for technology roll-out (of low-carbon power, electric vehicles, heat pumps, etc.) given cost, technical and supply chain barriers. These provide a more robust basis to plan for emissions reductions in the 2020s; we use them (i.e. not the high-level MARKAL analysis) as the basis for our budget proposals (see section 7, below).

Box 3.5: The MARKAL model

The high-level analysis of pathways to reduce domestic emissions of CO₂ to levels consistent with meeting the 2050 target has been undertaken using the UK MARKAL (MARKet ALlocation) model. MARKAL is a least-cost optimization 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 CO₂ 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 supply exist (e.g. bioenergy), insights can also be gained on the best use of this finite resource.

As an optimization 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 paths, 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.

By definition, the MARKAL model has to focus on characterising known ways of reducing emissions, and is therefore unlikely to include the full set of ways in which emissions might be reduced in the period to 2050. Furthermore, despite the characterization of the existing energy system and the possible ways in which it could evolve in the period to 2050, there are many areas of uncertainty that make precision impossible. The value in running the model is therefore in the more strategic insights derived from understanding how it responds to different sets of assumptions.

Multiple versions of MARKAL exist and it is used in many regions internationally. We have used the latest update to the UK MARKAL model: the stochastic version of MARKAL Elastic Demand (MED). In MED, demands for energy services are allowed to change in response to changes in costs of meeting them. The stochastic version of this model allows uncertainty to be placed on certain input assumptions (e.g. future fossil fuel prices or technology availability), with a specified date at which that uncertainty will be resolved. The model then finds an optimal 'hedging' strategy for the period until the uncertainty is resolved, with the subsequent 'recourse' strategy after this resolution depending on the state of the world (e.g. a high fossil fuel price world). While, in reality, uncertainty is not typically resolved at a single point in time known in advance, using this functionality helps to provide insights into appropriate planning responses under uncertainty.

The modelling for CCC has been undertaken by University College London. The assumptions and results for all of the runs undertaken can be found in the full report on our website⁶.

We now summarise the MARKAL analysis, and set out the bottom-up analysis in Section 6 below.

MARKAL modelling assumptions

We have used the MARKAL model to suggest the least-cost means of meeting energy service demands, subject to the emissions constraint proposed in Section 4 above (i.e. equal annual percentage emissions reductions from 2020 to the 2050 target).

⁶ University College London (2010), *UK MARKAL Modelling – Examining Decarbonisation Pathways in the 2020s on the Way to Meeting the 2050 Emissions Target*, www.theccc.org.uk

Figure 3.5: Fossil fuel price assumptions to 2050



We have modelled a range of scenarios with different assumptions about the 2050 target, fossil fuel prices, technology costs and availability, build rates and availability of sustainable bioenergy:

- We assume a 2050 target that is a minimum of 90% CO₂ emissions reduction relative to 1990, excluding international aviation and shipping (Table 3.4, above). We also model a more demanding 95% target to allow for the possibility that changing scientific evidence (e.g. on carbon cycles, the relationship between climate change and damage, non-CO₂ effects of aviation) suggests the need for deeper CO₂ emissions cuts.
- We model a range of fossil fuel prices corresponding to DECC's scenarios (Figure 3.5):
 - The range for oil prices in 2030 in these scenarios is \$61 to \$153/bbl, around a central price of \$92/bbl,
 - The range for gas prices in 2030 is 35 to 121 p/therm, with a central price of 76 p/therm.
- We model various scenarios for availability of key technologies (e.g. some scenarios exclude the possibility of CCS technology in energy-intensive industries such as iron and steel, cement).
- We allow for variation in the maximum build rate of low-carbon power generation, from 1 to 3 GW of adjusted capacity⁷ annually through the 2020s for each of nuclear, CCS and renewables.
- We have designed a number of scenarios for availability of sustainable bioenergy ranging from 11% to 17% of total primary energy in 2030. These are consistent with IEA scenarios and with analysis set out in our December 2009 aviation report.

⁷ Technologies with lower availability (e.g. wind) are adjusted to be on a comparable basis to baseload plant (e.g. nuclear or CCS).

MARKAL modelling results – feasible and cost-effective emissions paths to 2050

The broad picture of the 2050 energy system that emerges from the MARKAL modelling is consistent with previous modelling set out in our December 2008 report on carbon budgets and the 2050 target, and with DECC pathways to 2050 (Box 3.6).

Box 3.6: Comparison of MARKAL results with DECC 2050 pathways and other relevant work

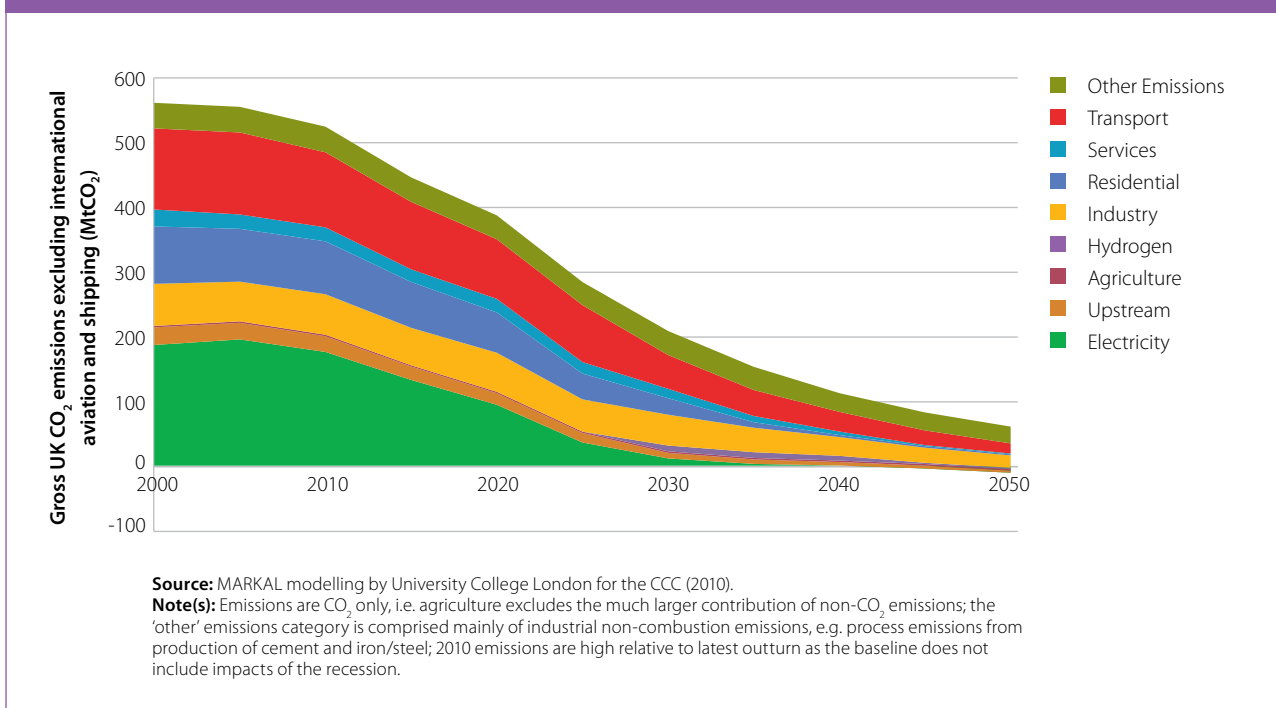
Several studies have looked at how to achieve a low-carbon energy system consistent with an overall reduction of 80% in the UK's greenhouse gas emissions by 2050. These include MARKAL modelling for the CCC, DECC's 2050 Pathways Analysis report, the European Climate Foundation (ECF) Roadmap 2050 project looking at decarbonisation across Europe, as well as less technology-focused work, such as the demand-side scenarios developed in the Energy Lifestyles component of the UK Energy Research Centre (UKERC) Energy 2050 project. Further work is ongoing in this area, for example in the development of the Energy Technologies Institute (ETI) energy system model Esme, and it is likely that scenarios will continue to be refined as understanding of the issues improves.

While there is considerable uncertainty about how a low-carbon energy system will or should develop in the period to 2050, there are nevertheless a number of common themes that emerge from these scenario exercises. These include the need for widespread improvements in the conservation of energy and end-use efficiency, prominent roles for electrified vehicles and heat pumps and the need to decarbonise electricity generation, possibly in a considerably larger system as a result of electrification of heat and transport.

The studies used different methodologies to arrive at their scenarios, which brings a valuable diversity to the evidence base regarding ways of meeting the 2050 goal. The approaches can broadly be grouped into three categories:

- **Primarily demand-focused:** The Energy Lifestyles part of the UKERC Energy 2050 project focused on the potential for cultural shifts and lifestyle changes, while recognising that low-carbon energy supplies would also be needed. This scenario includes very high standards of insulation, limiting of internal building temperatures, major improvements in lighting and appliance efficiency, dietary changes, reduced need to travel resulting from improved land-use planning and a shift to localism, car downsizing and modal shift to walking, cycling and public transport. The reduction in energy service demands resulting from these assumptions implies a smaller and less costly energy system than other studies.
- **Mixed:** The ECF report and the MARKAL modelling undertaken for CCC and UKERC both take an approach that seeks to optimise the energy system in order to minimise costs of meeting a given low-carbon objective. While in each case low-carbon supply technologies necessarily play a key role in such a radical decarbonisation of the system, the role of the demand side is also an integral part of limiting both costs and engineering challenges (e.g. in terms of build rates). The ECF study makes demand assumptions outside the optimization, while the MARKAL modelling, using the MARKAL Elastic Demand variant, does this via incorporating a demand-side response to costs of meeting energy service demands.
- **Primarily supply-focused:** The six indicative scenarios presented in the DECC 2050 Pathways Analysis report, based on their 2050 Pathways Calculator tool, all contain significantly higher levels of energy demand than the other studies outlined above. Their approach aims to ensure that supply meets demand and that scenarios meet the overall emissions target in 2050. It places emphasis on the identification of physically possible energy systems, including the potential for extremely high deployment levels for each technology. While radical options to limit energy demand are available in the Calculator, it is not important to select these in order to meet the emissions target, as the supply of low-carbon energy is not meaningfully constrained. Furthermore, as it does not compute the costs of each chosen system, the benefit from reducing demand in lowering overall system costs is not presented. While useful as a public engagement tool to explore long-term pathways in a transparent way, this lack of cost information limits the Calculator's current usefulness in exploring the trade-offs between different ways of achieving a low-carbon energy system.

Figure 3.6: MARKAL possible emissions trajectory (2000-2050)



On the path to a 90% cut in CO₂ in 2050 (relative to 1990), it suggests that an emissions trajectory of equal annual percentage reductions through the 2020s is feasible based on deep cuts in power sector emissions and extension of low-carbon power generation to other sectors, with use of limited sustainable bioenergy in niche markets (Figure 3.6).

In addition, the MARKAL analysis suggests that the cost-effective path to delivering a cumulative emissions budget requires early action. Specifically:

- Under a path with equal annual percentage reductions, marginal costs of emissions reduction in the 2020s are low relative to 2050 (this is because marginal costs increase with abatement effort as low-cost options are exhausted and notwithstanding that high-cost options may become cheaper in future with technology innovation – Figure 3.7).
- The analysis therefore suggests that equal annual percentage reductions are cost-effective when tested against more back-ended paths to deliver a given cumulative budget (Figure 3.8).

The modelling also suggests that deeper cuts than along the equal annual percentage reduction path through the 2020s would be possible. This could be useful as part of an increased UK contribution towards a global deal; we discuss whether this would be economically desirable in Section 9 below on the use of credits.

Figure 3.7: Trajectories of marginal costs for cumulative and non-cumulative MARKAL runs (2015-2050)

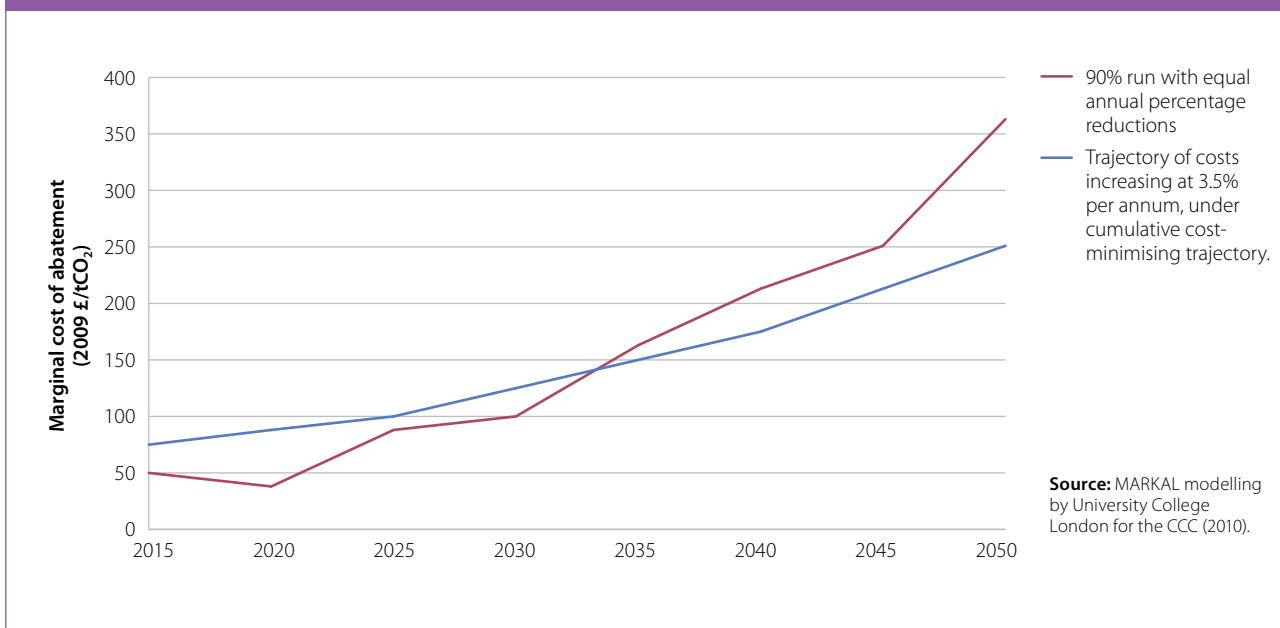
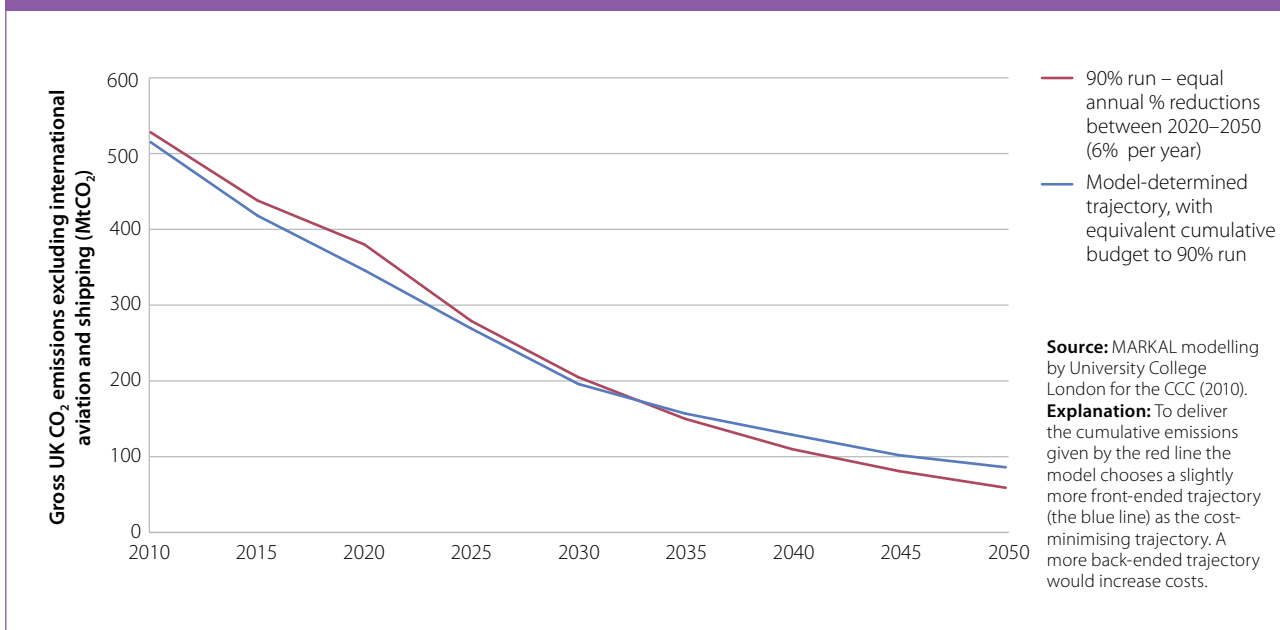


Figure 3.8: MARKAL emissions trajectory for a cumulative budget (2010-2050)

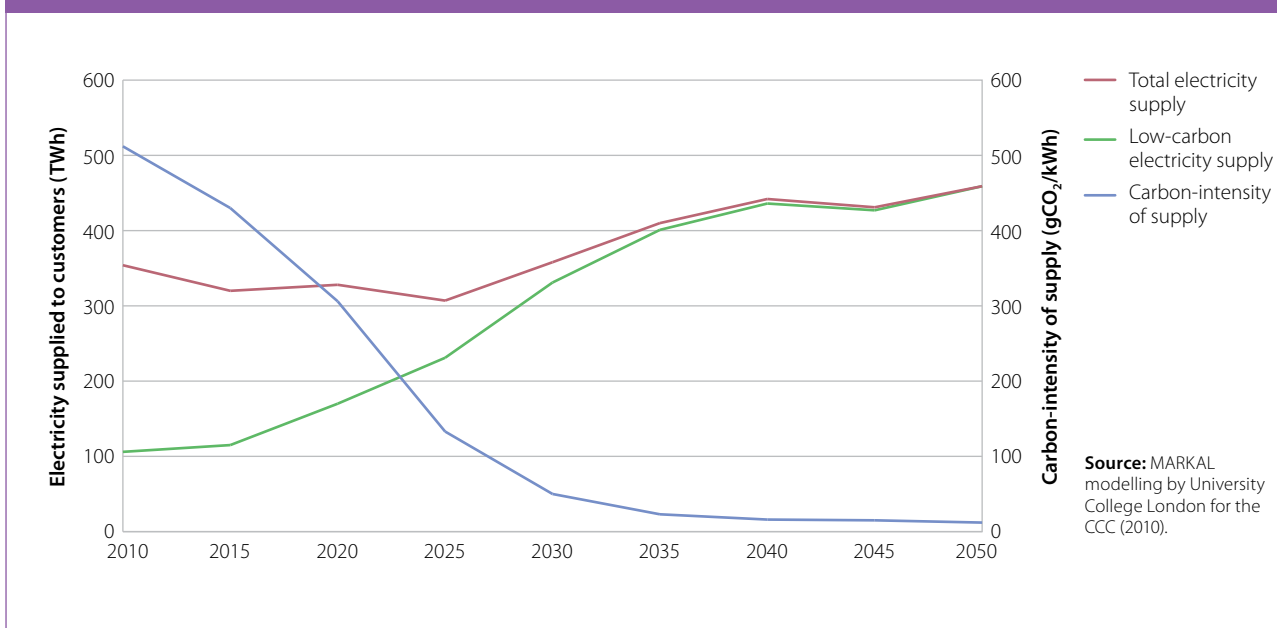


MARKAL modelling results – specific points

A number of specific points also emerge from the MARKAL analysis around the pace of emissions reduction in power generation, transport, and heat, the role for CCS in energy-intensive industry, and sectors where limited bioenergy is used to maximum economic benefit:

- The degree of heat and transport electrification by 2050 is such that the power sector may need to be around double today's size. This implies consistently high levels of investment in low-carbon capacity over the next four decades.

Figure 3.9: MARKAL trajectory for power sector (2010-2050)



- In order to meet the required path for electricity decarbonisation and sector expansion, power generation emissions should be well below 100 gCO₂/kWh in 2030 (e.g. around 50 gCO₂/kWh), compared to the current intensity of around 500 gCO₂/kWh (Figure 3.9). There are various alternatives for cutting emissions involving different combinations of nuclear, CCS and renewable generation. Whatever the combination, this should be added at a minimum build rate of 3 GW annually through the 2020s if the required path is to be achieved.
- There is a potentially crucial role for the use of CCS in heavy industry, especially in those applications where significant emissions result from chemical reactions as well as from fossil fuel combustion (e.g. iron and steel, cement). Deployment starts in the 2020s, becoming increasingly important in the period to 2050. This is particularly the case given a lack of alternative options for industry decarbonisation (see Chapter 5).
- In the near term, bioenergy yields maximum economic benefits when used in transport and heat for buildings. Towards 2050 it becomes increasingly important to use this finite resource to provide high-temperature heat in energy-intensive industries.
- There may also be an important role for combining bioenergy with CCS technology in the longer term⁸:
 - The inclusion of the option to co-fire bioenergy with fossil fuels in CCS plants is taken up both for coal CCS plants (co-fired with solid biomass) and gas CCS plants (running on a mix of biomethane and fossil natural gas).
 - The model also applies CCS to dedicated bioenergy power plants and to industrial boilers using biogas or solid biomass, to generate net negative emissions (i.e. less CO₂ is emitted to the atmosphere in combusting the bioenergy than was absorbed from the atmosphere in its growth).

⁸ We will address this option in more detail as part of our 2011 review of bioenergy – whilst it is taken up in the MARKAL modelling, resulting in a slightly carbon-negative power sector by 2050, it is not clear that this is essential or indeed desirable, given likely constraints on bioenergy supply and uncertainties over this currently untested technology.

6. Emissions reduction opportunities: bottom-up analysis

Reference emissions scenario

The starting point in our bottom-up analysis is to design a reference emissions scenario. This means no additional effort to reduce emissions after 2020 beyond those measures we have proposed as appropriate to deliver before 2020 in line with meeting the Intended budget (see section 1, above). Key emissions drivers in this scenario are GDP, population growth/household formation, and fossil fuel prices:

- **GDP.** Real GDP is projected to increase from £1.8 trillion in 2020 to £2.3 trillion in 2030 (compared to £1.4 trillion in 2009).
- **Population growth/household formation.** Projections for number of households are taken from CLG, based on ONS 2006-based mid-year population estimates. The number of households rises from 30 million in 2020 to 33 million in 2030 (compared to 26 million in 2009).
- **Fossil fuel prices.** We use DECC's central scenario for wholesale fuel prices (see Figure 3.5 above):
 - Gas prices increase from 69 p/therm in 2020 to 76 p/therm in 2030,
 - Oil prices rise from \$82/bbl in 2020 to \$92/bbl in 2030,
 - Coal prices remain broadly flat through the 2020s at around £51/tonne.

Given these assumptions, we project reference emissions to remain broadly flat through the 2020s decreasing slightly from 2020 to 2025 before rising again, resulting in 2030 emissions that are 33% below 1990 levels (9% below current levels).

We now use the reference projection as the starting point for our assessment of feasible and cost-effective emissions reduction potential.

Economy-wide abatement scenarios

We have developed economy-wide emissions reduction scenarios out to 2030 to inform suitable trajectories through the 2020s. These abatement scenarios are based on a bottom-up assessment against four criteria:

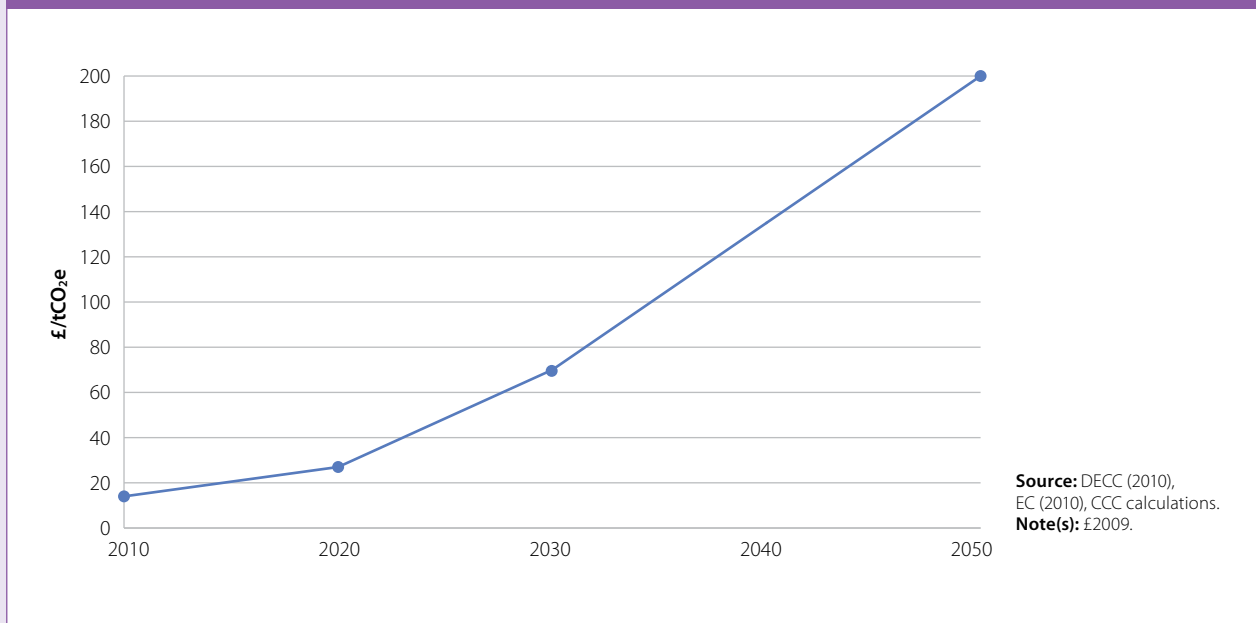
- **Feasibility.** We have considered feasibility of technological abatement options given technology readiness, capital stock turnover, policy effort and consumer acceptability.
- **Sustainability** of bioenergy in particular given tensions between use of land for growth of bioenergy feedstocks versus food, and possible air quality impacts from burning biomass.
- **Cost-effectiveness.** We have considered abatement options in terms of cost per tonne of CO₂ abated, and compared this with projected carbon prices for the 2020s and 2030s (Box 3.7).

- **Consistency with the 2050 target.** We should plan to achieve the 2050 target (which will require a reduction in CO₂ from sectors excluding international aviation and shipping of around 90% versus 1990 levels) largely through domestic effort. Given limits on scope for rapid penetration of low-carbon technologies (e.g. due to capital stock turnover, supply chain constraints), early action is required to be on track to meeting the 2050 target.

Box 3.7: Judging cost-effectiveness of abatement measures

In setting our scenarios we judge the cost-effectiveness of measures by reference to carbon price projections (based on the EC's projection for 2020 and DECC's central projection from 2030, as set out in chapter 2) across the asset lives of low-carbon investments. For example, the carbon savings from an electric vehicle purchased in 2025 will accrue from that year until the vehicle is replaced in the late 2030s (assuming an average lifespan of around 12 years for cars), and so the electric vehicle's cost-effectiveness would be compared to a carbon price rising from £45 in 2025 to £110 by 2036 (i.e. if the marginal cost of the vehicle is below £72/tCO₂ - the NPV of the rising carbon price - then it is considered to be cost-effective).

Figure B3.7: Carbon price projections (2010-2050)



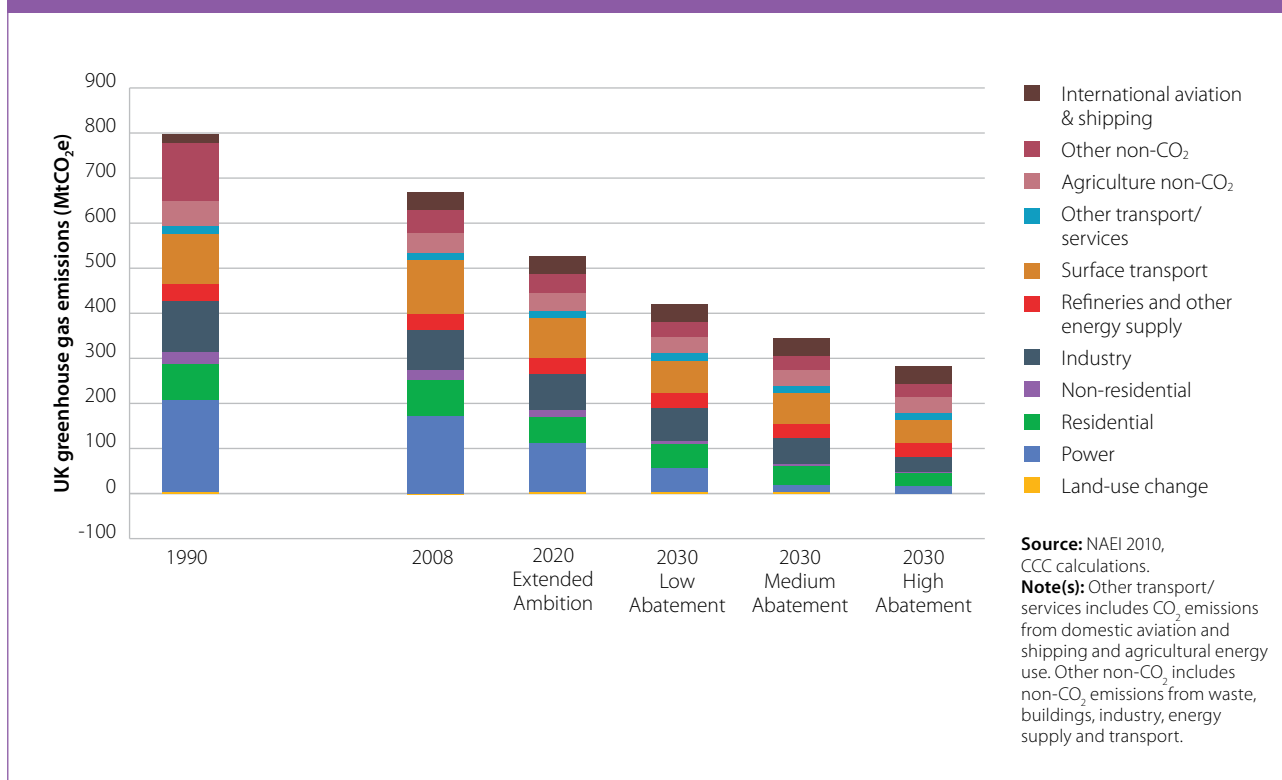
In chapter 2 (Box 2.5) we discuss difficulties with projecting the future carbon price, and conclude that the DECC central projection for the carbon price is a reasonable basis for judging cost-effectiveness. However, the carbon price could be higher, for example if complementarity rules limit trading between countries/regions.

A lower price is also possible (e.g. if global negotiations fail to achieve a deal that involves the early action that we suggest in chapter 2 would be optimal). However, it is unlikely that this would imply that the UK should plan for lower effort in the 2020s:

- Lower effort to 2030 would close down options that will be required on the path to 2050 (see section 8 below).
- A low carbon price in earlier years resulting from less than optimal early action would require more action in later years, bringing with it a higher carbon price, so that the cost-effectiveness across the asset lives of long-lived measures may be relatively unchanged.
- A low carbon price that reflects higher fossil fuel prices or lower costs for low-carbon technologies is likely to be accompanied by reduced relative costs of domestic abatement options for the UK.

Therefore, comparing cost-effectiveness against the carbon price across asset lives is likely to identify a set of measures that are broadly desirable across a range of scenarios.

Figure 3.10: Economy-wide abatement scenarios



We have constructed three abatement scenarios based on our detailed sectoral assessments in chapters 4 to 7. The scenarios meet the criteria above to differing degrees, and reflect different assumptions on technology innovation, policy effort and public acceptability:

- **Low abatement.** Our Low abatement scenario reflects limited uptake of key low-carbon technologies. This could be because currently promising technologies do not perform well or are more expensive than expected, or because there is limited policy effort to support demonstration and deployment of new technologies.
- **Medium abatement.** Our Medium abatement scenario reflects significantly increased penetration of low-carbon technologies across the economy, which would require technology innovation, cost reduction and policy effort.
- **High abatement.** Our High abatement scenario pushes the limits of what is potentially feasible (e.g. it involves very large emissions reductions from CCS in industry as well as in the power sector), sustainable (e.g. in the case of biofuels and biomass) and cost-effective (e.g. significant battery cost reductions would be required to support the very high penetration of electric vehicles in this scenario).

Our three abatement scenarios involve different levels of electrification of heat and transport, low-carbon generating capacity, energy efficiency, technology deployment, and use of bioenergy (Table 3.5). They achieve emissions reductions in 2030 of 51%, 60% and 69% relative to 1990 (Figure 3.10) when we include assumptions for reductions in non-CO₂ gases (Box 3.8).

Table 3.5: Key assumptions in economy-wide abatement scenarios

		2008	2020	2025 Medium abatement	2030 Medium abatement	2030 Low abatement	2030 High abatement
Power							
Demand (TWh)		319	325	355	425	385	435
gCO ₂ /kWh		544	320	150	50	130	40
Low-carbon capacity (GW)		16	26	33	58	34	59
Heat							
Solid wall insulation (million homes)		not available but estimated 5% stock	2.0 million	2.75 million	3.5 million	2.0 million	5.7 million
Heat pumps (TWh heat served)	Residential	544	10 (3%) (0.6 m homes)	33 (10%) (2.6 m homes)	81 (25%) (6.8 m homes)	26 (8%) (2.3 m homes)	97 (32%) (8.0 m homes)
	Non-residential		22 (22%)	42 (41%)	62 (59%)	51 (49%)	57 (54%)
	Industry (space)		3 (10%)	10 (36%)	17 (57%)	15 (53%)	16 (55%)
Biomass boilers (TWh heat served)	Residential	around 1%	<1 (<1%) (<0.1 m homes)	2 (1%) (0.3 m homes)	7 (2%) (0.9 m homes)	<1 (<1%) (<0.1 m homes)	11 (4%) (1.3 m homes)
	Non-residential		6 (6%)	6 (6%)	6 (6%)	7 (6%)	6 (6%)
	Industry (space)		2 (6%)	2 (6%)	2 (5%)	2 (6%)	1 (5%)
	Industry (process)		17 (13%)	26 (20%)	37 (25%)	24 (16%)	41 (28%)
Biogas			8 (1%)	17 (3%)	27 (4%)	27 (4%)	46 (8%)
DH		not available	6 (1%)	7 (1%)	9 (2%)	9 (1%)	40 (7%)

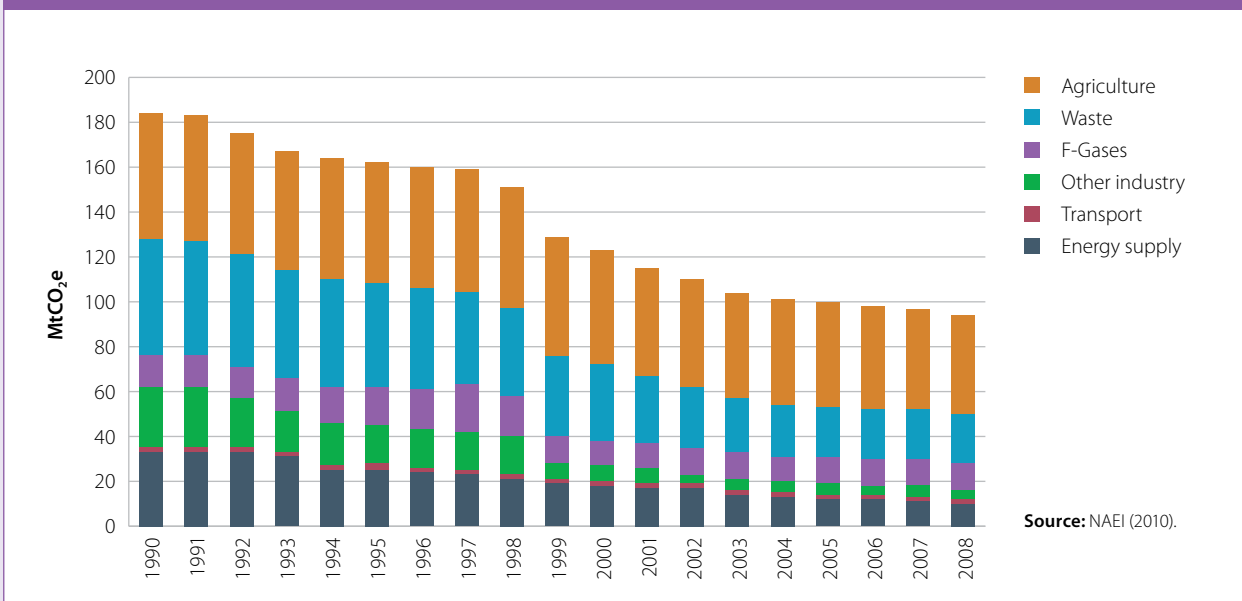
Table 3.5: Key assumptions in economy-wide abatement scenarios							
		2008	2020	2025 Medium abatement	2030 Medium abatement	2030 Low abatement	2030 High abatement
Transport (cars/vans/HGVs)							
Billion vehicle-km (inc. savings)	Car	418	420	440	460	460	460
	Van	69	90	100	110	110	110
	HGV	30	32	31	31	33	29
Smarter Choices savings	Car	0%	5%	5%	5%	5%	5%
Freight logistics savings	HGV	0%	0%	3.5%	6.5%	0%	13%
New conventional vehicle gCO ₂ /km	Car	158	110	90	80	80	70
	Van	206*	150	140	120	120	120
	HGV	799**	750	660	580	580	580
% electric cars/vans	new vehicles	0%	16%	31%	60%	16%	85% (95% inc. FVCs)
	stock	0%	5%	14%	31%	15%	37%
	vkm	0%	5%	14%	31%	15%	37%
% biofuels by energy***		3%	8%	9%	11%	10%	25%
Source: CCC analysis * 2009 value (no available estimates for 2008) ** Average of estimated g/km for small and large rigid and articulated HGVs *** Percentage emissions reductions from biofuels are calculated before demand-side measures							

Box 3.8: Non-CO₂ scenarios

Chapter 7 of this report sets out emissions reduction potential in the agriculture sector during the 2020s, estimated to be around 5 MtCO₂e under the Medium abatement scenario, rising to 7 MtCO₂e under the High abatement scenario.

The other key sources of non-CO₂ emissions are waste, F-gases, industry, transport and energy supply (Figure B3.8). The main driver of emissions reduction in the waste sector has been falling emissions from landfill sites. Other areas where emissions have fallen significantly are industrial processes due to the introduction of low-carbon technologies to abate N₂O emissions, and fugitive emissions from the gas distribution network and coal mines.

Figure B3.8: Non-CO₂ emissions by sector (1990-2008)



Waste

Waste emissions relate primarily to landfills (around 90%). Methane emissions from landfill generate 40% of the UK's methane emissions, and 3% of all the UK's greenhouse gas emissions. Landfill emissions result as food, paper and other rotting rubbish biodegrades without oxygen, thus producing methane.

Emissions from the waste sector have declined 57% over the period 1990-2008. 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. We estimate that methane emissions from waste could decline by a further 2-4 MtCO₂e between 2020 and 2030 as waste is diverted away from landfill in line with analysis set out in our 2008 report.

F-gases

Emissions of F-gases come primarily from buildings. They are used in applications such as refrigerators, inhalers, fire extinguishers and air conditioning. F-gas emissions from buildings increased significantly during the late 1990s and 2000s (rising from 2 MtCO₂e in 1995 to 12 MtCO₂e in 2008). This was due to the Montreal protocol phasing out the use of ozone-depleting gases, which were then replaced with HFCs. Over the same period F-gas emissions from industrial processes were declining (from 15 MtCO₂e in 1995 to close to zero in 2008).

We estimate that F-gas emissions from buildings could decline by around 3 MtCO₂e between 2020 and 2030, as F-gases are replaced by alternative coolants and leakage is reduced (e.g. as set out in our 2008 report).

Industry

The majority of non-CO₂ emissions from industrial processes are from nitrous oxide (N₂O). Historically, there has been a significant fall in industrial process N₂O emissions due to the installation of abatement equipment at nitric and adipic acid plants (falling from 25 MtCO₂e in 1990 to 2 MtCO₂e in 2008).

We assume that N₂O emissions from industrial processes will decline a further 0.2 MtCO₂e between 2020 and 2030, based on the Government's emissions projections and our analysis of abatement opportunities in industry.

Box 3.8: Non-CO₂ scenarios

Transport

Non-CO₂ emissions in the transport sector, mainly N₂O, are very low (around 1.6 MtCO₂e in 2008). Historical emissions have been revised downwards due to changed assumptions on the performance of catalytic converters.

As more electric vehicles penetrate the fleet, non-CO₂ emissions from transport will decline. We estimate that transport non-CO₂ emissions will fall by 0.4 MtCO₂e between 2020 and 2030 under our Medium abatement scenario for measures that reduce CO₂ emissions from transport.

Energy Supply

Methane is the main non-CO₂ gas emitted in the energy supply sector. Emissions have fallen from 29 MtCO₂e in 1990 to 8 MtCO₂e in 2008. A fall in coal mine methane emissions (due to industry decline) and a decrease in fugitive emissions from natural gas (due to gas pipe replacement), are the two main contributors to declining historic emissions.

We assume that coal mine methane and fugitive natural gas emissions will continue to decline, by around 1.5 MtCO₂e between 2020 and 2030, based on the Government's emissions projections.

Non-CO₂ scenarios

Table B3.8 summarises the reduction in non-CO₂ emissions that we estimate is possible through the 2020s. This is included alongside our CO₂ scenarios to give an overall GHG emissions reduction across the economy. In order to deliver this reduction, Government will need to ensure that a suitable policy framework is in place.

Table B3.8: Scenario assumptions for non-CO₂ GHGs, MtCO₂e

Sector	2008	2020	2030 Low abatement	2030 Medium abatement	2030 High abatement
Agriculture	44	41	37	36	34
Waste	22	20	18	17	16
F-gases	12	8	5	5	5
Industry	4	2	2	2	2
Transport	2	2	1	1	1
Energy Supply	10	8	6	6	6
TOTAL	95	82	69	67	64

Source: CCC analysis, NAEI (2010).

In the waste sector, Government plans to publish a Waste Review in spring 2011 and also aims to introduce new measures to promote use of anaerobic digestion. Reduction in F-gases will be driven by EU legislation and, in the energy supply sector, methane from disused coal mines will continue to decline and fugitive emissions from the gas network should fall as pipe replacement work continues.

Uncertainty

There is considerable scientific and analytical uncertainty regarding the modelling of non-CO₂ emissions, including modelling of abatement potential. For example, methane emissions in the waste sector are determined by waste that was landfilled many decades ago, for which good data do not exist. They are also subject to assumptions on the level of methane that is captured at landfill sites and data on which to base these assumptions is currently very limited. However, as measures are implemented across sectors to reduce CO₂ emissions, non-CO₂ emissions will begin to make up an increasing proportion of total GHGs. It is therefore important that measures to abate non-CO₂ gases are implemented alongside work to improve the modelling of these emissions. In many cases it is clear that abatement activities will reduce emissions, notwithstanding the significant uncertainties over precise impacts or indeed over the current level of emissions. The analysis for this report has been based on currently published non-CO₂ emissions trends and projections. We note that DECC plan to publish updated data very shortly.

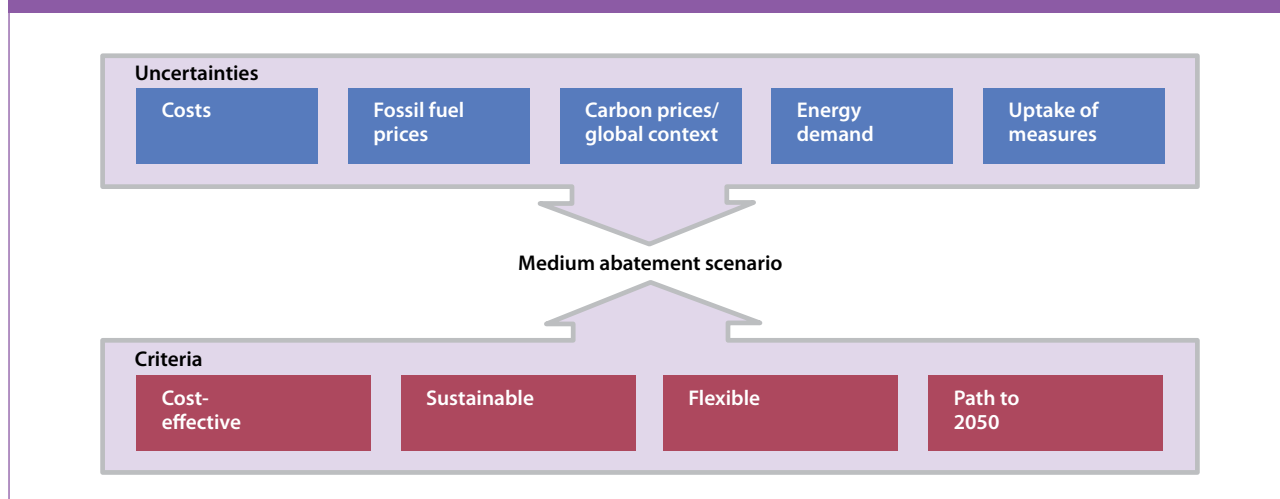
Developing options for reducing UK emissions

It is neither necessary nor appropriate to specify in advance a precise technology mix in each sector. However, it is important to plan now and put policies in place to drive emissions reductions in the 2020s, given the long lead times for investments and technology innovation. Planning and new policies are required to develop options across all of the key emitting sectors, in order to manage costs and risks of meeting carbon budgets against the many current uncertainties (e.g. required UK effort towards a global deal, the level of the carbon price and of fossil fuel prices, low-carbon technology costs, consumer acceptability).

Our Medium abatement scenario is our best estimate of the appropriate level of ambition to plan for in the 2020s. It would deliver significant progress to 2030, and sufficiently develop options ahead of 2050 without committing to unnecessary costs:

- The Medium abatement scenario includes feasible measures expected to be cost-effective against projected carbon prices and technology costs (see Box 3.7, above).
- Planning for the Medium abatement scenario would maximise flexibility and balance the costs and risks of under- and over-investment (Box 3.9 and Figure 3.11):
 - **Flexibility.** It would keep a range of other abatement scenarios in play. This could be useful both in terms of overall effort (e.g. allowing the possibility of delivering an international contribution of equal annual percentage reductions through increased domestic ambition) and in terms of the scenario composition (e.g. with the opportunity to increase effort in areas like district heating, should more cost-effective abatement prove to be available, and to switch to alternative approaches, like hydrogen cars, where barriers cannot be overcome).

Figure 3.11: Approach to uncertainty



- **Risks.** Planning for a lower level of ambition would carry three risks. It could result in investment in high-carbon assets in the period to 2020 which, while compatible with meeting the first three budgets, would impede further progress in the 2020s. It could fail to develop adequately technologies that will be required in the 2020s. It could also fail to put appropriate policies in place far enough in advance of the fourth budget, resulting in limited investments with long lead times and limited supply chain expansion. It could therefore necessitate scrapping of high-carbon assets and/or the purchase of high-cost carbon credits in the 2020s.
- **Costs.** Planning for higher abatement could significantly increase costs without a clear benefit in reducing post-2030 costs of meeting the 2050 target. This could become desirable in the future (e.g. depending on technology innovation and/or in the context of a global deal).
- The Medium scenario, if delivered, would put the UK on a path to achieving the 2050 target largely through domestic effort. This would require continued progress in key sectors such as power, electric vehicles and heat, with accelerated progress in other sectors such as HGVs and industry (see section 8 below). Lower cuts through the 2020s would not sufficiently develop abatement options required in subsequent periods, and would leave a need for very challenging and expensive emissions reductions beyond 2030, whilst higher cuts do not appear necessary and would involve additional costs on the path to 2050.

Box 3.9: Medium abatement as a suitable scenario to develop options for the 2020s

Planning is needed now given long lead times for some low-cost abatement options. A failure to develop these options would increase future costs:

- In chapter 4 we estimate that delaying the roll-out of electric vehicles by five years would have a net present value cost of over £5 billion when the extra credit purchase incurred is included (Box 4.8).
- A failure to increase build rates for nuclear would incur an annual cost of £1.1 billion in 2030 (and increasing thereafter) for every 5 GW shortfall in nuclear capacity installed as investment would revert to gas-fired plant instead, which would have to cover the costs of its carbon emissions and is likely to be scrapped early once low-carbon build rates do increase.
- More generally, and at the extreme, if all the abatement in our Medium abatement scenario was replaced by credit purchase this would result in rapidly escalating costs after 2030 as the carbon price rises.

It could be feasible and cost-effective to go beyond the Medium abatement scenario (e.g. by delivering elements of the High scenario), in particular if the carbon price turns out higher than expected and/or if low-carbon technologies develop better than expected (i.e. with lower costs, better performance or wider applicability). It may also be necessary to go further with certain abatement measures as a 'plan B', should current expectations for abatement opportunities prove optimistic in some cases. The Medium abatement scenario keeps these possibilities open, which would essentially involve wider deployment of the same measures:

- The Medium abatement scenario aims for mass-market deployment of electric vehicles and heat pumps, from which it would be plausible to increase penetration to higher levels,
- It requires at least some development and deployment of the key future technologies that would be rolled out further in the High abatement scenario (e.g. hydrogen for large vehicles, CCS in power and in industry, district heating, abatement in agriculture).

7. Advice on the fourth carbon budget

Level of the fourth budget and indicative 2030 target

We follow the approach in our advice on the first three carbon budgets, and set out two budgets for the fourth period (Table 3.6, Figure 3.12):

- **Domestic Action budget.** This is a budget to be achieved through domestic emissions reduction effort; it is based on our assessment of the feasible and cost-effective path through the 2020s to the 2050 target, as in our Medium abatement scenario above. The fourth carbon budget along this path is 1950 MtCO₂e. It embodies an emissions cut of 50% in 2025 relative to 1990 levels (32% relative to 2009) on the path to an indicative 2030 target of 60% cut in emissions relative to 1990 levels (46% relative to 2009).
- **Global Offer budget.** This is our indicative assessment of a minimum appropriate UK contribution to required global emissions reductions through the 2020s. The fourth carbon budget along this path is 150 MtCO₂e tighter than the Domestic Action budget at 1800 MtCO₂e, on the path to a 63% cut in 2030 relative to 1990 levels (50% relative to 2009).

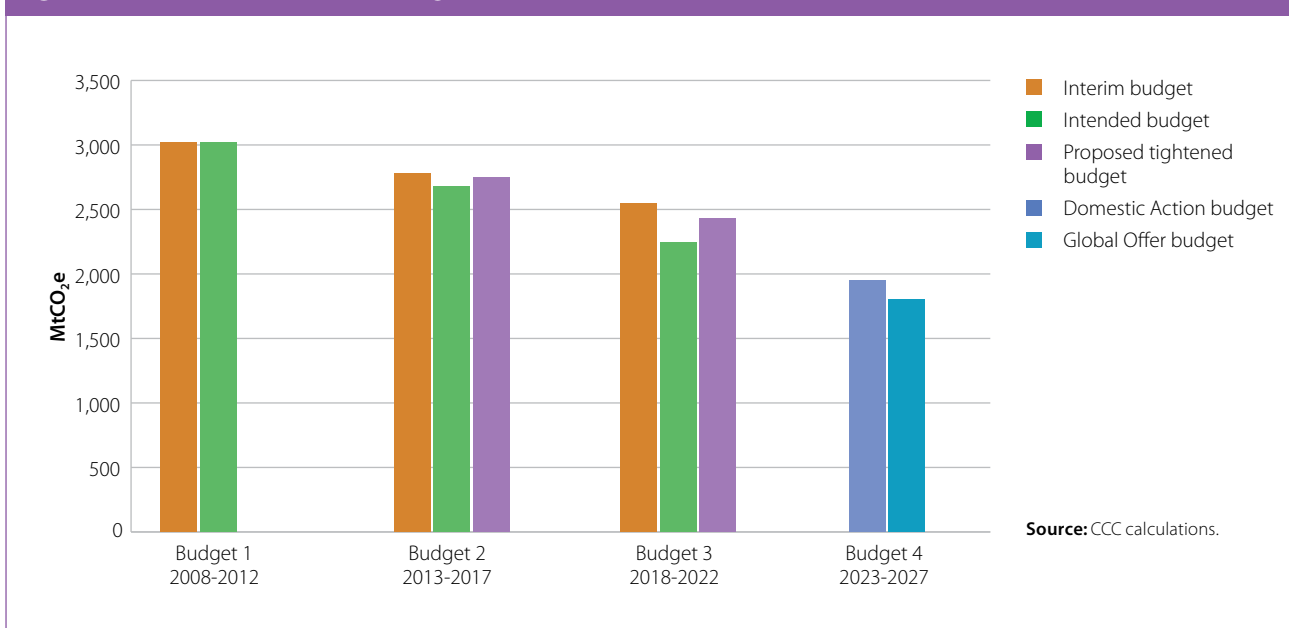
Table 3.6: Recommended options for the fourth carbon budget and 2030 emissions target

	2025	2030	Indicative 2050 emissions	The fourth budget 2023-2027
Global Offer GHG	360	288	118	1800
Domestic Action GHG	390	310	118	1950
Medium abatement scenario CO ₂	315	240	60-70	1580
Medium abatement scenario non-CO ₂	75	70	e.g. 55	370

Source: CCC analysis.

Note: GHG = greenhouse gases, excludes international aviation and shipping.

Figure 3.12: First four UK carbon budgets (2008-2027)



We recommend that the Domestic Action budget is now enacted. Under the Climate Change Act this budget will legally commit the UK to keeping net emissions (i.e. emissions adjusted for any net credit purchase in EU ETS or in global carbon markets) below the defined level. But the Domestic Action budget will only be a feasible stepping stone to the 2030 and 2050 targets if it is met on a gross basis (i.e. if the UK's domestic emissions are at or below this level). We therefore recommend that, alongside legislating this budget, the Government commits to bring forward policy measures which will make it attainable without the purchase of credits.

- We would expect part of the Government's response to this advice required under the Climate Change Act to be to set out a strategy including policies for development of the key options in this report, as highlighted in the concluding sections of chapters 4-7.
- Under the assumptions in our Medium abatement scenario, such a strategy would deliver a split for the fourth budget period (2023-2027) with 35% (690 MtCO₂e) of emissions in those sectors of the economy covered by the EU ETS (based on 2020 coverage) and 65% (1260 MtCO₂e) in the non-traded sectors of the economy. This compares to a traded/non-traded split of around 40%/60% for the first three carbon budgets.

It is important to recognise that the recommended budget requires steady acceleration of progress over time. Our proposed pace of progress through the 2020s is significantly faster than that required to meet carbon budgets in the 2010s, and faster still in the late 2020s and between 2030 and 2050. This is reflected in total required emissions reductions of 46% between 2009 and 2030 and 62% between 2030-2050. This acceleration is acceptable given the range of available technologies likely to be available through the 2020s and from 2030 to 2050. But the Committee judges any further 'back-ending' of the reduction path (i.e. a less ambitious budget, requiring further acceleration towards the end of the 2020s) would risk making the indicative 2030 target unattainable, which would in turn put the 2050 target at risk (see Section 8 below).

In addition, our recommended budget is based on uncertain reference emissions projections from the DECC Energy Model. The Committee has concerns that this model underestimates the long-term impact of the recession, particularly in the case of industry emissions projections. Therefore our reference emissions projections may be too high, in which case a tighter budget would be appropriate. We will work with DECC in 2011 to try to resolve this issue.

Therefore for these two reasons – back-ending and uncertainty over emissions projections – the recommended budget should be regarded as an absolute minimum level of ambition. This could be adjusted over time, and the precise mix of abatement options determined, as uncertainties over emissions projections and abatement opportunities are resolved. One opportunity for such an adjustment would be in the context of moving from the Domestic Action budget to the Global Offer budget.

8. The path from 2030 to 2050

The challenge from 2030

In the previous sections, we considered the feasible path of emissions reduction in the 2020s, and recommended a Domestic Action fourth budget for 2023-2027 on the way to a Domestic Action indicative 2030 target. These are likely to be attainable at acceptable macroeconomic cost (see Section 10 below on costs). We need to check, however, if this target and budget are sufficiently ambitious to make achieving the 2050 target feasible, given the further reductions that would be required between 2030 and 2050.

Given delivery of the Medium abatement scenario to meet the Domestic Action budget without purchase of credits, remaining UK emissions in 2030 would still be 310 MtCO₂e (excluding IA&S). Further reductions of around 200 MtCO₂e would then be required to meet the 2050 emissions target through domestic action (Figure 3.13).

To understand the scale and sectoral mix of further reductions required beyond 2030, it is useful to be clear about how emissions scenarios for progress vary by sector. Reductions achieved by 2030 in our Medium abatement scenario vary from over 90% below 2008 levels in power generation, to 56% in buildings and 43% in surface transport, to only 28% in industry (including refineries and other energy supply) and just 19% in agriculture.

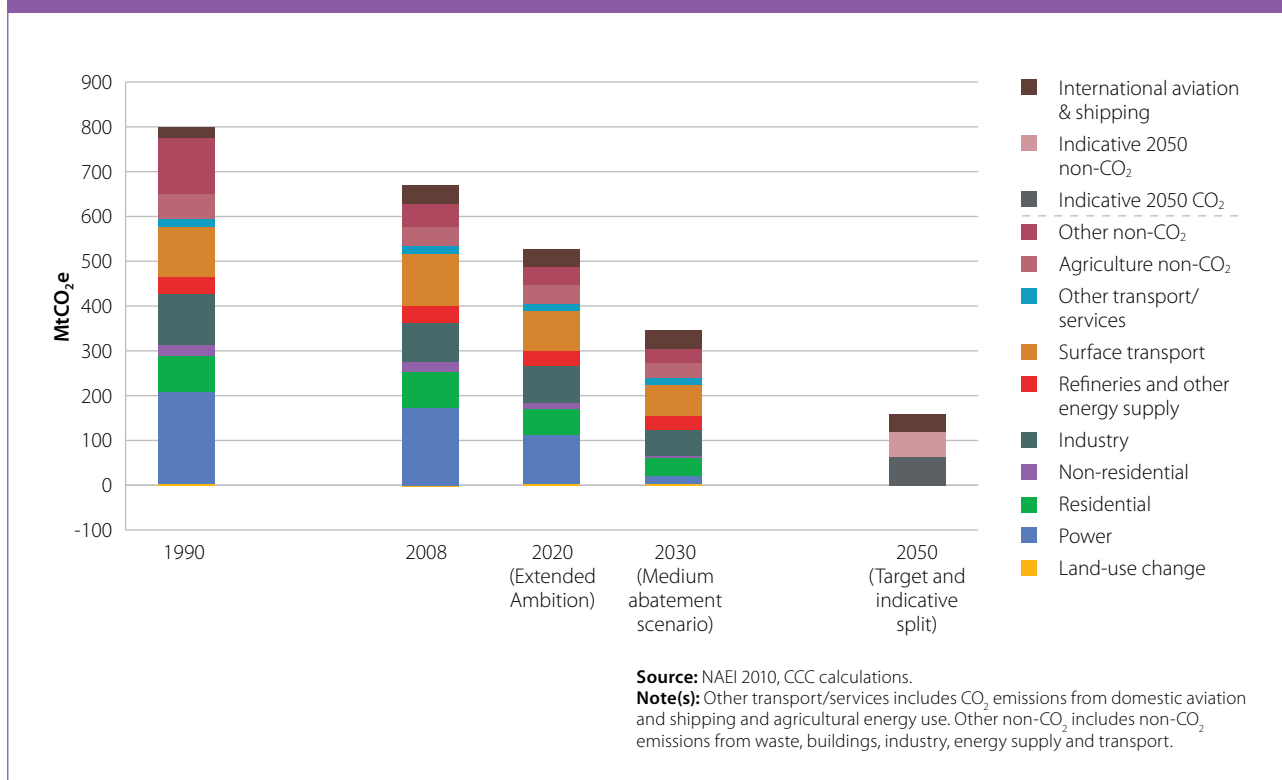
Options from 2030 to 2050

Reductions beyond 2030 will require both a move to near full decarbonisation of those sectors where this is technologically possible, and significant emissions reductions in industry and agriculture, two sectors where radical reductions pre-2030 may prove more difficult to achieve. While it is not possible or necessary to specify what mix of technologies and/or consumer behaviour change will provide the optimal path to reductions over the 2030-50 period, the following review of potential options suggests that the 2050 target of 160 MtCO₂e (around 120 MtCO₂e excluding IA&S) could be attained from the 2030 starting point defined by our indicative target:

- **Power sector.** Power sector emissions are reduced to low levels in 2030 under the Medium abatement scenario. Further reductions will be required to 2050, such that the sector is close to zero emissions (or even negative emissions if biomass generation with CCS features significantly). At the same time, demand is likely to increase considerably in line with increased penetration of electric vehicles and heat (e.g. from around 425 TWh in 2030 to well over 500 TWh total annual consumption in 2050)⁹. Continued investment in new power generation between 2030 and 2050 (e.g. at the rate assumed for the 2020s, 3-4 GW per annum) would be necessary to complete the decarbonisation of the power system and to meet likely increasing demand.

⁹ MARKAL modelling by University College London for the CCC suggests that power generation may need to increase to around 515 TWh per year by 2050, compared with today's 372 TWh per year, an increase of around 40%. DECC's 2050 Pathways work includes six indicative scenarios that meet the 2050 target, with power generation ranging from 744 (Scenario C) to 972 (Scenario F) TWh per year in 2050, i.e. an increase of 100-160% on today's system.

Figure 3.13: UK greenhouse gas emissions (1990-2050)



- **Buildings.** Direct emissions from heat in buildings are reduced significantly by 2030, as a result of major improvements in energy efficiency and roll-out of low-carbon heat, especially heat pumps. Beyond 2030, further reductions are required, through energy efficiency improvement, further deployment of heat pumps where suitable (e.g. to cover around 60% of homes and the large majority of non-residential buildings), possibly combined with conventional electric heat and a potentially important role for district heating in those built-up urban areas for which heat pumps are not suitable. A feasible pace of deployment could almost fully decarbonise heat in buildings by 2050.
- **Surface transport.** Emissions from this sector remain a large share (22%) of total emissions in 2030 under the Medium abatement scenario. However, this would fall through the 2030s and 2040s with increasing penetration of electric vehicles (e.g. with 100% penetration of pure electric cars and vans in new sales by 2035, there would be no emissions from these vehicles in 2050). Alternatively, if the experience to 2030 suggests limits to penetration of electric vehicles, there could be scope for increased penetration of hydrogen cars and vans. HGVs could be decarbonised through hydrogen produced from low-carbon sources (e.g. electrolysis using low-carbon electricity, pre-combustion CCS or bioenergy). Biofuels could meet any residual demand for liquid fuels, for example, from plug-in hybrid vehicles or those HGVs not using hydrogen, but should not be relied upon as the main decarbonisation strategy given sustainability concerns.
- **Industry.** By 2050 we would expect available biomass and biogas to be used in industry rather than residential and commercial buildings, where electrification would dominate. In addition, there should be scope for reducing industry emissions through deployment of CCS in the 2030s. Together these options could reduce industry emissions to close to

40 MtCO₂ in 2050. Further abatement potential may be available through electrification, product substitution (e.g. to low-carbon construction materials such as wood, in place of carbon-intensive materials like steel and cement), and restructuring of the refinery sector as downstream demand is reduced.

- **Agriculture.** With no further emissions reductions beyond 2030, non-CO₂ emissions from agriculture would be around 35 MtCO₂e. Emissions at this level, combined with those from other difficult to reduce sectors (e.g. IA&S, industry), would make the overall target of 160 MtCO₂e extremely difficult to attain. A long-term plan to achieve more radical agricultural emissions reductions will therefore be needed. Further work is required to identify the options for additional reductions, and the policy levers needed to ensure implementation, but these options may need to include radical and controversial measures on both the supply side (e.g. the use of GM organisms) and in consumer behaviour (e.g. waste reduction or rebalancing of diet).
- **Other non-CO₂ emissions.** Residual emissions of other non-CO₂ gases in 2030 (i.e. from waste, buildings, industry, energy supply and transport) would be around 30 MtCO₂e. Options to reduce emissions further to 2050 include further diversion of waste from landfill, reduction of energy supply and transport non-CO₂ emissions as fossil fuel use is reduced, and phasing out use of F-gases.

In addition it is important to remember that while the UK is now committed to keep aviation emissions in 2050 no higher than 2005 levels, and while we have assumed that the same is true for the UK's international shipping emissions, strong policy action and significant technological development is required to meet these targets. The policies and technologies required in aviation are set out in our December 2009 report *Meeting the UK aviation target*; those required in shipping will be set out in our review of international shipping emissions in 2011.

Domestic Action indicative 2030 target as a minimum ambition on the path to 2050

As noted above, the recommended budget and the indicative 2030 target imply accelerated progress from 2020, with further acceleration in the late 2020s, and from 2030 to 2050. This can be justified given abatement opportunities from 2030, provided key enabling technologies and conditions (in particular a largely decarbonised power sector) are by then in place. But setting a lower level of ambition to 2030 and for 2023-2027 would require a very challenging pace of annual emissions reduction from 2030, given rates of capital stock turnover, feasible investment levels, and new technology deployment:

- At the economy-wide level, the Stern report suggested that annual emissions reductions beyond even 3% would be very challenging .
- Lower ambition on key abatement options would be incompatible with meeting the 2050 target, based on current understanding of sectoral opportunities:
 - As noted above, decarbonisation of surface transport requires that all new vehicles beyond 2035 should be ultra low-carbon; this implies the need for very significant penetration of ultra low-carbon vehicles by 2030.

-
- A similar point applies to low-carbon heat, given a fifteen-year period for turnover of the boiler stock.
 - Deep decarbonisation of the power sector is required through investment in low-carbon technologies through the 2020s, given asset lives of forty years or longer.
 - Some progress in less well understood areas (e.g. agriculture and industry) will be required to lay the foundations for potentially more radical options beyond 2030.
 - The DECC 2050 pathways scenarios reflect the need for deep cuts in emissions by 2030 on the path to 2050, and actually include more aggressive emissions reductions to 2030 than in our Medium abatement scenario (e.g. the range for emissions excluding international aviation and shipping in 2030 in the DECC scenarios is 248-297 MtCO₂e, compared to our indicative Domestic Action target for 2030 of 310 MtCO₂e).

Overall therefore, our conclusion is that there is a feasible pathway from our 2030 indicative target of 310 MtCO₂e (excluding IA&S) to the required 2050 target (160 MtCO₂e in total, but around 120 MtCO₂e excluding IA&S). But any less stretching target for 2030 risks making the 2050 goal unachievable over the subsequent 20 years.

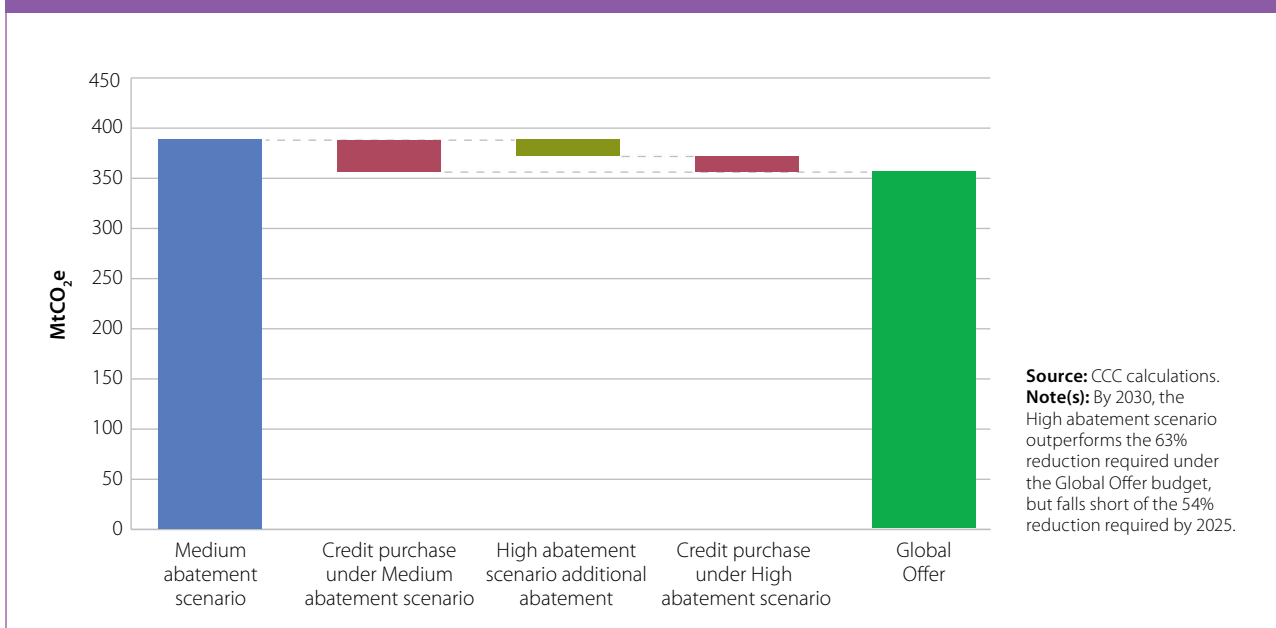
9. Role for purchase of offset credits

In our 2008 report we noted that there should be limited reliance on purchase of offset credits. Specifically a minimum level of domestic action is required in developed nations in order to ensure sufficient progress towards delivering longer-term (i.e. 2050) targets largely through domestic emissions reduction. In addition, developed nations should demonstrate that a low-carbon economy is possible and compatible with economic prosperity.

- In the longer term all countries will need to be on a strong downward emissions path, so opportunities to exploit low-cost abatement opportunities elsewhere will reduce.
- Differences in production technologies across countries are likely to be reduced over time by the global flow of capital and technology.
- Therefore the vast majority of the required 80% reduction by 2050 would have to be achieved through domestic abatement.

However, during the transitional period, credit purchase and the accompanying financial flows could reduce the cost of meeting carbon budgets, help in negotiations towards a global deal and bring forward emissions reductions in developing countries. Therefore, whilst it is important to deliver a minimum level of emissions reductions domestically, it may also be appropriate to supplement this with credit purchase – we reflect this in our advice on credit purchase under our proposed budgets:

Figure 3.14: Options for delivering the Global Offer budget in 2025



Credit purchase to meet the Domestic Action budget

The **Domestic Action budget** is designed to reflect emissions reductions that are available domestically and are cost-effective given our projection of the global carbon price and on the path to meeting the 2050 target. It will have to be achieved largely through domestic action. Therefore there should be no planned purchase of credits (either by government or private firms) to meet the Domestic Action budget.

Credit purchase to meet the Global Offer budget

The **Global Offer budget** goes further than this level of domestic abatement, with a gap in 2025 (i.e. the mid-year of the budget) of around 30 MtCO₂e (Figure 3.14). This gap could be closed through credit purchase, which would cost 0.1% of GDP at our central projection of a carbon price around £45/tCO₂ in 2025 (see Chapter 2). Further credit purchase could be appropriate depending on specific financing solutions as part of a future global deal (e.g. if the UK emissions constraint is tighter than the Global Offer budget).

Alternatively the Global Offer budget could be met by increasing domestic effort through measures in the High abatement scenario, with reducing credit purchase at the margin. Whilst the feasibility and cost of delivering these extra measures are currently uncertain (see section 6 above), they are likely to be desirable if future carbon prices are towards the high end of the range of projections.

10. Costs and investment requirements

Cost of meeting the Domestic Action budget

Using a resource cost methodology (i.e. based on summing the direct additional costs of implementing measures to reduce emissions), we estimate that the Domestic Action budget and indicative 2030 target are technically feasible at a cost of under 1% of GDP (Table 3.7):

- The first step in estimating the resource cost is to multiply emissions reductions by abatement costs for each measure implemented through the 2020s, giving a cost of the order 0.5% of GDP in 2030.
- We add to this the cost of measures to deliver 2020 ambition which will still be in place by 2030 and cost of the order 0.2% of 2030 GDP. This gives a total cost of around 0.6% of GDP in 2030¹⁰.
- The average annual cost of meeting the fourth carbon budget for 2023-27 is similar to that for the 2030 emissions reduction (as the level of abatement continues to increase beyond the budget period, offset by reductions in technology costs with learning). We estimate that the annual resource cost in 2025 (i.e. the middle year of the fourth budget period) is also around 0.6% of GDP.

Various uncertainties exist around these cost estimates, but the order of magnitude of the estimated cost is likely to be fairly robust (Table 3.8):

- Based on sensitivities for capital costs of abatement options, we estimate a range for the cost of meeting the budget in 2025 of around 0.3-0.8% of GDP.
- Based on fossil fuel price sensitivities, we estimate a range for the cost of meeting the budget in 2025 of around 0-0.7% of GDP. We also note that although the relative cost of low-carbon options generally increases in a low fossil fuel price world, the overall affordability of energy improves.
- Whilst we have not undertaken detailed macroeconomic modelling for this report, we consider the resource cost estimates presented above to capture the most important elements of the GDP cost. This reflects the findings of our macroeconomic modelling in 2008, which suggested a range of costs, which the resource cost estimate fell within:
 - HMRC's general equilibrium model suggested that the GDP cost would be slightly below the resource cost,
 - The Cambridge Econometrics macroeconometric model suggested that the cost would be higher than the calculated resource cost. Since the Cambridge model does not include any automatic mechanism for the economy to return to full resource use we suggested in 2008 that some of the additional effects might be considered as 'transitional'.

¹⁰ Figures do not sum due to rounding.

- Our estimates are comparable to other available cost estimates:
 - Our MARKAL analysis also suggests costs of under 1% of GDP in 2030,
 - In the recent World Energy Outlook 2010, the IEA estimated global abatement costs of around 2% for 2030 on a path consistent with our climate objective¹¹. Previously, the Stern Review has estimated global abatement costs at around 1% of GDP for 2025 and 2050 for a similar emissions trajectory¹².

In the context of an economy that is expected to return to medium-term growth of at least 2% per annum, the cost of our proposed budgets is equivalent to sacrificing around half a year's growth out of twenty.

Table 3.7: Estimated costs (as % of GDP) for the Domestic Action budget and indicative 2030 target		
	2025	2030
Medium Abatement scenario costs (%GDP)	0.4%	0.5%
Of which:		
Power	0.3%	0.3%
Buildings	0-0.1%	0-0.1%
Industry (including refineries)	-(0-0.1)%	-(0-0.1)%
Transport (domestic)	0-0.1%	0-0.1%
Non-CO ₂ *	0%	0%
International aviation and shipping (credit purchase)**	0-0.1%	0-0.1%
Extended Ambition abatement costs (%GDP)	0.2%	0.2%
TOTAL abatement costs (%GDP)	0.6%	0.6%

Source: CCC analysis.
Notes: Costs of low-carbon electricity are allocated to power for increased demand in the transport sector (which will largely use off-peak electricity) and to buildings and industry for increased demand there (which will generally be peak or seasonal demand). Numbers may not sum to totals due to rounding.
 * We expect net abatement costs in agriculture and other non-CO₂ emitting sectors to be negative; in these calculations we assume zero costs due to uncertainties around exact magnitudes.
 ** Costs for IA&S are indicative. International aviation based on the 'Likely' scenario from our 2009 Aviation Report. International shipping based on DECC's 2050 Pathways Analysis (will be revisited in light of our forthcoming Shipping Report in 2011).

¹¹ IEA (2010) *World Energy Outlook 2010*, "450 scenario".
¹² Stern Review *The Economics of Climate Change* (2006).

Table 3.8: Sensitivity of costs to fossil fuel prices and capital costs (2025)

	Fossil fuel prices		Technology costs	
	High	Low	Low	High
Medium Abatement scenario costs (% of GDP)	-(0-0.1)%	0.5%	0.2%	0.6%
Of which:				
Power	0-0.1%	0.3%	0.2%	0.5%
Buildings	-(0-0.1)%	0-0.1%	-(0-0.1)%	0-0.1%
Industry (including refineries)	-(0-0.1)%	0-0.1%	-(0-0.1)%	-(0-0.1)%
Transport (domestic)	-(0-0.1)%	0-0.1%	0-0.1%	0-0.1%
Non-CO ₂ *	0%	0%	0%	0%
International aviation and shipping (credit purchase)*	0-0.1%	0-0.1%	0-0.1%	0-0.1%

Source: CCC analysis.

Notes: These sensitivities are for the additional measures in our Medium abatement scenario. As such, costs are additional to the costs of delivering the Extended Ambition scenario to 2020. Fossil fuel price sensitivities are based on the highest and lowest DECC scenarios (see Figure 3.5 above). Technology cost sensitivities are for capital costs and reflect detailed assumptions across the low-carbon technologies (e.g. assumed learning rates for electric vehicles and heat pumps); they are generally around +/- 25% in 2030.

* We do not assume any impact on the indicative non-CO₂ or IA&S costs.

Cost of meeting the Global Offer budget

The cost of meeting the Global Offer budget is the cost of meeting the Domestic Action budget plus the cost of credit purchase, or additional domestic action used to meet the budget. Assuming that credits are used to make up the additional effort, and at our central carbon price projection of around £45/tCO₂e in 2025, we estimate the additional cost of meeting the Global Offer budget of around 0.1% of GDP in 2025. This cost could be reduced to the extent that cheaper domestic action can be deployed in place of credit purchase.

Investment requirements

Investment costs to meet the fourth carbon budget will be far higher than recently seen in the energy sector, reaching up to £16bn annually in the 2020s¹³. This compares to £2bn average annual investment in the electricity sector and £200bn average annual investment across the economy in the early 2000s¹⁴.

- The largest investment costs in the Medium abatement scenario relate to low-carbon power generation with, for example, average annual costs of around £10bn over the period 2020 to 2030.
- Annual investments in abatement technology in the industry sector would be around £1bn on average (and higher in specific years, e.g. when major sites are fitting CCS).

¹³ Our estimates for investment costs are based on our detailed bottom-up modelling. They sum the assumed capital costs across the various low-carbon technologies

¹⁴ Source: ONS (2010) *Blue Book Gross Fixed Capital Formation (2001-05 average)*. Other energy investment costs include £1 billion primarily for the downstream gas sector and over £4 billion in offshore oil and gas.

-
- There will also be significant up-front costs in the buildings sector, which if financed via energy companies may also be considered as investment costs. These costs are around £6bn annually in our Medium abatement scenario.
 - There may be additional investment costs related to this scenario for rolling out a charging network for electric cars, and associated power distribution and transmission network strengthening (see Chapters 4-6). However, much of this cost may fall before 2020, so we do not include it in the investment requirements in this section.

This order of magnitude of investment costs raises questions about appropriate market arrangements, and the ability of capital markets as currently configured to provide required finance (see chapter 6). Going forward, it will be important to allow for investments of this order in any discussions about a new UK infrastructure/green investment bank.

11. Implications for the first three budget periods

Besides the tightening of the second and third carbon budgets proposed above, a number of new policy approaches are required to develop options for meeting the fourth budget. These include power market reform, a carbon price underpin, support for technology development, policies to drive emissions reductions through the first three carbon budgets, and improving the evidence base to inform design of new policies and a set of implications for EU policies and measures.

- **Electricity market reform.** Our analysis suggests the need to decarbonise the power sector through the 2020s, by adding 30-40 GW of low-carbon plant. This would reduce average emissions from current levels of around 500 gCO₂/kWh to around 50 gCO₂/kWh by 2030. Existing electricity market arrangements are not well designed to ensure this progress occurs in a cost-effective fashion. Therefore we propose that new arrangements are introduced entailing competitive tendering of long-term contracts for investment in low-carbon capacity.
- **Carbon price underpin.** Given carbon price volatility and the current low level, a carbon price underpin would complement electricity market reforms. It could also strengthen incentives for investment in low-carbon technologies in other sectors, subject to competitiveness and affordability concerns being addressed. A carbon price underpin which reached at least £27/tCO₂ (i.e. 30 euros per tonne) in 2020 and rising through the 2020s would provide appropriate signals.
- **Funding and policies to support development of technologies and new markets.** Key technologies which should be demonstrated now for deployment in the 2020s include CCS in power generation and industry, electric cars and vans, and electric heat pumps. Comprehensive programmes in each of these areas including greater clarity of long-term vision should be developed as a matter of urgency to ensure timely disbursement of funds committed in the 2010 Spending Review.

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- **New policies to deliver the first three budgets.** Our recommended fourth budget builds in emissions reductions to achieve the first three budgets. Given limited progress reducing underlying emissions in recent years, a step change in the pace of emissions reduction is required. New policies to drive the step change include approaches to energy efficiency improvement in residential and non-residential buildings, consumer behaviour change in transport, and more widespread use of carbon-efficient practices on farms.
 - **Further evidence to resolve uncertainties** around certain options to cut emissions in the 2020s. These include district heating, abatement options in agriculture and industry, and implications of electric vehicle deployment for power networks. The evidence base should be developed in these areas, with new policies introduced as appropriate.
 - **Implications for EU policies and measures.** There is a set of policies that the UK Government should push for to set the EU on a cost-effective and credible path to its 2050 target, and which would reinforce UK action to meet the fourth carbon budget, including:
 - Supporting the move to an EU 30% emissions reduction target in 2020 relative to 1990 levels.
 - Agreeing an appropriate emissions reduction target for 2030 (e.g. around a 55% reduction relative to 1990).
 - Tightening of the EU ETS emissions cap, both in 2020 and through the 2020s.
 - Setting 2030 targets for new car and van emissions (e.g. around 50 gCO₂/km for cars and 80 gCO₂/km for vans).
 - Reforming the EU Common Agricultural Policy, which is due for revision in 2013, so that it links subsidies and incentives to climate change mitigation objectives.
 - Supporting technology development, particularly for CCS in industry.

We discuss these implications in detail in chapters 2 and 4 to 7, then consider the implications for the wider economic and social circumstances laid out in the Climate Change Act in chapter 8.

12. Key findings



The proposed carbon budget for 2023-27, to be delivered through Domestic Action.

1,950
MtCO₂e

Reduction in emissions by 2030 (relative to 1990) consistent with the Domestic Action budget.

60%

Proposed credit use to plan for in meeting the Domestic Action target.

0
MtCO₂e

Indicative tighter carbon budget for 2023-27, as a potential global offer.

1,800
MtCO₂e

Reduction in emissions in 2030 (relative to 1990) consistent with the Global Offer budget.

63%

Required CO₂ reduction by 2050 (relative to 1990), assuming less progress in international aviation and shipping and non-CO₂.

Around
90%

Estimated cost of meeting the fourth carbon budget.

Under
1%
GDP



Chapter 4

1. Reference emissions projections
2. Scope for further improvements in conventional vehicle efficiency
3. Scaling up electric vehicle and plug-in hybrid penetration
4. Scope for increased use of biofuels
5. Opportunities for use of hydrogen in vehicles
6. Ongoing role for demand-side emissions reduction
7. The role for decarbonised rail
8. The role of freight operations and logistics
9. Surface transport emissions scenarios for the 2020s
10. Implications for first three budget periods
11. Key findings

Chapter 4: Decarbonising surface transport

Introduction

Surface transport currently accounts for around 19% of total UK GHG emissions, and 22% of CO₂ emissions. By 2020, there is scope to reduce emissions by around 26% relative to 2008 levels through lower carbon vehicles (including electric vehicles), increased penetration of sustainable biofuels and behaviour change. These measures are in our Extended Ambition scenario to meet the first three carbon budgets and to prepare for meeting subsequent budgets.

In this chapter we consider scope for further cuts in transport emissions in the 2020s through improved efficiency of conventional vehicles, increased penetration of electric vehicles (battery electric, plug-in hybrid and potentially hydrogen fuel cell vehicles), biofuels, behaviour change, freight efficiency improvement and electrification of rail. We develop scenarios for each of the key technologies through the 2020s based on an assessment of feasibility and cost. These are then incorporated in the economy wide scenarios that underpin our advice on the fourth carbon budget.

The key messages in the chapter are:

- Under our Medium Abatement scenario surface transport emissions reduction of around 44% relative to 2008 levels is achieved by 2030.
 - Given scope for battery cost reduction and a rising carbon price, we envisage that battery electric and plug-in hybrid electric cars and vans will become cost-effective during the 2020s. This will provide scope for 60% electric vehicle penetration in new cars and vans by 2030.
 - There is scope to reduce conventional vehicle average tailpipe emissions between 2020 and 2030 by around 30% for new cars, and around 25% for new vans and HGVs. Building on improvements made in the 2010s this would result in average new car emissions of 80 gCO₂/km and average new van emissions of 120gCO₂/km in 2030.
 - Given current uncertainties over technologies for advanced biofuels and availability of land for growth of feedstocks, we limit take up of biofuels in the 2020s to the level suggested in the Gallagher Review for 2020 (i.e. around 2.7 million tonnes of oil equivalent, or 31.2 TWh).
 - There is scope for emissions reduction through the 2020s through improved efficiency of freight operations.
 - There may be significant scope for emissions reduction electrification of rail. However, further evidence is required to better understand this opportunity.
 - The cost associated with this emissions reduction is around 0.1% of GDP in 2030, mainly due to the cost of battery electric and plug-in hybrids cars.

-
- The Medium Abatement scenario is one possible path to delivering this level of abatement in surface transport. Depending on the pace of technology innovation, it is possible that other technologies (e.g. hydrogen vehicles) could contribute to the emissions reduction in this scenario, or deliver additional emissions reduction.
 - In order to prepare for deep cuts in transport emissions through the 2020s, it is vital that support for electric vehicle market development is provided in the next few years. In the spending review the Government announced £400 million funding to promote the take up of ultra-low carbon vehicle technologies, including electric vehicles. Whilst this is a useful start, more resource is likely to be required to deliver the penetration of electric vehicles set out in our scenarios.

The analysis that underpins these conclusions is set out in ten sections:

1. Reference emissions projections
2. Scope for further improvements in conventional vehicle efficiency
3. Scaling up electric vehicle and plug-in hybrid penetration
4. Scope for increased use of biofuels
5. Opportunities for use of hydrogen in vehicles
6. Ongoing role for demand-side emissions reduction
7. The role of decarbonised rail travel
8. The role of freight operations and logistics
9. Surface transport emissions scenarios for the 2020s
10. Implications for the first three budget periods

1. Reference emissions projections

Current emissions

Surface transport CO₂ emissions¹ in 2008 were 119 MtCO₂, accounting for around 22% of economy-wide CO₂ emissions and around 19% of greenhouse gas emissions (Figure 4.1). Cars account for around 60% of surface transport CO₂ emissions, with vans accounting for 13% and HGVs for 20% (Figure 4.2).

The recession contributed to reduced transport emissions in 2008 and 2009. However, total surface transport emissions have increased significantly since 1990 with improvements in vehicle fuel efficiency more than offset by increased miles travelled:

¹ Unless otherwise indicated, this chapter refers to the direct emissions of transport throughout. Emissions associated with power generation or refineries are covered in the chapters related to Power generation and Industry.

Figure 4.1: GHG emissions from surface transport in the context of total UK emissions (2008)

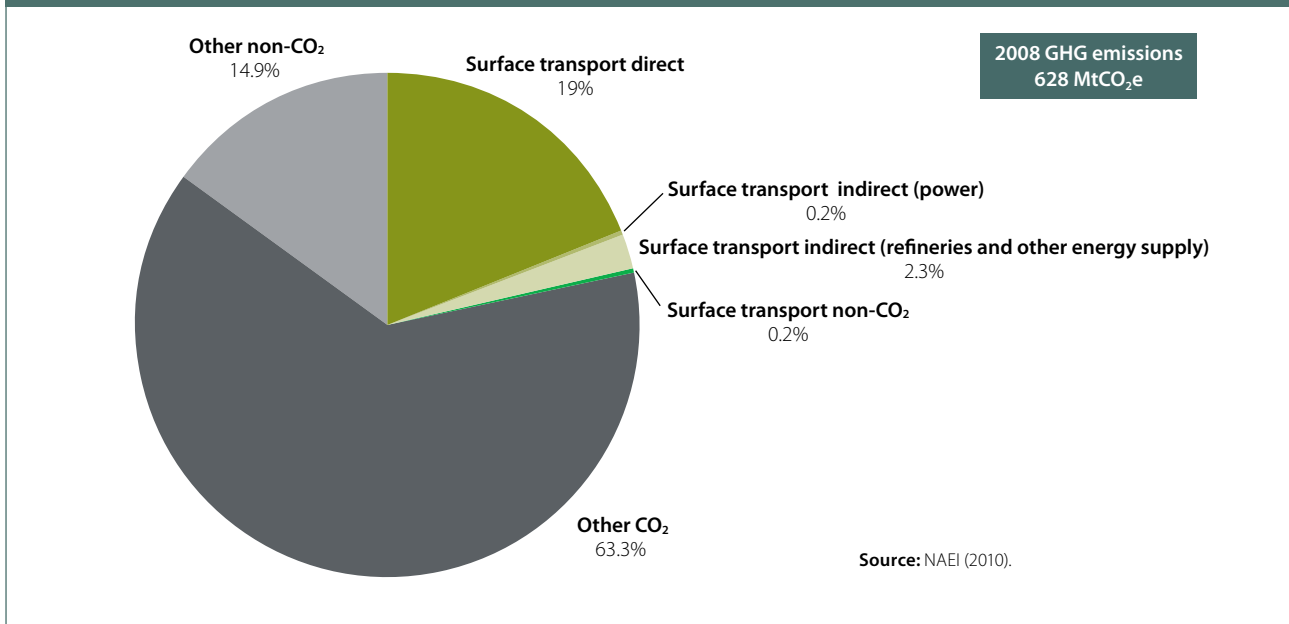


Figure 4.2: Breakdown of surface transport CO₂ emissions by mode (2008)

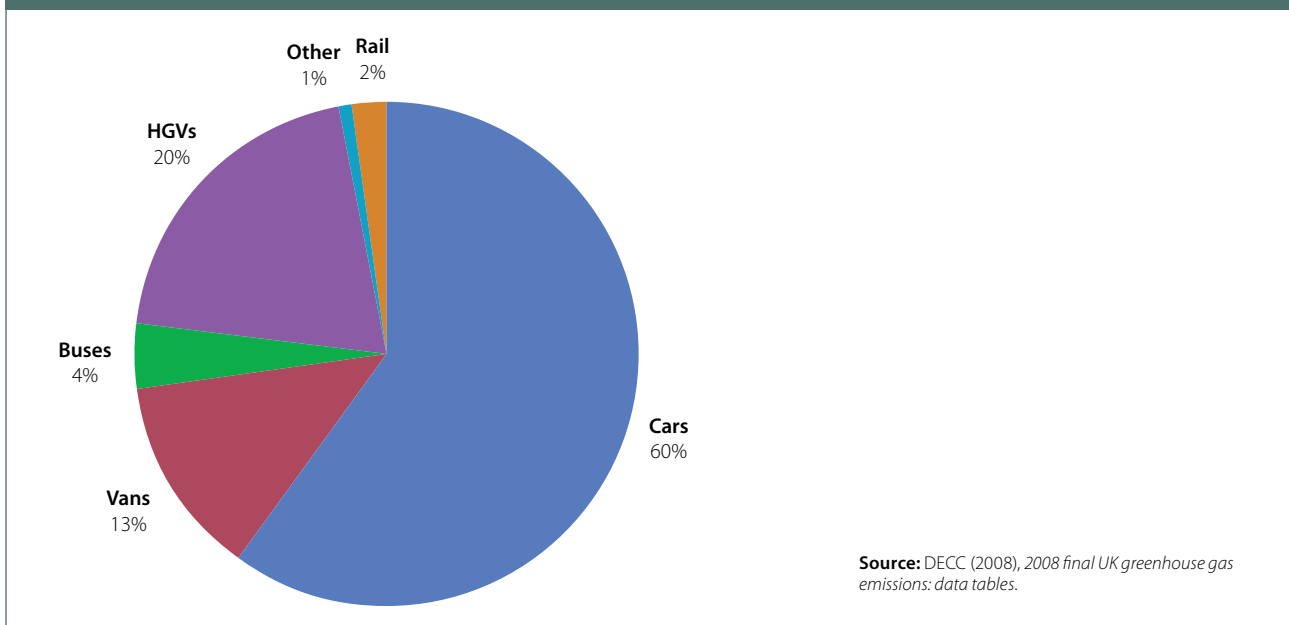


Figure 4.3: Historical trends of vehicle km, MtCO₂ and gCO₂/km for cars (1990-2008)

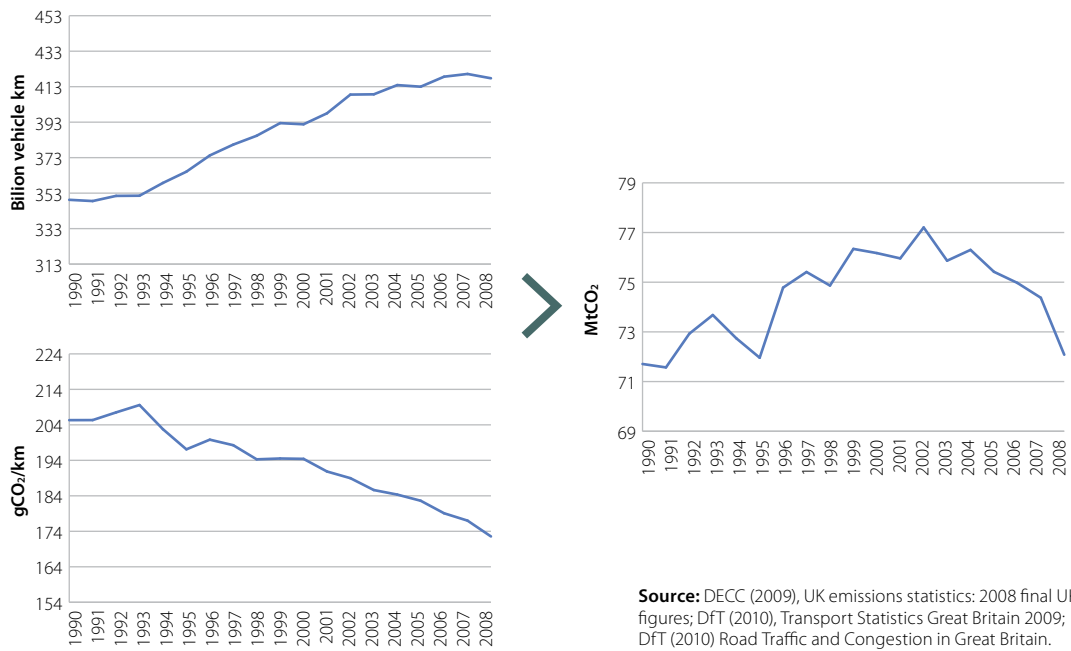


Figure 4.4: Historical trends of vehicle km, MtCO₂ and gCO₂/km for vans (1990-2008)

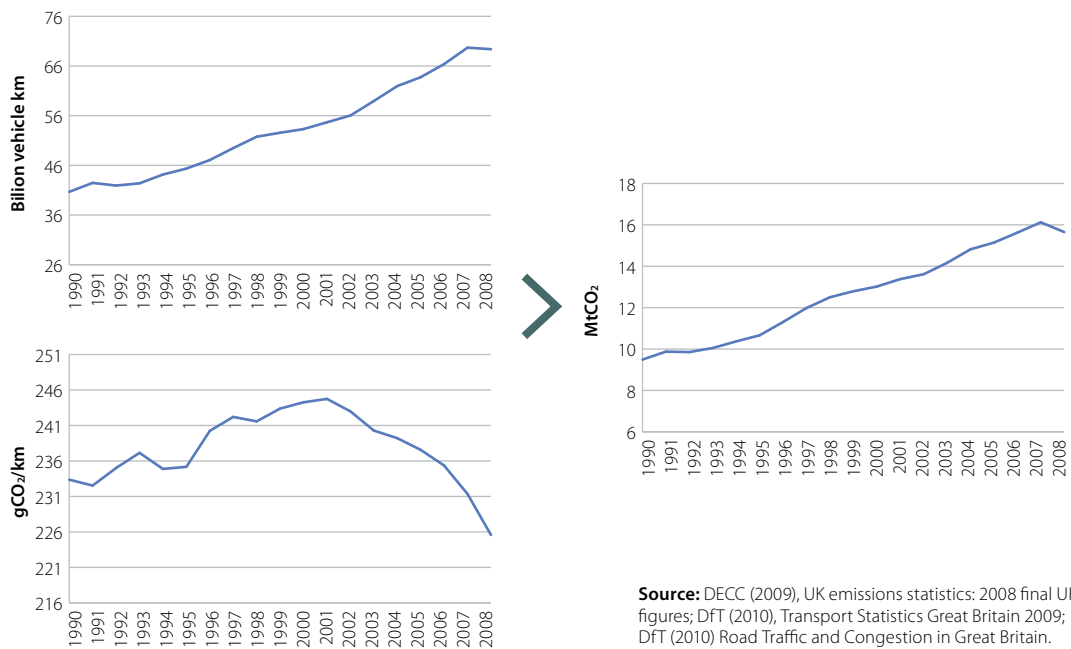
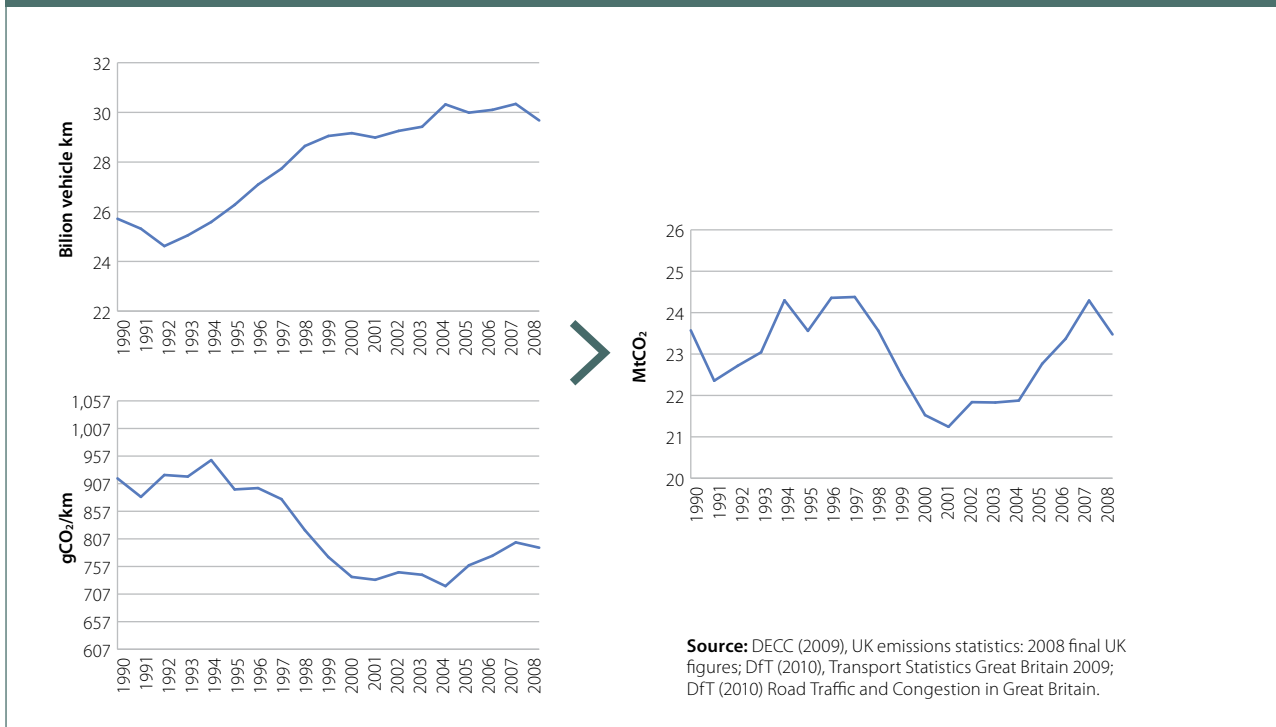


Figure 4.5: Historical trends of vehicle km, MtCO₂ and gCO₂/km for HGVs (1990-2008)



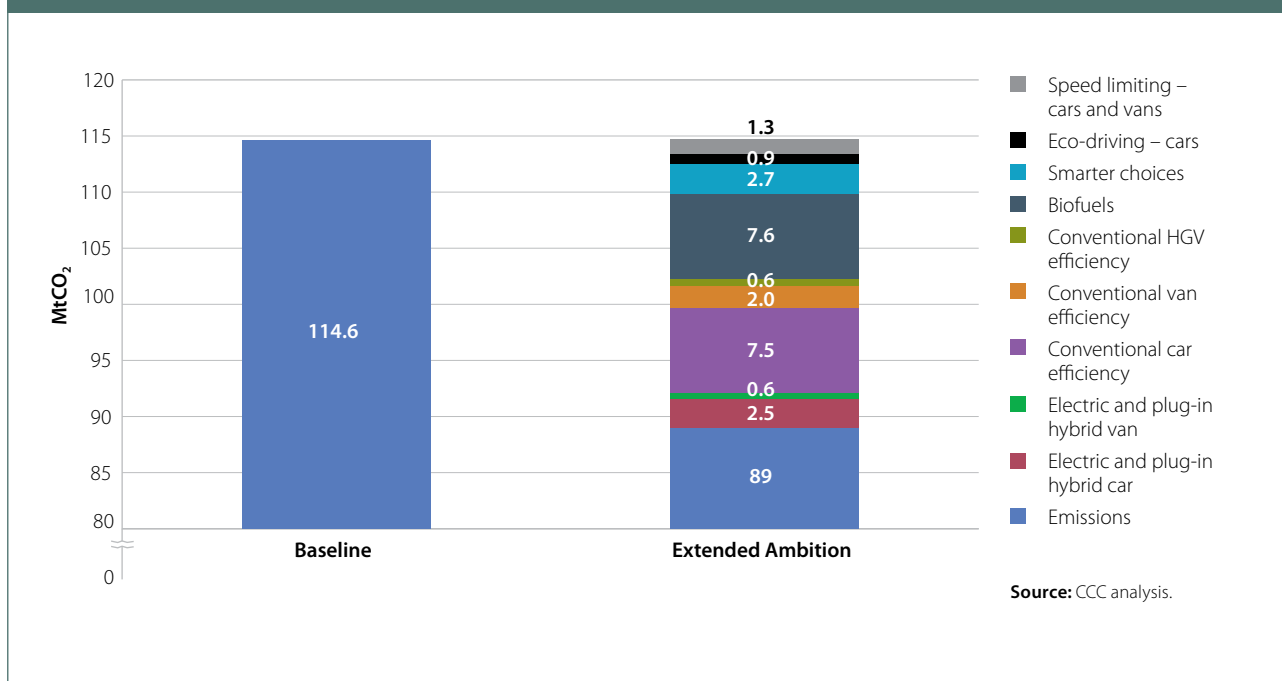
- Total surface transport emissions increased by 7% between 1990 and 2008. This was due to:
 - Between 1990 and 2008 emissions intensity of cars fell by 16% from 205 gCO₂/km to 173 gCO₂/km, whilst distance travelled increased by 20% from 350 billion km to 418 billion km (Figure 4.3).
 - Between 1990 and 2008 emissions intensity of vans fell by 3% from 233 gCO₂/km to 226 gCO₂/km, whilst distance travelled increased by 71% from 41 billion km to 69 billion km (Figure 4.4).
 - Between 1990 and 2008 emissions intensity of HGVs fell by 14% from 917 gCO₂/km to 791 gCO₂/km, whilst distance travelled increased by 15% from 26 billion km to 30 billion km (Figure 4.5).
- Total surface transport emissions decreased by 1.7% in the period from 2004-2008. In 2008 road transport emissions fell by 3.5% with a preliminary estimate of a further 3.9% reduction in 2009. Emissions reduction in 2008 and 2009 were due to the purchase of more efficient vehicles, increased penetration of biofuels and reduced mileage.

Emissions projections to 2020

We have previously defined Extended and Stretch Ambition scenarios for transport, including both technology and behaviour change measures for emissions reduction, and covering the first three budget periods:

- The **Extended Ambition** scenario includes a range of measures relating to the uptake of technologies and behavioural change. The majority of these measures are either negative cost (i.e. cost saving) or cost-effective compared to the UK carbon price over this period.

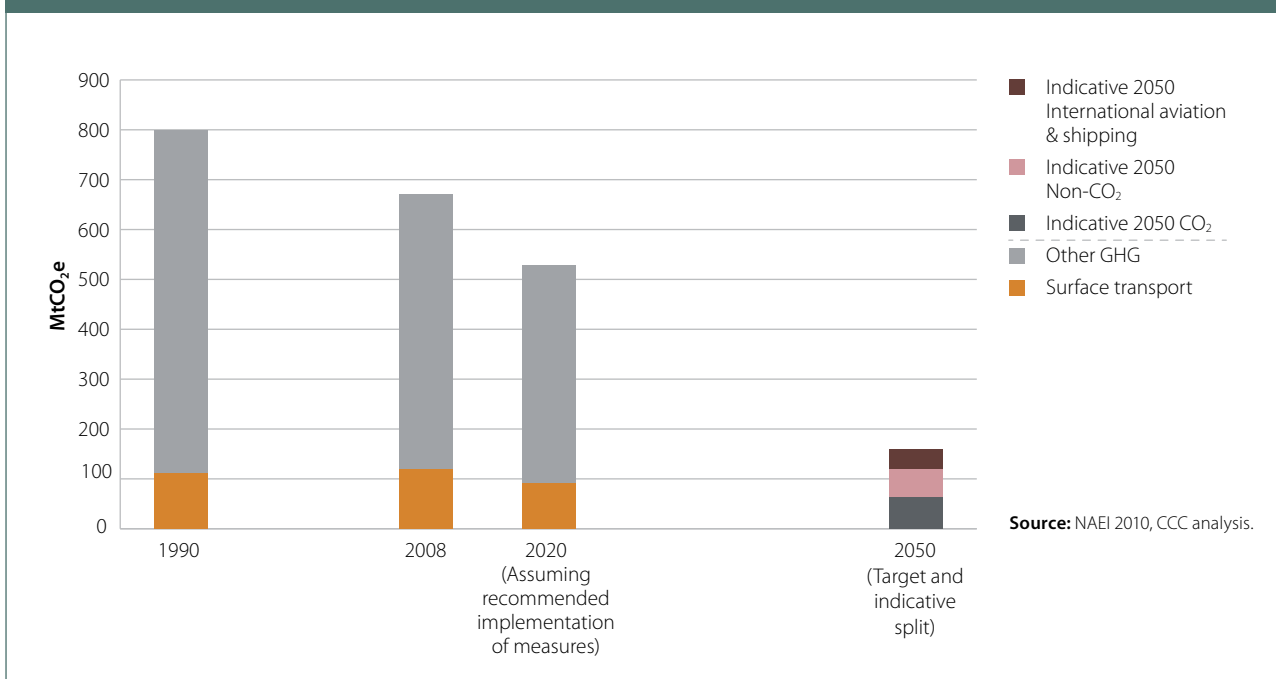
Figure 4.6: Extended Ambition emissions reductions in 2020



The remainder (electric and plug-in hybrid vehicles) would bring to market technologies that will be required to meet the 2050 target and are likely to be cost-effective in meeting carbon budgets through the 2020s. Key measures in the Extended Ambition scenario are (Figure 4.6):

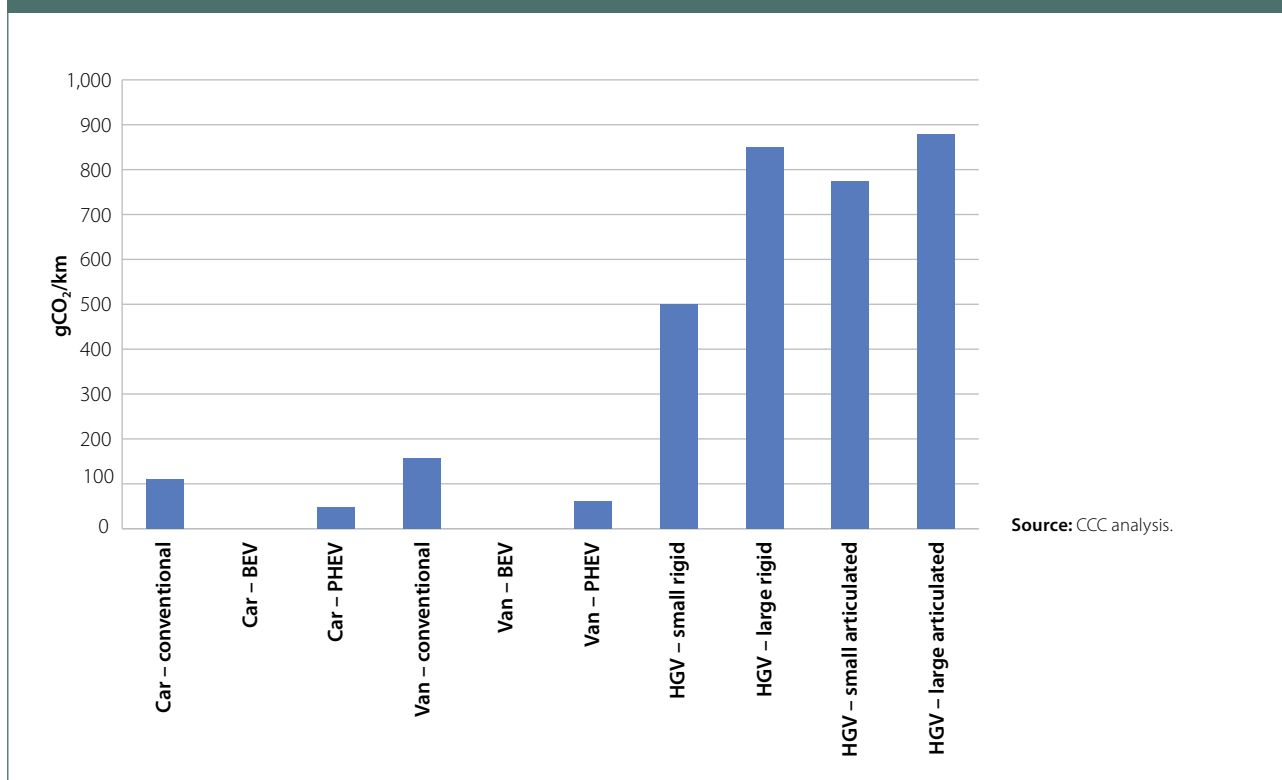
- **New car efficiency of 95 gCO₂/km in 2020.** New car CO₂ emissions in the UK should decrease from around 150 gCO₂/km in 2009 to the EU target levels of 130 gCO₂/km in 2015 and 95 gCO₂/km in 2020. This can be achieved by a range of feasible and cost-effective measures to improve engine efficiency and non-powertrain measures. We allow electric vehicles to contribute to meeting this limit. Excluding these, conventional car efficiency is 110 gCO₂/km by 2020.
- **Battery electric and plug-in hybrid car penetration of up to 1.7 million in 2020.** The introduction of battery electric and plug-in hybrid cars is technically feasible, and desirable given that this technology is the most promising for the deep emissions cuts required in transport through the 2020s. We have recommended that by 2020 around 5% of all cars and 16% of new cars should be battery electric and plug-in hybrid in order to address market barriers and provide critical mass for roll-out in the 2020s.
- **New van efficiency of 135 gCO₂/km in 2020** in line with the proposed EU target, to be achieved by a combination of more efficient conventional vans, and battery electric and plug-in hybrid vans
- **HGVs.** Uptake of non-powertrain technologies and the introduction of hybrid rigid HGVs could reduce emissions by 0.6 MtCO₂ in 2020.

Figure 4.7: Surface transport emissions in the context of UK greenhouse gas emissions (1990-2020, 2050)



- **Biofuels penetration of 8% in 2020.** Increased penetration of biofuels up to 8% of total liquid fuel consumption (by energy) would be consistent with broader sustainability limits, as recommended by the Gallagher review.
- **Roll-out of Smarter Choices to all UK cities and towns.** Evidence from the Sustainable Travel Town pilot projects suggests that people respond to policies encouraging car sharing, working from home and use of public transport (e.g. resulting in a reduction in car km of around 5-7%).
- **Take up of eco-driving.** Training 10% of car and van drivers and 100% of HGV drivers in eco-driving techniques (e.g. gentle braking and accelerating, not driving with excess weight, etc.) could result in an emissions reduction of 0.9 MtCO₂ in 2020.
- **Enforcing the speed limit.** If the existing 70 mph speed limit were strictly enforced, this could reduce emissions by 1.3 MtCO₂ in 2020.
- The **Stretch Ambition** scenario includes measures which are likely to be cost-effective in reducing emissions, but where political considerations may pose a more significant barrier. Key measures in the Stretch Ambition scenario are:
 - **Introduction of road pricing.** If introduced in addition to existing fuel duty, rather than as an alternative, this would result in significant emissions reduction (e.g. 5.6 MtCO₂ in 2020) due principally to a reduction in total distance travelled.
 - **Reduction of the speed limit.** Significant fuel efficiency improvements and emissions reduction (around 1.5 MtCO₂ in 2020) are available through reducing the existing 70 mph speed limit to 60 mph.

Figure 4.8: Carbon intensities by mode in 2020



- We have also highlighted the risk of increased emissions depending on land-use and planning decisions, and recommended development of an **integrated land-use and transport planning strategy** to ensure that these potential emissions are avoided.

Our analysis suggests that an emissions reduction of around 26 MtCO₂ is available in 2020 under the Extended Ambition scenario, with an additional 7 MtCO₂ emissions reduction under the Stretch Ambition scenario.

If the Extended Ambition is delivered then surface transport emissions in 2020 would be around 89 MtCO₂. This would be high relative to total allowed emissions of 160 MtCO₂e in 2050, particularly given the difficulty in reducing emissions in other sectors such as aviation and shipping (Figure 4.7). Therefore deep cuts in transport emissions beyond 2020 will be required, to which we now turn.

Reference emissions projections for the 2020s

In developing reference emissions projections for the 2020s, we assume that emissions reduction effort remains constant at levels in the Extended Ambition scenario (e.g. conventional car efficiency remains at 110 gCO₂/km, electric car penetration is 16% of new cars).

We use travel demand projections from DfT's National Transport Model. This allows for changing fossil fuel prices, economic growth and changing demographics. It projects that car travel distance increases by 9%, van distance by 24% and HGV distance by 5% in the period from 2020 to 2030 (Box 4.1).

Combining the assumptions on carbon intensity (Figure 4.8) and the travel demand projections gives a reference emissions projection under which surface transport emissions decrease by around 8% in the period to 2030. This defines a benchmark, against which we now consider opportunities to reduce emissions through the 2020s.

Box 4.1: National Transport Model projections

The National Transport model forecasts total road traffic and emissions for cars, vans, HGVs and public service vehicles (buses and coaches) in Great Britain. Our reference emissions projection is based on National Transport Model forecasts of total road traffic which are consistent with the following assumptions:

- The number of households in Great Britain is forecast to rise from 26.0 million in 2010 to 31.5 million in 2030, according to DfT's Trip End Model Presentation Program (TEMPRO).
- The total number of cars in Great Britain is forecast to rise from 28.5 million in 2010 to 36.4 million in 2030 (an increase in car ownership from 1.10 cars per household in 2010 to 1.16 in 2030), according to DfT's Car Ownership Model based on TEMPRO data.
- GDP is forecast to increase by 62% between 2010 and 2030. This is based on the forecast for the next five years of GDP growth published by the Office of Budget Responsibility in the June 2010 Budget and forecasts of subsequent GDP growth from HMT's long-term forecasts.
- Petrol prices are forecast to rise from 110 p/litre in 2010 to 128 p/litre in 2030, while diesel prices are forecast to rise from 115 p/litre in 2010 to 131 p/litre in 2030. These prices are based on the DECC-DfT road fuel price forecasting model using DECC's oil price projections; oil prices are forecast to rise from \$72/bbl in 2010 to \$92/bbl in 2030.

We adjust the National Transport model forecast figures to account for traffic in Northern Ireland. With these assumptions, total road traffic is forecast to

- rise from 409 billion vehicle-km in 2010 to 446 billion in 2020 and 485 billion in 2030 for cars;
- rise from 72 billion vehicle-km in 2010 to 92 billion in 2020 and 114 billion in 2030 for vans;
- rise from 30 billion vehicle-km in 2010 to 32 billion in 2020 and 33 billion in 2030 for HGVs;
- remain relatively constant at 5 billion vehicle-km between 2010 and 2030 for public service vehicles.

2. Scope for further improvements in conventional vehicle efficiency

If the EU target for new car emissions and the proposed target for new van emissions are achieved in the UK in 2020, in part through the contribution of electric and plug-in hybrid cars and vans set out in our Extended Ambition scenario, the implication is that conventional car emissions would be around 110 gCO₂/km, and conventional van emissions around 150 gCO₂/km.

Going beyond 2020, it is likely that there will be further scope for fuel efficiency improvement in conventional cars, vans, and HGVs, for example, through increased hybridisation, downsizing of engines with turbocharging and use of advanced light weight materials.

Although there is uncertainty over precisely how far efficiencies can be improved, there is strong evidence to suggest that conventional car emissions could be reduced to at least 80 gCO₂/km by 2030 (while some industry participants suggest a level as low as 60 g/km), with van emissions falling to 120 gCO₂/km, and HGV emissions falling to 415-705 gCO₂/km depending on size.

In modelling our Medium Abatement scenario for surface transport, we assume conventional car efficiency of 80 gCO₂/km and conventional van efficiency of 120 gCO₂/km in 2030, and a 15-30% efficiency improvement between 2020 and 2030 for HGVs (Box 4.2). In modelling our High Abatement scenario we assume a conventional car efficiency of 70 gCO₂/km, reflecting more optimistic assumptions on the efficiency improvement that can be achieved cost-effectively.

These efficiency improvements could potentially make a useful contribution to meeting the fourth and subsequent carbon budgets. However, there is a limit to how far the efficiency of conventional vehicles can be improved, and new technologies will be required to achieve deep cuts in transport emissions. We now consider these new technologies, starting with electric vehicles, then biofuels and hydrogen.

Box 4.2: Reduction in conventional vehicle CO₂ emissions

We have based our assumptions on the efficiency of new conventional vehicles (vehicles powered principally by an internal combustion engine, including hybrid but not plug-in hybrid vehicles) on two main sources:

- a study by AEA for the European Commission for cars and vans²
- a study by Ricardo for the Department for Transport for Heavy Goods Vehicles (HGVs)³

The AEA study was produced to inform development of the European Commission's proposals for long-term targets as part of the regulation of the CO₂ emissions from new passenger cars and light commercial vehicles. The study evaluated the technical potential of achieving a range of new car and van CO₂ targets, and the expected costs of doing so. The study concluded that targets of 85 gCO₂/km in passenger cars and of 125 gCO₂/km in light commercial vehicles are achievable by 2020 with the application of either extra strong downsizing with turbo charging; or full hybridisation, as well as a range of additional technologies to further reduce emissions.

AEA note that although unlikely to be a feasible and economically viable option for the 2020 time frame, from a technical point of view extra strong downsizing with turbo charging and full hybridisation can in principle be combined. Given AEA's conclusion that 85g CO₂/km in passenger cars and 125 gCO₂/km in light commercial vehicles are achievable by 2020 with the application of one or other technology, we considered that CO₂ emissions consistent with the combination of both technologies would be an appropriate target level for vehicles in 2030. We have therefore assumed that

- new conventional car CO₂ would decline from around 110 gCO₂/km in 2020 to around 80 gCO₂/km in 2030
- new conventional van CO₂ would decline from around 150 gCO₂/km in 2020 to around 120 gCO₂/km in 2030.

The Ricardo study was produced to inform future UK Government policy on reducing emissions from HGVs. The study identified a range of technologies with potential to reduce emissions from different categories of HGV as well as their likely costs. Further work is required to determine the likely optimal combination of these technologies and the emissions reduction resulting from combining several technologies. We have therefore taken a conservative approach and selected a small number of technologies to apply to each class of HGV:

² AEA, CE Delft, TNO et al (2009), Assessment with respect to long term CO₂ emission targets for passenger cars and vans.

³ Ricardo (2010), Technology Roadmap Study for Low Carbon HGVs.

Box 4.2: Reduction in conventional vehicle CO₂ emissions

- Rigid HGVs
 - Low rolling resistance tyres
 - Stop start hybrid
- Articulated HGVs
 - Low rolling resistance tyres
 - Flywheel hybrid
 - Aerodynamic trailer/body
 - Aerodynamic fairings
 - Single wide tyres

This reduces emissions from the Extended Ambition scenario

- from 500 gCO₂/km in 2020 to 415 in 2030 for small rigid HGVs (a 17% reduction)
- from 845 gCO₂/km in 2020 to 705 in 2030 for large rigid HGVs (a 17% reduction)
- from 775 gCO₂/km in 2020 to 555 in 2030 for small articulated HGVs (a 28% reduction)
- from 880 gCO₂/km in 2020 to 640 in 2030 for large articulated HGVs (a 27% reduction)

3. Scaling up electric vehicle and plug-in hybrid penetration

Battery electric and plug-in hybrid electric vehicles are very promising options for cutting transport emissions in the 2020s given the need to decarbonise power generation. The pace and scale of roll-out of these vehicles will depend on battery cost reductions and range increases; where there is more battery cost reduction and where range is longer, there is greater scope for electric vehicle penetration.

In this section we:

- Set out scenarios for electric vehicle penetration through the 2020s reflecting different assumptions about battery cost and public acceptance.
- Assess the cost of delivering these scenarios.
- Consider implications of increased penetration of electric vehicles for the power system (generation and networks).

We set out our analysis in four sections:

- i. Scenarios for electric and plug-in hybrid cars
- ii. Scenarios for electric and plug-in hybrid vans

iii. Implications for the electricity system

iv. The rationale for an early stage market in electric and plug-in hybrid vehicles

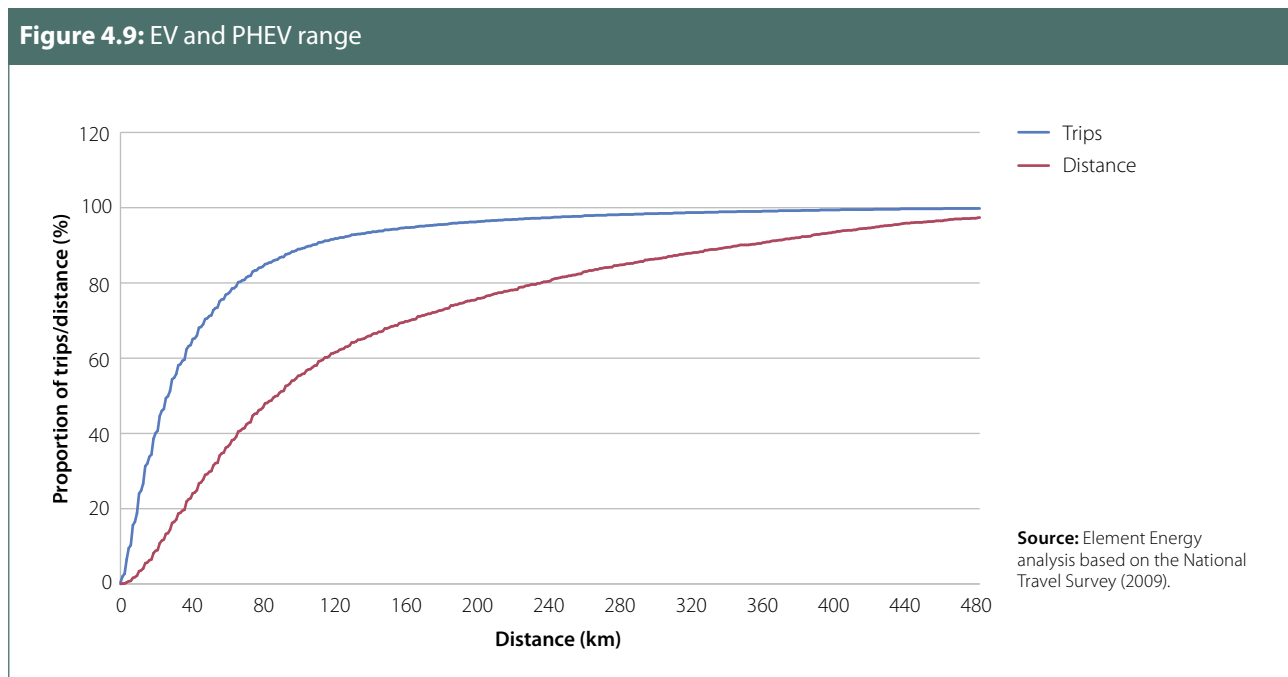
We do not consider the scope for electric HGVs. We recognise that a number of small electric HGVs are available today and that wider uptake could provide a valuable opportunity to reduce emissions in the city delivery vehicle segment of the HGV market. However, the majority of HGVs have much larger range requirements than cars (e.g. small rigid HGVs have annual mileage 170% greater than cars and large articulated HGVs have mileage over 600% greater). Therefore, the scope for widespread deployment of electric HGVs is likely to be limited, with emissions reduction more likely to ensue from biofuels and hydrogen (see sections 4 and 5 below).

(i) Scenarios for electric and plug-in hybrid cars

Electric vehicle purchase to 2020

Under our Extended Ambition scenario electric and plug-in hybrid cars account for 16% of new cars and around 5% of the car fleet by 2020. This scenario reflects market developments to address barriers and provide a critical mass for roll-out in the 2020s. It is based on analysis that shows electric and plug-in hybrid cars are likely to be attractive in terms of performance characteristics and to become cost-competitive with conventional cars:

- **Range.** The performance characteristics of electric cars will allow them to compete with conventional cars. Analysis by Element Energy indicates that 96% of car trips and 73% of total car distance travelled are covered by individuals driving no more than 100 miles in a single day – the range of current batteries (Figure 4.9). Whilst battery ranges are likely to improve, options for situations where a battery range of 100 miles is insufficient are:



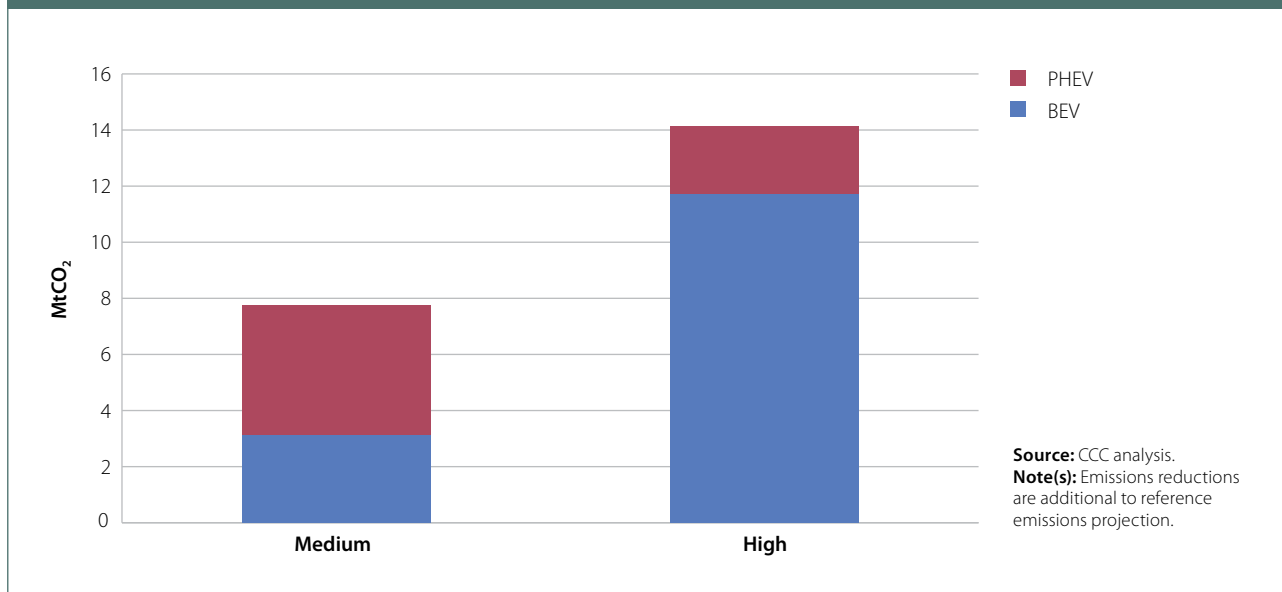
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- Switching longer trips to a conventional car in two-car households.
 - Renting conventional cars for longer journeys, or using alternative modes of transport.
 - A widespread national fast charging infrastructure to reduce the effective range limitations of battery electric vehicles.
 - Use of plug-in hybrid vehicles.
 - **Cost.** The economics of electric vehicles are such that these will be competitive with conventional cars under an assumption that existing fuel duty remains, and following a transitional period where electric battery costs fall as a result of learning through deployment (see below).

Scenarios for electric car deployment through the 2020s

Given sufficient progress in the period to 2020, there will be the option to roll out electric cars in the 2020s. Key drivers on the pace and scale of roll-out will be battery cost reductions and range increases (e.g. penetration is likely to be higher the more that battery costs are reduced and/or range is increased). Therefore our scenarios for roll-out in the 2020s reflect different assumptions on battery costs and range:

- **Low scenario.** This assumes no increase in market share of electric cars beyond 2020. These continue to account for around 16% of new cars, and around 15% of the fleet in 2030. Limited uptake could reflect a world where electric cars are overtaken by other options for cutting car emissions (e.g. because battery costs fail to fall and/or there are breakthroughs that bring abundant and low-cost sustainable biofuels to market). Alternatively, limited uptake could result if the public failed to embrace electric cars (e.g. because these were perceived as being deficient in terms of performance).
- **Medium scenario.** Under this scenario take-up of electric cars reaches 60% of new vehicles (31% of the fleet) in 2030, of which 30% are battery electric and the remaining 70% are plug-in hybrid cars. This outcome reflects the following assumptions:
 - Battery costs fall to around \$200/kWh by 2030 (Box 4.3), with no change in assumed range.
 - Battery electric cars replace conventional vehicles that are rarely or never used for long-range trips – 85% of cars do not drive more than 100 miles within the average week, and 73% of car drivers undertake a long distance trip (greater than 50 miles) less than once a month.
 - Battery electric cars replace conventional vehicles in multi-car households (30% of all households) that sometimes make long-range trips; in this case longer trips are switched to the household's conventional car.
 - Consumers requiring significant range purchase plug-in hybrid cars which do not have range constraints and can therefore perform as well as conventional cars.

Figure 4.10: Emissions reductions in 2030 from battery electric and plug-in hybrid cars in Medium and High abatement scenarios



- **High scenario.** Under this scenario take up of electric cars reaches 85% of new vehicles (37% of the fleet) in 2030. Of these, 70% are battery electric and the remaining 30% are plug-in hybrid cars. This outcome reflects the following assumptions:
 - Battery costs are significantly lower than our central estimate of \$200/kWh, such that it is cost-effective to deploy battery electric cars with significantly longer range than 100 miles; or
 - A degree of behaviour change such that drivers motivated to purchase an electric vehicle due to the operating cost savings switch to public transport or use car clubs for long distance trips, or seek alternatives to travel.

Electric car emissions reduction

Emissions reduction from electric car penetration depend on the carbon intensity of power used for battery charging. For example, charging based on gas-fired power generation offers limited saving relative to a conventional engine with emissions of 80 gCO₂/km. In contrast, electric cars may be regarded as zero- or very low-carbon when charging is based on low-carbon generation (i.e. nuclear, CCS, renewable – see Chapter 6).

Provided that charging is based on low-carbon generation, the emissions reduction in the Medium scenario compared with the reference emissions projection is 7.8 MtCO₂ in 2030, rising to 14.1 MtCO₂ in the High scenario (Figure 4.10). By 2030 average car fleet emissions in the Medium scenario are around 81 gCO₂/km.

Electric car costs: social perspective

The electric car costs in the above scenarios can be justified on two grounds:

- The cost per tonne of CO₂ abated from electric cars is less than the carbon price in 2030. The relevant carbon price here is the average over the life of an electric car, which we project to be around £65/tCO₂ for a car purchased in 2020, rising to £103/tCO₂ for a car purchased in 2030 (see Chapter 2 for our carbon price projections).
- 100% electric car penetration in the fleet is required by 2050 to meet the 2050 emissions reduction target. Given the delays caused by fleet rollover early deployment of electric vehicles is required, even though this may initially cost more than the carbon price, to ensure that electric vehicles deliver the required amount of abatement in 2050.

In considering electric car costs versus conventional alternatives, two factors are relevant:

- The purchase costs of electric cars are relatively high compared to conventional alternatives, primarily due to battery costs; current battery costs of under \$1000/kWh are expected to fall to \$285/kWh by 2020, with further reductions to as low as \$200/kWh by 2030 (Box 4.3).
- Electric cars are cheaper to run than conventional cars, given their significantly greater efficiency. We estimate a cost differential of around 1.6-2.5 pence/km depending on assumptions about electricity costs (Box 4.4).

Box 4.3: Electric vehicle battery costs

There is no accepted, reliable source of data on past and current prices for electric vehicle batteries. Previous studies have reported estimates of battery costs of around \$1,000 (at time of publication), although anecdotal evidence suggests that current purchase prices at volume are significantly lower than this⁴.

A number of studies have estimated prospects for near-term cost reduction. For example, Argonne National Laboratories (2000) estimate an 'optimistic future' cost of \$250/kWh, while more recent estimates include California Air Resources Board's (2007) future cost estimate of \$342-\$475 and Boston Consulting Group's (2010) estimate of \$360-\$440.

Such prospects for near-term reduction and likely stronger prospects for longer term reduction are reflected in a number of industry targets. For example:

- EUROBAT (the trade organization for European manufacturers of storage batteries) has a current objective for cost reduction in Li-Ion battery packs of €200 (\$246)
- The United States Advanced Battery Consortium (USABC), a subsidiary of the United States Council for Automotive Research (an organization comprising Chrysler Group, Ford Motor Company and General Motors Company) has defined a 'minimum goal for commercialization' of \$150/kWh and a long-term goal of \$100/kWh
- The Japanese Ministry of Economy, Trade and Industry (METI) has announced a target cost of 5% of 2010 levels, which equates to around \$50/kWh.

Following our 2009 report, we continue to use our working assumption that costs will fall to \$285/kWh in 2020. We reflect the scope for continued cost reductions, as indicated by the manufacturer targets above, in a cost of \$200/kWh by 2030.

4 E.g. Arup/Cenex (2008), Ricardo (2009), BCG (2010).

Box 4.4: Operating costs of electric and conventional vehicles

The Department for Energy and Climate Change (DECC) forecast that the variable cost of petrol (i.e. the resource cost net of fuel duty) will be around 44 p/litre in 2030. With 35 MJ of energy per litre of petrol, this equates to 1.3 p/MJ.

DECC also forecast that the variable cost of electricity will be 14 p/kWh in 2030, or 4 p/MJ. However, in our Medium power sector scenario (Chapter 3), 80 GW of total installed nameplate low-carbon capacity by 2030 would result in a variable cost of off-peak electricity of 2.7 p/kWh, or 0.8 p/MJ (around half the cost of petrol on an energy basis).

In addition to the lower cost of electricity in our Medium power sector scenario, electric vehicles are significantly more efficient than internal combustion engine vehicles. AEA (2008) estimate that the energy consumption of a conventional medium-sized petrol car is 2.4 MJ/km, whereas that of the equivalent electric car is 0.7 MJ/km.

Taking account the forecast costs of petrol and electricity and the relative fuel efficiency of petrol and electric cars, we estimate the energy costs of a conventional petrol car to be around 3.1 p/km, and those of an electric car to be around 0.5 p/km in 2030.

An efficient conventional (e.g. hybrid) petrol car in 2020 that achieves 95 g/km in line with the EU target would have an energy consumption of 1.4 MJ/km and an energy cost of 1.8 p/km, while a car achieving 80 g/km would have an energy consumption of 1.2 MJ/km and a cost of 1.5 p/km – such cars would still not be as efficient or as cheap to run as an electric car with today's technology.

Our assessment is that electric car and plug-in hybrid cars are cost-effective relative to our projected carbon price in 2030 across a range of sensitivities, with significant penetration in 2030 required on the path to meeting the 2050 target:

- We estimate a range of abatement costs from -£63 to £73/tCO₂ for battery electric cars and -£9 to £127/tCO₂ for plug-in hybrid cars depending on assumptions about battery costs, electricity prices and fossil fuel prices (Box 4.5); our central estimate of £26/tCO₂ (battery electric car) and £80/tCO₂ (plug-in hybrid electric car) is less than the average carbon price over the lifetime of a car bought in 2030 of £103/tCO₂⁵.
- All cars are likely to have to be electric (battery electric, plug-in hybrid or hydrogen fuel cell) by 2050 in order to meet the 80% reduction target. Given an average twelve to thirteen year stock turnover, the implication is that almost all new cars will have to be electric by 2035. In turn, this implies the need for significant penetration by 2030, given limits on scope for accelerating the pace of take-up.

Applying these abatement cost estimates to the Medium scenario suggests a total cost of around 0.06% of GDP in 2030, with a range from -0.01% to 0.1% of GDP depending on assumptions about battery costs and fossil fuel prices.

Electric car costs: private perspective

Although the analysis above justifies our scenarios from an economic perspective, divergence between social and private costs raises a question about whether these will ensue in practice:

- Social costs are calculated using a social discount rate of 3.5% as recommended by the HMT Green Book, and fuel duty is netted out of petrol and diesel prices.

⁵ This represents the discounted average carbon price over the life of a car brought in 2020 or 2030.

-
- Private costs are those faced by the consumer, reflecting a higher discount rate and including fuel duty; the former increases and the latter reduces the relative cost of electric cars.

There is evidence to suggest that consumers can be myopic and use very high discount rates (e.g. 25%), which may be prohibitive for the purchase of electric cars (i.e. heavily discounted operating cost savings would be insufficient to cover battery costs). However, this possibility has been recognised by the industry, which is introducing innovative business models such as battery leasing to better align the time profile of costs and benefits from electric car purchase.

However our analysis suggests that electric cars are likely to be competitive with conventional alternatives for a discount rate of 7.5% and forecast fuel costs including fuel duty by 2020, and it is appropriate to aim to deliver significant electric car penetration through the 2020s.

(ii) Scenarios for electric and plug-in hybrid vans

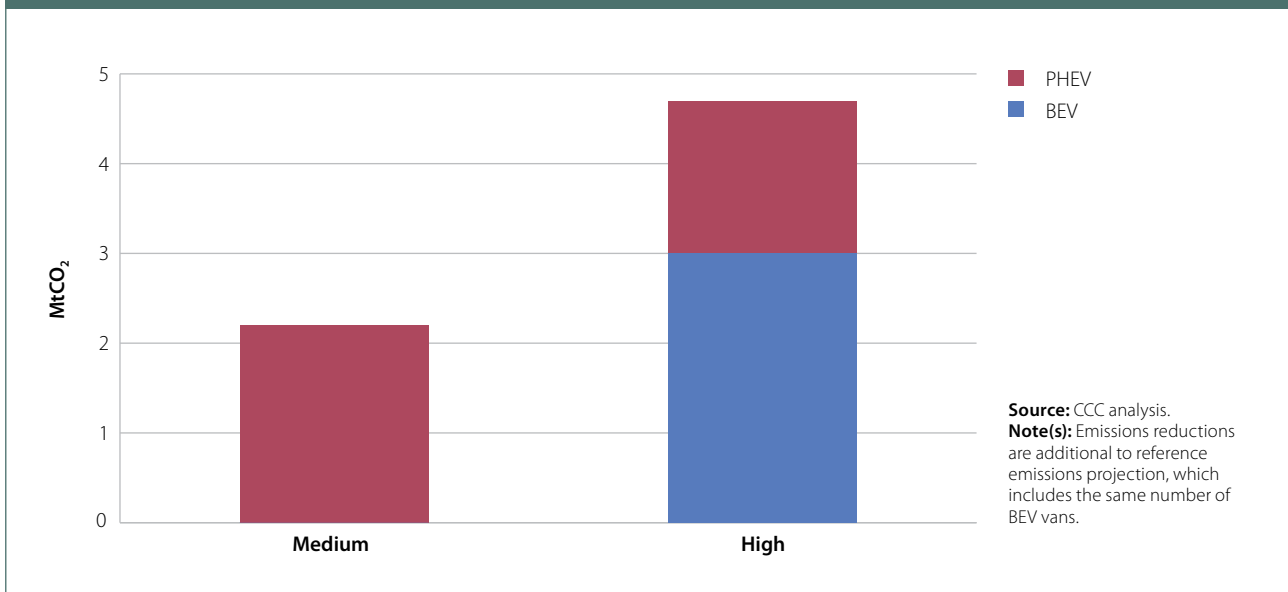
Electric van scenarios

Our approach to electric van scenarios is similar to that for electric cars: we assume a 2020 penetration as defined under the Extended Ambition scenario (i.e. electric and plug-in hybrid vans account for 16% of new vans in 2020 and 5% of the fleet); we set out three scenarios reflecting different assumptions about battery costs and range, and tracking the electric car scenarios.

- **Low scenario.** There is no increase in market share of electric vans beyond 2020 (i.e. electric vans continue to account for 16% of new vans and reach a 14% share of the fleet by 2030).
- **Medium scenario.** This tracks the Medium scenario for electric cars, such that take up of electric vans reaches 60% of new vehicles (29% of the fleet) in 2030; given uncertainty over the extent to which van miles are within battery range, we assume a high proportion (87.5%) of plug-in hybrid vans in this scenario.
- **High scenario.** This tracks the High scenario for electric cars, such that electric vans account for 85% of new vans in 2030 and 39% of the van fleet. Given uncertainty over the extent to which van miles are within battery range, but allowing for improvements in range with battery cost reductions, in this scenario 50% of new electric vans are battery electric and the remaining 50% are plug-in hybrid vans.

Under an assumption of overnight charging from low-carbon generation, the emissions reduction in the Medium scenario compared with the reference emissions projection is 2.2 MtCO₂ in 2030, rising to 4.8 MtCO₂ in the High scenario (Figure 4.11). By 2030 average van fleet emissions in the Medium scenario are 118 gCO₂/km.

Figure 4.11: Emissions reductions in 2030 from battery electric and plug-in hybrid vans in Medium and High abatement scenarios



Electric van costs

As with electric cars, the economics of electric vans depend on battery costs, electricity costs and petrol/diesel prices. Our assessment is that electric vans are cost-effective compared to the carbon price across a range of sensitivities, with significant penetration required on the path to meeting the 2050 target:

- We estimate a range for battery electric van marginal costs of -£52 to £82/tCO₂ in 2030 and for plug-in hybrid vans of -£62 to £72/tCO₂ in 2030, relative to the average carbon price projected over the life of a van purchased in 2030 of around £103/tCO₂ (Box 4.5).
- If vans are to be fully decarbonised by 2050, this implies that almost all new vans purchased in 2035 are electric. Without significant uptake in 2030 (e.g. as in our Medium scenario), it is unlikely that such penetration would be plausible in 2035.

Box 4.5: PHEV and EV marginal costs

We estimate abatement costs in 2030 for electric vehicles as follows:

- £26/tCO₂ for BEV cars
- £80/tCO₂ for PHEV cars
- £37/tCO₂ for BEV vans
- £26/tCO₂ for PHEV vans

These abatement costs are based on the following assumptions:

- For cars, the comparator vehicle is a medium-sized conventional petrol car
- Battery costs fall to \$200/kWh in 2030
- Fuel prices are consistent with DECC's central fuel price scenario
- Electricity costs are 2.7 p/kWh in 2030 based on overnight charging (Box 4.4)
- Fuel savings are discounted at 3.5%.

We have also performed sensitivity tests to determine the extent to which capital costs (i.e. battery costs) and fuel prices affect the abatement costs. Table B4.5 sets out our estimates of abatement costs under the following assumptions:

- Electricity costs reflect the long run marginal cost of nuclear generation.
- DECC's lowest and highest fossil fuel price forecasts.
- A 25% decrease and 25% increase in battery costs.

Table B4.5: Abatement costs in 2030.

Assumption		BEV Cars	PHEV Cars	BEV Vans	PHEV Vans
Central		£26	£80	£37	£26
Electricity costs reflecting long run marginal cost of nuclear generation		£73	£127	£82	£72
Capital cost	High	£66	£103	£76	£49
	Low	-£14	£57	-£2	£4
Fuel prices	High	-£63	-£9	-£52	-£62
	Low	£70	£124	£81	£71

(iii) Implications for the electricity system

Power generation

The scenarios for electric vehicles above would create electricity demand of around 31 TWh per year (Medium scenario) and 51 TWh per year (High scenario). This would require capacity of around 12-20 GW per year of the 80 GW total installed nameplate low carbon capacity in 2030 in the Medium Abatement scenario (Chapter 6) (Box 4.6).

Charging during off peak periods (e.g. home charging overnight, daytime workplace charging) would minimise the requirement for additional power generation capacity. It would also allow utilisation of spare low-carbon capacity, and therefore maximise emissions reduction. This would require smart meters and time of day tariffs to signal the underlying economics to drivers.

We model this demand for electricity and capacity in our scenarios for development of the power sector (see Chapter 6).

Box 4.6: Estimated electricity demand and capacity requirements

Electricity demand from transport in the Low, Medium and High scenarios will arise from:

- BEV cars and vans
- PHEV cars and vans
- Hydrogen production for fuel cell vehicles

We estimate this electricity demand based on the following assumptions:

- 100% of BEV mileage is done in electric mode
- 30% of PHEV mileage is done in electric mode
- Total annual distance travelled is around 13,000 km per car and 27,000 km per van
- Energy consumption of BEV and PHEV (electric mode) is 0.72MJ/km for cars and 0.91MJ/km for vans

With the above assumptions, we estimate annual electricity demand from take up of BEV, PHEV and hydrogen fuel cell PHEV cars and vans in our Low, Medium and High scenarios as follows:

- Low scenario: 4.4 TWh in 2020 rising to 15 TWh in 2030
- Medium scenario: 4.4 TWh in 2020 rising to 30.6 TWh in 2030
- High scenario: 4.4 TWh in 2020 rising to 51 TWh in 2030

In order to estimate the required generation capacity we assume that overall charging will be spread equally throughout the year, and throughout a seven hour period each day. This would require:

- Low scenario: 1.7 GW in 2020 rising to 5.9 GW in 2030
- Medium scenario: 12 GW in 2030
- High scenario: 20 GW in 2030

Power transmission and distribution

In principle, there could be significant implications for investment in power transmission and distribution networks from the deployment of electric vehicles. In practice this will depend on the way consumers use their vehicle and different charging models (e.g. home charging versus battery exchange).

- With overnight home charging, batteries could be charged at a rate such that overnight demand would be no more than demand in the peak, and therefore require no extra network capacity. This would also be true of limited levels of slow charging at work during the day. In either case, this would require smart meters/a smart grid, which we consider further in Chapter 6.

- Any battery exchange would likely to involve a mix of overnight and peak charging depending upon the pattern of demand and the costs of holding spare batteries compared to the costs of recharging.
- Further network investment would be required for fast charging during peak periods. Our analysis suggests that there could be significant costs associated both with the installation of an extensive fast charging network, and with the further distribution network investment to support this (Box 4.7). However, it is not clear that an extensive fast charging network is required, and the costs of fast charging at lower levels are likely to be more manageable.

This reinforces the point that battery charging should be off-peak in order to minimise costs, which will require smart meters and time of day tariffs.

Box 4.7: Cost associated with fast charging

In our 2009 Progress Report we estimated that the total costs of an extensive infrastructure to support the roll-out of 1.7 million BEVs and PHEVs to 2020 might cost around £1.4 billion, comprising:

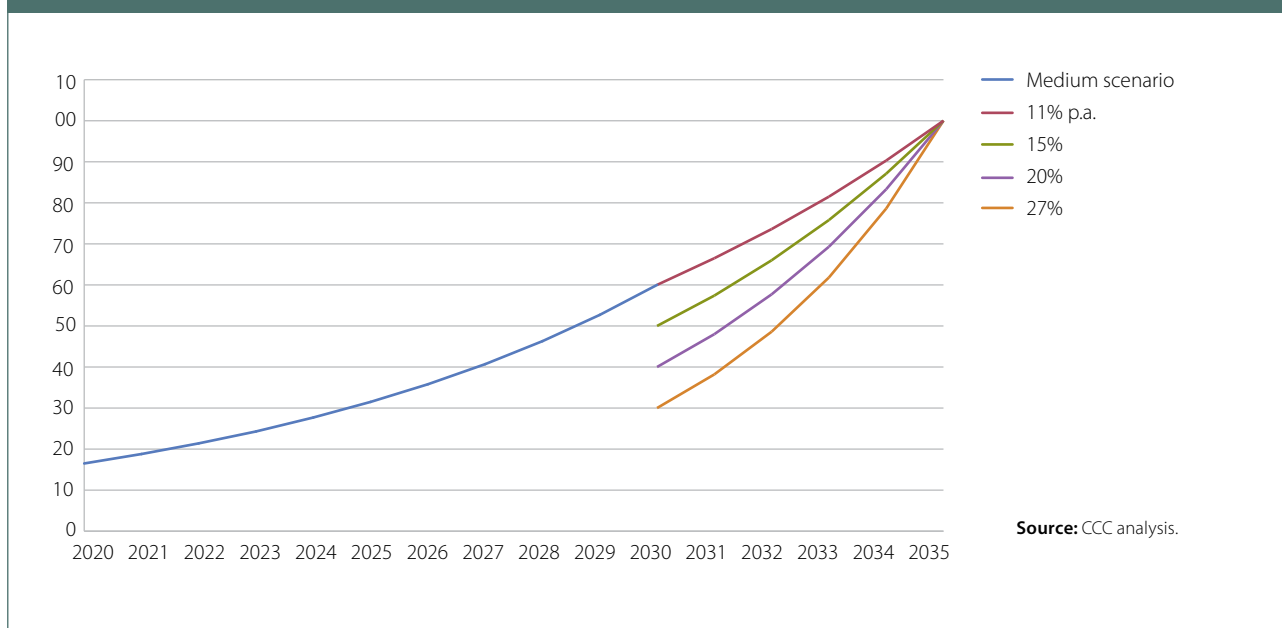
- dedicated slow-charging posts for the 25% of drivers who do not have off-street parking, at a cost of around £1 billion.
- charging posts in work-places for 5% of drivers, at £210 million.
- a total of 3,200 fast-charging points (i.e. two for every 1,000 electric cars) in public places, e.g. supermarkets, at a cost of £130 million.
- provision of four fast-charging points every 35 km in each direction on motorways and every 50 km on trunk roads, at £70 million.

(iv) The rationale for supporting an early stage market in electric and plug-in hybrid vehicles

It is important for the Government to provide support for the early market and to develop the electric vehicle option:

- By 2050 the entire car stock needs to be electric in order to meet the Climate Change Act's 2050 emission reduction target. Given the lifetime of vehicles, this means that 100% of new cars in 2035 need to be electric (battery electric, plug-in hybrid or hydrogen fuel cell). This requires significant penetration by 2030 given limits on scope for accelerating the pace of take up. For example, delays in the pace of take up before 2030 require very rapid acceleration in rates of take up in the period to 2035 (Figure 4.12).
- Our analysis shows that electric vehicles will be cost-effective compared to the carbon price in the 2020s.
- Delay in the take-up of electric vehicles would require the Government to purchase credits in later years when these credits are likely to be in short supply and the carbon price is likely to be very high. We estimate that these costs could be substantial – over £5 billion in present values using the battery costs in our Medium scenario – even taking into account the higher technology costs incurred through earlier deployment (Box 4.8).

Figure 4.12: Required rates of take up (2030-2035)



We therefore restate our previous recommendations on transitional price support and investment in battery charging infrastructure:

- Transitional support should be provided for purchase of electric vehicles to cover the initial period where battery costs net of any operating cost savings are high.
- The Government should fund and facilitate investment in a network of battery charging points. This should initially be based on home charging overnight, both to utilise spare low-carbon generation capacity, and given the high cost of fast charging points in public places.

We estimate that required public funding would be around £800 million to cover purchase cost premiums, with further funding required depending on the extent of fast battery charging. In the spending review the Government announced £400 million for measures to promote the take up of ultra-low carbon technologies, including electric vehicles. Whilst this is a useful start, more resource is likely to be required to deliver the penetration of electric vehicles set out in our scenarios.

Box 4.8: Costs of delaying investment in electric cars

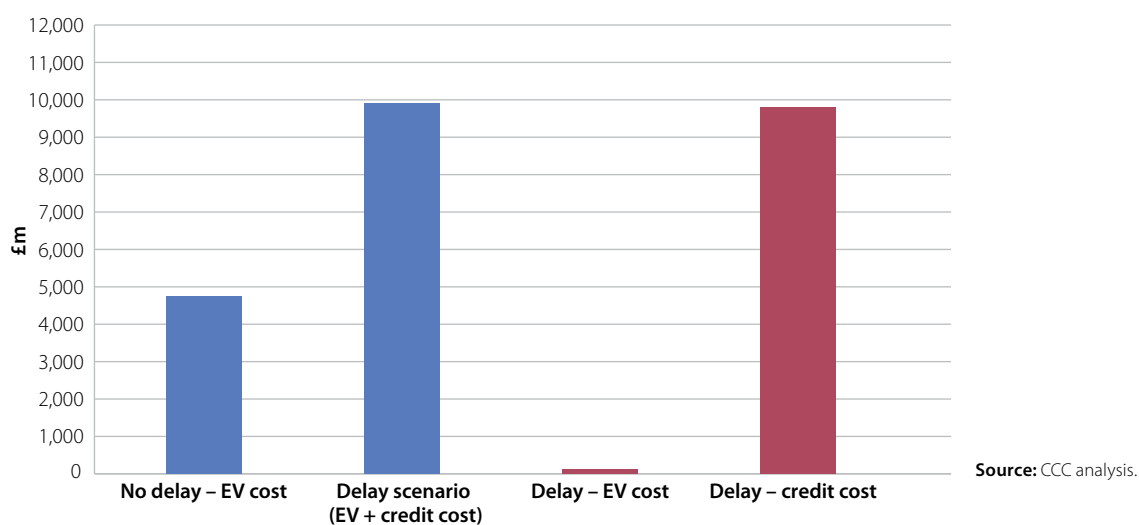
We estimate that the cost to the UK of delaying the introduction of electric vehicles by 5 years is over £5 billion in present values. This is much larger than the £800 million cost we estimated to support the roll-out of electric cars in line with our Extended Ambition scenario. Our analysis compares one scenario where 100% of the car stock is electric by 2050 with another which achieves 100% by 2055.

In the analysis:

- Both scenarios aim to deliver the same level of net abatement. Where electric vehicles are delayed the shortfall in abatement is made up with credit purchase.
- We use the carbon price set out in chapter 2 which reaches £200/tCO₂ by 2050.
- Abatement costs decline over time as batteries improve in cost and performance. This means that the delay scenario benefits from lower abatement costs from electric cars.
- All cash flows are discounted at 3.5% real, the Government's social discount rate.

The figure below shows that the costs of delay are much higher than the costs of not delaying. Although the cost of electric vehicles is lower in the delay scenario – because the technology is more mature – the cost of credit purchases in later years more than offsets this.

Figure B4.8: Cost of delaying investment in electric cars



4. Scope for increased use of biofuels

Our Extended Ambition scenario assumes 8% penetration by energy of biofuels in 2020 in line with the Gallagher review recommendations. In this section we consider scope for increased penetration of biofuels in the 2020s subject to technical feasibility and sustainability constraints. We set out scenarios for penetration of biofuels to 2030, and assess the role for biofuels as a complement to other options for cutting transport emissions (e.g. plug-in hybrid vehicles). We also provide high-level estimates of costs associated with increasing biofuels penetration.

We now consider:

- i. Feasibility and sustainability of biofuels
- ii. Scenarios for biofuels penetration in the 2020s
- iii. Possible roles for biofuels in road transport, emissions reduction and costs

(i) Feasibility and sustainability of biofuels

We have previously considered feasibility and sustainability constraints on increasing biofuels use in the context of our aviation review.

- **Feasibility.** It is likely that second generation biofuels will be available for use in the 2020s through a range of processes currently under development, although the precise timing and scale of availability remains uncertain:
 - hydrocracking vegetable oil and animal fats,
 - gasification of biomass combined with Fischer-Tropsch synthesis,
 - hydrothermal upgrading of biomass, where cellulosic materials are dissolved in water under high pressure and low temperatures to form a biocrude liquid, or
 - fast pyrolysis, in which biomass is heated rapidly in the absence of air and cools to a bio-oil.

However, the timing and order of magnitude of availability is currently uncertain, given need for innovation in feedstocks and processing plants and the investment required to produce at scale.

- **Lifecycle emissions reduction.** The extent to which biofuels can be regarded as zero carbon depends upon land-use impacts from growth of biofuels feedstocks and emissions from the production of biofuels. Sustainability standards are likely to be required, such as those required under the Renewable Energy Directive, to ensure genuine emissions reduction. We will address the role and design of sustainability standards in our bioenergy review to be published in 2011.

- **Sustainability and land availability.** There is uncertainty over whether there will be sufficient land available to grow biofuels feedstocks given increased demand for food from growing populations. In addition, there is the potential for adverse impacts on biodiversity as more land is brought into production.

(ii) Scenarios for biofuels penetration in the 2020s

Given these considerations, we base our scenarios for biofuels penetration in the 2020s on the Gallagher Review, and analysis by the IEA (Box 4.9):

- In the Low and Medium scenarios the level of UK biofuels suggested in the Gallagher Review for 2020 defines the amount of biofuels available in the 2020s (around 2.7 million tonnes of oil equivalent, or 31.2 TWh p.a.).
- The High scenario includes biofuels penetration according to the Gallagher Review in 2020s, rising above this in line with the IEA's BLUE Map scenario through the 2020, such that there is a 95% increase in UK biofuel consumption between 2020 and 2030.

Box 4.9: Biofuel assumptions in CCC scenarios

Biofuels in our Low and Medium scenarios are consistent with the Gallagher Review, which recommended a range for use of sustainable biofuels in the UK of 5-10% of total fuel consumption (4-8% of total energy for road transport) in 2020. Reflecting this, the Extended Ambition scenario includes uptake of biofuels reaching a total of 10% by volume (8% by energy), equating to 2.7 mtoe (31.2 TWh) in 2020.

The Low and Medium scenarios are both based on the conservative assumption that uptake of biofuels is limited to the Extended Ambition level of 2.7 mtoe between 2020 and 2030. Abatement from biofuels is therefore fixed at around 8 MtCO₂.

Biofuels in our High scenario are consistent with the International Energy Agency's BLUE Map scenario.

Under this scenario,

- total global transport energy use increases from around 2150 mtoe in 2007 to 2760 mtoe in 2050, and
- total global biofuel consumption increases from 34 mtoe in 2007 to 745 mtoe in 2050.

Assuming a linear increase in both total transport energy use and biofuel consumption suggests

- total global transport energy use of around 2476 mtoe in 2030, and
- total global biofuel consumption of around 414 mtoe in 2030.

Our High scenario is based on the principle that the UK's share of total global biofuel consumption should be equal to its share of total transport energy consumption. To establish the appropriate UK share of total transport energy consumption, we estimate UK energy consumption in 2030 if it were on a path consistent with the IEA BLUE Map scenario at 30.9 mtoe, or 1.2% of global transport fuel use.

This implies a share of biofuels for the UK of 1.2% of the global total of 414 mtoe in 2030, or 5.2 mtoe (60.8 TWh). We model linear take up from 2.7 mtoe in 2020 to 5.2 mtoe in 2030.

(iii) Possible roles for biofuels in road transport, emissions reduction and costs

Roles for biofuels

Whilst biofuels will not by any means provide the sole basis for transport decarbonisation in the 2020s, our scenarios suggest that they have a potentially important role in catering for market segments where there is limited scope for emissions cuts through electrification:

- **Conventional cars and vans:** in our Medium and High scenarios for penetration of electric vehicles (Section 3) and hydrogen vehicles (Section 5), the car fleet will still comprise 60-69% conventional vehicles and the van fleet 58-71% conventional vehicles in 2030.
- **Plug-in hybrid vehicles:** our scenarios allow for the possibility that there may be significant uptake of plug-in hybrid rather than pure electric vehicles. Biofuels offer a good opportunity for cutting emissions from plug-in hybrids for those journeys beyond the electric range.
- **Buses and coaches:** in our Medium and High scenarios for penetration of hydrogen buses and coaches (Section 5), the combined bus and coach fleet will still comprise 94-96% conventional vehicles in 2030.
- **HGVs:** there is limited scope for use of battery electric technologies on HGVs given technical barriers. Therefore biofuels are a key option for decarbonising HGV emissions.

We estimate that total demand for conventional fuel in 2030 from these various segments could be up to 27 million tonnes of oil equivalent (315 TWh) in our Medium electric car and van scenarios, compared to available sustainable biofuels of up to 2.7 mtoe (31.2 TWh). Therefore sustainable biofuels make a significant contribution in our scenarios notwithstanding significant deployment of electric vehicles through the 2020s.

Emissions reduction from biofuels

Given scope for biofuels to complement rather than displace other abatement options, these will result in emissions savings:

- In the Low and Medium scenarios, biofuels do not deliver emissions savings beyond those achieved by the reference emissions projection.
- In the High scenario, emissions savings are around 7 MtCO₂ in 2030 greater than those achieved by the reference emissions projection.

Notwithstanding issues around lifecycle emissions, these savings assume that biofuels are zero carbon in line with the definition of the Net Carbon Account under the Climate Change Act. We will consider lifecycle emissions in more detail in our bioenergy review to be carried out in 2011.

Costs of biofuels

Biofuels abatement costs are a function of production costs and the relative cost of petrol and diesel, both of which are highly uncertain. IEA analysis aims to address this uncertainty and provides a range of cost estimates compared to the oil price:

- For an oil price of \$60/bbl the IEA analysis suggests that there is a 39% cost penalty for biofuels.
- At \$120/bbl the IEA estimates that biofuels are 16% cheaper than conventional fuels.
- DECC's central projection is of an oil price around \$90/bbl in 2030, in which case the cost of biofuels and conventional fuels is broadly similar.

Therefore our scenarios for biofuels penetration do not involve any cost under DECC's central case price projection. Under a low oil price projection, costs in the Medium scenario would be around 0.02% of GDP in 2030, whereas under a high oil price projection there would be a saving of around 0.01% of GDP in 2030.

5. Opportunities for use of hydrogen in vehicles

Overview of hydrogen transport technologies

In contrast to biofuels, but similar to electricity, hydrogen is a carrier of energy rather than a source. It can be produced via electrolysis (using electricity to decompose water), gasification of biomass or coal and reforming of natural gas or biomethane. Each of these processes is potentially low-carbon (e.g. with electrolysis based on low-carbon power generation, and with carbon capture and storage for natural gas reforming or coal gasification).

Hydrogen can then be used in transport either in fuel cells (i.e. to generate electricity onboard the vehicle) or in internal combustion engines (ICEs) – use in fuel cells is expected to have a significant efficiency advantage, as they are electrochemical devices and therefore are not subject to the thermodynamic limits of ICEs. There are currently a number of projects demonstrating fuel cell technology for cars, vans, buses and motorbikes (Box 4.10).

Box 4.10: Hydrogen fuel cell demonstration projects

Buses:

- The Clean Urban Transport for Europe (CUTE) project demonstrated three Daimler-Chrysler Citaro fuel cell buses for three years in each of nine European cities between 2003-2007. Associated projects demonstrated a further three buses each in Reykjavik and Perth, Australia.
- Following a three-year trial of three hydrogen-powered fuel cell buses as part of the CUTE project in 2004-2007, eight new hydrogen buses (both fuel cell and ICE hybrids) are due to commence service by the end of 2010, operating on the RV1 bus route in London.

Cars:

- The Honda FCX Clarity, which has a driving range of around 400 km, is being leased to members of the public in California, Japan and Europe.
- The Mercedes-Benz F-CELL hydrogen vehicle was used during the 2010 US Open tennis tournament, and represented a significant portion of the fleet used for player and VIP transportation.⁶
- About 5,000 people have driven the fuel cell Chevrolet Equinox in short test drives, as part of Project Driveway, the world's largest market test and demonstration fleet of fuel cell electric vehicles that began in late 2007 and amassed nearly 1.3 million miles of everyday driving in cities around the world.⁷
- Thirty of the Riversimple two-seater cars will be demonstrated in Leicester from 2012. This vehicle has taken a radical approach to vehicle design, using lightweight materials to reduce fuel consumption, giving the vehicle an efficiency equivalent to around 300 miles per gallon.

Taxis, utility vehicles and vans:

- A fleet of Lotus Engineering Zero Emission Black Cabs should be operational for the London 2012 Olympics.
- West Midlands. Five fuel cell vehicles in routine utility applications such as postal deliveries on the University of Birmingham Campus were tested over a year.
- Basle, Switzerland. The world's first fuel-cell driven street cleaning vehicle, Proton Motor Empa Bucher CityCat H2, has been in use in the city since 2009.
- The ITM Power Hydrogen on Site Trials Programme (HOST), starting in 2011, encompasses the operation and refuelling of two Revolve Technologies hydrogen Ford Transit vehicles. Participants include public sector organisations, logistics providers and utility companies.

Further developments:

- A memorandum of understanding has been signed in Germany between leading industrial companies and the Government, agreeing plans for a nationwide infrastructure of Hydrogen fuelling stations by the end of 2011. The H2 Mobility initiative anticipated several hundred thousand hydrogen fuel cell vehicles from 2015.

Sources: GM, London Hydrogen Partnership, Mercedes Benz, Riversimple, ITM Power, Honda and DECC websites

6 www.mercedesbenz.com/autos/mercedes-benz/s-class/mercedes-benz-usa-provided-hybrids-and-f-cell-vehicles-for-2010-us-open/
7 www.gm.com/vehicles/innovation/fuel-cells/news/2009/million_091109.jsp

The use of hydrogen in fuel cells generates electricity onboard the vehicle, rather than requiring electricity to be stored directly in a battery. This decoupling of energy storage (hydrogen) from electricity delivery (the fuel cell) enables hydrogen vehicles to have greater range than battery electric vehicles. The reason for this is that increasing the range is a matter of increasing the volume of hydrogen storage, rather than increasing the size of the fuel cell. It therefore seems possible that there is an important future role for hydrogen PHEVs (i.e. vehicles with a battery to cover shorter journeys and a fuel cell plus hydrogen storage to enable longer journeys).

Challenges in producing low-carbon hydrogen at scale

In order for hydrogen fuel cell vehicles to deliver substantial emissions reduction, the hydrogen would need to be produced by low-carbon processes, which include:

- **Electrolysis using low-carbon electricity.** Although hydrogen production in this way is relatively inefficient thermodynamically, it has the advantage that the hydrogen could be generated when low-carbon generating capacity is underutilised (e.g. if a nuclear or CCS plant were generating electricity with a load factor of 50% or 60% rather than 90% – see Chapter 6 for discussion of this). This would imply a more distributed system of hydrogen production – with production taking place at or near hydrogen fuel stations – rather than the extensive use of pipelines or the energy-intensive hydrogen liquefaction process that would enable distribution by road.
- **Direct production from fossil fuels with ‘pre-combustion’ CCS.** Subject to the successful demonstration of pre-combustion CCS, hydrogen could be co-produced with electricity at large-scale directly from fossil fuels. The plant could produce electricity at peak times and hydrogen for transport off-peak (e.g. overnight). This method of hydrogen production is more thermodynamically efficient than electrolysis, but would result in hydrogen being produced at relatively large scale at power plant sites, and would therefore require considerable infrastructure (e.g. dedicated hydrogen pipelines) to transport it to areas of demand.
- **Production from bioenergy,** e.g. via gasification of biomass or reforming of biomethane. Using biomethane delivered via the gas grid would enable distributed production, avoiding the need for hydrogen distribution. However, there are many possible uses for bioenergy, so hydrogen would have to compete with other uses for this finite resource.

Challenges to deployment of hydrogen vehicles

Each of the processes above involves significant challenges (e.g. they would require power sector decarbonisation, or technology innovation, or abundance of sustainable bioenergy). In addition to these production challenges, other challenges relating to storage and distribution would make it easier for widespread deployment of this technology:

- There are challenges in hydrogen storage, particularly inside a vehicle. Compressed hydrogen is used for storage onboard most of the current hydrogen demonstration vehicles, which typically have a range of around 400 km (e.g. the Honda FCX Clarity). However, the weight and relatively low energy density of this solution mean that there is substantial scope for improvement. Liquid hydrogen has a greater energy density, but is very energy-intensive to produce. Research into alternatives with suitable characteristics for vehicular hydrogen storage is ongoing.
- Where hydrogen is produced at large scale away from areas of demand (e.g. with CCS), it will need to be transported. There are two main options for this, either using pipelines or liquefying the hydrogen and transporting it by road. Hydrogen pipelines are capital-intensive and expensive for long distances and/or small volumes. Laying of an extensive new hydrogen pipeline network may also face challenges relating to planning. For the liquid hydrogen option, the cost and energy consumption of the hydrogen liquefaction plant makes this expensive and energy-intensive.

Costs of hydrogen vehicles and fuel supply

From an economic perspective, use of hydrogen in vehicles is relatively expensive:

- Many ways of supplying hydrogen involve significant energy losses relative to generating electricity and using this via an electric car battery rather than a fuel cell (Box 4.11)
- The challenges in hydrogen storage and distribution have significant infrastructure cost implications, more so for centralised large-scale hydrogen production (e.g. from pre-combustion CCS).
- Hydrogen vehicle costs have so far not fallen to a point where they are competitive with conventional vehicles.

Estimates of hydrogen abatement costs are therefore relatively high compared to those for electric vehicles (e.g. around £220/tCO₂ for cars in 2030, (Box 4.12).

Box 4.11: Hydrogen – Energy losses

There are many possible ways of supplying hydrogen to fuelling stations, based on different methods and scales of production, combined with options for its distribution (if required). These different pathways for hydrogen supply require different amounts and types of energy, and therefore have varying implications for the costs and overall emissions of hydrogen supply.

The production processes considered here have different characteristics in terms of thermodynamic efficiency:

- Hydrogen production via electrolysis. This is relatively thermodynamically inefficient, as there are energy losses involved in using electricity to produce hydrogen, compressing it and then using a fuel cell to turn it back into electricity onboard the vehicle. This chain has an efficiency of around half that of an electric vehicle, i.e. a given amount of low-carbon electricity could power around twice as many miles for an EV than for a hydrogen fuel cell vehicle.
- Hydrogen production via pre-combustion CCS. The use of pre-combustion CCS technology essentially involves splitting a hydrocarbon (e.g. natural gas) into component parts – carbon and hydrogen – and extracting the carbon in the form of CO₂ for sequestration. The hydrogen can then be used to generate energy, e.g. generating electricity at the CCS plant site, or fuelling a vehicle with the hydrogen and generating electricity onboard. Because generating electricity onboard the vehicle will have a broadly similar efficiency to its generation at the CCS site, the overall efficiency of the hydrogen chain is closer to that of a battery electric vehicle, such that a given quantity of natural gas used to produce hydrogen (with CCS) could power a fuel cell vehicle for around 90% of the distance achievable if the natural gas were used to generate electricity with CCS and power a battery electric vehicle.

However, electrolytic hydrogen production does have two key advantages: it can occur off-peak, using low-carbon electricity generation capacity that is otherwise unused – which makes concerns over thermodynamic efficiency less important – and it can be undertaken on a distributed basis, avoiding the need for hydrogen distribution infrastructure. By contrast, producing hydrogen on a large scale at a CCS plant would imply the need for extensive hydrogen distribution infrastructure, which itself has implications for cost and energy consumption:

- Liquefaction and distribution by road. This method of distribution, analogous to the way petrol and diesel are distributed now, requires hydrogen to be liquefied at the production site. Due to the very low boiling point of hydrogen (-253°C), the liquefaction process is very energy intensive, requiring an electricity input equivalent to around 30% of the energy contained in the hydrogen. The liquid hydrogen would then revert to gaseous form immediately before vehicle fuelling. Due to the cost of the electricity input and the liquefaction plant, this option is also expensive.
- Distribution via pipeline. Pipeline distribution of hydrogen is considerably more energy efficient than distribution by road, with a relatively small amount of electricity being required for hydrogen compression at the production site, prior to hydrogen injection into the pipeline. However, it is a capital-intensive solution that is well suited to relatively short distances and high hydrogen flow rates in order to minimise the cost per unit of hydrogen transported.

Box 4.12: Hydrogen vehicle abatement costs

In the absence of a comprehensive published study on hydrogen fuel cell vehicle costs for all modes, our estimates of fuel cell vehicle abatement costs reflect the proportional capital cost premium (19%) estimated in a recent study⁸ for a hydrogen fuel cell car over an internal combustion engine car in 2030. This premium is then applied to vans, HGVs and buses. We intend to revisit these abatement costs as further evidence emerges.

Our preliminary estimates of abatement costs in 2030 for hydrogen fuel cell vehicles are then as follows:

- £221/tCO₂ for hydrogen fuel cell cars
- £96/tCO₂ for hydrogen fuel cell vans
- £54-66/tCO₂ for hydrogen fuel cell HGVs
- £73/tCO₂ for hydrogen fuel cell buses

These abatement costs are based on the following assumptions:

- For cars, the comparator vehicle is a medium sized conventional petrol car
- Fuel prices are consistent with DECC's central fuel price scenario
- Hydrogen production and distribution costs are £2.92/kg (electrolysis) and £2.84/kg (pre combustion CCS)
- Fuel savings are discounted at 3.5%.

We have also performed sensitivity tests to determine the extent to which capital costs and fuel prices affect the abatement costs. Table B4.6 sets out our estimates of abatement costs under the following assumptions:

- DECC's lowest and highest fossil fuel prices
- A 25% decrease and 25% increase in battery costs.

Table B4.12: Hydrogen abatement costs in 2030

Assumption		Cars	Vans	HGVs	Buses
Central		£221	£96	£54 – £66	£73
Capital cost	High	£267	£111	£58 – £73	£81
	Low	£175	£82	£50 – £59	£64
Fuel prices	High	£107	-£17	-£60 – -£47	-£34
	Low	£278	£153	£111 – £123	£126

⁸ McKinsey et al (2010), A portfolio of power-trains for Europe: a fact based analysis.

Feasible uses of hydrogen in transport

The principal advantage of hydrogen over electric vehicle batteries is for applications for which pure battery electric vehicles are unsuitable, e.g. vehicles requiring longer range. Therefore if challenges in hydrogen infrastructure development can be addressed, there may be a useful role in niche markets, with more widespread deployment if for some (unanticipated) reason battery electric vehicles do not fulfil current promise:

- Buses provide a good opportunity for hydrogen given depot fuelling.
- Hydrogen could be used in HGVs with depot fuelling and fuelling stations along motorways and main roads.
- High-mileage fleet vans could use hydrogen based on depot fuelling.
- Widespread uptake of hydrogen cars and vans would require major investment in a national network of hydrogen fuelling stations, at a scale close to that for petrol and diesel today, together with an accompanying infrastructure for hydrogen production and distribution.

Scenarios for hydrogen vehicle take up in the 2020s

We have developed three scenarios for deployment of hydrogen fuel cell vehicles in the 2020s reflecting different assumptions on the extent to which current barriers are addressed and uptake in niche markets versus more widespread deployment:

- Under our Low scenario take up of fuel cell vehicles is limited to a small number of demonstration projects and these vehicles do not achieve a significant market share for any mode. Emissions reduction from fuel cell vehicles is assumed to be negligible.
- Our Medium scenario models achievement of low-carbon hydrogen production and the availability of vehicles at reasonable cost such that fleets capable of depot-fuelling can deploy fuel cell vehicles, but without the development of a (partial or more extensive) national distribution network. In this scenario uptake is limited to buses, which come in around 2021 and account for a market share of 50% of new buses in 2030.
- Our High scenario models a world where challenges in production, storage and distribution are addressed, such that there is a national fuelling network in place supporting uptake in cars, vans, HGVs and buses:
 - Take up in cars and vans begins in 2025, with market share rising to 10% in 2030.
 - Take up in HGVs and coaches begins in 2025, with market share rising to 20% in 2030.
 - Take up in buses begins in 2021, with market share rising to 50% in 2030.

Hydrogen supply in the Low and Medium scenarios is assumed to be from off-peak decentralised electrolysis. In the High scenario, a combination of off-peak distributed electrolysis and large-scale production from fossil fuels with CCS is assumed, with distribution where necessary via dedicated hydrogen pipelines.

6. Ongoing role for demand-side emissions reduction

We assume in this chapter that the demand-side emissions reduction achieved in the period to 2020 (4.9 MtCO₂ in 2020) persist through the 2020s. Policy levers are likely to be required to lock in this emissions reduction, given evidence that consumers may revert to previous behaviours beyond an initial period (e.g. network measures and ongoing implementation would help to reinforce initial impacts of Smarter Choices programmes, etc.).

In addition to locking in pre-2020 emissions reduction, there are also opportunities for further emissions cuts in the 2020s through encouraging behaviour change and other demand-side measures:

- Given that there could still be up to 69% conventional cars in the car fleet in 2030, there is scope for further emissions cuts through demand-side measures. For example:
 - The effects of Smarter Choices measures on travel choices could be increased with greater investment in public transport infrastructure (e.g. light railway systems).
 - Adoption of eco-driving by the 80% of drivers remaining untrained by 2030 in our reference emissions projection.
 - The introduction of road pricing, which would also be consistent with the Government's objective to increase the proportion of tax revenue accounted from environmental taxes.
- CLG forecast that the number of households will increase by around 6.3 million in England by 2030. This will translate to increased demand for housing and building of new houses. Although in themselves new houses will be zero-carbon (see Chapter 5), there is a risk that these will be located far from places of work, and therefore that transport emissions will increase. This underscores the importance of developing an integrated land-use and transport planning strategy to ensure that decisions on new residential and commercial developments fully account for transport emissions.

7. The role for decarbonised rail

Direct rail emissions were 2.2 MtCO₂ in 2008, and indirect (i.e. electricity related for that part of the network which is electrified) 1.8 MtCO₂; in total, the share of rail emissions in total surface transport emissions was around 3%.

In the period to 2020 demand for rail travel is expected to increase by around 35%, with emissions from diesel trains decreasing by around 12%, with the emissions impact for electric trains uncertain given scope for significant reduction in the carbon intensity of power generation over the next decade (see Chapter 6).

Our Extended Ambition scenario to 2020 includes a small emissions reduction (around 0.6 MtCO₂ in 2020) to reflect scope for efficiency improvement both due to the introduction of new trains and through initiatives by passenger and freight operating companies to save energy.

Electrification of rail

In the medium term, there is scope for emissions reduction through increased electrification. Electric rail is much more carbon efficient than diesel rail even based on current grid carbon intensity, with emissions of around 50 gCO₂ per passenger-km compared to 75 gCO₂ per passenger-km for diesel, and scope for deep emissions cuts with an increasing proportion of low-carbon generation.

Electrification of the entire rail network combined with zero-carbon electricity generation would reduce emissions from rail to zero. The scope to achieve 100% electrification would be limited by:

- The cost of electrifying the track, which varies depending on the specific features of each section of track, e.g. elevation, cutting, tunnels etc.
- The cost of alternatives to electrifying the track (e.g. discontinuous electrification, where a train has batteries which charge on the electrified portion of a track to supply electricity to an electric motor that can power the train on sections of track that are too costly to electrify) or the use of other energy sources e.g. bio diesel.
- The cost savings realised from electrification of the railway lines resulting from the lower operating costs of electric trains; the cost savings will be greater on lines with high passenger demand (and therefore energy consumption), and lower on lines with low passenger demand.
- The feasibility of investment in sufficient additional low-carbon generation capacity to accommodate the increase in electricity demand from electrification of the rail network given the very challenging investment schedule required to meet demand from electric vehicles and heat pumps (see Chapter 6).

Thus, it is likely that electrification would be cost-effective on lines which are relatively straightforward to electrify (or whose sections of track which are difficult to electrify are short enough that discontinuous electrification is cost-effective) and which are busy enough to generate significant cost and carbon savings from electrification. It would be less cost-effective on lines that are both difficult to electrify and not busy enough to generate significant cost and carbon savings.

There is too much uncertainty over the above factors to accurately estimate the costs of electrifying each section of the UK rail network, and therefore to set out how much of the network should be electrified in order to contribute to reducing transport emissions in a cost-effective way. However, a conservative estimate of the cost of electrifying the entire railway network suggests that a substantial programme of electrification is likely to be cost-effective (Box 4.13).

Box 4.13: Cost effectiveness of electrifying UK rail network

The UK rail network consists of around 34,000 single track km of which 35% (12,000 km) are electrified and 65% (22,000 km) continue to run diesel trains.

Network Rail cites estimates of the cost of electrification at £500,000 to £650,000 per single track km, and notes that there are further opportunities to reduce costs.

If the entire rail network could be electrified at a capital cost of £500,000 per km total costs of electrification would be around £11 billion. Current emissions from combustion of diesel fuel in rail are around 2 MtCO₂ and forecast to remain at this level by 2030. Assuming a 35 year investment period (the lifetime of a diesel train) implies an abatement cost of around £160/tCO₂. DECC's carbon price reaches £160 by 2044, such that it is possible that electrifying a very significant proportion of the rail network might constitute a cost-effective abatement option by this date.

While in practice there would be some lengths of track that are either more costly to electrify than the above estimate, or not possible to electrify due to technical constraints, there would also be sections of track where capital costs would be significantly lower, and where such costs would be partly (and in some cases fully) offset by operating cost savings. In the latter case electrification could be undertaken cost-effectively well before 2044. We therefore recommend that the total costs of electrifying the entire rail network are established, so that all routes that can be electrified cost-effectively are identified.

Given uncertainties of feasibility and cost, we do not rely on emissions reduction from rail electrification and high speed rail in our transport scenarios (Section 9 below). We will however continue to monitor developments in these areas and will undertake more detailed analysis as appropriate.

High-speed rail

There is also the possibility of high-speed rail, for example, the proposed High Speed 2 linking London to Birmingham, and beyond to the North of England and Scotland (Box 4.14). The main means for this to reduce emissions is through switching from domestic and short-haul aviation. In our review of UK aviation emissions, we assessed a maximum potential emissions reduction of 2 MtCO₂ annually through switching from aviation to high-speed rail, with two caveats that this would require a low-carbon electricity system, and would also need complementary levers such as withholding any slots released at capacity constrained airports.

Box 4.14: High Speed 2

The previous Government's proposals for high-speed rail are set out in 'High Speed Rail for Britain'. It stated that High Speed 2 would transform the long-distance rail market, reducing capacity constraints of the West Coast Main line, lowering journey times, as well as providing opportunities for regeneration and development. The report states an inconclusive impact on total transport (surface transport and aviation) emissions, ranging from a reduction of 25 MtCO₂ to an increase of 27 MtCO₂ over a 60 year period.

First stage proposals suggest building a track capable of speeds up to 400 kph, between London Euston and Birmingham, to be later extended through a 335 mile high speed rail network in a Y-Shape to cities further north, including Liverpool, Manchester, Leeds and potentially Edinburgh and Glasgow.

The coalition manifesto supports proposals for a high-speed rail network as part of their measures for creating a new low-carbon economy, but also accepts, given financial constraints, that this would have to be done in phases. In the 2010 Spending Review the Government confirmed that it will bring forward legislation during this Parliament that would allow the project to proceed.

Source: High Speed Rail for Britain (March 2010)

We estimate that the effects of the high-speed rail proposals on surface transport emissions (i.e. the combined effect of the increase in emissions from electricity generation and any reduction in car emissions through modal shift) would be negligible.

8. The role of freight operations and logistics

Trends and projections at the UK level

Freight comprises around 24% of surface transport sector and 5% of total UK CO₂ emissions. Road travel dominates freight movements, carrying two-thirds of goods moved – a large share compared to other EU countries.

CO₂ emissions of HGVs – which account for the largest share of road freight movements – have been broadly stable at around 24 MtCO₂ since 1990:

- This has happened against a background of increasing amounts of freight tonnes lifted by all modes (around 4% greater in 2008 compared to 1990) and a 20% increase in road tonne-km travelled.
- Despite increased journey lengths since 1990, average HGV payloads have increased and there has been a reduction in the amount of empty running. Consequently, HGV vehicle-km travelled has increased at a slower rate (15%) than the amount of tonne-kms travelled.
- HGV carbon intensities have also fallen since 1990, by around 14%, which when combined with the other trends means that total emissions have remained broadly flat.

However van emissions have been rising over the same period (the reason for this increase is not known but the Commission for Integrated Transport argue that it is largely due to an increase in home deliveries associated with online shopping). Thus since 2000 the trend in total van and HGV emissions has been upwards.

Abatement opportunities

Abatement in freight can be achieved through reducing either distances travelled (measured in vehicle-km) or carbon intensity of travel (measured in gCO₂/km). Evidence suggests that there are particular opportunities for abatement from modal shift, supply chain rationalisation and better vehicle utilisation (Box 4.15):

Box 4.15: Abatement possibilities in freight

Key areas in freight logistics that may offer potential are:

- **Modal Shift** – from high emitting road travel to rail or water.
 - Rail is currently taking advantage of some modal shift opportunities.
 - Intermodal transfer where containers are shifted from trucks to rail for regular shipments between terminals is increasingly being employed by retailers such as Tesco, Ikea and ASDA (63% increase in intermodal tonne-km from 2002-2009).
 - Work by AECOM for DfT has identified opportunities for rail in a number of markets. However further work is needed to identify the optimal rail network.
 - Water – A case can be made that missing infrastructure is prohibiting freight transport, and that strategic investment in ports would facilitate modal shift to water.
- **Supply Chain rationalisation** – optimising distribution centre locations, sourcing produce locally and greater use of consolidation centres.
- **Vehicle utilisation** – increasing load sharing, backloading initiatives and software for routing and load consolidation.
 - Case study evidence from John Lewis, Waitrose, Boots and Tesco indicates that **backloading** vehicles can achieve 4-20% vehicle-km savings.
 - Evidence from Boots, Musgrave-Budgens, Londis, Sainsbury's and leading supermarket chains suggests reduction of 2.5-6% in vehicle-km are achievable through **inter-company collaboration**.
- Other measures such as reducing 'just in time' business practices and increasing the size and weight of trucks may also provide emissions savings.

Various scenarios for freight emissions suggest scope for significant reduction (Box 4.16). However, these scenarios are highly uncertain, and further evidence is required on:

- The long-term potential for transfer of freight from road to rail and water transport and cost-effectiveness of further network/infrastructure investment.
- Availability of backhauls and load sharing opportunities which could be taken up by hauliers in the 2020s.
- Abatement potential from changes in business practice such as just in time delivery, vendor managed inventories and supply chain event management.

Box 4.16: Freight scenarios

Alan McKinnon, Professor of freight logistics at Heriot-Watt University, has produced scenarios with Maja Piecyk for 2020 and 2050 examining possible changes in logistics variables.

- For 2020, seven focus group discussions and a large-scale Delphi Survey detail what logistics professionals consider to be business as usual for changes in modal split, vehicle loading and empty running for 2020.⁹ In a central scenario, logistics measures are forecast to reduce distance travelled by 22% of vehicle-km in 2020 with no further policy intervention. In the optimistic and pessimistic scenarios 39% and 1% reductions in vehicle-km are achieved respectively.
- For 2050, a set of possible scenarios for changes in modal split, empty running and average laden payloads result in vehicle-km reductions of up to 58%¹⁰. Abatement measures considered include a return to the road share of freight movement of the early 1980s and an increase in average laden payloads to 16 tonnes.

DECC also set out four scenarios for HGV vehicle km between 2007 and 2050 in their 2050 Calculator:

- Scenario 1: total HGV distance rises from 29 billion vehicle-km in 2007 to 35 billion in 2030 and 41 billion in 2050
- Scenario 2 ('current policy direction'): total distance rises to 33 billion vehicle-km in 2030 (a 7% reduction over business as usual) and 35 billion in 2050 (a 14% reduction). This scenario is consistent with our reference emissions projection.
- Scenario 3: total distance decreases to 28 billion vehicle-km in 2030 (a 19% reduction over business as usual) and 26 billion in 2050 (a 36% reduction)
- Scenario 4: total distance decreases to 27 billion vehicle-km in 2030 (a 23% reduction over business as usual) and 22 billion in 2050 (a 47% reduction)

We model two scenarios for reduction in HGV vehicle-km:

- HGV vehicle-km in our Medium Abatement scenario are 6.5% lower than the reference
- HGV vehicle-km in our High Abatement scenario are 13% lower than the reference. This is consistent with the reduction delivered by DECC's Scenario 3 over Scenario 2 (current policy direction).

9. Surface transport emissions scenarios for the 2020s

The path to 2030

Our surface transport abatement scenarios are built up from the scenarios for more efficient conventional vehicles, electric vehicles, biofuels and hydrogen vehicles (see Figures 4.13-15):

- The Low Abatement scenario (i.e. the combination of Low scenarios for individual measures) results in surface transport emissions of 72 MtCO₂ in 2030, compared to emissions in the reference emissions projection of 79 MtCO₂ (i.e. a 8% reduction).
- Emissions in the Medium Abatement scenario are 67 MtCO₂ in 2030 (i.e. 15% lower than in the reference emissions projection).

⁹ Piecyk, M. and McKinnon, A. (2010) 'Forecasting the carbon footprint of road freight transport in 2020,' *International Journal of Production Economics*, 128, pp31-42.

¹⁰ McKinnon, A. and Piecyk, M. (2010) 'Logistics 2050: Moving Freight by Road in a Very Low Carbon World'.

- Emissions in the High Abatement scenario are 50 MtCO₂ in 2030 (i.e. 36% lower than in the reference emissions projection).

In our Medium Abatement scenario

- Average emissions intensity of cars falls by 39% from 132 gCO₂/km to 81 gCO₂/km, whilst distance travelled increases by 9% from 446 billion km to 485 billion km 2020-2030
- Average emissions intensity of vans falls by 33% from 175 gCO₂/km to 118 gCO₂/km, whilst distance travelled increases by 24% from 92 billion km to 114 billion km 2020-2030 (Figure 4.16).

The cost in the Medium Abatement scenario is in the range -0.1 to 0.2% of GDP in 2030 depending on assumptions about technology costs and fossil fuel prices (Table 4.1).

We incorporate these scenarios and cost estimates into our economy-wide analysis of options for meeting the fourth carbon budget in Chapter 3.

Table 4.1: Cost sensitivity

Central costs		High capital costs		Low capital costs		High fossil fuel prices		Low fossil fuel prices	
Cost (£m)	% GDP	Cost (£m)	% GDP	Cost (£m)	% GDP	Cost (£m)	% GDP	Cost (£m)	% GDP
£1,890	0.08%	£3,773	0.17%	£7	0.00%	−£2,595	−0.11%	£4,133	0.18%

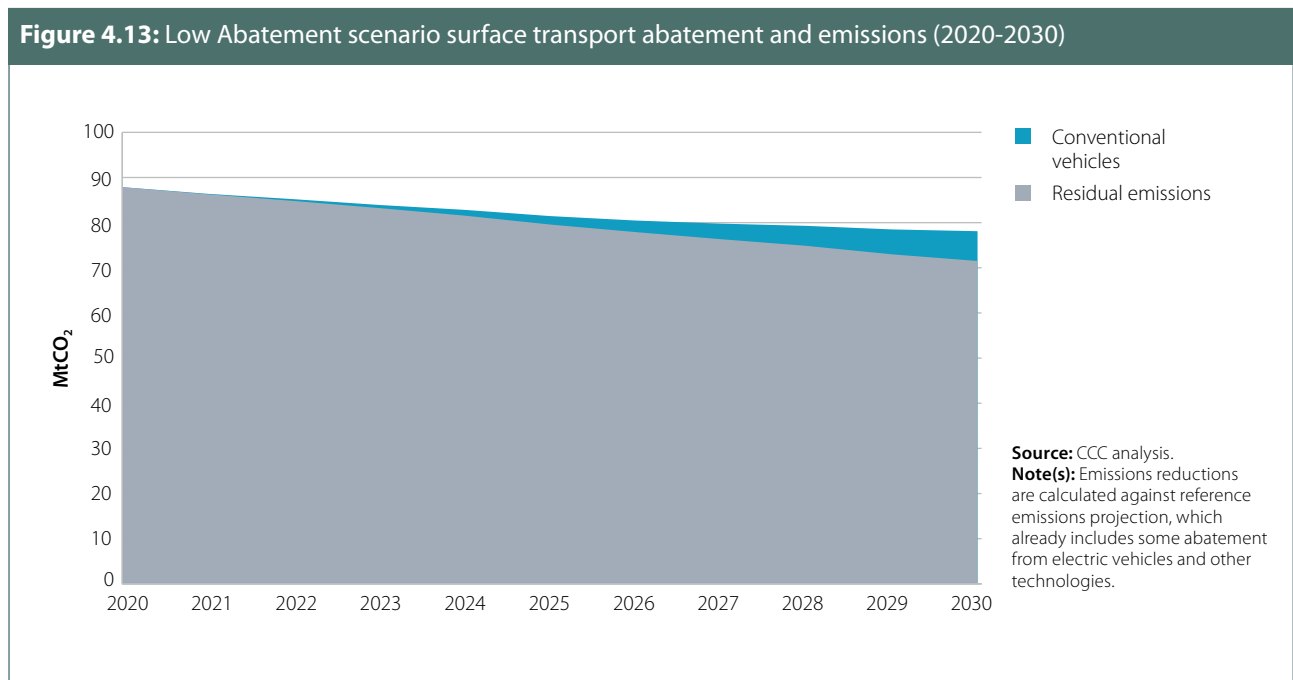


Figure 4.14: Medium Abatement scenario surface transport abatement and emissions (2020-2030)

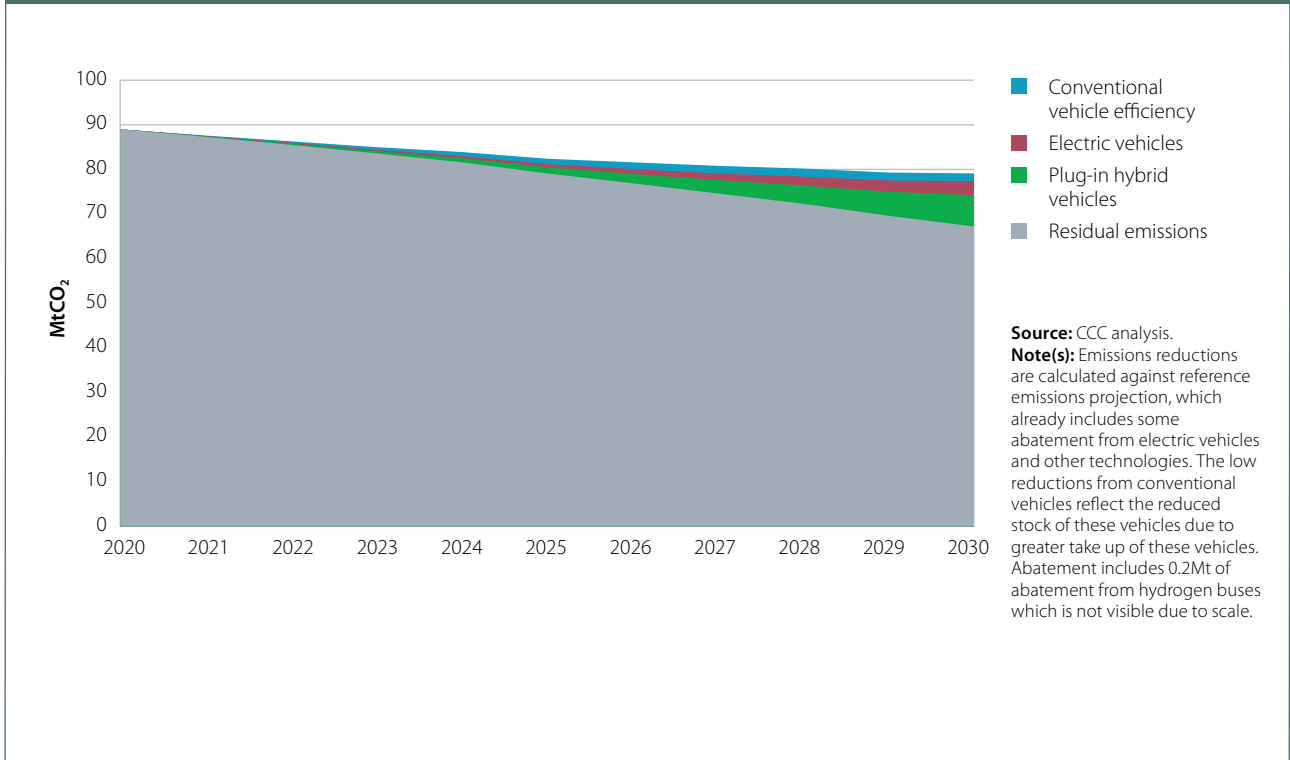


Figure 4.15: High Abatement scenario surface transport abatement and emissions (2020-2030)

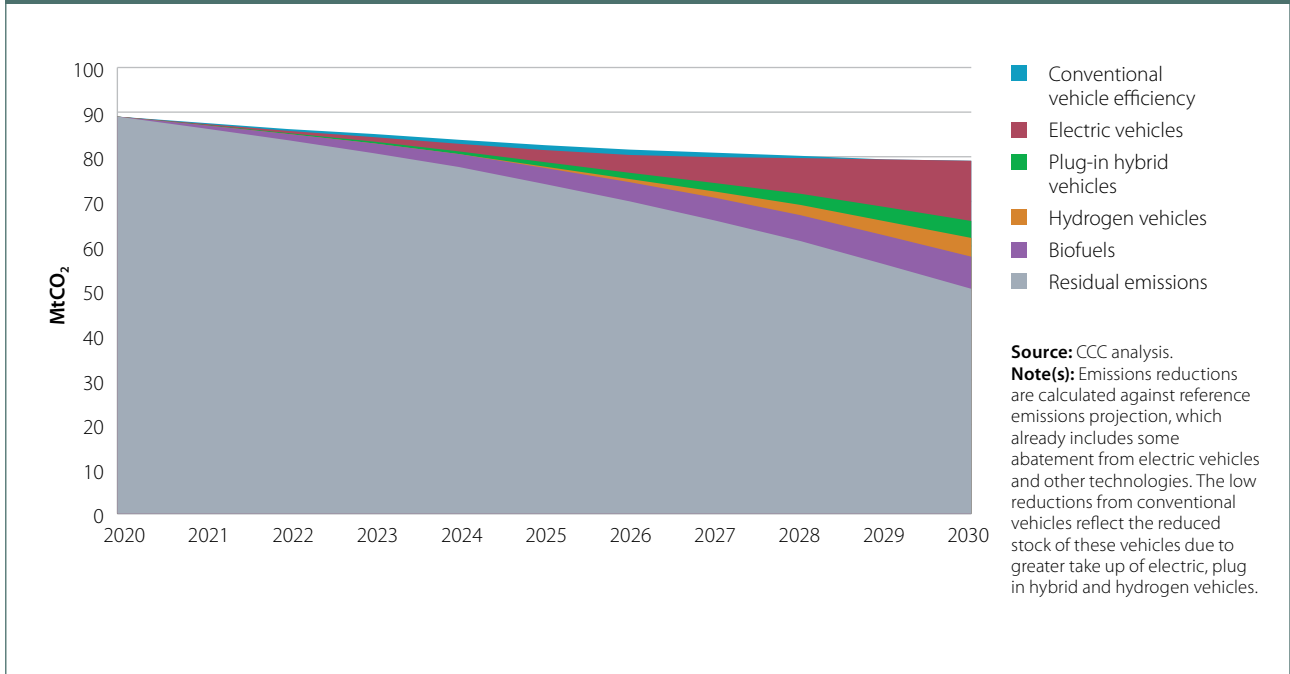


Figure 4.16: Historical trends and Medium Abatement scenario projections of vehicle-km, MtCO₂ and gCO₂/km for cars (1990-2030)

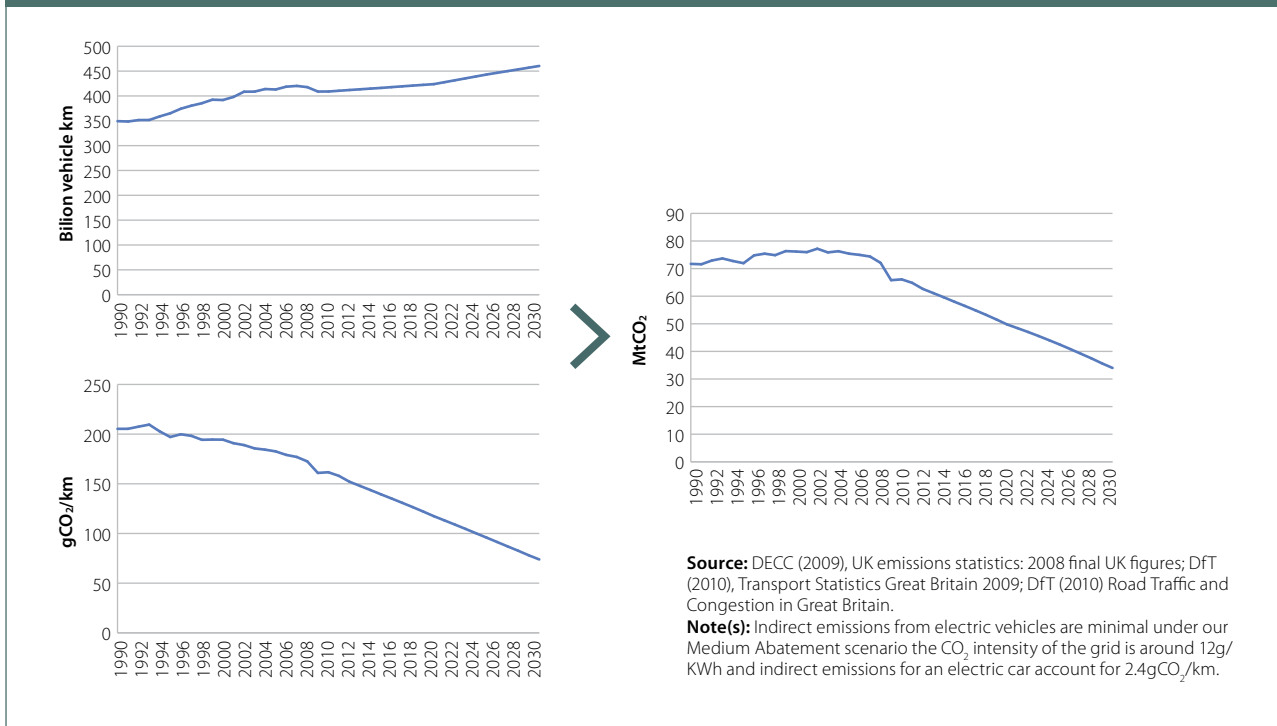
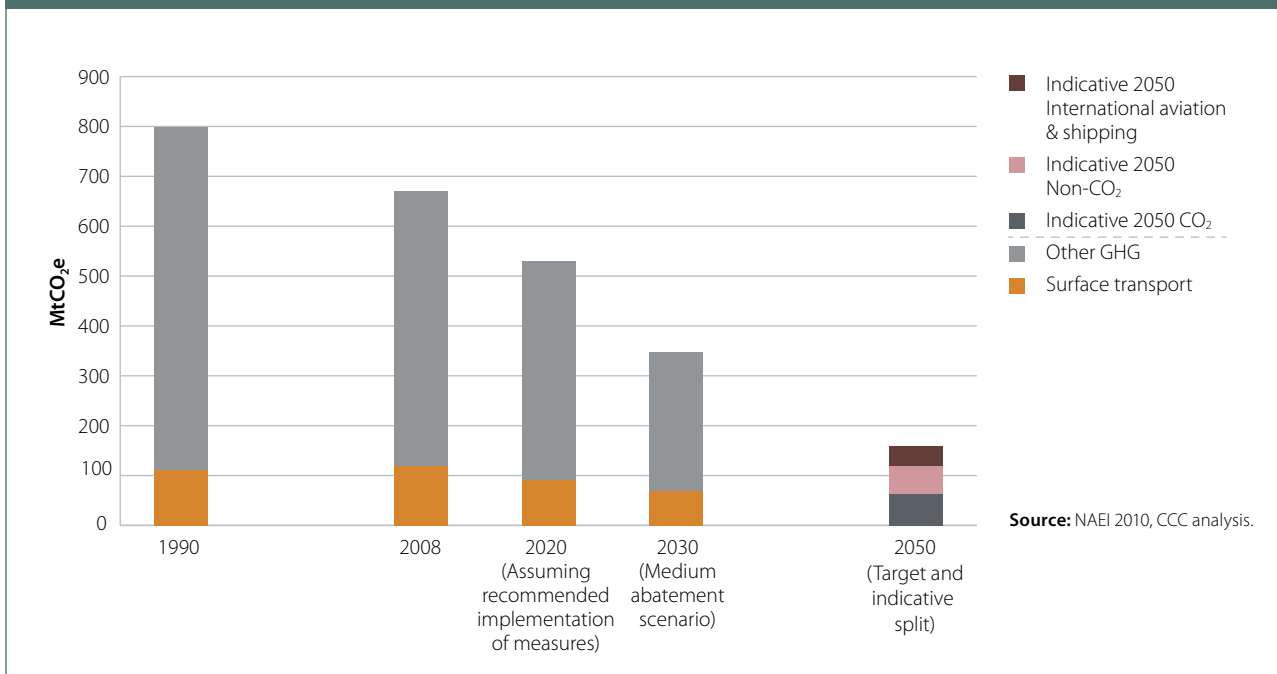


Figure 4.17: Surface transport emissions in the context of UK greenhouse gas emissions (1990-2030, 2050)



The path from 2030 to 2050

Emissions in 2030 are 67 MtCO₂ in our Medium Abatement scenario, with further reduction required to 2050 including (Figure 4.17):

- A low or zero-carbon car and van fleet, comprising electric and plug-in hybrid vehicles, with the possibility of hydrogen vehicles.
- The possibility of hydrogen HGVs.
- Biofuels meeting demand for residual liquid fuels (e.g. from plug-in hybrid vehicles, HGVs).
- Rail electrification

Given our assessment of what is possible in other sectors, it is likely that an emissions reduction of 90% or more will be required in surface transport to meet the economy-wide 80% target. The implication of this is that conventional cars and vans should be fully phased out by the mid-2030s, in order that the car and van fleet is zero- or low-carbon by 2050.

10. Implications for first three budget periods

The main implications for the first three budget periods relate to electric vehicles, biofuels and hydrogen:

- **Electric vehicles.** It is unlikely that there could be very significant roll-out of electric cars and vans in the 2020s from a standing start in 2020. Therefore in order to support required decarbonisation in the 2020s, it will be important to make progress on electric vehicle deployment in the first three budget periods. This reinforces the need for transitional Government support to cover the cost of electric car batteries, together with investment in a battery recharging network. In addition, the economics of electric vans should be assessed in more detail and transitional support arrangements introduced as appropriate. Assessment of network implications from significantly increased penetration of electric cars should be undertaken and used to inform design of investment programmes.
- **Second generation biofuels.** Research, development and demonstration of second generation biofuels is required if these are to play an important role in the 2020s. Consideration should be given to options for supporting R&D and pulling through second generation biofuels (e.g. through a requirement to meet EU biofuels targets with a greater proportion of second generation biofuels).
- **Hydrogen.** There should be continued support for hydrogen technologies as part of a wider technology strategy in order to support deployment in the 2020s in markets where vehicle range is of particular importance.

The Committee will continue to monitor progress developing a framework for and rolling out electric cars in the period to 2020, and will explore scope for adding indicators relating to progress in electric vans, second generation biofuels, and hydrogen.

11. Key findings



44% emissions reduction in surface transport can be achieved by 2030.

44%

60% of new cars and vans in 2030 could be electric.

60%

Potential volume of biofuels consumed each year during 2020s.

2.7m
tonnes oil
equivalent

Potential carbon efficiency of new conventional cars in 2030.

80
gCO₂e/km

50% of new buses in 2030 could be powered by hydrogen.

50%

Potential reduction in car trips from smarter travel choices.

5%

Potential cost of reducing surface transport emissions by 44%.

0.1%
GDP

Chapter 5



1. The entry point: buildings and industry emissions in the first three budgets
2. Emissions reductions in buildings through the 2020s
3. Emissions reductions in industry
4. Implications for the first three budgets
5. Key findings

Chapter 5: Reducing emissions from buildings and industry through the 2020s

Introduction and key messages

Emissions from buildings currently account for 36% of total UK GHG emissions, while emissions from industry make up for 35% of the total. Our previous analysis suggests that there is scope for a 35% reduction in buildings emissions and a 16% cut in industry emissions by 2020, primarily through energy efficiency improvement and increased deployment of renewable heat. In this chapter we consider scope for further cuts in buildings and industry emissions through the 2020s.

The key messages in the chapter are:

- There is scope for emissions reductions by 2030 (relative to 2007) of 74% in buildings and 48% in industry.
 - The potential for cutting direct (i.e. heat related) emissions from buildings is mainly through increased home insulation (in particular solid wall insulation), widespread deployment of heat pumps in residential and non-residential sectors, and district heating using waste heat from low carbon generation.
 - There is also potential for reducing indirect (i.e. electricity related) emissions from buildings through energy efficient appliances and lighting.
 - There is considerable scope for cutting industry emissions through the burning of biomass and biogas rather than fossil fuels, the use of CCS technology and further abatement options in energy intensive industries. There may also be significant opportunities for emissions reductions through product substitution and materials efficiency. These should be considered further given the need for further industry emissions reductions over and above what we have identified to ensure that the 2050 target remains attainable.
- We estimate the cost of cutting buildings and industry emissions to be around £1.4bn (<0.1% of GDP) in 2030 in our Medium Abatement scenario, with a range of -£2.5bn to £5.3bn for sensitivities on technology costs and fossil fuel prices.
- To ensure that the potential we have identified remains an option for the 2020s, it is important now to proceed with major energy efficiency improvements of the housing stock, to develop markets for renewable heat, to demonstrate industry Carbon Capture and Storage (CCS), and to further assess the scope for district heating using waste heat from low carbon power generation.

We set out the analysis that underpins these messages in four sections:

1. The entry point: buildings and industry emissions in the first three budgets
2. Emissions reductions in buildings
3. Emissions reductions in industry
4. Implications for the first three budget periods

1. The entry point: buildings and industry emissions in the first three budgets

Emission trends from buildings and industry

Emissions from buildings and industry currently account for more than two-thirds of total GHG emissions in the UK (Figure 5.1):

- The residential sector accounts for 23% of total UK GHG emissions.
 - Residential CO₂ emissions comprise 56% direct emissions (i.e. non-electricity related, mainly due to heat) and 44% indirect emissions (i.e. electricity use for lighting, appliances, etc.).
 - Residential emissions fell by 6% between 1990 and 2008. This was driven mainly by falling indirect emissions in the 1990s as a result of the switch from coal to gas-fired power generation (Figure 5.2).
 - More recently, residential emissions fell by 5% between 2004 and 2008. Although there was a small increase in 2008, residential emissions fell by 5% in 2009, due mainly to rising fuel prices and the recession.
- The non-residential sector accounts for 12% of total UK GHG emissions.
 - Within this sector, commercial buildings account for 9% of total UK GHG emissions, with the remainder from public buildings. Commercial buildings CO₂ emissions are largely (around 80%) indirect, with public sector emissions equally split between direct and indirect emissions.
 - Commercial sector emissions have remained broadly flat since 1990, with the impact of falling carbon intensity in electricity generation offset by increased electricity consumption (Figure 5.2). The recession appears to have had a major impact on this sector with a reduction of approximately 19% estimated in 2009.
 - In the public sector, emissions have fallen by 30% since 1990 but have stayed broadly flat in recent years.
- Industry emissions account for around 35% of total UK GHG emissions and comprise around two-thirds direct emissions, with the remainder indirect. Energy intensive industries covered by the EU Emissions Trading System (ETS) accounts for around two-thirds of total industry emissions.
 - Industry CO₂ emissions fell by around 20% between 1990 and 2008 due to fuel switching and industrial restructuring, with large reductions in the mid to late 1990s (Figure 5.3).
 - In the five year period before the recession, industry emissions fell by 7%. As a result of the recession, emissions fell by 5% in 2008 and 11% in 2009.

Figure 5.1: GHG emissions from buildings and industry in the context of total UK emissions (2008)

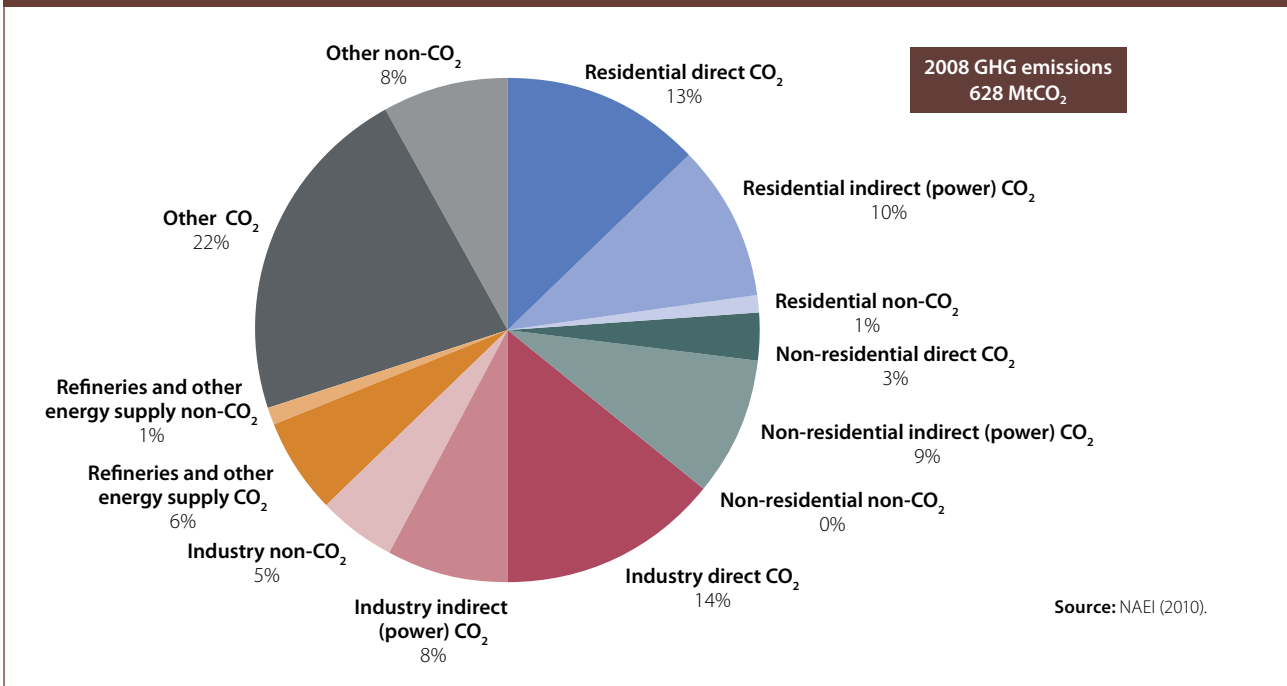


Figure 5.2: Energy consumption, carbon intensity and CO₂ emissions from buildings (1990-2008)

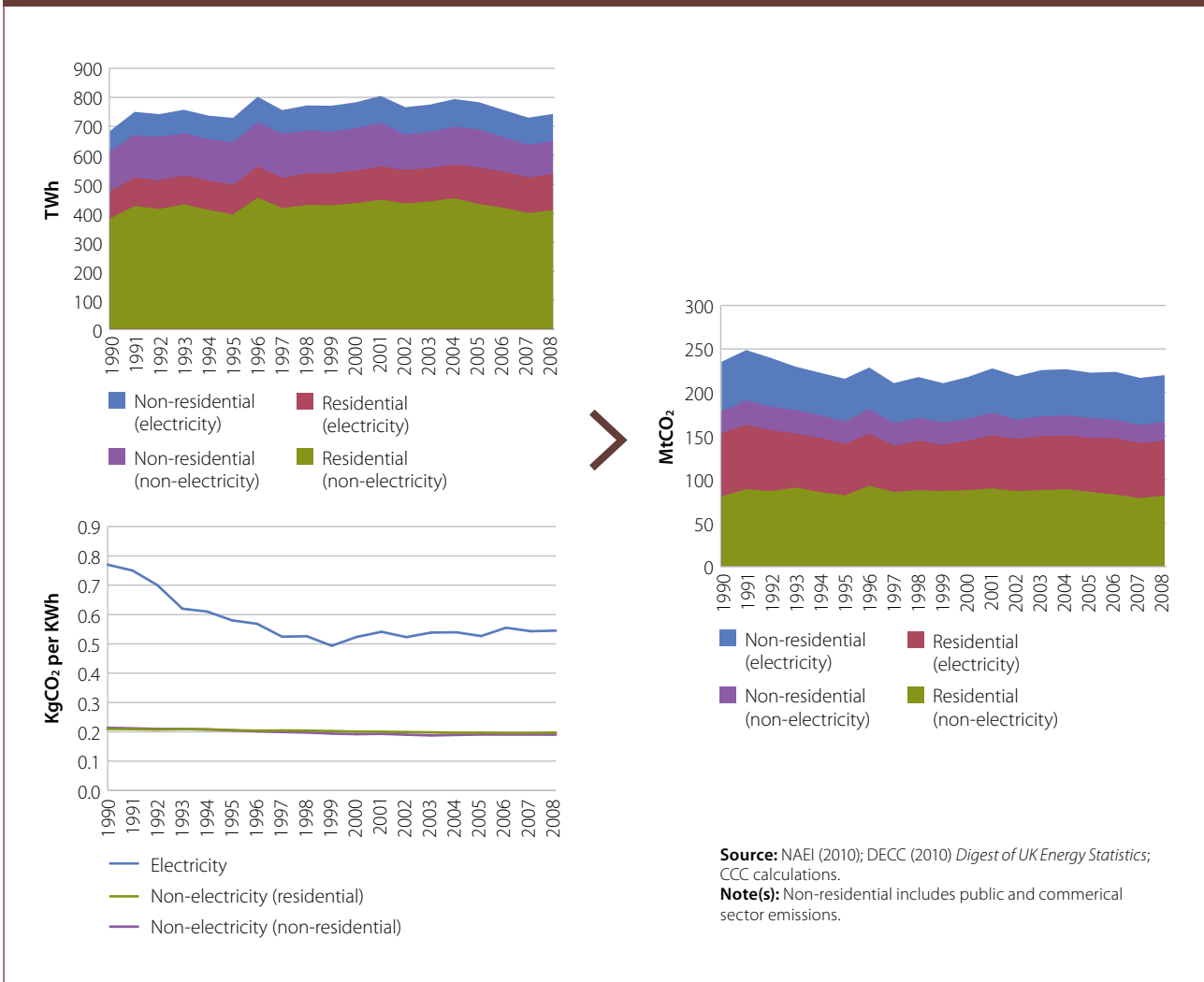
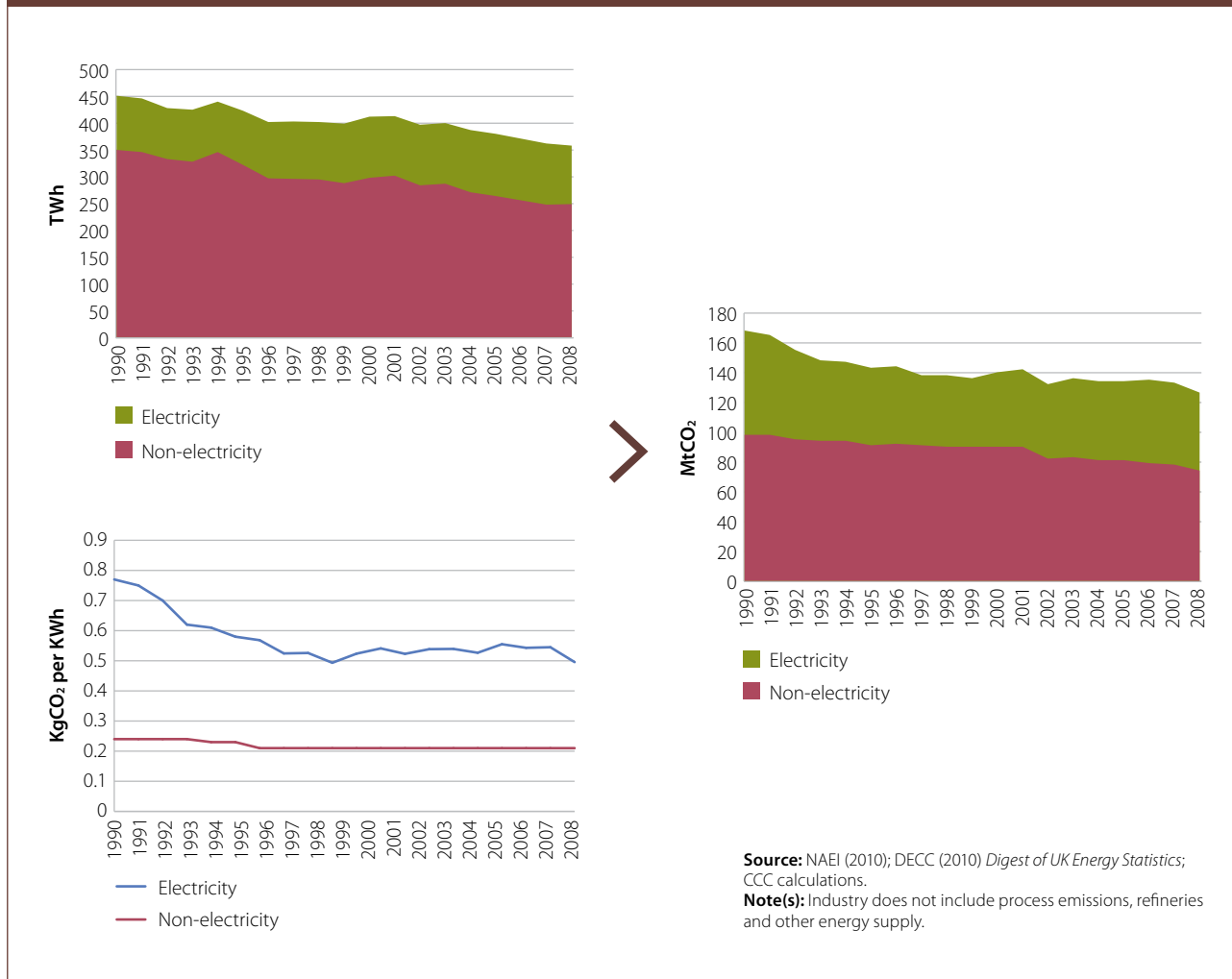


Figure 5.3: Energy consumption, carbon intensity and CO₂ emissions from industry (1990-2008)

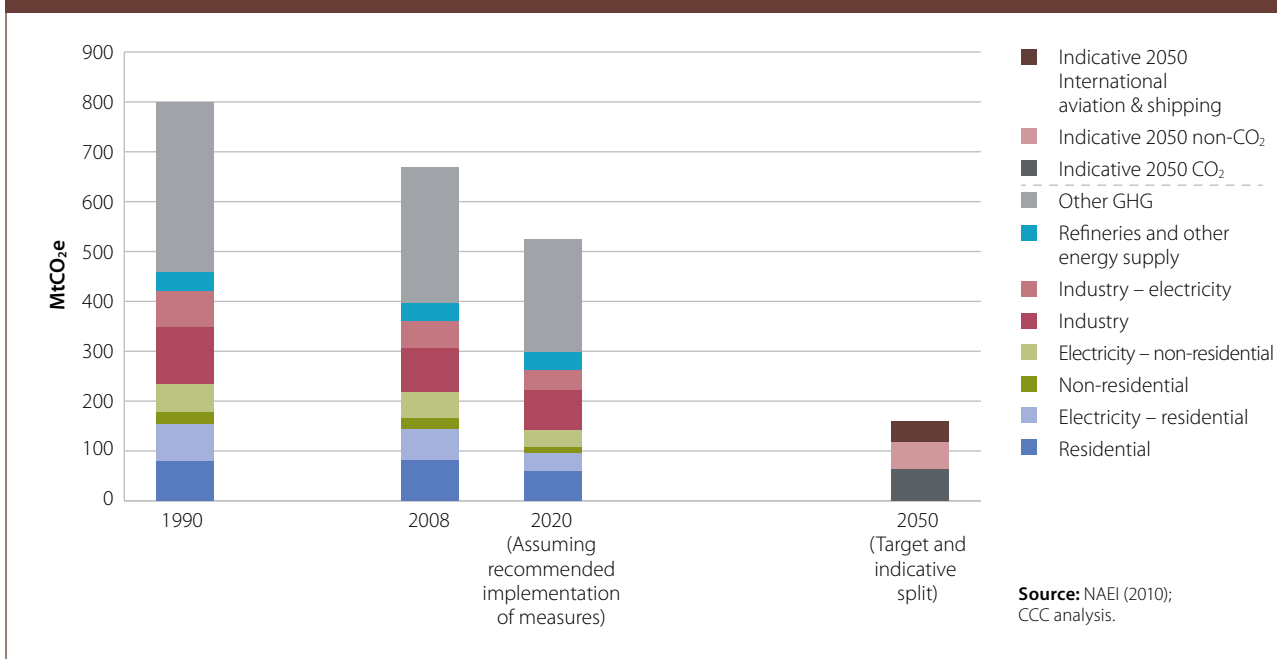


Scope for reducing buildings and industry emissions to 2020

Our previous analysis identified significant opportunities for reducing emissions from buildings and industry over the next decade through energy efficiency improvement and deployment of renewable heat. We developed scenarios for feasible emissions reductions based on a three step approach:

- **Technical emissions reduction potential.** We assessed the quantity and cost of emissions reduction potential from a range of energy efficiency improvements (e.g. insulation, efficient appliances and motors), low carbon heat technologies and behaviour change measures (e.g. turning down thermostats).
- **Barriers to unlocking technical potential.** The fact that there remains significant potential for implementation of cost saving measures suggests the presence of barriers to action. We reviewed a range of barriers (lack of information, transaction costs, etc.) and means for addressing these (i.e. through new policy approaches).

Figure 5.4: Buildings and industry emissions in the context of UK greenhouse gas emissions (1990-2020, 2050)



- Feasible emissions reduction potential.** Our assessment of feasible emissions reduction reflected a judgment on the extent to which new policy approaches could be introduced to address barriers to action. A number of new approaches are now being taken forward by the Government in the form of the Green Deal, the Renewable Heat Incentive (RHI), and the Carbon Reduction Commitment (CRC) energy efficiency scheme.

Our Extended Ambition scenario, which forms the basis for our Interim target, assumes that effective new policies are introduced and result in buildings emissions reductions of 37 MtCO₂ in 2020 and industry emissions reductions of 12 MtCO₂ in 2020. However, even with these significant reductions over the next decade, very deep cuts are required in subsequent years given the 2050 economy wide target and the limited range for reducing emissions in some sectors (Figure 5.4).

- Residential buildings.** We assume that new policies successfully address barriers to action and deliver significant energy efficiency improvements in the UK housing stock, including the insulation of 90% of lofts and cavity walls, as well as 2 million solid walls (from a total of nearly 8 million) by 2020. We also assume that 13 million boilers are replaced with new efficient boilers and that substantial increases in appliance efficiency are achieved. In total this could result in a 2020 emissions reduction of 17 MtCO₂ in the residential sector.

-
- **Non-residential buildings.** We assume that most cost effective emissions reductions (energy efficiency improvement, better energy management, etc.) are achieved through a combination of the CRC and new policy approaches (e.g. for small and medium sized enterprises (SMEs)). In 2020, we assume emissions reductions from non-residential buildings of 9 MtCO₂.
 - **Industry.** We assume that around 90% of cost effective industry emissions reductions from short pay-back energy efficiency improvements are achieved, due to incentives provided under the EU ETS and Climate Change Agreements. Alongside new policies to strengthen incentives for smaller firms this could result in an emissions reduction from industry of 6 MtCO₂ by 2020. We regard this as a lower bound given that existing emissions reduction models (e.g. ENUSIM) do not include the full range of abatement options for industry.
 - **Renewable heat.** We assume that the RHI is introduced and results in a 12% penetration of renewable heat in 2020 and 17 MtCO₂ emissions reductions, mainly through the deployment of biomass boilers and heat pumps. Recent announcements in the 2010 Spending Review cut the funding for the RHI by 20%. Final proposals will be published at the end of 2010 and we will look at the implications for carbon savings in the period to 2020 in our renewable energy review, to be published in spring 2011.

Buildings and industry emissions reference projection for the 2020s

The Extended Ambition scenario defines the starting point for our 2020s scenarios (see Section 2.3 for buildings and 3.3 for industry). We also incorporate the Extended Ambition scenario in a reference emissions projection for the 2020s, but assume that there is no additional abatement effort beyond 2020. Therefore emissions in the reference projection grow in line with GDP growth, population growth, and household formation (see Chapter 3 for assumptions on key variables underpinning reference projections across all sectors). This results in a 7% increase in buildings emissions and a 4% rise in industry emissions between 2020 and 2030 (Figure 5.5 and 5.6).

We now consider options to offset this projected emissions growth, and develop scenarios for emissions abatement through the 2020s, which include options that we assess to be both feasible and cost-effective.

Figure 5.5: CCC reference projection for buildings (2008-2030)

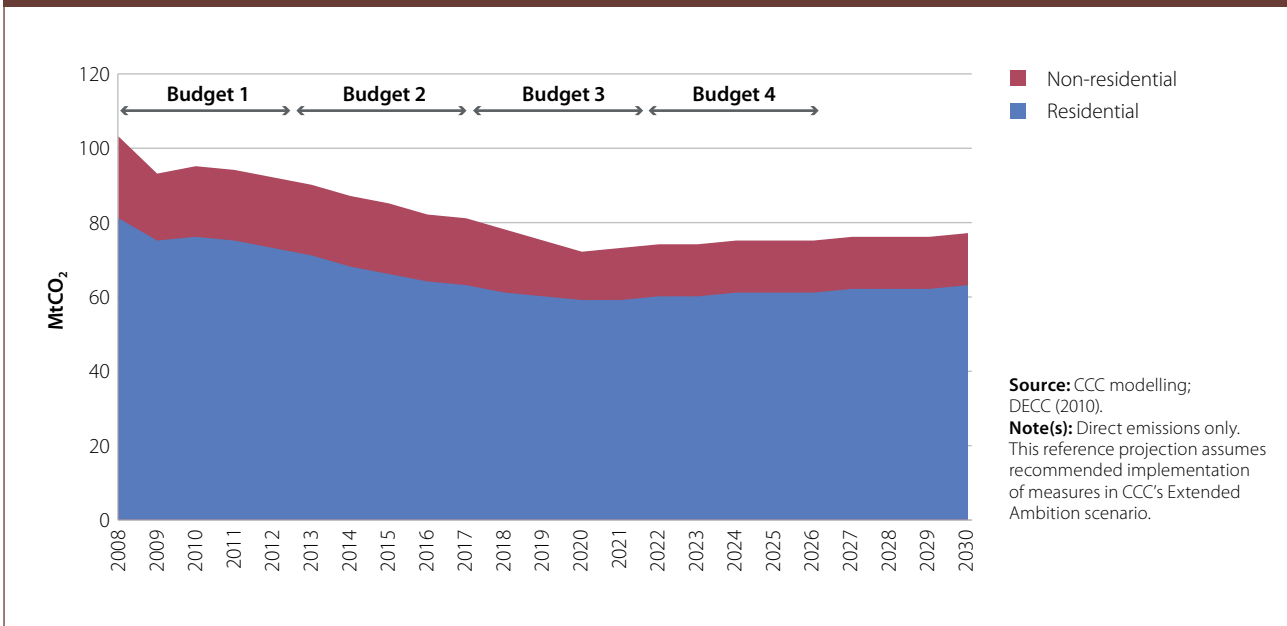
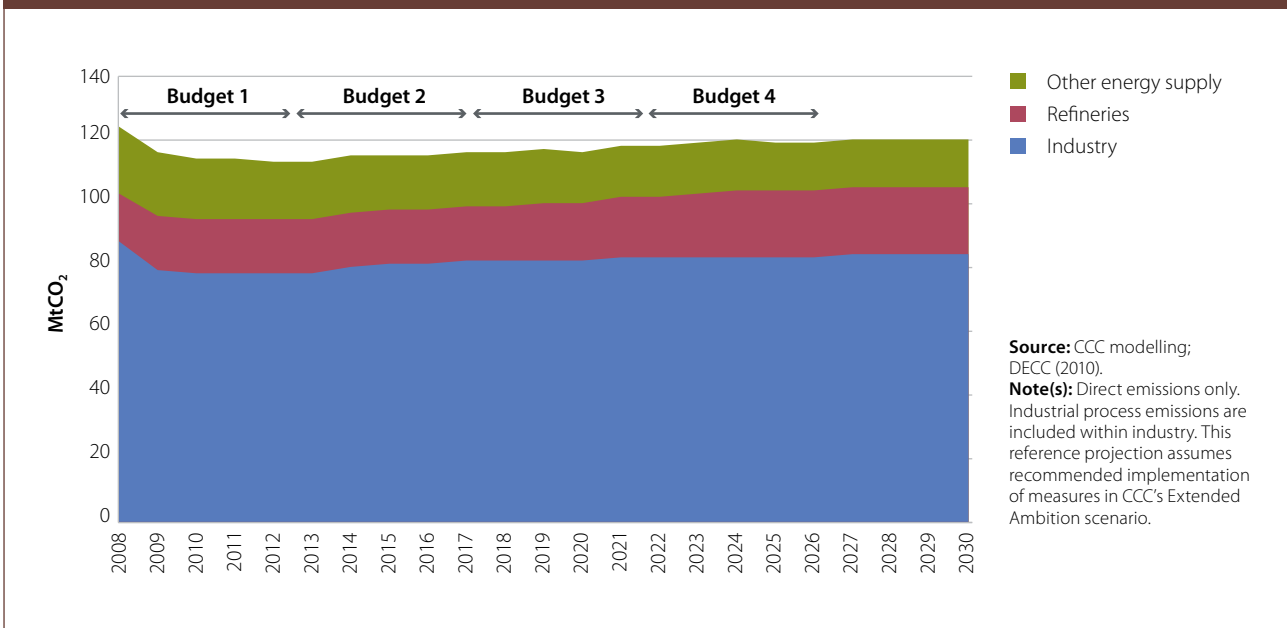


Figure 5.6: CCC reference projection for industry, refineries and other energy supply (2008-2030)



2. Emissions reductions in buildings through the 2020s

Given a buildings emissions share of more than one third of total emissions in 2020 (on an end-use basis), it will be important to cut emissions further through the 2020s in order to meet carbon budgets. We now consider the scope for reducing emissions through energy efficiency improvement and renewable heat deployment, and then combine both sets of options in our scenarios for buildings emissions to 2030.

2.1. Energy efficiency improvement

(i) Residential sector – household and emissions growth to 2030

The context for residential buildings emissions in the 2020s is one where there is projected, if highly uncertain, growth of around seven million households relative to current levels. Projected household growth is due to a growing population and demographic change:

- Official projections suggest that the UK population will grow from current levels of around 62 million to 66 million in 2020 and to 71 million by 2030.
- Household size is projected to fall from the current level of 2.3 people to 2.1 people by 2030 due to an increasing number of single person households.
- The combination of these effects would increase the number of households from the current level of 26 million to around 33 million by 2030 (i.e. a 30% increase).

Therefore the rising population and increasing number of households could increase buildings emissions by up to 20 MtCO₂ if new household energy consumption was to mirror that of current¹ new build homes (2.8 tCO₂ per household, excluding transport).

(ii) Residential fabric improvements through the 2020s

Some of this potential emissions growth is likely to be offset through new build properties achieving zero carbon standards, as envisaged under current policies in England and the devolved administrations (Box 5.1). However, even with a high rate of construction, zero carbon homes are unlikely to account for more than around 10% of the total housing stock by 2030, with the implication that existing houses will still account for at least 90% of the total stock in 2030. Accelerated replacement of the existing stock, while reducing operational emissions compared to older houses, would have to take account of the issue of embodied carbon (Box 5.1).

¹ Consistent with Part L of the 2006 building regulations.

Box 5.1: Zero carbon homes and embodied carbon

Zero carbon homes

From 2016, new homes in England will have to be built to level 6 of the Code of Sustainable Homes, as 'zero carbon homes'. The exact definition of 'zero carbon' is yet to be decided but it is likely to require high energy efficiency standards (with energy demand for space heating expected to be around 40 kWh/m², compared to an average of around 200 kWh/m² in the existing stock), as well as on-site or off-site renewable energy generation for all building-related energy demand (e.g. lighting, ventilation). The devolved administrations are also introducing zero carbon building standards. By 2030, we can thus expect a stock of new homes built to zero carbon standards of around 2-3 million, primarily driven by the demand for extra dwellings.

Embodied carbon

Improving the energy efficiency of existing homes to levels similar to those found in new-build homes is difficult and expensive. This raises the question over whether replacement of the housing stock should be accelerated. However, accelerated replacement of the existing stock does not necessarily make sense from a carbon perspective:

- A typical new 2 bed home built with traditional materials (brick, concrete foundations etc) embodies around 80 tCO₂.
- The carbon payback time (through lower operational CO₂ emissions) is several decades, and is thus likely to only be a solution for the least efficient buildings where refurbishment is prohibitively expensive.
- One possibility, which should be considered further, is to build new houses with natural building materials that sequester carbon (e.g. wood, hemp and straw). For example, the Stadthaus block of flats in London, the world's tallest timber residential building, has been estimated to store almost 700t CO₂. In addition, its construction has avoided 450 tCO₂ compared to using a typical reinforced concrete frame.

Given that our Extended Ambition scenario includes the widespread take-up of loft and cavity wall insulation, there should be little left to do on these measures in the 2020s. The focus at this time should therefore shift to measures where there is limited implementation envisaged in the period to 2020, and where abundant cost-effective potential remains. The greatest opportunity is for internal and external wall insulation, primarily in solid-walled houses:

- Even if 2 million solid wall houses are insulated in the period to 2020, as envisaged in our Extended Ambition scenario, this will leave a further 6 million houses that could be insulated through the 2020s and beyond.
- The heat demand reduction associated with further widespread solid wall insulation in the 2020s is around 13TWh, or 3% of total residential demand for heat in 2030 (Figure 5.7).
- Solid wall insulation is cost-effective, with a cost per tonne of CO₂ abated of around £18t/CO₂. It will become increasingly attractive assuming that heat is subject to a carbon price, and that the latter rises through the 2020s.
- Solid wall insulation is necessary to support deployment of heat pumps (see section 2.2 (i) below).

While solid wall insulation provides the greatest potential for energy efficiency improvement in the 2020s, there is likely to be scope for savings from other building fabric measures such as underfloor insulation and energy efficient glazing and other building fabric measures, resulting in further scope for emissions reductions up to 11 MtCO₂ (Figure 5.8).

Our Medium Abatement scenario for energy demand and emissions from buildings includes a high take-up of solid wall insulation (i.e. total 3.5 million by 2030), while the High Abatement scenario includes further solid wall insulation take-up (a total of 5.7 million by 2030) and also includes these additional measures (e.g. floor insulation and energy efficient glazing).

Figure 5.7: Heat demand in different housing stock segments in the Medium scenario (2008-2030)

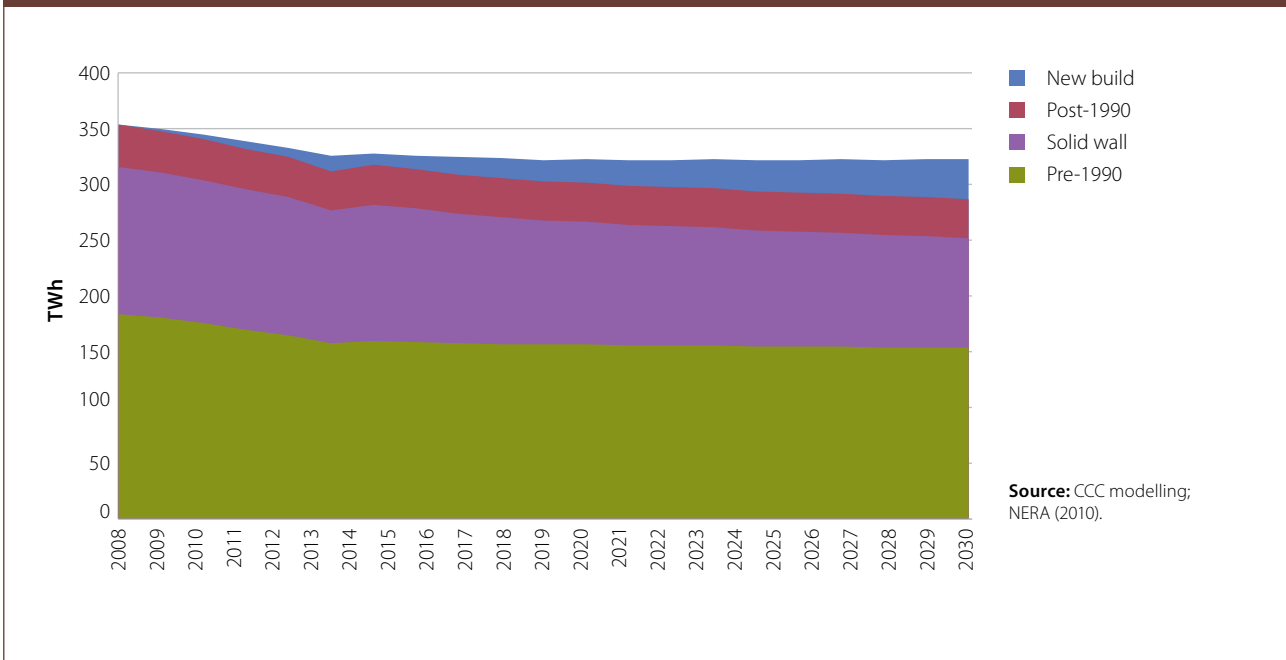
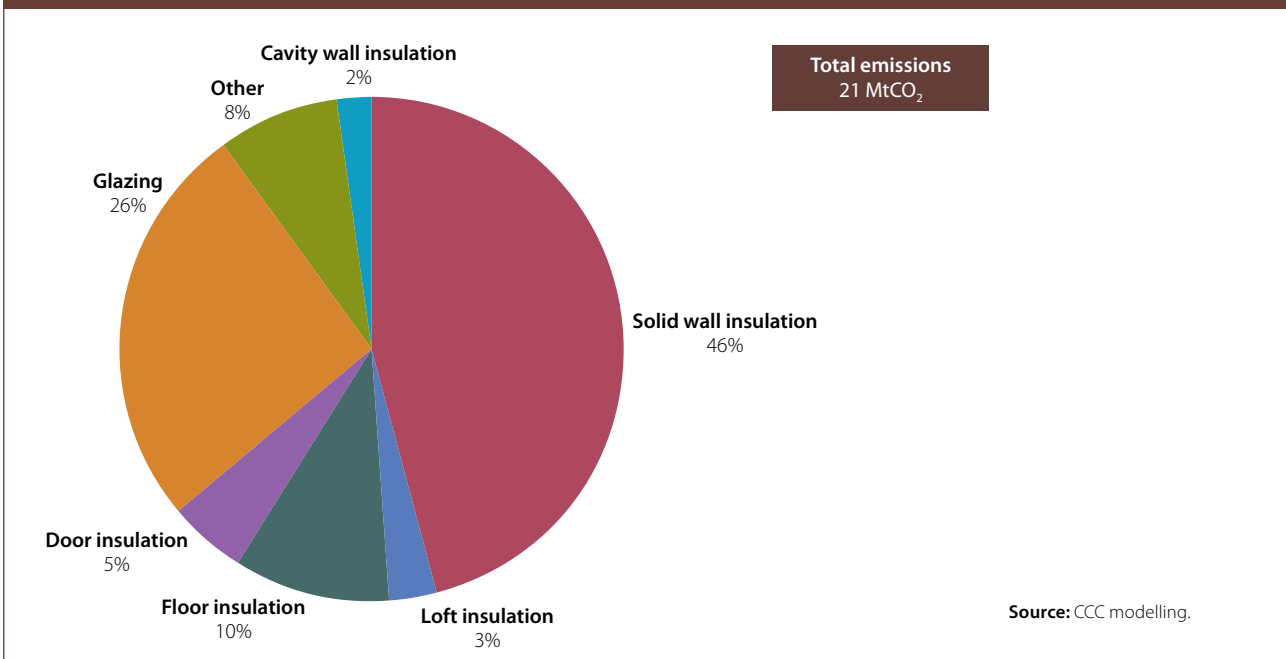


Figure 5.8: Remaining building fabric energy efficiency potential (2020)



(iii) Residential sector – energy efficiency improvement in appliances and lighting

Residential demand for electricity currently accounts for approximately 40% of total electricity demand, having increased by around 34% since 1990 despite major improvements in appliance energy efficiency. Increased demand is primarily due to the growth in ownership of household and electronic appliances, which account for two-thirds of household electricity consumption.

There is a significant difference between the energy consumption of the least and most efficient appliances (e.g. the most efficient A++ rated fridge-freezer currently on the market consumes 85% less energy than a similar sized A rated fridge-freezer). With lifecycle costs of more efficient appliances lower than those of less efficient appliances, this provides a significant opportunity for cost-effective emission reduction.

We reflect this opportunity in our Extended Ambition scenario, where we assume emissions reductions of approximately 5 MtCO₂ by 2020 as the share of more efficient appliances in the stock increases. Beyond 2020, there is scope for further efficiency improvement given the time taken for turnover of the appliance stock (e.g. 15 years for fridge-freezers, 12 years for washing machines and driers) and expected technology improvements.

Given the underlying economics, we assume that there is widespread take-up of the most efficient appliances through the 2020s, together with the scope for electricity demand reduction from more efficient lighting in households (Box 5.2). We reflect this in our modelling of the power sector in Chapter 4. Our analysis suggests that if primarily efficient appliances and lighting systems were purchased in the 2020s, this would result in electricity demand reduction of around 10 TWh (around 3% of total UK electricity demand in 2030) between 2020 and 2030.

Box 5.2: Efficient lighting

Lighting currently accounts for around 20% of residential electricity consumption. Our Extended Ambition scenario to 2020 includes falling emissions from residential lighting as compact fluorescent bulbs replace incandescent bulbs. Going beyond this, there is scope for further reductions through light-emitting diodes (LEDs). Recent developments in LED technology have resulted in an exponential rise of their efficiency and light output, with LED bulbs becoming available for some household applications. Uptake is expected to increase from currently low levels (1% of installed bulbs), as costs fall. Additionally, significant savings can be made from switching to energy efficient lighting fittings, systems and controls (e.g. automatic presence detection). In new homes, design to maximise daylight gains can reduce lighting needs.

(iv) Energy efficiency improvement in non-residential buildings

Our Extended Ambition scenario for non-residential buildings includes the uptake of all cost effective measures in companies and organisations covered by the CRC by 2017. Additionally we assume that cost-effective and more practical measures such as energy management are taken up elsewhere in the non-residential sector by 2020. This could be accelerated by the setting of minimum energy performance ratings for buildings.

There is some evidence that further abatement potential is likely to be available beyond 2020. For example, recent analysis by the Carbon Trust suggests that there is scope for further energy efficiency improvements to deliver a reduction of 2 MtCO₂ by 2030, with savings equally split between measures that are cost effective (non-fabric measures such as timers and programmable thermostats) and measures that are more costly (such as major building fabric upgrades where costs are driven by the labour intensive nature of the installation).

However, as noted in our previous reports, the evidence base for abatement potential in the non-residential sector is weak due to data and model limitations. Therefore, we have been cautious in our scenarios and assumed no further uptake of heating related energy efficiency measures in the 2020s beyond those included in the reference scenario, whilst recognising that more may be possible. For non-heat electricity demand (lighting, refrigeration, computing etc) we have assumed that continuing efficiency improvements deliver a further reduction of 5 TWh by 2030; (5% of non-residential electricity demand in 2030). This has been reflected in our electricity demand scenarios (Chapter 3).

2.2 Deployment of low carbon heat technologies

A large proportion of the energy consumed in homes (around 80%) and the commercial and public sector (56%) is currently used for space and hot water heating, mainly from gas. Reducing emissions from heat, through a combination of energy efficiency improvements and heat decarbonisation, will therefore play an important role in achieving carbon budgets. The 12% renewable heat penetration we assume in our Extended Ambition scenario leaves 90 MtCO₂ residual emissions from heat in buildings, accounting for approximately 17% of economy-wide emissions in 2020. Options for reducing emissions from heat through the 2020s include heat pumps, various forms of bioenergy, and district heating.

We now consider these options from both technical and economic perspectives, drawing on analysis that we commissioned from NERA and AEA (Box 5.3) and use this as the basis of our scenarios for emissions from buildings through the 2020s (section 2.3).

Box 5.3: NERA/AEA low carbon heat model

Our scenarios for the uptake of low carbon heat are underpinned by a detailed cost-effectiveness model, developed by NERA and AEA. This model has drawn upon and extended the evidence base used for previous low carbon heat work for DECC and the CCC that looked at the period to 2020. Technology assumptions and input data have been extended to 2030, and additional technologies have been incorporated to reflect possible future developments (e.g. synthetic biogas from the gasification of biomass, and heat pumps with heat storage that can shift electricity load profiles).

The model calculates uptake by considering the cost effectiveness of low carbon heat technologies relative to a carbon price projection of £70 per tonne abated in 2030 and rising through the 2030s. Where technologies are cost-effective, the level of uptake in each year depends upon a complex interaction of factors including the size of the heat market, the ability of industry to deploy low carbon heat and a range of suitability constraints discussed in Box 5.7.

The sensitivity of the results was tested by varying many of the key input parameters, including technology performance and cost, levels of building insulation and energy efficiency, availability of biomass resource, fuel prices and discount rates. The results of these sensitivities are reflected in our uptake scenarios.

We set out our analysis in three parts:

- (i) Heat pumps
- (ii) Bioenergy
- (iii) Combined heat and power (CHP) and district heating

(i) Heat pumps

Heat pumps use electricity to extract heat from the surrounding environment and transmit this for space and hot water heating. One unit of electricity from heat pumps can generate between 2.5 and 4.5 units of heat (Box 5.4), compared to less than one unit of heat via conventional electric heating systems such as storage heaters or immersion heating.

Box 5.4: Performance of heat pumps

The performance of heat pumps is described in terms of its Coefficient of Performance (COP), or the amount of heat the heat pump produces compared to the total amount of electricity needed to run it. The higher the COP, the lower the electrical energy required to deliver a given amount of heat, and therefore the better the performance.

For this analysis, it has been assumed that COPs start from current levels of 2.0 to 2.5. They are projected to increase towards an eventual plateau in the 2020s, with space heating COPs in the range 3.5-5.5 (up to 4.5 in residential applications and 5.5 in non-residential).

The performance of heat pumps depend on a range of factors, including type of heat pump, building insulation levels, type of heating system and weather conditions:

- GSHPs have slightly higher COPs as ground temperature is less variable than air temperature.
- We have assumed higher COPs in new houses built to high insulation standards and able to make use of lower temperature underfloor heating or low temperature radiators. For older properties, we have assumed the use of higher temperature radiators, with COPs correlated to insulation levels.
- The COP of a heat pump varies according to the magnitude of the temperature difference between the heat source and the heat load. The COP is calculated as the weighted average of reported seasonal performance factors, but during spells of cold weather COPs can decrease significantly.

The Energy Saving Trust (EST) recently published the results of the first large scale trial of heat pumps at 83 sites in the UK². A key finding was that heat pump performance can vary considerably between installations, and is particularly sensitive to installation and commissioning practices and customer behaviour.

In the trials, GSHPs had a mid range of around 2.3-2.5, with the highest figures above 3.0. The mid range of COPs for ASHPs was around 2.2, with the highest figures over 3.

The results of the EST field trial have important implications for the roll out of heat pumps in the UK:

- In general, well installed and operated heat pumps are a suitable technology for reducing emissions in the UK.
- Given the sensitivity of performance to design and commissioning, there is a requirement for improved training for installers.
- Many customers expressed difficulty understanding the instructions, and this underlines the importance of improved information provision and technical support.

2 <http://www.energysavingtrust.org.uk/Generate-your-own-energy/Heat-pump-field-trial>

Reflecting this major efficiency advantage, and the fact that significantly increased deployment of conventional electric heating would require prohibitively high build rates of low carbon power generation, our analysis is focused on heat pumps. However, we recognise that there may be niche applications for conventional electric heating in 2030, for example in highly energy efficient houses with a low heat demand or where there are space constraints.

Potential applications

We have assessed three types of heat pumps:

- **Air Source Heat Pumps (ASHPs)** can be used in buildings with vent or wet (i.e. radiator or underfloor heating based) heating systems. ASHPs work well with vent heating systems, and can work in reverse to provide air conditioning, which has led to increasing uptake rates in the commercial sector. In the residential sector, where heating systems are predominantly wet, ASHPs can replace conventional boilers depending on the energy performance of the building (i.e. ASHPs are best suited to modern houses with loft and cavity wall insulation and double glazing).
- **Ground Source Heat Pumps (GSHPs)** will work with the same types of buildings as ASHPs. The key consideration here is outdoor space, with a GSHP requiring a large enough area to locate ground loops. Bore hole applications are an alternative option but are more expensive. GSHP are not subject to the fluctuations in outdoor temperatures in the same way as ASHPs and can thus potentially provide slightly higher COPs, especially in residential applications.
- **Heat pumps with storage** are able to recharge during off-peak periods (e.g. overnight), thereby making use of spare low carbon power generation capacity. However, with current storage options (i.e. large hot water tanks) these units are limited to installation in larger premises only.

While there is currently limited deployment of heat pumps in the UK, these are a relatively mature technology and are widely used in other countries (e.g. both in France and Sweden heat pump sales exceeded 100,000 units in 2009, while in the UK less than 15,000 were sold). Early experience in the UK has suggested the presence of deployment barriers which need to be addressed in the near term to support more widespread uptake (Box 5.4).

Emissions reductions and economics

Emissions reductions from heat pumps depend on operating efficiency and whether the electricity consumed is generated from fossil fuels or low carbon sources:

- **Operating efficiency.** This depends on outdoor temperatures, whether heat pumps are used for hot water in addition to heating (Box 5.5), and whether (wet) heating systems are radiator or underfloor based. Energy demand reductions in households for heat pumps vary by up to 35% depending on assumptions about operating efficiency.
- **Power generation source.** At current grid intensities, carbon savings for heat pumps compared to gas boilers are not significant. However in the future, emissions savings of up to 100% are available if the marginal source of power generation is low carbon.

The cost effectiveness of heat pumps in reducing emissions depends primarily on four factors:

- **Heat pump costs.** In the residential sector, the current cost of an ASHP is around £6,000-£10,000 and £9,000-£17,000 for a GSHP, with NERA/AEA's analysis suggesting scope for cost reductions of around 30% by 2030 (Box 5.6).
- **Efficiency of heat pumps:** Efficiency of heat pumps can vary by around 100%, see above (Box 5.4).
- **Heat source replaced:** The economics of heat pumps are currently most favourable when displacing (carbon intense) oil boilers, although going forward there is also scope for cost effective displacement of gas boilers.
- **Power generation source:** This impacts the cost effectiveness of heat pumps both because it determines the level of abatement and because the cost of abatement depends on the technology used for power generation.

Box 5.5: Hot water

At present heating hot water accounts for 6% of the UK's CO₂ emissions. Conventional heating equipment such as gas boilers provide both heat and hot water. In the 2020s, the following will be important:

- If a renewable system is providing hot water as well as space heating, the provision of hot water can lower system efficiencies, therefore making running costs higher.
- Our analysis has assumed that heat pumps can heat hot water with a COP of around 2. In summer, it is assumed that the heat pumps are supplemented by an immersion heater in the domestic sector, which has an efficiency of around 1.
- By 2030, nearly 50% of the additional electricity demand from heat is used for heating water, and this is higher in the domestic sector. The implications of this for the power sector are explored in chapter 3.
- The options for reducing hot water use have not been specifically addressed in this analysis. However, various options exist:
 - On the supply side, more efficient water heating and storage systems and hot water recovery systems.
 - On the demand side, efficient taps and shower heads and behavioural change measures (e.g. shorter showers).
- Hot water will make up a significant proportion of energy demand in highly efficient new homes. To meet zero carbon standards, from 2016 this demand will have to be met from renewable sources.

We estimate that the combination of these factors give a weighted average cost of heat pumps from -£18 per tonne of CO₂ abated (i.e. heat pumps reduce costs) for ASHP to £7 for GSHP.

Box 5.6: Cost of low-carbon heat technologies

NERA and AEA developed detailed estimates of technical cost characteristics associated with each of the low carbon heat technologies. These characteristics varied across different customer types according to building type, location, use of the heat load, etc.

The following quantities were estimated, building upon a previous database compiled for DECC:

- Capital costs, including equipment costs, installation costs, auxiliary works, etc.
- Fixed operational costs, chiefly maintenance costs
- Lifetime
- Thermal efficiency and seasonally adjusted coefficient of performance
- Load factor
- Representative size
- Costs of low-carbon heat in the non-residential sector are generally lower due to returns to scale.
- The capital costs of each technology fall in the following ranges:

Technology	Domestic (£/kW)	Non-domestic (£/kW)
ASHP	625 – 2,150	568 – 635
GSHP	1,003 – 2,768	521 – 1,627
ASHP with storage	1,010 – 2,650	636 – 1,101
GSHP with storage	1,145 – 3,269	568 – 1,960
Biomass boilers	344 – 686	286 – 683
Solar Thermal	1,682	1,359
Biogas	1,014 – 2,500	
CHP	N/A	592 – 1,223
District Heating	111-592	N/A

Box 5.6: Cost of low-carbon heat technologies

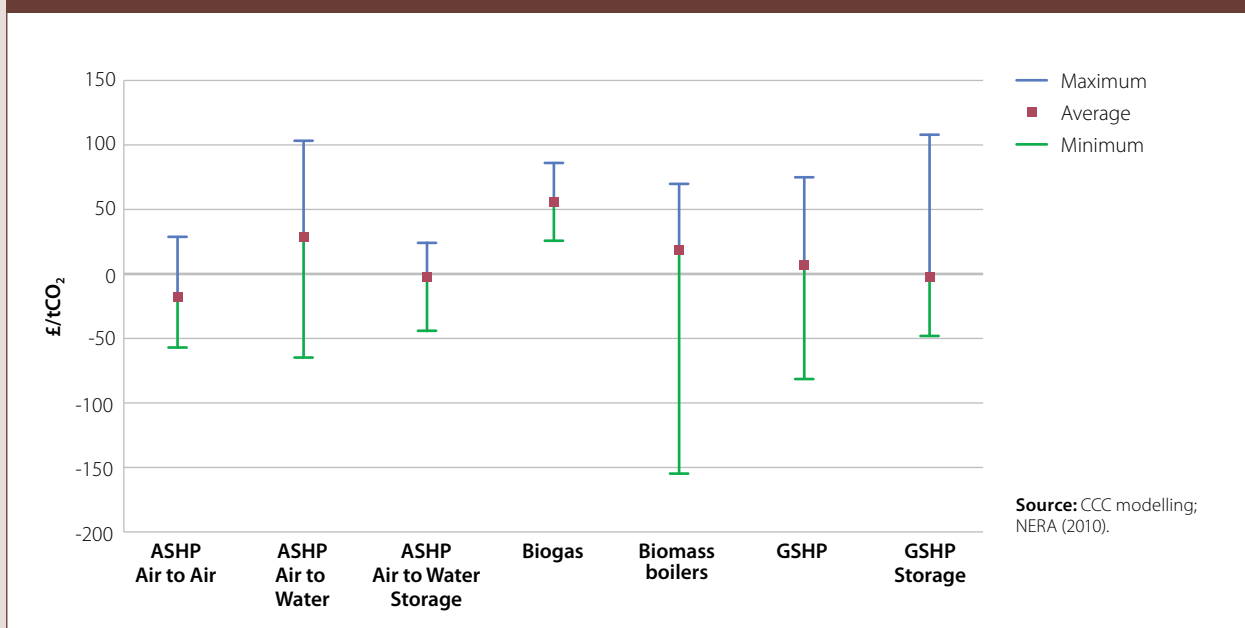
- Costs per tonne of carbon vary between different demand segments (e.g. one of the lowest cost applications for biomass boilers is in rural off-grid properties, while the highest cost GSHPs with storage are in new build detached properties replacing gas, Figure B5.6).
- These costs are then projected to 2030, based on assumptions about likely cost reductions, (38% for heat pumps, 32% for biomass and 44% for solar thermal).
- As these cost assumptions are uncertain and are a key driver of results, this forms a part of the sensitivity analysis in our low and high scenarios.
- Capital and operating costs are calculated on a levelised basis over the equipment lifetime, using additional assumptions about fuel prices and discount rates. Costs per tonne of carbon vary as shown in Figure B5.6.
- We have also included barriers to low-carbon heat to account for costs that may not be fully reflected in the cost or performance characteristics of technologies. These barriers ultimately split into two categories:
 - Suitability constraints: these barriers are central to the selection of the correct renewable heat technologies. For example, if adequate space for locating ground loops for a GSHP is not available in a particular household, then this technology is not suitable.

These factors were included in our analysis via a preliminary suitability assessment of each renewable heat technology, across each building type and heat use.

- Quantifiable barrier costs: These are factors that do not necessarily make a technology unsuitable, but may increase the burden associated with installing and operating a low-carbon heat technology in a particular location. Some of the most important barrier costs include the risk of reduced performance or comfort, disruption to production, hassle or time costs, value of space given up for equipment or fuel stores, nuisance factors such as noise.

These factors were included in our analysis via a sensitivity in the estimation of private costs, and in uptake in our low scenario. This drew from work conducted by Enviro on the barriers to renewable heat forms the basis of the estimation of these costs.

Figure B5.6: Abatement costs of low-carbon heat technologies in 2030



(ii) Bioenergy

Within bioenergy, we distinguish between biomass and biogas, and now consider each in turn.

Biomass

There is a range of potential uses of biomass to produce heat, including biomass boilers in residential and non-residential buildings, CHP for community and larger scale district heating (see Section 2(iii) below) and process heat for industry (see Section 3 below).

The key issues here are the level of sustainable biomass that is available, and where this is best used (e.g. across different heat options, and between heat, transport and power). Burning of biomass also has associated air quality considerations, particularly in dense urban areas.

- We have developed three scenarios for available biomass based on global scenarios published by the IEA (Box 5.7).
- The range in these scenarios is from 50 – 200 TWh annually.
- The high end of the range would exhaust UK capacity for domestic biomass production as estimated by E4Tech.

The economics of biomass heating depends on up-front costs, ongoing biomass costs and emissions savings versus alternatives (gas, oil, etc.). Based on this set of considerations, we estimate an average cost for biomass of around £18t/CO₂ abated in 2030.

Given the economics, and the fact that air quality impacts (Box 5.8) are easier to address in larger scale biomass boilers, the results of our modelling show that cost-effective use of biomass is limited in residential and non-residential buildings, with the bulk of use in the industrial sector. We reflect this in our scenarios for industry decarbonisation (see Section 3 below).

Box 5.7: Biomass resource availability and energy intensity

Given the uncertainty surrounding resource availability for bioenergy, scenarios were constructed based on existing projections of resource availability. Our approach differs slightly between biomass and biogas.

In biomass, we considered both a UK share of global bioenergy use in the IEA's Blue Map scenario (Energy Technology Perspectives 2010), and estimates of the UK's indigenous biomass resource:

- From the IEA Blue Map scenario, we estimate that approximately 320 TWh of primary bioenergy is available for the UK in 2030 (pro-rated according to total energy consumption). This total includes approximately 60 TWh of biofuels (130 TWh on a primary energy basis), leaving 190 TWh for heat and power.
- From the E4Tech supply curves for DECC (2009, central Renewable Energy Strategy scenario), the total UK resource of solid biomass is around 200 TWh in 2030.

The extent to which this resource is available for heat depends upon the resource made available to the power sector, and to transport. The following figures were used to define the upper bound for our scenarios of resource availability in heat:

- High: 200 TWh, all of the UK's resource dedicated to heat
- Medium: 100 TWh, half of the UK's resource dedicated to heat
- Low: 50 TWh, a quarter of the resource dedicated to heat

The Medium Abatement scenario gives total bioenergy use consistent with the IEA BLUE Map.

Biogas feedstock availability is highly uncertain, as it depends upon the availability of food waste, which in turn depends upon diets, recycling rates, and the success of efforts to reduce waste.

- In developing our scenarios, biogas feedstock availability was based on estimates of available waste streams, agricultural residues and energy crops. These estimates drew from the trends in availability observed to date (WRAP, 2009). AEA/NERA extended this analysis of trends out to 2030 based on a range of reports that have estimated the likely pathways for biogas feedstock over the medium term (WRAP, 2008, NNFCC, 2009, Defra, 2005 and 2009).
- This resulted in a total technical potential of feedstock availability of around 20 TWh in 2030. Around 20 TWh of solid biomass from the biomass scenarios described above is also assumed to contribute as a feedstock for gasification into biogas.
- A nominal amount of biogas feedstock is also required in the power sector, where it is assumed that the level of biogas specified in the Renewable Energy Action Plan is taken up. This amount does not compromise the ability to roll out biogas in heat as we assume that it can be constituted from other feedstocks than are used in heat (e.g. through a greater use of energy crops).

In the modelling of biomass and biogas uptake we have assumed the following:

- The value of the lifecycle emissions of biomass is drawn from analysis by AEA for the Environment Agency³, as approximately half the emissions intensity of gas.
- The emissions intensity of biogas is assumed to be zero, on the basis that different feedstocks have different lifecycle emissions intensities, some of which could reasonably be assumed to be zero (or even negative, e.g. food waste). Other feedstocks, such as energy crops, would have a positive emission intensity but given the low levels of energy crops used in these scenarios a zero value is considered reasonable. However, in calculating resulting emissions savings, we have assumed the emissions intensity of biomass to be zero in line with carbon budget accounting and the national emissions inventory.

³ http://www.environment-agency.gov.uk/static/documents/Leisure/Biomass__carbon_sink_or_carbon_sinner_summary_report.pdf

Box 5.8: Low carbon heat and air quality

Switching from a system with a predominance of gas boilers to one with a high penetration of low carbon heat can have both positive and negative impacts on air pollution:

- Heat pumps can result in lower air pollutant emissions provided the electricity used comes from low pollution sources.
- CHP at the power station level will make heat and electricity generation more efficient, with the likely result that total emissions will reduce.
- Residential biomass boilers generally produce more pollution than similar gas systems but sometimes less than an oil boiler:
 - Biomass boilers emit a number of pollutants including nitrogen oxides (NO_x), and small particulates (PM). The mix and amounts of pollution produced will depend on the size and design of the boiler, the quality of the fuel used and the presence of any emissions abatement equipment.
- Industrial size biomass plants have to meet more stringent pollution standards and are generally fitted with pollution abatement equipment.
- The new EU directive for Ambient Air Quality and Cleaner Air (which was transposed into national legislation in 2010), has tightened the regulations for PMs in urban areas. A promising new filter technology has recently been developed which can remove almost all PM_{2.5} and PM₁₀ particles at relatively low cost even in smaller boilers.

Location is of key importance – in the residential sector, we have assumed that most biomass boilers are primarily installed in off-grid homes outside of urban areas, replacing oil rather than gas heating. Most deployment in the industrial sector is likely to be outside inner-city areas, so air quality should be less of an issue.

Biogas

Biogas can be used to produce high grade heat, and can therefore be used as a substitute for fossil fuels in residential, non-residential and industrial sectors, either through grid injection or use in CHP plants or in industrial boilers. It is primarily produced by the anaerobic digestion of waste streams, and predominantly from agricultural and food waste. In addition, biogas can be produced from dedicated crops or a combination of waste (e.g. slurry) and crops. Solid biomass can also be gasified but the development and deployment of such systems is still at an early stage.

Biogas is a relatively low cost form of renewable heat, requiring upfront plant costs which are offset by marginal costs of production that are lower than conventional gas. The analysis that we have commissioned from NERA suggests that the balance of these two cost impacts is such that the net abatement cost of biogas is around £56/tCO₂ (Box 5.6).

Given its cost effectiveness, the key issue for deployment of biogas in the 2020s is its availability. The NERA analysis suggests that there is likely to be sufficient biogas available from anaerobic digestion to generate up to 10% of total heat, which is within the range suggested by other studies. In addition, there may be scope to double this through the production of biogas from biomass gasification. However, this is more uncertain, given the need for technology development to unlock biomass gasification, and questions over whether this would be the best use of biomass.

Whether available biogas is best used for generation of heat in buildings, electricity generation or in industry depends on alternative options in these sectors. Due to current uncertainties over the best use of the resource, for the purposes of this analysis we assume that the bulk of available biogas in the 2020s is injected into the gas grid. However, to the extent that there are more alternatives in the buildings sector, over time we would expect biogas to be used where alternatives are not applicable (e.g. in industry rather than buildings) or where there is limited scope for transport of biogas. We will look at this issue in more detail in our bioenergy review in 2011.

(iii) Combined heat and power and district heating

Combined heat and power plants (CHP) can potentially increase the overall efficiency of energy production, with the use of otherwise wasted heat from thermal combustion either directly (e.g. in industry) or via district heating systems. Although CHP accounts for less than 10% of electricity generation in the UK, the share is much higher in other countries (e.g. 40% in Denmark and Latvia). New investment in CHP could be on the basis of gas-fired, biomass or low carbon generation, each of which offers different potential in an increasingly carbon constrained world:

- **Natural gas fired CHP.** This can be at a power station scale (e.g. larger than 300 MW), in industrial scale units (typically 5 MW to 50 MW), in smaller scale CHP units (typically between 50 kW and 5 MW), or mini and micro-CHP (e.g. 2 – 50 kW). CHP is more efficient than conventional Combined Cycle Gas Turbine (CCGT) power generation (e.g. thermal efficiency can be in excess of 80% compared to around 50% for CCGT), but results in emissions reductions only if there is demand for the heat produced. However, natural gas fired CHP would result in higher emissions relative to a situation where both heat and power are decarbonised. Given the need to decarbonise both power and heat on the path to meeting the 2050 target, the role for natural gas CHP generation is therefore limited beyond the early 2020s.
- **Biomass CHP.** Biomass CHP is potentially attractive as a form of low carbon electricity and heat. However, biomass CHP is not as thermally efficient as conventional CHP (45%-60% for biomass compared to 80% for gas fired CHP). This is reflected in a cost for biomass CHP of around £160/tCO₂ abated, which is relatively high compared to electric heat pumps (costing -£18 to 7/tCO₂ abated), and excludes any costs of investing in district heating networks. Given the existence of alternatives for reducing emissions in buildings, we will assume that the role for biomass CHP is largely limited to some niche applications (e.g. in new zero carbon developments).

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- **Low carbon generation CHP.** Our power sector scenarios in Chapter 4 assume that around 30 GW of thermal low carbon power capacity (nuclear and CCS) could be added to the system in the period between 2020 and 2030. There is the possibility that this could be designed to allow off-take into district heating networks of heat that would otherwise be wasted (accounting for up to 55% of total energy input). The costs of incorporating CHP technology in low carbon power stations is relatively small relative to the potential lifetime heat demand, reflected in an abatement cost of -£238/tCO₂. Heat off-take from nuclear plants for district heating and industry applications is already common place in a number of countries (e.g. Russia, Czech Republic, Switzerland). However, while some low carbon power generation may be located close to heat loads (e.g. CCS in Teesside), nuclear power stations tend to be remotely located, suggesting additional costs of linking to heat demand (see below).

In summary, there may be near term opportunities for investment in conventional gas CHP as a cost effective means for reducing emissions. Beyond the near term, cost-effective emissions reductions would be available from CHP using low carbon power generation, subject to the costs of investing in infrastructure and transporting heat to demand centres.

District heating costs

Heat is typically supplied into district heating networks from CHP plants or from large-scale district heating boilers. Networks can be large (e.g. city-wide) but there are also smaller community networks. In the UK, district heating only supplies 1% of heat, while in Denmark and Sweden the share is around 50%. Currently, most district heating networks are primarily based on heat produced by fossil fuelled plant, although there are examples of low carbon district heating systems (e.g. in Sweden, where 70% of district heating comes from mixed low carbon sources including biomass, geothermal, municipal waste and solar thermal).

To utilise heat from low carbon power generation, it would be necessary to transport this from the power station to the source of heat demand. Given that low carbon power stations will typically be located in coastal areas, this would require transport from power stations to urban areas (where demand is sufficiently dense to potentially justify network investment), and local distribution:

- **Transport from power stations to urban areas.** District heat can be economically transported several tens of kilometres, depending on the pipeline cost, the pipeline energy loss, the density of the urban heat load and the cost of alternative heat provision. Well insulated pipes can reduce transmission losses but add to the cost. For example in the Czech Republic a 40km heat pipeline from the Dukovany nuclear plant is currently being assessed.

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- **Local distribution.** Data on existing district heating projects shows that the levelised cost of installing a network can be high, at around £22/MWh. The capital cost of large scale district heating schemes is around £1,500/kW, and the operating cost around £15/kW per year. District heating networks can typically have a life up to 50 years, and cost effectiveness of the network relies on a demand for heat throughout this period (we assume 4,000 hours per year). Local distribution of heat also leads to some losses, which typically are around 10% of total heat supplied.

Adding transport and distribution costs to the costs of fitting CHP technology to low carbon generation suggests a total cost of around -£110/tCO₂ abated, which is attractive relative to the cost of heat pumps (i.e. from -£18 to £7/tCO₂).

Our approach to district heating

There is a high degree of uncertainty around the technical and economic aspects of district heating based on low carbon CHP, due to the site specific considerations such as the availability of a low carbon heat source near heat loads. However, our preliminary analysis suggests that this may be a promising option, and one that should be explored further. It could for example help to reduce emissions from the section of the building stock which is particularly difficult to treat (e.g. urban conservation areas with a large proportion of solid walled buildings). Also, as stated above for CHP, the use of waste heat from power stations and industry makes the use of energy in these applications more efficient.

However, and given current uncertainties, we adopt a cautious approach whereby our buildings scenarios include relatively low penetration rates for district heating in 2030 (e.g. in our Medium Abatement scenario, district heating accounts for up to 10% of heat demand in 10 cities with high heat density by 2030 – see Section 2.3). Importantly, our analysis suggests that the cost-effective level of roll out from district heating may be in excess of these levels, but non-financial barriers (e.g. lack of certainty about number of customers) to implementation currently constrain investment. Further work is required to determine both the optimal role of district heating in contributing to carbon budgets and ways of overcoming non-financial barriers to implementation.

Buildings emissions scenarios

Scenarios for energy efficiency improvements to reduce heat emissions

Our scenarios for buildings model a range of energy efficiency improvements in the residential and non-residential sectors.

- In the residential sector, we model three energy efficiency scenarios, centred around the roll-out of solid wall insulation. Our low efficiency scenario assumes no further take up of solid wall insulation beyond our Extended Ambition scenario (i.e. 2.3 million by 2022), with a total of 3.5 million by 2030 in our medium scenario, rising to 5.7 million in our high scenario.

- In the non-residential sector, our scenarios assume continuing savings from energy efficiency measures installed during the first three budget periods, as well as from new buildings during the 2020s. Due to the weak evidence base (see section 2.1 (iv)) we have assumed no further uptake of energy efficiency measures in the existing stock through the 2020s.

Scenarios for low carbon heat deployment

In developing scenarios for low carbon heat, we have used a model developed for us by NERA/AEA (see box 5.3 above). The model considers the full set of options for low carbon heat and selects those that are cost effective relative to a carbon price projection. We have developed three scenarios for low carbon heat deployment based on different assumptions around suitability, cost and efficiency (Table 5.1, Figures 5.9 and 5.10):

- **Low Abatement scenario.** The low scenario includes limited departure from the reference scenario, with low levels of heat pump, biomass and biogas penetration, together with some district heating. It reflects low levels of energy efficiency improvement, limited suitability and high costs (including hidden costs).
- **Medium Abatement scenario.** The medium scenario includes significantly increased heat pump penetration, together with some further biomass deployment. It is consistent with the wider uptake of energy efficiency measures and hence building stock suitability, technology innovation to reduce costs, and the potential to reduce hidden costs.
- **High Abatement scenario.** There is further penetration of both heat pumps and district heating in our high scenario, based on faster district heating network roll-out and further energy efficiency improvements.

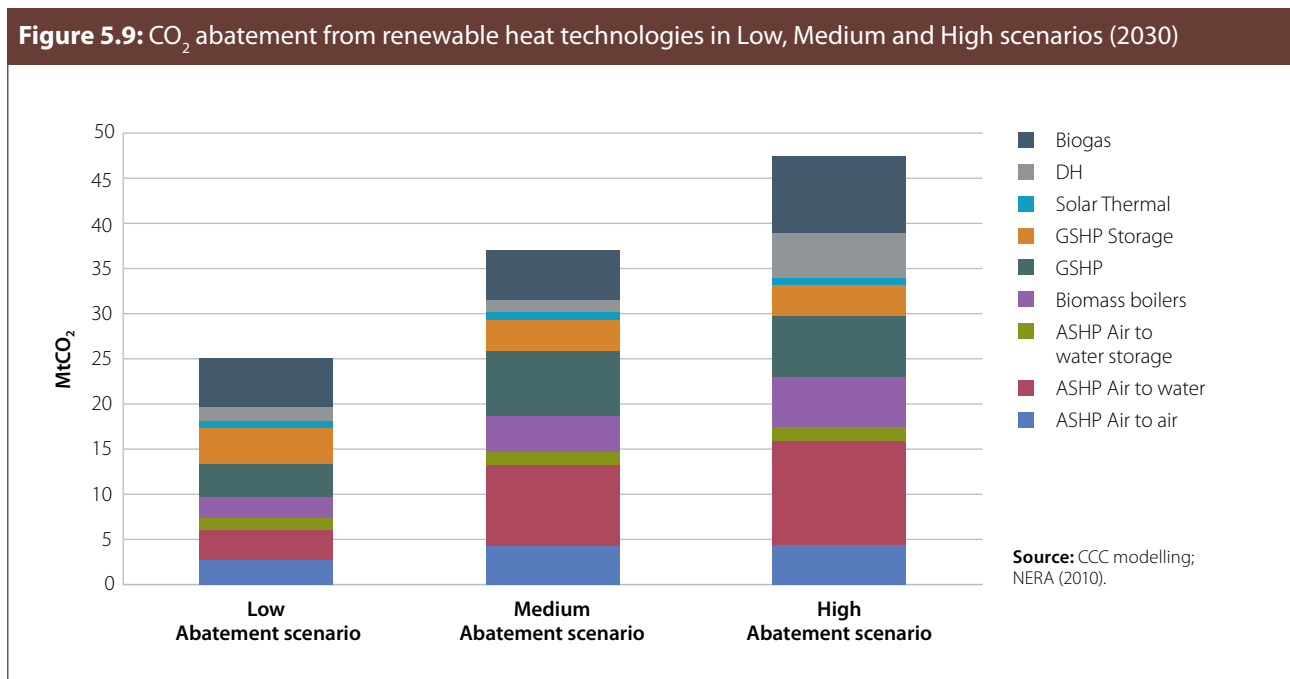
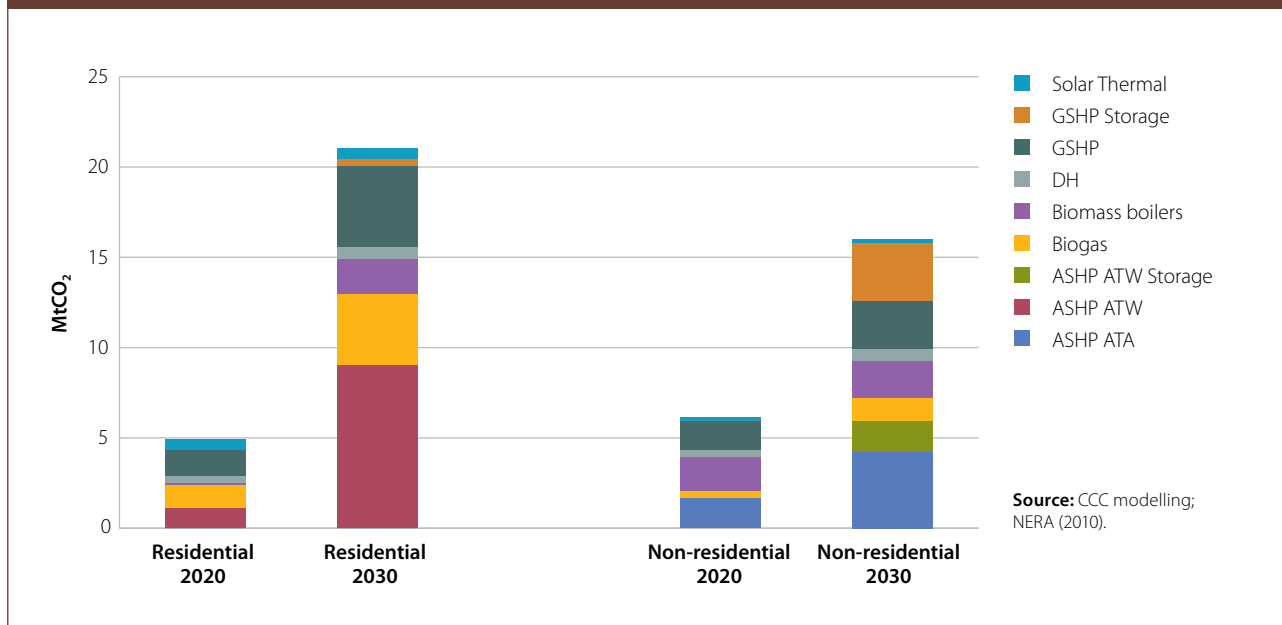


Table 5.1: Penetration of Low Carbon Heat Technologies			
Scenario		TWh	% of total heat demand (in 2030)
Low Abatement scenario	Heat Pumps	78	13%
	Biogas	20	3%
	Biomass	7	1%
	District Heating	10	2%
	Total	115	19%
Medium Abatement scenario	Heat Pumps	143	24%
	Biogas	20	4%
	Biomass	13	2%
	District Heating	10	2%
	Total	186	32%
High Abatement scenario	Heat Pumps	154	26%
	Biogas	35	6%
	Biomass	17	3%
	District Heating	40	7%
	Total	246	42%

Our scenarios for low carbon heat technologies are therefore dominated by heat pumps (e.g. these account for around 70% of emissions reduction potential in our Medium Abatement scenario, see figure 5.9 and 5.10). Limited use of biomass and biogas in buildings reflects the fact that there is scope for cost effective application in industry (see Section 3). Limited penetration of district heating in our scenarios is a cautious approach reflecting current uncertainties over technical and economic aspects of this option.

Figure 5.10: CO₂ abatement from renewable space heating technologies in the Medium scenario by sector (2020 and 2030)



Total abatement potential from buildings

The sum of direct emissions abatement potential from the range of measures – energy efficiency improvement and deployment of low carbon heat – is up to 57 MtCO₂ in 2030 (Figure 5.11). With maximum implementation of measures, buildings CO₂ emissions would account for a share of around 18% in total emissions in 2030, compared to 35% currently (i.e. buildings emissions reductions would move at a faster pace than the economy as a whole). The carbon intensity of the buildings sector falls considerably (Figure 5.12). We include the full range of scenarios for buildings emissions in our economy wide assessment (Chapter 3).

Figure 5.11: Medium scenario for residential and non-residential buildings (2008, 2020 and 2030)

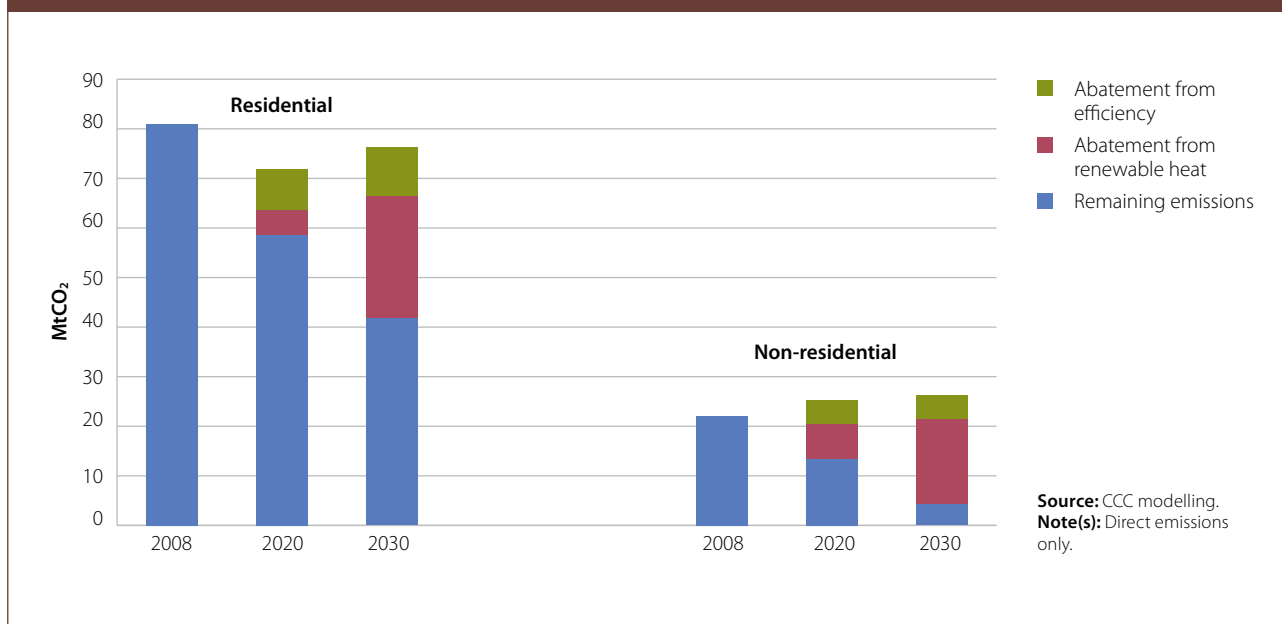
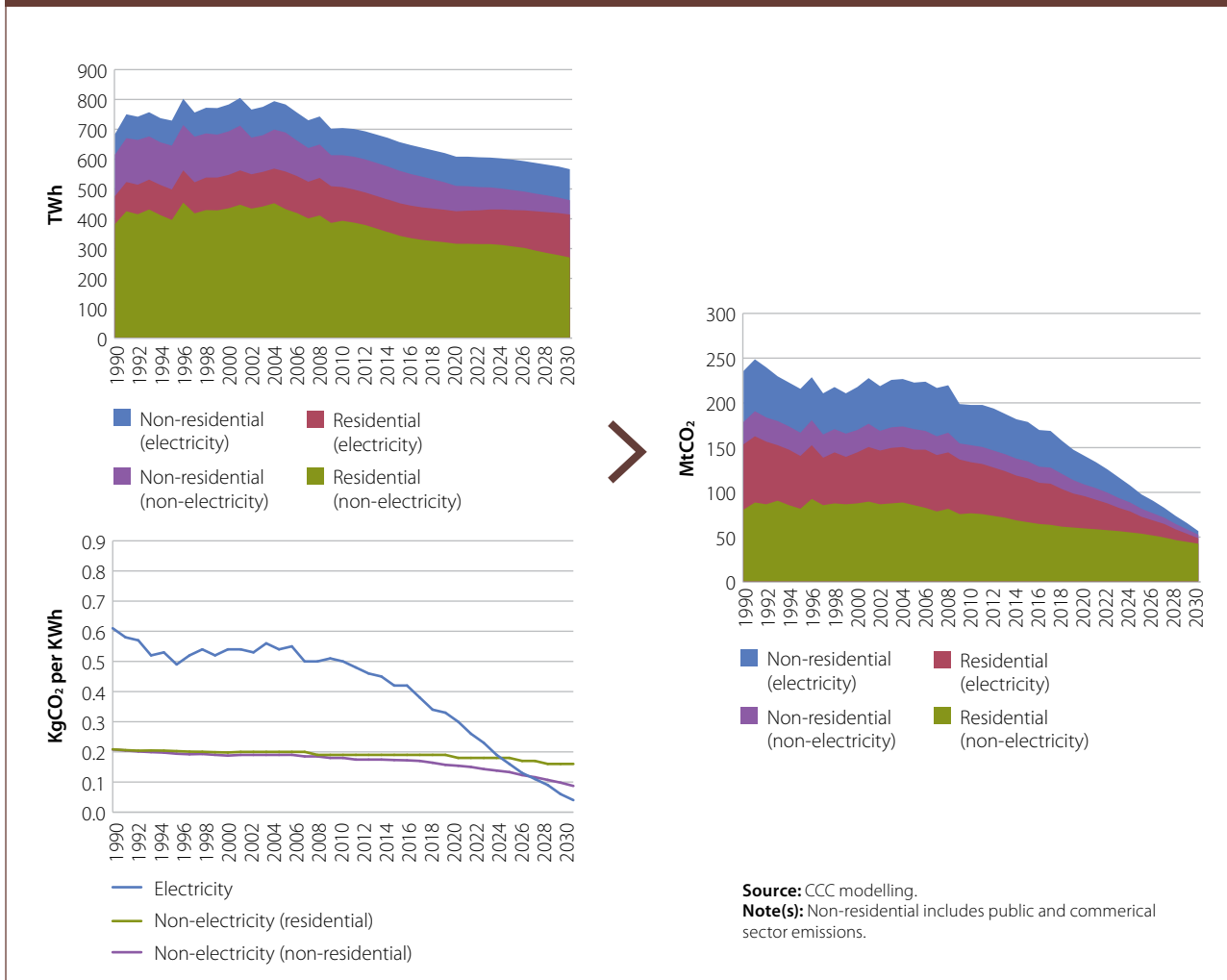


Figure 5.12: Energy consumption, carbon intensity and CO₂ emissions from buildings (1990-2030)

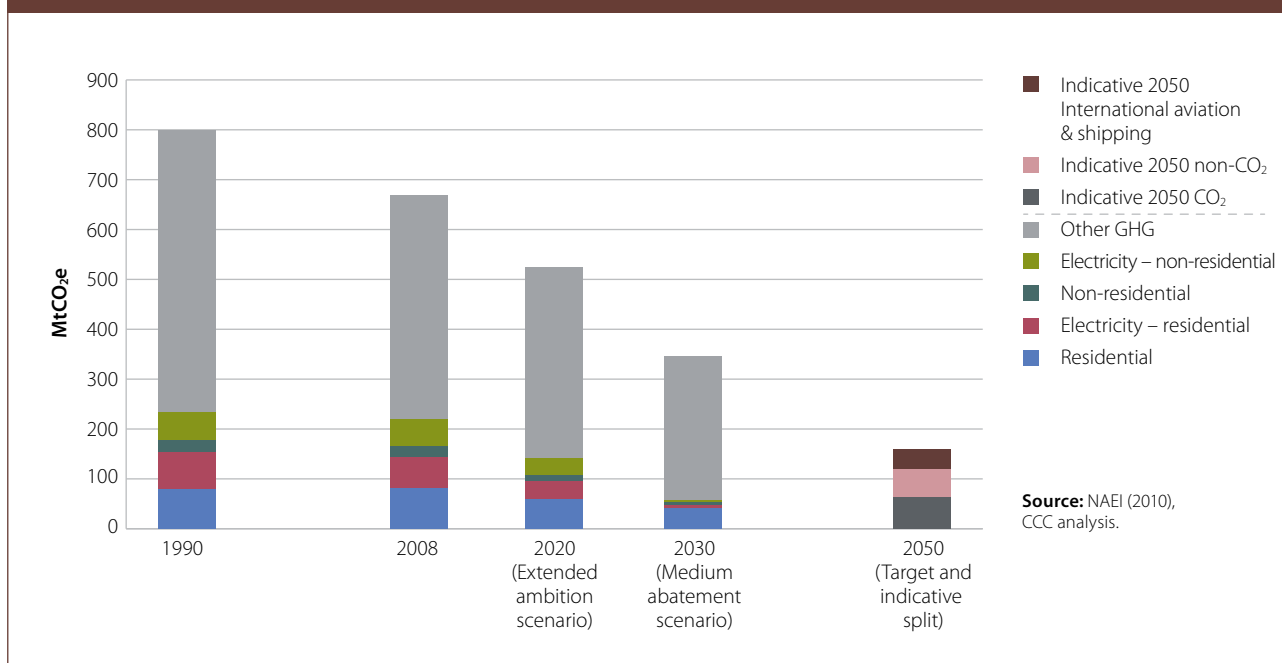


Path from 2030 to 2050

Options for further reductions after 2030 for the buildings sector include:

- Further improvements in fabric energy efficiency in the residential sector, with insulation of many of the remaining four or so million solid wall properties, as well as potentially additional insulation measures to some of the lower efficiency cavity-walled stock.
- Further efficiency improvements in the commercial sector, linked to refurbishment opportunities.
- Further roll-out of heat pumps and low carbon district heating to all sectors.
- By 2050, we expect the buildings sector to be highly energy efficient and most heating requirements to be met by low carbon sources. This will ensure that the buildings sector is zero carbon or close to zero carbon as required to meet the economy wide 2050 target and given limited scope for reducing emissions in some sectors (Figure 5.13).

Figure 5.13: Buildings emissions in the context of UK greenhouse gas emissions (1990-2030, 2050)



Scenario costs – social basis

Uptake in the scenarios above is based on the Treasury’s Green Book social discount rate of 3.5%, which is appropriate to identify options that should be part of a national strategy to reduce emissions.

We build up our estimate of scenario costs based on abatement costs for individual low carbon heat options and for reducing buildings emissions.

- Based on a solid wall insulation cost of £18/tCO₂ and savings of up to 2 MtCO₂, the cost associated with insulation of solid walls in our Medium Abatement scenario is £41m in 2030 (<0.1% of GDP). This cost rises in a low gas price scenario, for example, where the 2030 gas price is 35 p/therm as in DECC’s low scenario, compared to 76 p/therm as in DECC’s central scenario; the cost increases to £93m at this lower gas price. In DECC’s high gas price scenario, where the 2030 gas price is 121 p/therm, the cost associated with maximum insulation of solid walls falls to -£42m.
- Low carbon heat technologies costed at the values indicated above, with emissions reductions of 36 MtCO₂ in 2030 in our Medium scenario would result in a cost of £1.2bn (<0.1% of GDP), inclusive of £0.8bn for deployment to 2020 (Table 5.2). This cost would increase in a low gas price world (e.g. to around £3.9bn in 2030) and fall in a high gas price world (e.g. to around -£1.1bn in 2030). Reverting to a central case gas price world, the range of costs depending on cost and efficiency sensitivities is £0.1bn to £2.2bn.

In summary total costs of reducing buildings emissions would be <0.1% of GDP in our Medium scenario.

Scenario	Costs (£bn)
Medium	£1.2
Medium – high fossil fuel prices	-£1.1
Medium – low fossil fuel prices	£3.9
Medium – high capital costs	£2.2
Medium – low capital costs	-£0.1

Scenario costs – private basis

However, when considering the implementation of options, it is important to recognise that households and businesses will not use this social discount rate:

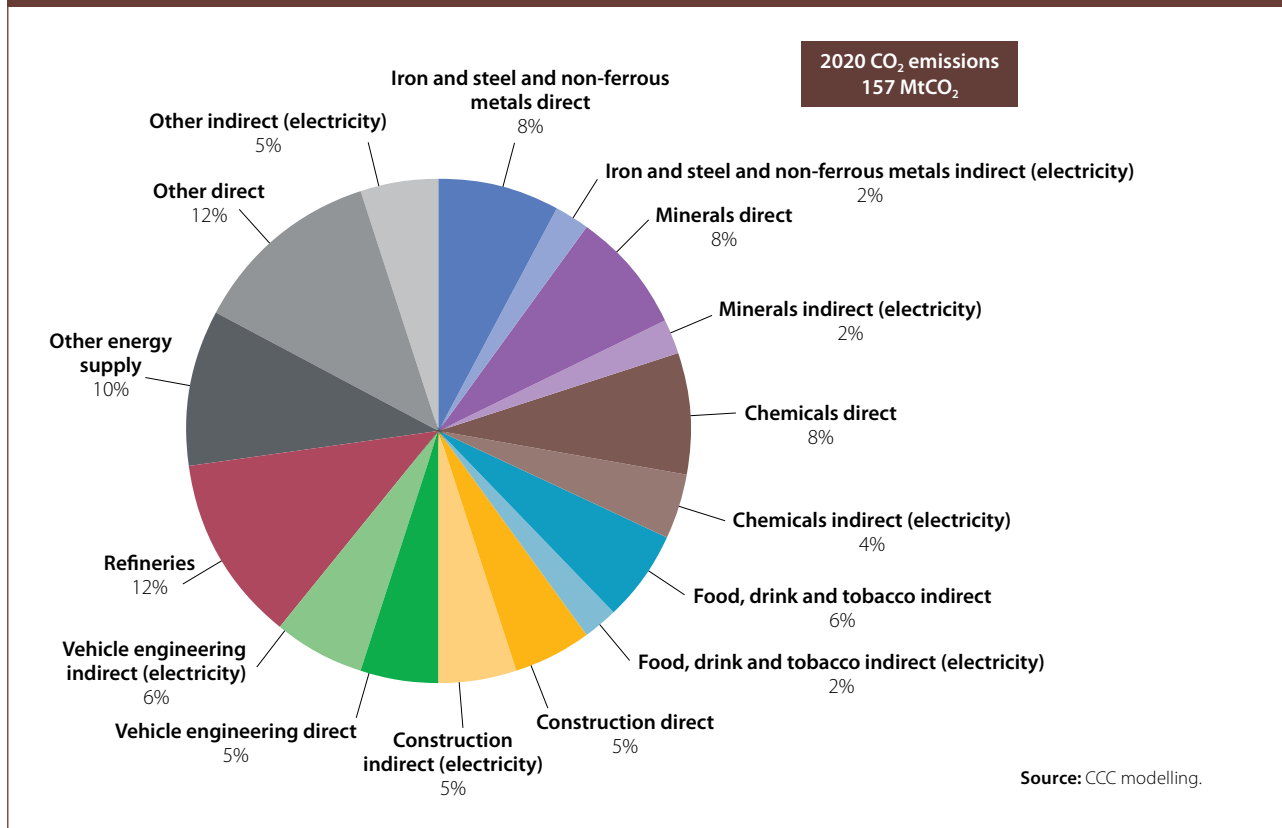
- Households may attach more weight to upfront costs than future benefits.
- A related point is that future benefits may be over-discounted where there are uncertainties around technology performance.
- Even when attaching appropriate weight to the future versus the present, finance may not be available at the social discount rate (e.g. due to household credit risk).
- At the corporate level, required returns for projects are typically higher than the social discount rate, which can result in a lack of priority for investments to reduce emissions, especially where they compete for capital with other investments that have higher returns.

In order to reflect divergence between social and private costs, we have modelled sensitivities based on a 10% discount rate:

- The cost of solid wall insulation in a medium gas price scenario rises from £41m to £93m at a 10% discount rate.
- The cost of low carbon heat technologies in a medium gas price scenario rises from £1.2bn to £4.8bn at a 10% discount rate.

The fact that costs rise significantly with higher discount rates does not suggest that these options are not viable in terms of meeting the fourth carbon budget. Rather, it suggests that policy approaches are required to bring private discount rates closer to social discount rates. Policies may include providing better information about future benefits, raising the profile of emissions reducing measures on the corporate agenda, and development of specific financial instruments that extend finance at social discount rates on the basis of appropriate financial security packages (e.g. energy efficiency financing through a Green Investment Bank). Given such policies, and with some residual hidden costs (e.g. space loss due to solid wall insulation), the range of options in our scenarios appear to be economically viable.

Figure 5.14: Industry emissions by sector (2020)



3. Emissions reductions in industry

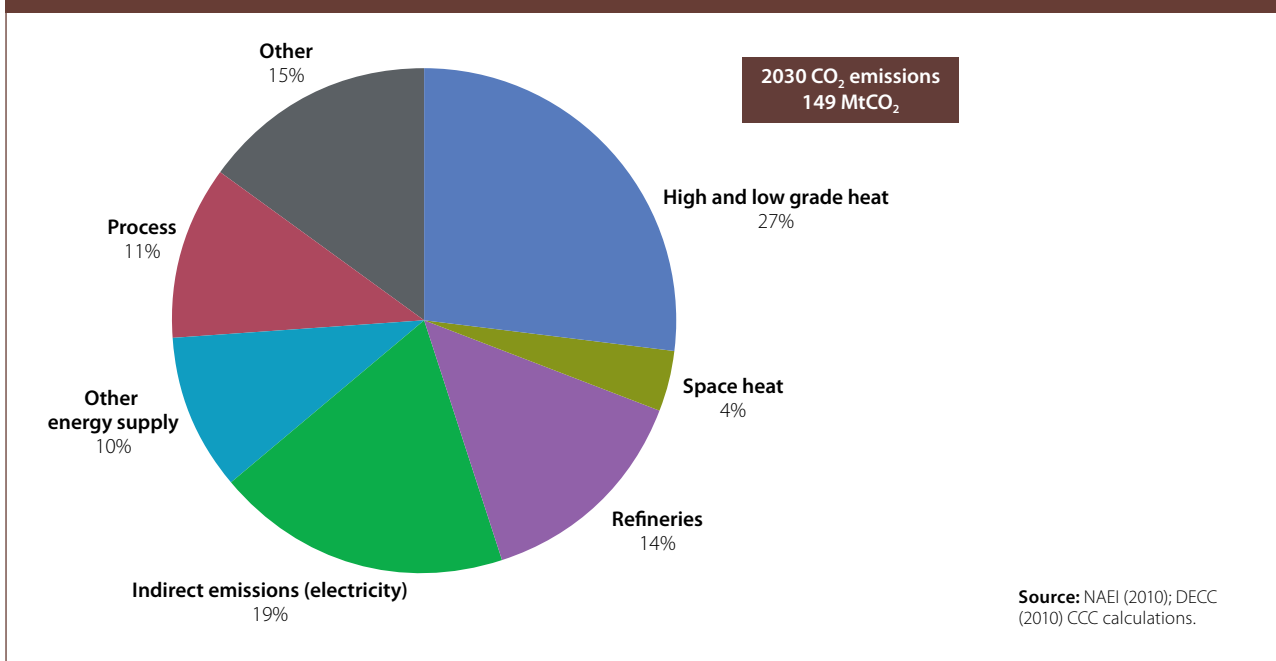
Our Extended Ambition scenario includes industry emissions reductions in the period to 2020 through a range of measures including switching to less carbon intense fossil fuels, and increased penetration of biomass and biogas under the RHI. Emissions in 2020 under this scenario are around 157 MtCO₂ (i.e. 30% of total UK GHG emissions), with energy intensive industries accounting for around 50% of this total (Figure 5.14).

In the absence of any further measures beyond the Extended Ambition scenario, industry emissions could account for almost all of total allowed UK emissions in 2050. It is therefore important that industry emissions are further reduced, both to meet carbon budgets through the 2020s and in the context of the 2050 target, where there is a very limited envelope for all emissions including industry emissions. This section focuses on opportunities for further abatement across the 2020s.

In understanding options for reducing emissions, we first develop a reference emissions projection for the 2020s. This reflects changes in GDP, fuel prices and industry specific factors (e.g. planned changes in regulation of refineries), and results in emissions of approximately 150 MtCO₂ in 2030.

We then disaggregate the reference projection in 2030 to highlight options for emissions reductions:

Figure 5.15: Industry emissions by use in reference case (2030)



- The majority of direct emissions in industry in the reference projection come from the combustion of fuels (68 MtCO₂, Figure 5.15):
 - A significant portion of this is used to generate heat (47 MtCO₂), including space heating (7 MtCO₂ considered in section 2 above) and low and high grade heat for industrial applications (40 MtCO₂). Typically low grade heat is used in non-energy intensive industries, raising the possibility, for example, that these could switch to use of electricity or biomass. Energy intensive industries (such as iron and steel) typically require high grade heat, suggesting that switching to biomass, biogas and CCS may be the most promising options.
 - The remainder of combustion (around 22 MtCO₂) is comprised predominantly of drying and separation (this includes drying materials using air flow/ventilation, rather than heat) and a range of other smaller uses.
- Process emissions are projected to make up a further 16 MtCO₂, which arise from chemical reactions within industry (e.g. the calcination of limestone in the production of cement).
- Emissions from the use of electricity are projected in the reference case to constitute around 28 MtCO₂ of emissions by 2030, mainly for running motors and electric heating. This is a substantial reduction on 2008 levels (52 MtCO₂), primarily due to decarbonisation of the power sector.
- In addition to the above, 36 MtCO₂ are projected in the reference case to come from refineries and other energy supply, which are categorised separately from the rest of industry to highlight that these industries produce fuels for downstream combustion, which is detailed below. These emissions could be reduced both through the optimisation of refineries and declining demand for fuels due to the decarbonisation of the economy (e.g. transport sector).

Opportunities for abatement during the 2020s

We now consider in more detail the following options for reducing emissions through the 2020s:

- Conventional energy efficiency
- Renewable space heating
- Use of biomass
- Use of biogas
- CHP
- CCS
- Further options within carbon-intensive industry

Owing to the limited availability of low carbon generation to 2030 (see chapter 6), we do not assess the potential for widespread application of electricity within industry (e.g. electrolysis for steel making industry). However, electrification in industry may provide an additional abatement opportunity beyond 2030.

Conventional energy efficiency

Our analysis of emissions reductions in industry has previously focused on cost-effective, short pay-back options for abatement such as improvements to the efficiency of motors (which we refer to here as conventional energy efficiency). As outlined in our 2010 Progress Report to Parliament, the evidence base for assessing emissions reductions from conventional energy efficiency requires strengthening:

- Analysis relies predominantly on the “ENUSIM” model, which under-represents the opportunities for fuel switching and longer payback options within industry
- The accuracy of the data underpinning ENUSIM is reliant on the often limited ability and/or willingness (given commercial considerations) of industry to provide information regarding abatement opportunities.

Reflecting these shortcomings, we have not identified any further abatement from energy efficiency in industry during the 2020s.

Renewable space heating

The 7 MtCO₂ emissions from space heating in industry in 2030 can be reduced through the use of the low carbon heat technologies discussed in section 2. Using a combination of heat pumps, biomass, biogas, our analysis suggests that around 4 MtCO₂ of abatement is cost effective in the 2020s relative to a carbon price of £70 per tonne of carbon abated. This is additional to the 1 MtCO₂ that is cost-effective in 2020.

Use of biomass

Our Medium Abatement scenario suggests that biomass could be used to meet around 55% of industrial heat demand in 2030.

- The biomass resource for heat is 100 TWh in our medium biomass scenario.
- Projections of heat loads in industry suggest that there will be approximately 180 TWh of industrial heat load in 2030. Of this, 140 TWh is suitable for biomass use (many applications are unsuitable due to gas quality constraints e.g. clean burning fuels are required for ceramic kilns).

Our analysis suggests that the cost of biomass in industry is around £18/tCO₂ abated relative to heat from gas boilers. Based on this, biomass is a cost-effective option for reducing around 39 TWh (22%) of industrial heat demand by 2030 when compared with a carbon price of £70/tonne, resulting in around 13 MtCO₂ emissions savings.

Use of biogas

Our Medium Abatement scenario suggests that around 20% of industrial heat demand in 2030 could be met with biogas, with around half of this from anaerobic digestion and half from gasification of biomass:

- The biogas resource from anaerobic digestion could account for up to 20 TWh of industrial heat demand in 2030. A further 18 TWh of additional biogas is available through the gasification of biomass.
- Heat from biogas is suitable for the majority of industrial heat demand and for applications which require a high quality of gas (where biomass may be unsuitable). This suggests that biogas could provide 20% of industrial heat demand in 2030, additional to that provided by biomass.

As set out in section 2.2 (ii) above, biogas is a relatively cost-effective renewable heat option, with a cost of around £56/tCO₂ abated. Based on this, biogas is a cost-effective option for reducing around 6 TWh (around 5%) of industrial heat demand by 2030 at a carbon price of £70/tCO₂.

CHP

As outlined in section 2.2 (iii) above, given the need to decarbonise both power and heat on the path to meeting the 2050 target, the role for natural gas CHP generation is limited in the 2020s.

The analysis carried out for us by NERA/AEA suggests that costs of biomass CHP are relatively high compared to biomass boilers. In our Medium Abatement scenario, almost all of the available resource is thus taken up either directly in biomass boilers, or through gasification of this resource to make biogas.

There may be potential for use of heat networks to supply industrial heat demand, particularly where industrial heat loads are co-located with a heat source (e.g. CHP and/or waste heat sources). There may also be further scope for using industrial waste heat in district heating networks to supply heat to homes and businesses. As indicated above, further work to explore this option is required to estimate costs and delivery risks. However, our initial analysis indicated that this may be a low cost form of emissions abatement.

CCS

Carbon Capture and Storage (CCS) technology is most frequently discussed in the context of power generation, and specifically coal-fired power generation. In Chapter 6, we set out the role for CCS applied to both coal and gas-fired generation and suggest that both applications are likely to be important and should be demonstrated in the period to 2020.

As with power generation, there are currently no examples of scale application in industry. However, it is likely that this technology will be feasible in energy intensive industries including iron and steel, industrial CHP, refining, cement and chemicals.

We commissioned analysis from Element Energy to assess the viability of CCS in industry. With the caveat that this is highly uncertain given the current stage of technology development, their analysis suggests that CCS could be both widely applicable in energy intensive industries and cost effective:

- CCS could reduce emissions from energy intensive industry by 5 MtCO₂ in 2030 and 37 MtCO₂ in 2050.
- The associated abatement costs are within projected carbon prices over the period to 2030.

Given the need to reduce industry emissions, the potential of CCS and the limited potential from other options, particularly in the energy intensive sectors, industry CCS should be demonstrated in the period to 2020. This would lay the foundations for deep cuts in industry emissions in the period to 2030 and beyond.

Further options within carbon-intensive industry

Several recent reports (e.g. IEA Energy Technology Perspectives) have identified a number of future technologies and approaches in carbon-intensive industry which may result in substantial opportunities for abatement. We commissioned analysis from AEA to assess the feasibility and cost effectiveness of a wide range of future technologies within the six most carbon intensive industries in the UK, accounting for nearly half of industrial emissions as projected by the DECC energy model.

Assessing further abatement opportunities in the industrial sector is particularly challenging due to:

- Uncertainties surrounding the future shape of industry and demand for products, including what proportion of this demand will be met by manufacturing in the UK.

-
- Uncertainty surrounding the options for reducing industry emissions, and in particular accurate costs and abatement potential of these options.
 - Deployment of these technologies is highly dependent on non-financial and/or site specific practical considerations. For example, options that involve significant new infrastructure may have to be installed simultaneously with the refurbishment cycles of existing plant.

Given these challenges, a bottom-up approach to calculating industrial abatement was adopted, employing the knowledge of key sector experts to identify opportunities for abatement in each of the sectors considered.

Iron and steel

Emissions from the production of steel in the UK arise primarily through process emissions in the blast furnace (the smelting process that turns iron ore into pig iron) and through primary steelmaking (which removes the carbon content from pig iron to create steel). Approximately 25% of steel output in the UK is through an alternative steel production route – electric arc furnaces – which uses electricity and is therefore responsible for indirect emissions.

Although a wide range of options was considered for this sector, only a small number was deemed capable of delivering substantial cost effective abatement by 2030. Most significantly, increased recycling of steel could deliver around 5 MtCO₂ at a cost of -£22/tCO₂, although there is some uncertainty surrounding this option.

Further abatement was provided through improvements to the blast furnace (e.g. use of fuel injection, neural networks to improve productivity) and improvements to the electric arc furnace (e.g. continuous strip production, continuous charging).

The ability to increase the use of scrap steel is limited by the level of impurities within scrap, and much of the high quality scrap is already reused. Further work is required to refine the estimates used within this study.

Cement

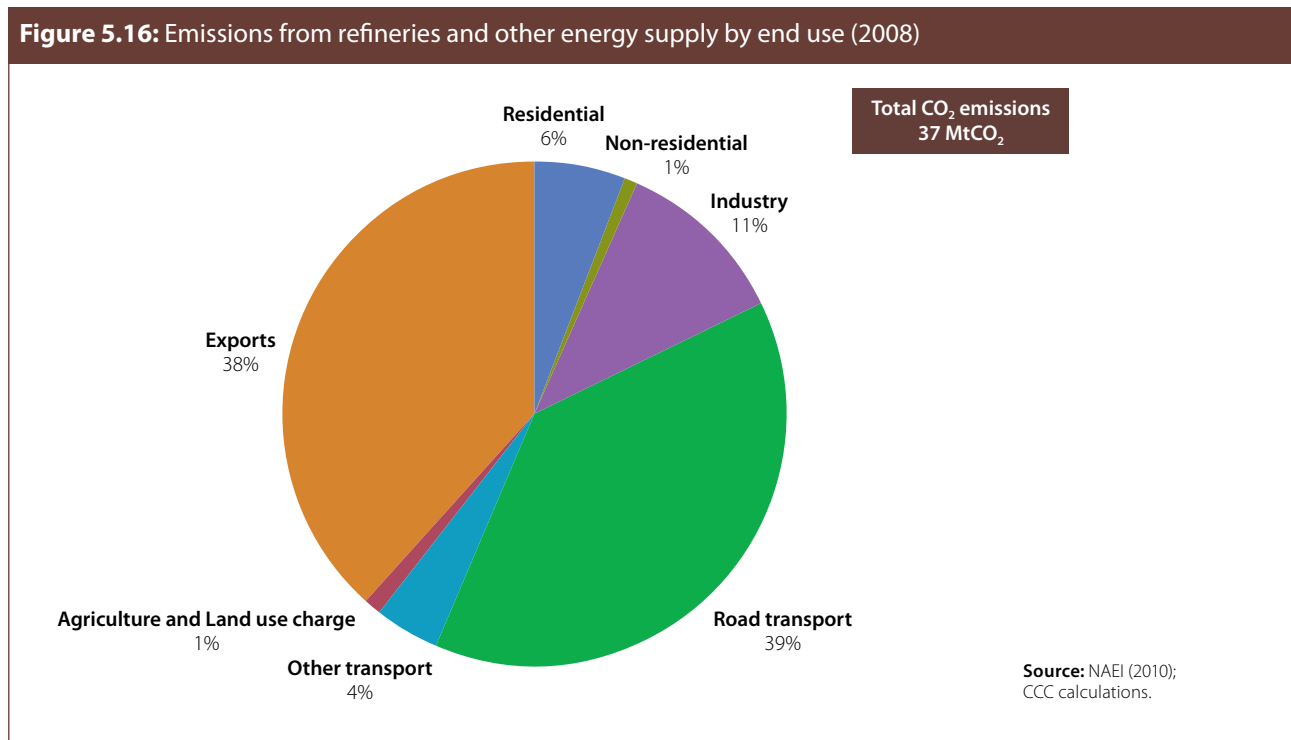
Emissions in the cement sector arise both from energy use (around 30% of emissions, through firing of cement kilns) and from processes (around 70%, primarily through the calcination of limestone).

Further abatement in the cement sector can be principally achieved through the use of clinker substitutes. The use of these substitutes reduces the energy required for calcinations and the emissions from the clinkering reaction. Clinker substitutes could contribute around 1.5 MtCO₂ of abatement by 2030, at a cost of -£34/tCO₂.

We also considered the potential of other cement substitutes, such as low carbon cement. However, given the early stage of development of these alternatives, we assume that these are unlikely to play a major role until after 2030.

Refineries and other energy supply

Refineries produce emissions from a range of different operations, including heat, and the flaring of waste products. Refineries and other energy supply (e.g. collieries, offshore oil and gas) are distinct from other industry sectors in that they produce fuels for downstream consumption. Fuels produced by refineries are used predominantly in the transport sector, but also within industry and in the residential sector (Figure 5.16). This implies that changes in fuel consumption from abatement opportunities in other sectors (e.g. due to a switch from petrol cars to electric cars, see Chapter 4) may reduce the emissions from refineries and reduce what potential for abatement is available, although there is uncertainty surrounding how the sector might respond to a reduction in domestic fuel demand.

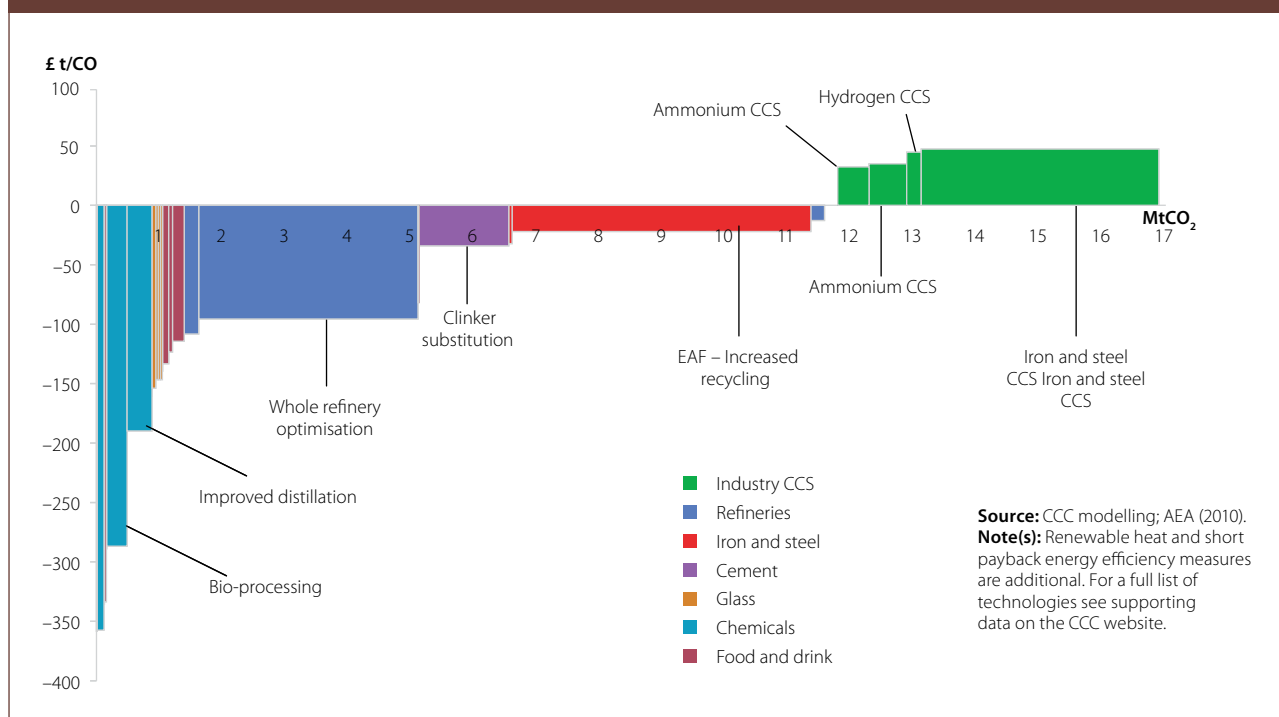


Within the upstream emissions from refineries, there is significant scope for emissions abatement in the UK by bringing them up to the standard of the best performing plant in the Benelux and Scandinavian countries. The energy efficiency of refineries may be improved through a number of measures that can optimise operation (e.g. through the elimination of flaring). There is around 3.5 MtCO₂ of abatement available in 2030 from the implementation of these measures across many of the refineries in the UK, at an average cost of -£96/tCO₂.

A number of barriers are present that make these cost-effective opportunities difficult to realise:

- A number of substantial changes are likely in the refining industry to 2030 and the net impact on emissions is highly uncertain (e.g. declining throughput from refineries and potential closures, regulation and potential future requirements at the EU level and increasing demand for diesel aviation fuel).

Figure 5.17: Marginal abatement cost curve for carbon intensive UK industry Medium Abatement scenario (2030)



- The vertical integration of oil companies means that there is a lot of competition for capital investment across the whole supply chain for petroleum products. In the current environment of low margins on refining operations, oil companies may find better investment opportunities in other parts of the petroleum products supply chain.

Chemicals, food and drink, glass

There are several low cost opportunities for abatement in these sectors which could be rolled out by 2030, together contributing around 1 MtCO₂ of abatement by 2030:

- In the chemicals sector many low cost opportunities exist, including for example the replacement of distillation with less energy intensive membrane processes.
- In food and drink, options including more efficient heating and cooling (e.g. through heat recovery) and the use of membranes for concentrating/purifying liquids.
- In the glass sector, the abatement opportunities are mainly focused on reducing emissions from the melting process in the glass furnace.

Scenarios for reducing industry emissions

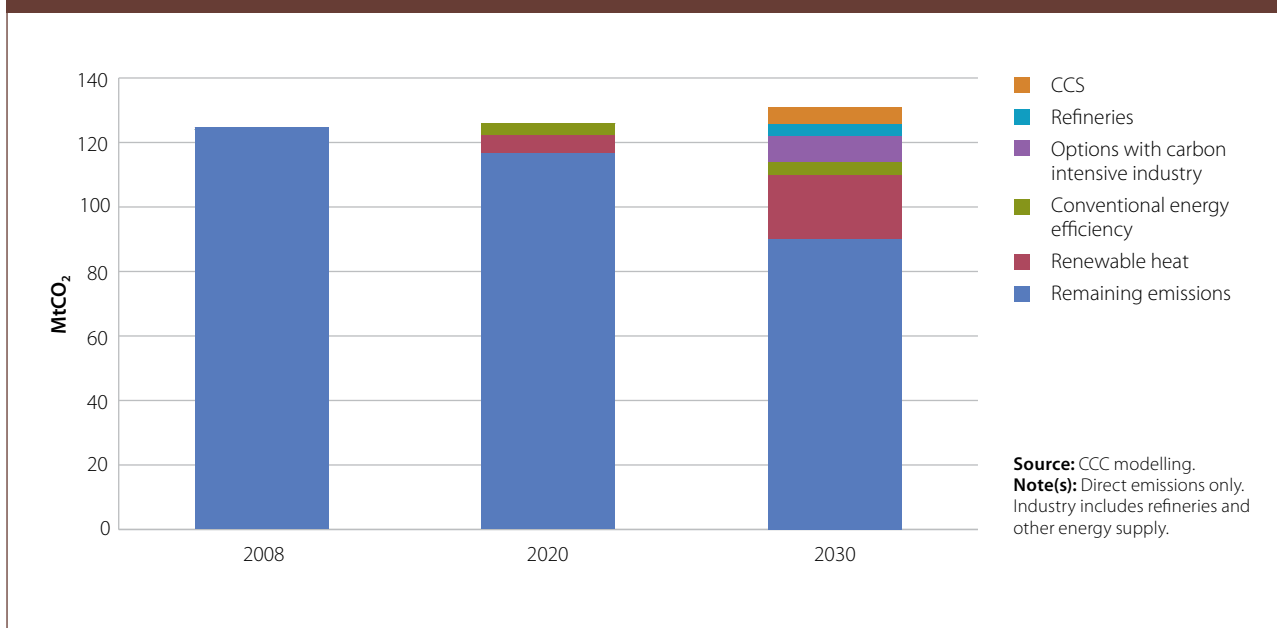
As with our buildings scenarios, our starting point in developing industry scenarios is a reference projection. This projection assumes a level of direct industry emissions commensurate with our Extended Ambition scenario for 2020 (i.e. 117 MtCO₂), and that this grows in line with GDP such that emissions in 2030 are around 121 MtCO₂.

Our emission reduction scenarios then net off emission reductions from the options that we have considered above, selecting a level of uptake that is cost-effective relative to a carbon price of £70/t in 2030 (Figure 5.17):

- Low abatement. The low scenario represents a low level of uptake of biomass, no deployment of CCS prior to 2030, and a less optimistic level of uptake within the carbon intensive industries (reflecting a high degree of constraints on deployment e.g. lower availability of scrap metal of sufficient quality for recycling)
 - Biomass, biogas, CHP, heat pumps = 8 MtCO₂
 - Carbon intensive sectors = 7 MtCO₂
- Medium abatement. The medium scenario represents further availability of biomass, together with options from CCS that are both cost-effective and could be deployed based on the refurbishment rate of major industrial plant. Further options are included in the energy intensive sectors reflecting a lower degree of constraints on deployment (e.g. higher availability of scrap metal for recycling).
 - Biomass, biogas, CHP, heat pumps = 14 MtCO₂
 - CCS = 5 MtCO₂
 - Carbon intensive sectors = 12 MtCO₂
- High abatement. The high scenario reflects a higher availability of biomass, more deployment of gasification technologies which increases the availability of biogas, a higher deployment of CCS and an even lower degree of constraints on deployment for options in the carbon intensive sectors.
 - Biomass, biogas, CHP, heat pumps = 17 MtCO₂
 - CCS = 20 MtCO₂
 - Carbon intensive sectors = 18 MtCO₂

In total for the Medium Abatement scenario, these options offer potential direct emissions reductions of 31 MtCO₂ during the 2020s, which would result in direct industry emissions of 90 MtCO₂ in 2030 (Figure 5.18). The associated cost would be of the order of up to £0.1bn (<0.1% of GDP, with the bulk of this cost accounted for by CCS and to a lesser extent biomass).

Figure 5.18: Medium Abatement scenario in industry (2008, 2020 and 2030)



Therefore, while there is a great deal of uncertainty over the scope for industry emissions reductions, both as regards levels of sustainable biomass and biogas and applicability/cost of CCS, there are plausible scenarios where significant emissions reductions are available at affordable cost through the 2020s. We reflect these scenarios in our economy wide scenarios and recommendations in Chapter 3.

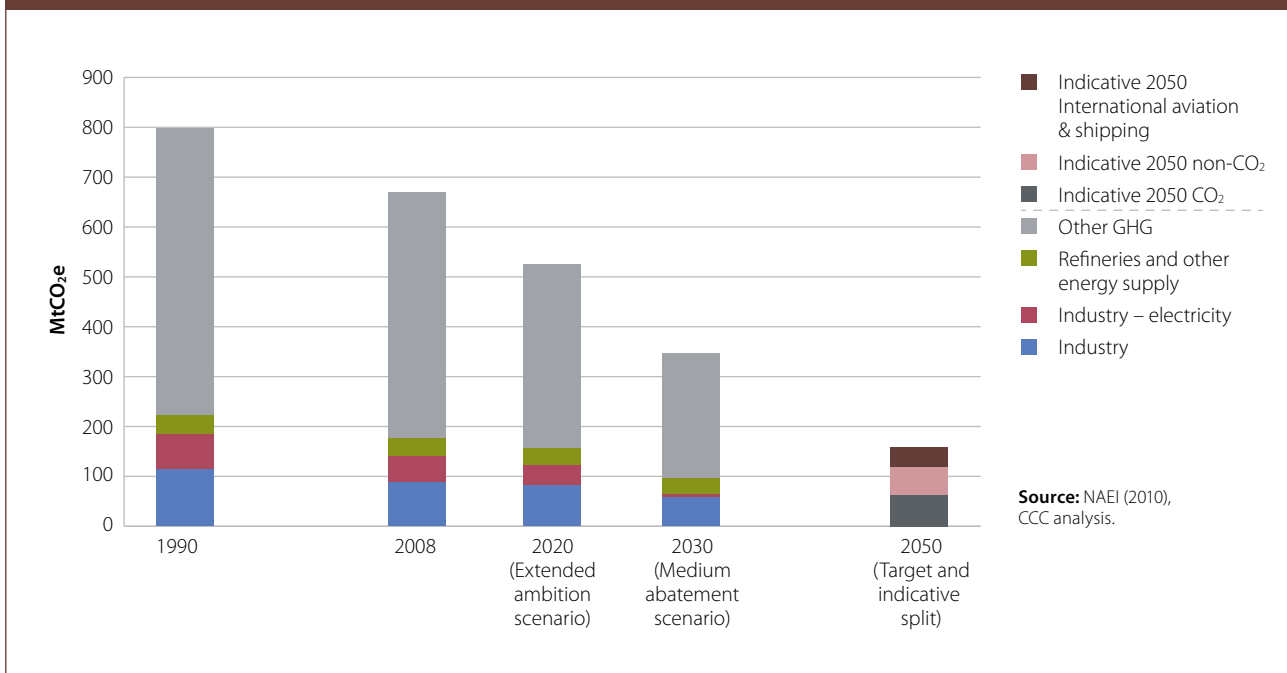
Path from 2030 to 2050

The main options for further reductions after 2030 include increased roll-out of CCS and increased penetration of bioenergy:

- **CCS:** Analysis for the CCC by Element Energy projected the potential contribution from the contribution from the roll-out of CCS to be 37 MtCO₂ in 2050 (32 MtCO₂ additional to that assumed in our Medium scenario).
- **Biomass:** In our scenarios, biomass is distributed across space heating and industrial applications according to where it is most cost-effective. However, after 2030 further electrification of space heating suggests that this resource could be shifted to industrial applications. Similarly, electrification of heat could lead to more biogas resource being made available, which could also be shifted to the industrial heat sector. A combination of these options could lead to a further 17 MtCO₂ abatement of direct emissions.

A combination of these options could reduce industry emissions to around 41 MtCO₂ by 2050. However, this would still account for a large share of economy wide emissions in 2050 (e.g. around 25%), and could be problematic given residual emissions from other sectors (Figure 5.19). The majority of remaining emissions would consist of drying and separation, other energy use and some miscellaneous applications. Further analysis is required to assess the extent to which these could be reduced, with additional potential likely from electrification (depending upon the development of technologies for using electricity in industry, for example, electrolysis in iron and steel), and product substitution options (such as use of alternative low carbon cements, and material efficiency).

Figure 5.19: Industry emissions in the context of UK greenhouse gas emissions (1990-2030, 2050)



4. Implications for the first three budgets

To deliver the emissions reductions required from buildings and industry which we have outlined in this chapter, there are a number of implications for action in the first three budgets:

- **Energy efficiency improvement.** The path for heat decarbonisation reinforces the need for ambitious energy efficiency improvement in the period to 2020 and beyond. Improved building stock energy efficiency enables the large-scale deployment of heat pumps and reduces emissions from those buildings which will continue to be served by fossil-fuelled heating. Therefore it is important that new policy approaches currently under development (e.g. the Green Deal for the residential and non-residential sectors and the new supplier obligation) are finalised and implemented. These need to deliver significant emission reductions, especially from solid-walled houses.
- **Renewable heat deployment.** Given the potentially high levels of renewable heat deployment needed in the 2020s, it will be important to make progress in this area in the period to 2020 (i.e. high levels of deployment in the 2020s are not plausible unless there is significant progress over the next decade). The RHI is key here, and based on the analysis in this chapter, it should be focused on delivering heat pumps (prioritising off-grid and commercial sector deployment), biomass and biogas in order to lay the foundations for required heat decarbonisation in the 2020s.
- **Fuel poverty mitigation.** Both energy efficiency and renewable heat deployment can help to reduce the incidence of fuel poverty in the face of rising energy and carbon prices. Therefore, the Government needs to fund specific programmes targeted at implementing these measures in vulnerable households (e.g. through the future supplier obligation and additional Government funded programmes), see Chapter 8.
- **Power market reform.** We propose in Chapter 6 that current electricity market arrangements should be reformed, and that a quantity instrument be introduced to provide confidence about the level of low carbon generation capacity that will come onto the system in the 2020s. The level of heat pump deployment in the 2020s, together with the level of electric car penetration (Chapter 4) will have crucial implications for the appropriate quantity of low carbon generation investment through the 2020s.
- **Industry CCS.** This is a promising technology in an area which accounts for a significant proportion of total emissions and where emissions reductions will be required to meet carbon budgets in the 2020s and beyond. The challenge now is to demonstrate industry CCS in tandem with demonstration of this technology on coal and gas-fired power stations.

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- **R&D.** Further technology research and development is needed including:
 - Advanced insulation materials
 - Biomass gasification & CHP
 - Heat pump COPs

There are also three areas that we have identified where further evidence is required:

- **Biomass.** This is a potentially important option for decarbonisation of industry, but with uncertainties over available sustainable supply. Further evidence is required on likely sustainable biomass availability through the 2020s and beyond. The Committee will report on this as part of a broader review of bioenergy, to be published before the end of 2011.
- **District heating.** The possibility of using waste heat from low carbon power generation is attractive but uncertain. Further evidence is required on technical and economic aspects of heat generation, transport, distribution and heat demand in order to better understand the extent to which this is likely to provide a viable option for deployment in the 2020s.
- **Industry.** The evidence base for abatement potential within industry needs strengthening. This includes both the sectors we have covered in this report and additional sectors (e.g. the construction sector), as well as non-heat related combustion (e.g. drying and separation). In addition, there may be scope for abatement through reducing demand in industry (e.g. light-weighting of steel products) and reduction in consumption by end consumers, although further data on this is required.

5. Key findings



The UK's total emissions coming from buildings and industry.

70%

Energy consumed in homes for space and water heating.

80%

Leaky solid walled houses should be properly insulated by 2030, that's about half of the total.

3.5
million

Number of homes which could be heated by low carbon heat by 2030.

9
million

Heat pumps can be up to 4 times more efficient in generating heat from electricity when compared to conventional electric heating systems.

4x

By 2050, we expect the buildings sector to be zero carbon in order to meet the 80% target.

Zero
Carbon
by 2050

There is scope for reducing industry emissions by almost half between now and 2030.

50%



Chapter 6



1. Role of power sector decarbonisation and entry point to 2020s
2. Assessment of power generation technologies
3. Options for increasing flexibility of the power system
4. Scenarios for power sector decarbonisation
5. Implications for reform of the current electricity market arrangements
6. Other implications for the first three budgets
7. Key findings

Chapter 6: Power sector decarbonisation to 2030

Introduction and key messages

Power is a key sector in economy-wide decarbonisation, both because it is a major source of emissions and because of scope for extending clean power generation to electric vehicles and electric heat.

In 2008 power sector emissions accounted for around 28% of total greenhouse gas (GHG) emissions, with average emissions in power generation of around 540 gCO₂/kWh; this will fall to around 300 gCO₂/kWh by 2020 if current Government ambition on renewable electricity and other low-carbon generation sources is delivered.

In this chapter we assess paths for power sector emissions through the 2020s. We consider the various options for power sector decarbonisation – nuclear, coal and gas carbon capture and storage (CCS), renewables – in terms of economics, timing of possible deployment, and impact on security of supply. We next develop scenarios for investment in low-carbon power generation reflecting cost-effectiveness, potential build constraints, and a range of possible growth scenarios for electric vehicles and heat. We then consider at a high level the types of market mechanisms that could provide confidence in delivering these scenarios.

The key messages in the chapter are:

- **Sector decarbonisation.** Deep cuts in power sector emissions through the 2020s are feasible, cost-effective and desirable in meeting the fourth carbon budget and preparing for meeting subsequent carbon budgets. Our analysis suggests the need for investment in 30-40 GW of low-carbon capacity¹ in the decade from 2020, to replace ageing capacity currently on the system, and to meet demand growth; this would drive average emissions from generation down to around 50 gCO₂/kWh by 2030².
- **Electricity market reform to deliver required investment.** Current market arrangements are highly unlikely to deliver required investments in low-carbon generation. Tendering of long-term contracts (e.g. Low-Carbon Contracts for Differences or Power Purchase Agreements) would reduce risks which energy companies are not well placed to manage (i.e. carbon price, gas price and volume risk), and would provide confidence that required investments will be forthcoming at least cost to the consumer. Other mechanisms (e.g. reliance on a carbon price alone or extension of the current Renewables Obligation) would not ensure the required investment, and would involve unnecessarily high costs and electricity prices. Given the need to decarbonise the power sector and the long lead-times for low-carbon investments, reform of the current market arrangements to include a system of tendered long-term contracts is an urgent priority.

¹ Intermittent technologies are adjusted in this figure by the difference between their average availability and the availability of non-intermittent plants in order to put all plants an equivalent GW basis. GW are presented in this way throughout this chapter, unless otherwise indicated.

² Emissions intensity in our Medium scenario is 38 gCO₂/kWh excluding autogeneration and 52g CO₂/kWh including autogeneration.

- **Costs and investment requirements.** The costs of sector decarbonisation would be of the order 0.4% of GDP in 2030, with investment requirements in generation capacity through the 2020s of the order £100 billion.

We set out the analysis that underpins these messages in six sections:

1. Role of power sector decarbonisation and entry point to 2020s
2. Assessment of low-carbon power generation technologies
3. Options for increasing flexibility of the power system
4. Scenarios for power sector decarbonisation to 2030
5. Implications for reform of current electricity market arrangements
6. Other implications for the first three budget periods

1. Role of power sector decarbonisation and entry point to 2020s

Current power sector emissions

Power sector emissions in 2008 were around 170 MtCO₂, relative to economy-wide emissions of around 630 MtCO₂e (i.e. power sector emissions accounted for around 28% of total GHG emissions – see Figure 6.1). Coal-fired generation accounted for around 33% of generation and 63% of emissions in 2008, with gas-fired generation accounting for around 46% of generation and 35% of emissions. Average emissions including generation from nuclear (14% share) and wind (2% share) were around 540 gCO₂/kWh in 2008.

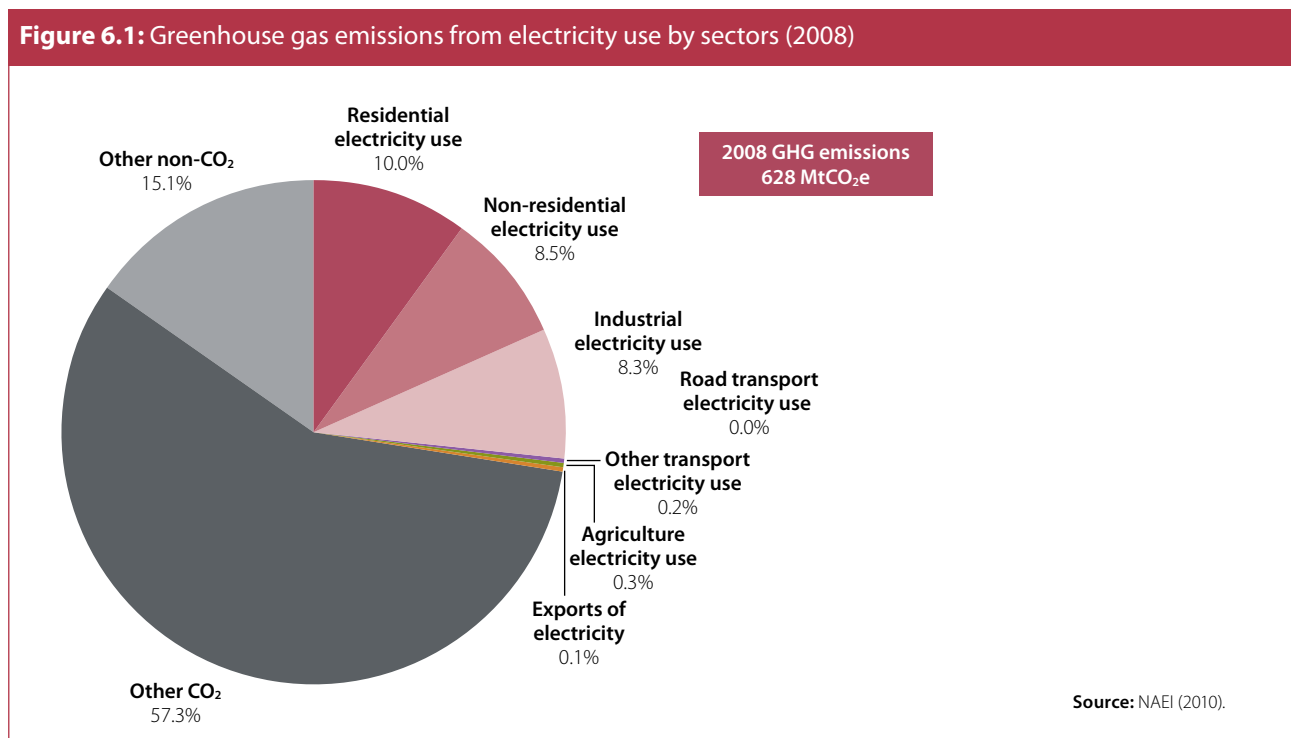


Figure 6.2: Electricity consumption (1990-2009)

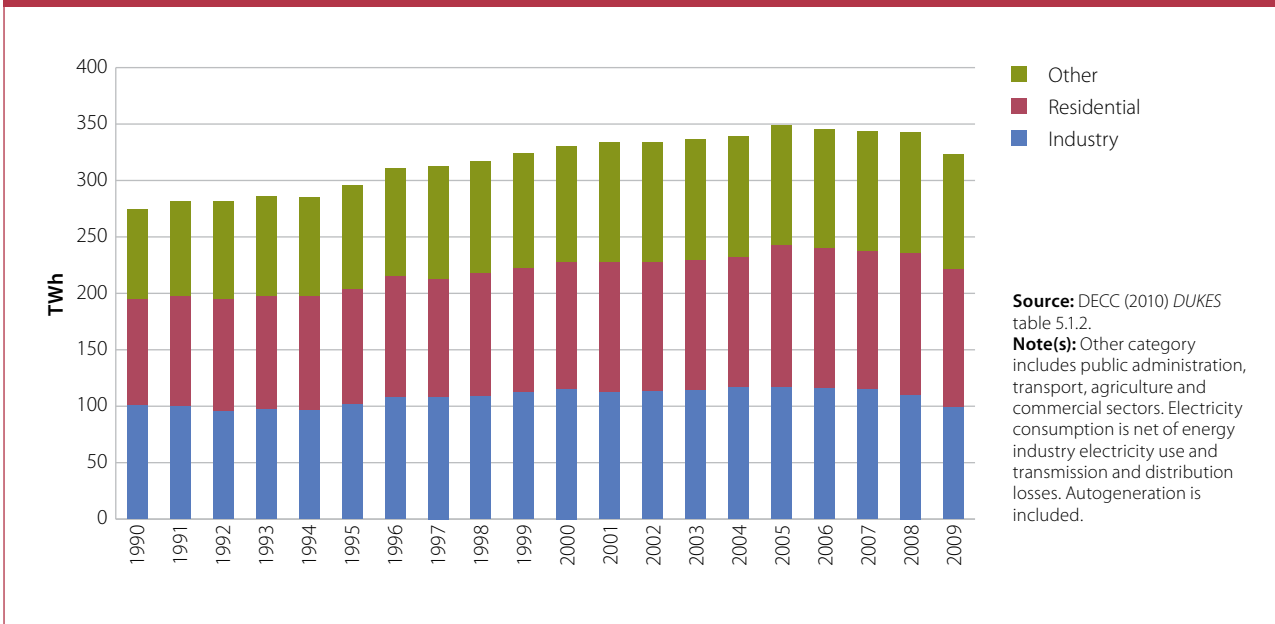
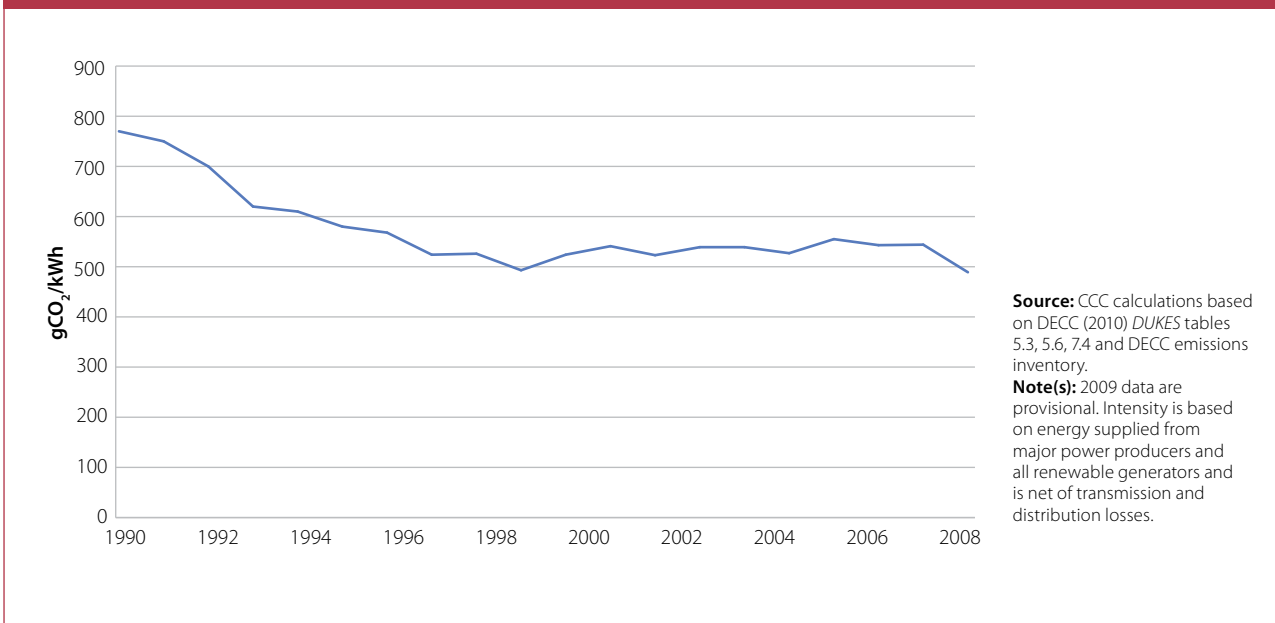


Figure 6.3: Emissions-intensity of electricity supply (1990-2009)

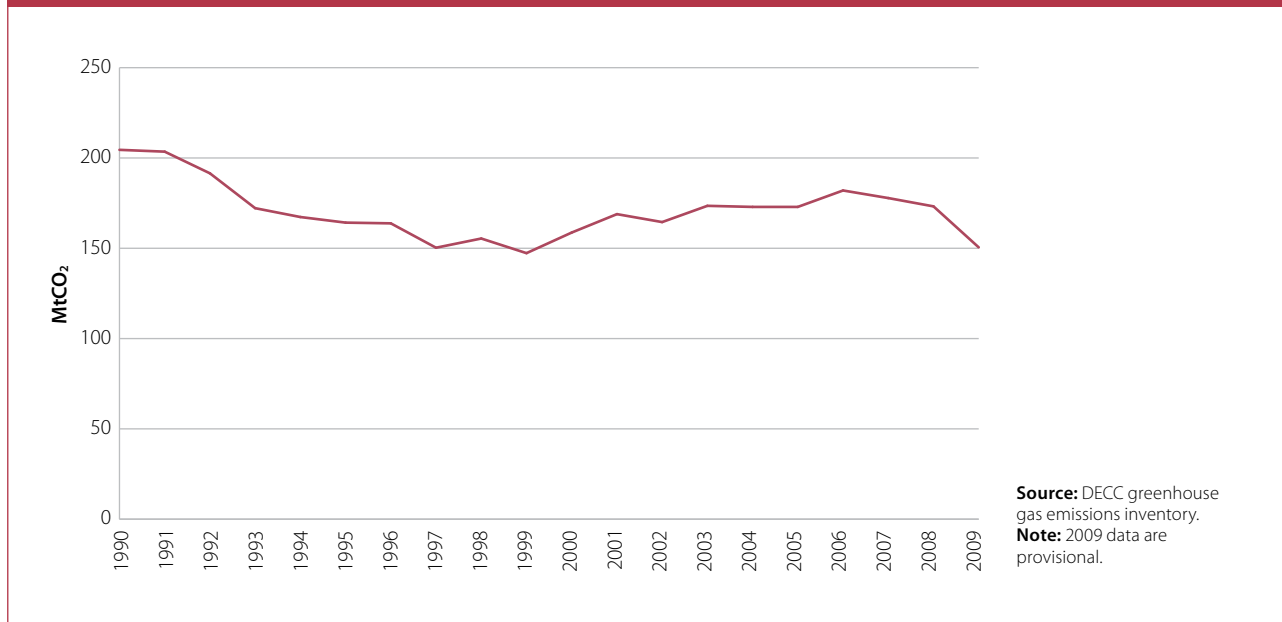


Emissions trends

Power sector emissions fell from 1990 to 1999 due to the ‘dash for gas’, then increased slightly in the period from 2004 to 2008 as a result of rising electricity demand. In 2009, emissions fell both due to a demand reduction as a result of the recession, and due to a fall in carbon-intensity (Figures 6.2 to 6.4):

- Emissions fell by 28% from 1990-1999. Key drivers of emissions were: investment in around 9.5 GW of new gas-fired capacity in the early 1990s which substituted for coal-fired generation (the ‘dash for gas’); demand growth averaging around 1.5% annually.

Figure 6.4: Power sector emissions (1990-2009)



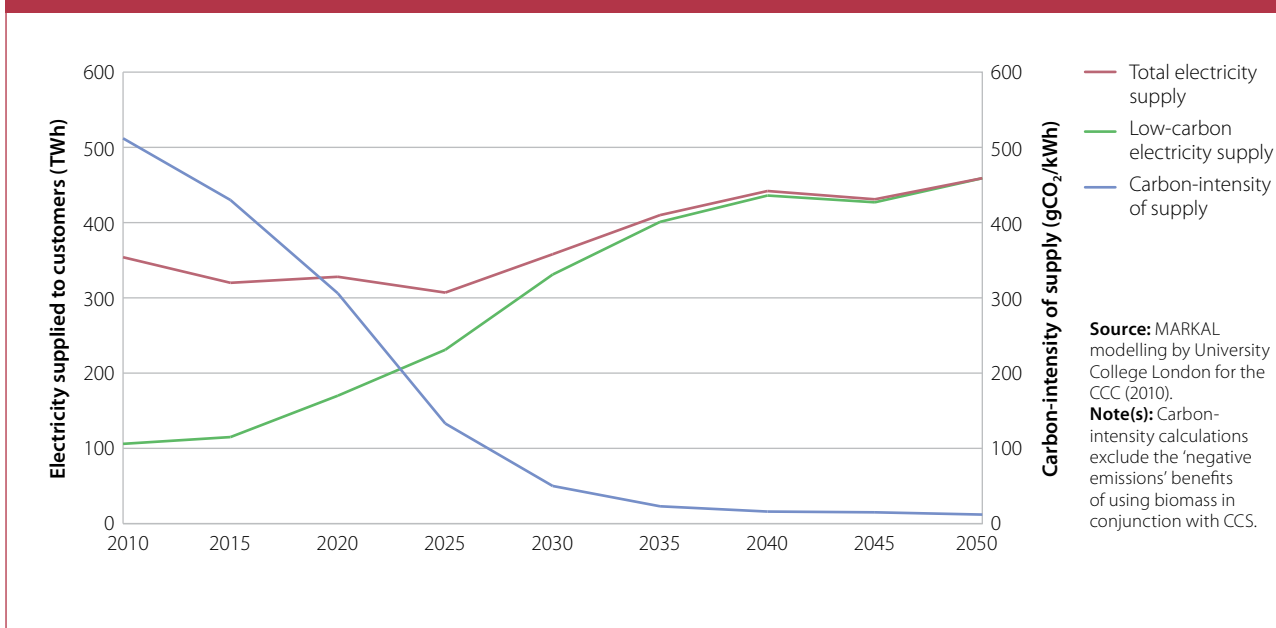
- From 2004-2008, emissions increased by 0.2%, as demand continued to rise but the rate of substitution of gas-fired capacity for coal-fired capacity slowed.
- In 2009, emissions fell by 13%, driven by a reduction in both demand and emissions-intensity:
 - Electricity demand fell by 7%, having remained constant in 2008. It is likely that this reduction was largely a result of the recession rather than implementation of policies to improve energy efficiency.
 - Carbon-intensity of power generation fell by 10% to around 490 gCO₂/kWh, reflecting an increase in nuclear generation (due to the return to operation of two plants which had outages in 2008) and a reduction in coal-fired generation (due to low gas prices), alongside a small increase in renewable generation.

Power sector decarbonisation on the path to the 2050 target

Our previous analysis has highlighted the crucial role of early power sector decarbonisation on the path to meeting the 2050 economy-wide emissions target. The high-level story is one of investment in low-carbon power generation, and extension of low-carbon generation to other sectors, namely transport (through electric vehicles – see Chapter 4) and heat (through electric heat pumps – see Chapter 5). Therefore the carbon-intensity of electricity generation should fall significantly at the same time as electricity demand increases (Figure 6.5).

We first highlighted the need for early power sector decarbonisation in our 2008 report on the level of the 2050 emissions reduction target. This path has been broadly accepted by, amongst others, DECC, the Energy and Climate Change Select Committee, and industry (Box 6.1).

Figure 6.5: MARKAL trajectory for the power sector (2010-2050)



Box 6.1: Early power sector decarbonisation on the path to 2050

In setting out a high-level vision for the path for meeting the 2050 target in our 2008 report, we recommended that the path should include the radical decarbonisation of electricity (i.e. a reduction in carbon-intensity to below 100 gCO₂/kWh) by 2030. This was based on two key arguments:

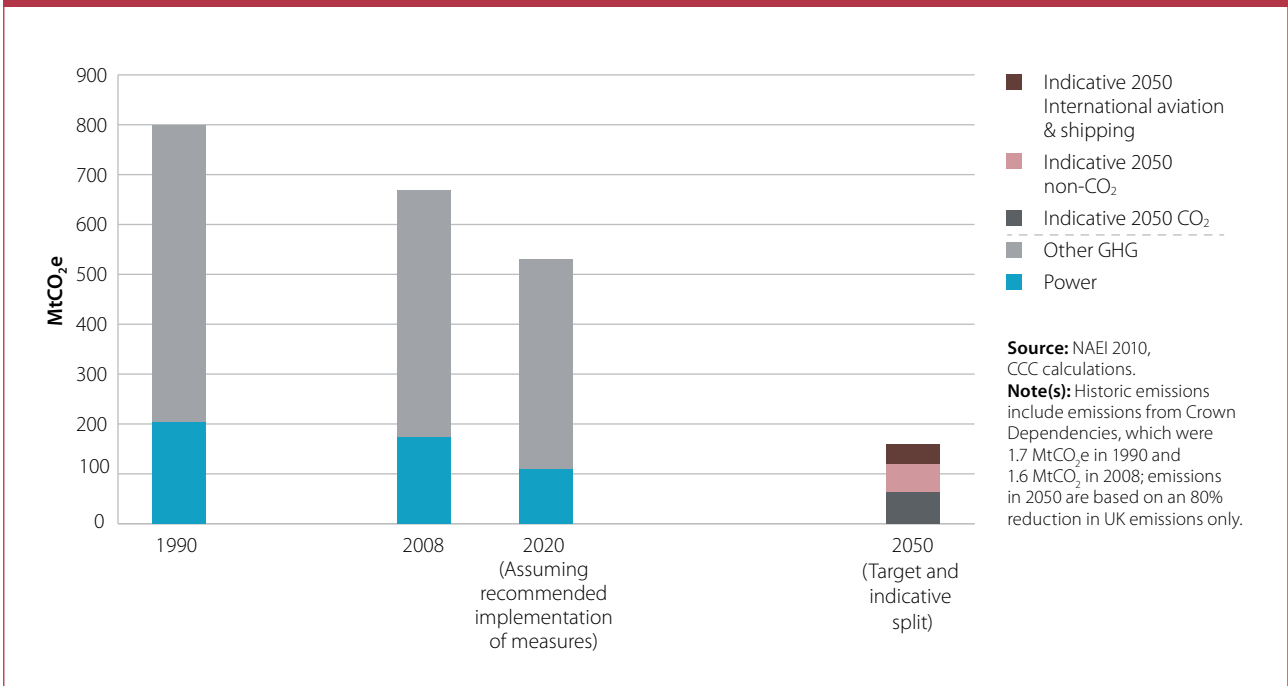
- The quantity of low-carbon electricity required by 2050 (e.g. a possible doubling of supply) implies high rates of low-carbon capacity addition throughout the period to 2050, and therefore implies low-carbon generation by 2030 at a level close to total electricity generation today.
- The costs of reducing carbon-intensity in the power sector are generally lower than doing so in other sectors, and the least-cost path towards 2050 is therefore likely to involve early decarbonisation of electricity supply.

This 2030 decarbonisation goal has been accepted by a wide range of stakeholders, including the Energy and Climate Change Select Committee, the Confederation of British Industry, the Business Council for Sustainable Energy, the Institution of Mechanical Engineers, the Scottish Government, E3G, WWF and the Carbon Capture and Storage Association.

The need both to decarbonise the power sector and to expand it to meet new demands for low-carbon electricity from the heat and transport sectors was a cornerstone of DECC's *2050 Pathways* report, which set out six indicative scenarios for meeting the 2050 emissions target via different combinations of measures. Common to all six of these scenarios was the decarbonisation of electricity, combined with an expansion of the sector for electrification of heat and transport, in the period to 2050.

By 2030, DECC's indicative pathways contain between 285 TWh and 428 TWh per year of low-carbon generation, which implies similar levels of low-carbon investment as those presented in our scenario in Section 4 below.

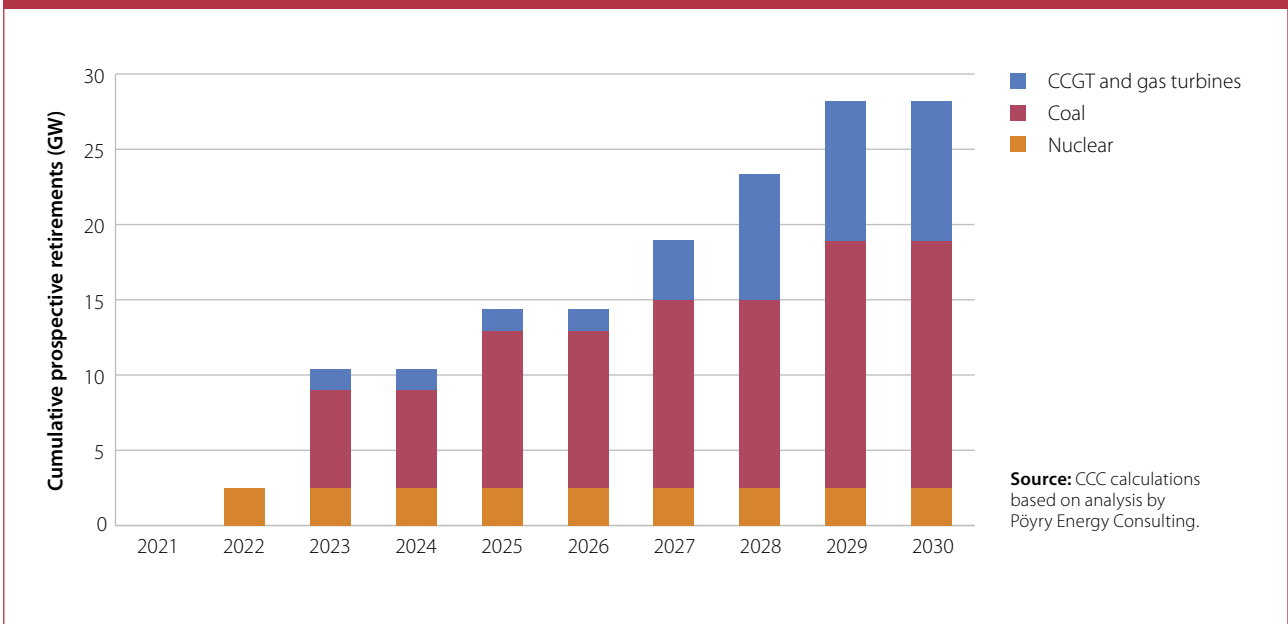
Figure 6.6: Power sector emissions in the context of UK greenhouse gas emissions (1990-2050)



The path to 2020: laying the foundations

In our 2009 Progress Report to Parliament, we set out an Extended Ambition scenario for investment in low-carbon power generation. This would put the UK on track for early decarbonisation of the power sector, and is the basis for our assessment of progress in reducing power sector emissions during the first three budgets.

Figure 6.7: Capacity retirement (2021-2030)



-
- The scenario includes 23 GW new wind capacity and 4 GW of new non-wind renewables (on a nameplate basis), and four CCS demonstration plants by 2020, with three new nuclear plants by 2022.
 - This would result in a total of around 45 GW (approximately 25 GW when wind is adjusted for its lower annual availability³) of low-carbon plant on the system in 2020 after allowing for closure of existing nuclear plant in the 2010s.
 - Emissions reductions of around 40% in 2020 would ensue relative to current levels. This would be due to both a fall in average emissions from around 490 gCO₂/kWh in 2009 to around 300 gCO₂/kWh in 2020, as well as efficiency-driven demand reductions.

Our analysis suggests that the scenario is feasible and desirable:

- Investments in renewables, new nuclear and CCS demonstration are feasible subject to there being grid investment, planning reform, supply chain development and appropriate financial support.
- These investments are desirable in developing options for power sector decarbonisation throughout the 2020s, based on a diverse generation mix rather than reliance on one or two technologies.

Therefore we will assume that the level of ambition in this scenario defines the entry point to the 2020s (Figure 6.6).

The path through the 2020s: challenges decarbonising the power sector

There is a very good opportunity for power sector decarbonisation through the 2020s. This comes from the profile of prospective plant closure and therefore the need for investment in at least 27 GW new capacity between 2021 and 2030 (Figure 6.7), with additional investment required where existing plant is operated at lower load factors or retires early, and to meet demand growth.

However, there are several challenges relating to decarbonisation of power through the 2020s. These include technology readiness, the need for system flexibility, the economic characteristics of low-carbon plants, demand uncertainty, and feasibility constraints:

- **Technology development:** Currently onshore wind and nuclear are at the deployment stage, offshore wind is at the early stages of deployment, marine technologies are being demonstrated, and CCS (coal and gas) and geothermal will soon enter the demonstration phase. Therefore the contribution of some technologies in the 2020s will be limited, particularly in the first half of the decade.
- **The need for system flexibility:** Currently there is power system flexibility on the supply side (e.g. fossil fuel plant can be operated flexibly), but limited demand-side flexibility (e.g. only the largest customers are able to respond to high prices when the system is operating at capacity). Going forward, most low-carbon plants are likely to be less flexible

³ Intermittent technologies are adjusted by the difference between their availability and the availability of non-intermittent plants in order to put all plants on an equivalent GW basis.

than fossil fuel plants, but the electrification of heat and transport will increase the potential for demand-side flexibility. Increased demand response will be desirable as the level of intermittent wind generation increases (i.e. to avoid the need for back-up capacity and balancing generation when the wind does not blow). In addition, flexible low-carbon generation capacity, storage capacity and interconnection with north-west Europe are likely to be required to balance intermittent generation, to meet demand peaks, and to meet seasonal demand for electric heat.

- **Economic characteristics of low-carbon plant:** Low-carbon plants have different economic characteristics to conventional plants such as CCGT. Their higher upfront costs and lower running costs make them much more economic if they can run at higher load factors (although this applies less to CCS technologies than it does to renewables and nuclear – Figure 6.8). The capital-intensity of low-carbon plant makes this particularly sensitive to the cost of capital, and therefore in turn to political, regulatory and market risks.
- **Demand uncertainty:** In addition to normal uncertainty over future demand, there is considerable uncertainty over the extent to which there will be increased baseload demand as new markets for electric vehicles and electric heating develop (e.g. due to technology and policy uncertainty). This is an important consideration in the context of power sector decarbonisation given that it will significantly impact the economics of low-carbon investments, and given the long lead-times of many of these investments (i.e. investment decisions will be required before markets for electric vehicles and heat have matured).
- **Feasibility constraints:** Projects to build (capital-intensive) low-carbon capacity are large and complex. This raises questions about industrial capacity and the ability of supply chains to mobilise where significant expansion might be required if power sector decarbonisation is to be achieved.

We now consider each of these challenges in more detail, starting with technology development (Section 2), then options for flexibility (Section 3), and moving to scenarios for power sector decarbonisation in the context of which we consider demand uncertainty and feasibility constraints (Section 4).

2. Assessment of power generation technologies

As well as reducing emissions, it is crucial that policy maintains security of supply and affordability. These objectives frame our assessment of power generation technologies, where we consider scope for cost-effective emissions reductions (both as regards economics, and the pace at which technologies could be deployed), and impacts on security of supply in terms of operational characteristics and contributions to diversity.

Analysis in subsequent sections suggests that extensive deployment of low-carbon technologies will be desirable and some low-carbon plant will operate outside of baseload. In this section we therefore also consider constraints on deployment and costs/operability at lower load factors.

We consider in turn:

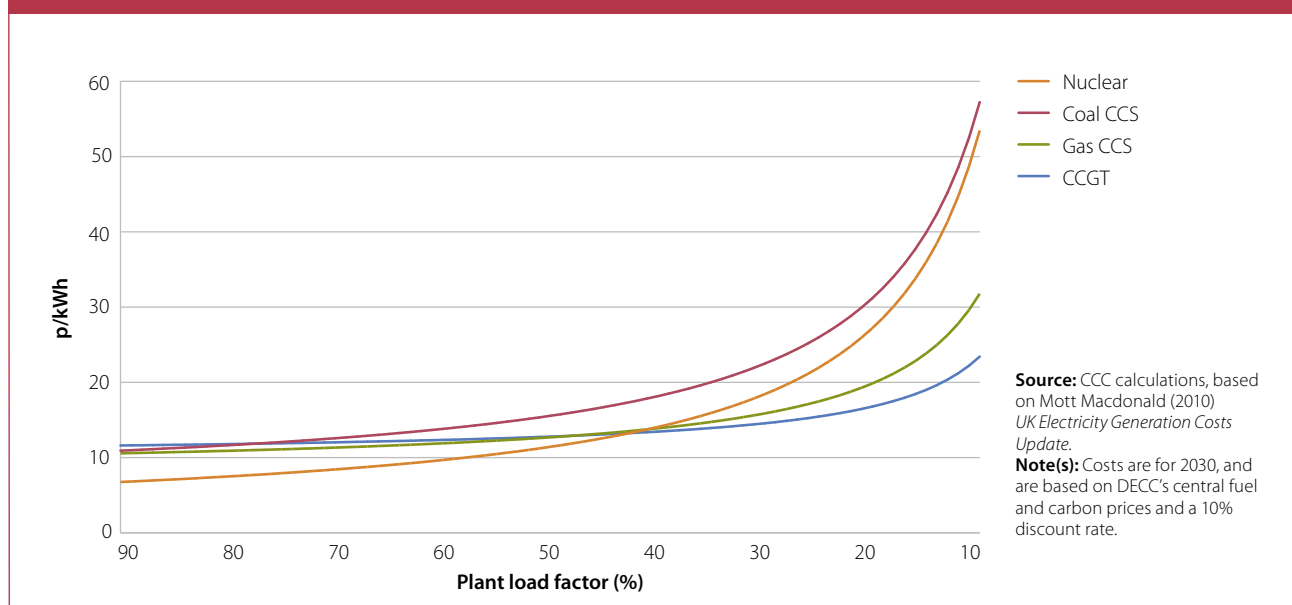
- (i) Conventional fossil fuel generation
- (ii) Renewable generation
- (iii) Nuclear new build
- (iv) Coal CCS
- (v) Gas CCS
- (vi) Overview of low-carbon generation technologies

(i) Conventional fossil fuel generation

Our previous analysis has suggested an increasingly limited role for investment in and operation of unabated fossil fuel plant in a decarbonising power system:

- **Coal:** as we showed in our 2008 report, the carbon-intensity of unabated coal plant is sufficiently high that it can have no role in the power system beyond the early 2020s, by which time the rising carbon price will make its continued operation uneconomic (Box 6.2). The options for unabated coal capacity would then be to retrofit carbon capture and storage (CCS) or to close the plant.
- **Gas:** unabated gas generation (CCGT) is likely to become more expensive than low-carbon alternatives at high load factors by the end of the 2020s (Figure 6.8). While there will still be an important role for flexible gas capacity to provide back-up to wind generation and to generate at peak times, operation is likely to be at low load factors. The implication is that there is limited scope for investment in unabated gas capacity beyond 2020, with a choice for plant already on the system at this time to retrofit CCS, fall into a back-up/peaking role or, if these options are uneconomic, to close the plant.

Figure 6.8: Estimated levelised cost of low-carbon technologies by load factor (2030)

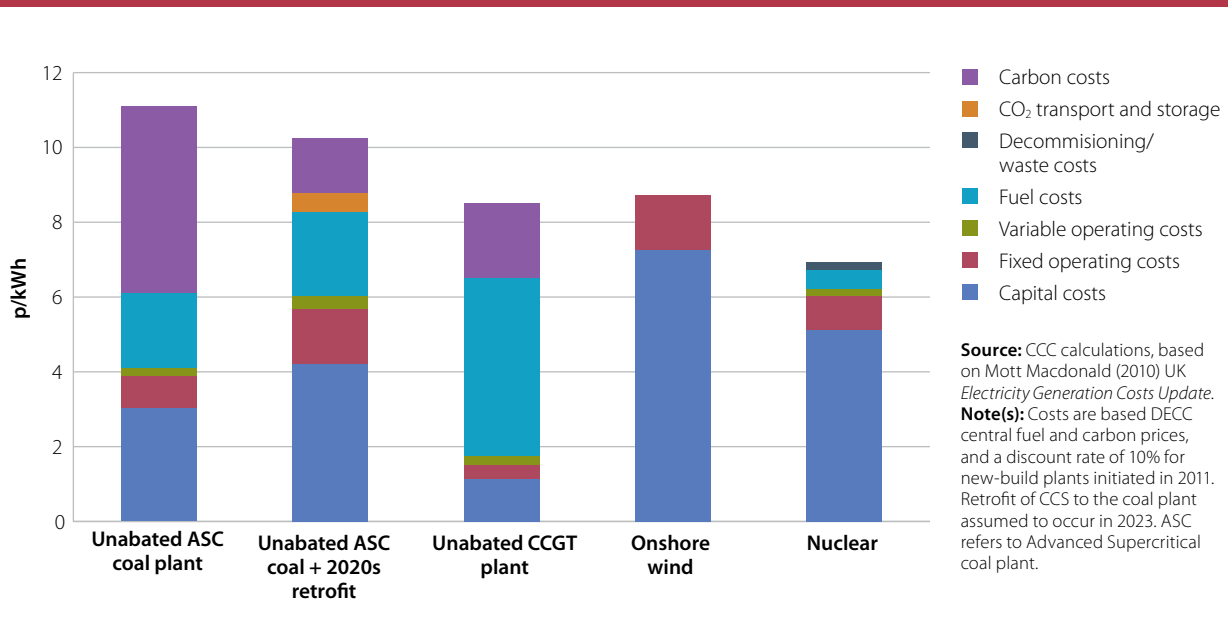


Box 6.2: Limits to operation of unabated coal plants

In our 2008 report, we highlighted the very limited role for unabated coal in a decarbonising power system. In particular we said that there should be an expectation – and a strong signal from Government – that coal plants would not run unabated beyond the early 2020s.

Updated analysis, using the latest estimates from Mott Macdonald of power technology costs, reaffirms this message. Taking into account carbon costs, a new unabated coal plant commissioned today would have a considerably higher levelised cost than wind, nuclear or unabated CCGT plant. Assumed retrofit of the unabated coal capacity in 2023 is cost-effective compared with continued unabated operation (Figure B6.2).

Figure B6.2: Long-run marginal cost of unabated coal plant vs. near-term alternatives



(ii) Renewable generation

Wind generation

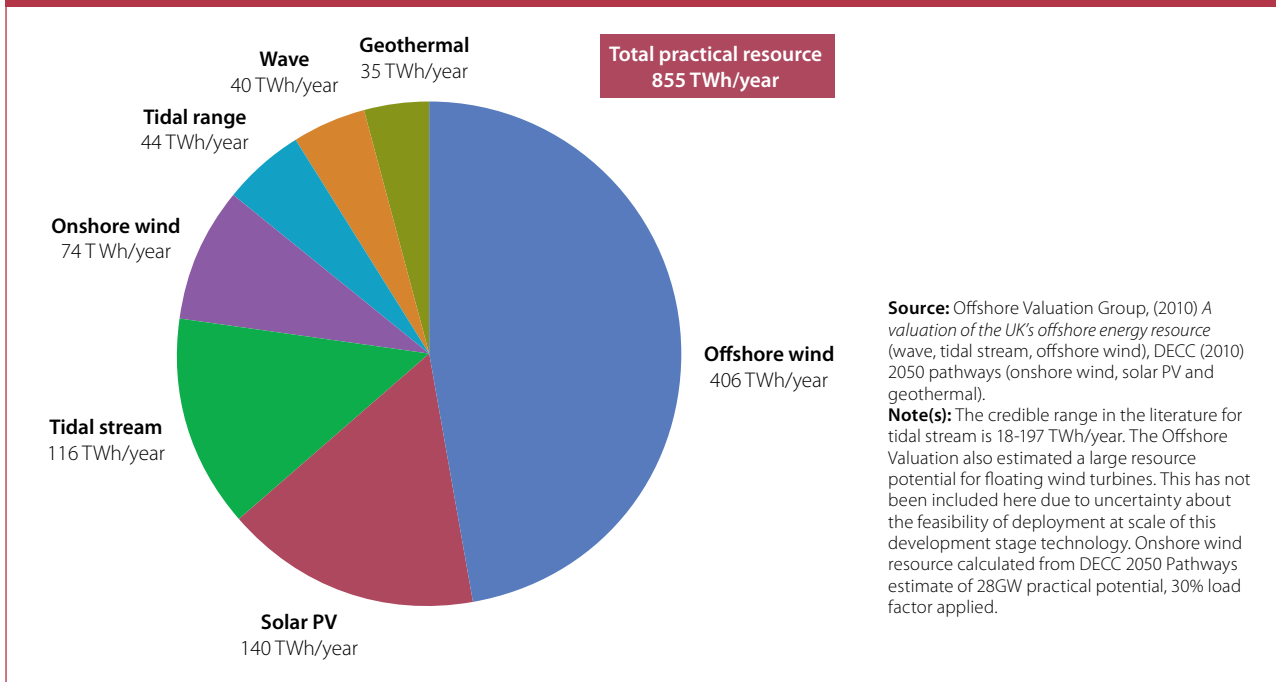
Onshore wind generation is a relatively low-cost mature technology, and is competitive with CCGT under our projected carbon prices. However, there are questions over the extent to which the full practical potential can be exploited, given local opposition in some areas:

- **Economics of onshore wind:** Analysis for DECC suggests that onshore wind could deploy in 2030 at around 9 p/kWh⁴, making it an attractive investment option compared to unabated gas with a carbon price.
- **Scope for investment in onshore wind:** DECC estimate that the resource potential for onshore wind is around 74 TWh/year⁵ (Figure 6.9). However, the extent to which the remaining resource will be deployable beyond the 37 TWh/year generated by 2020 under our Extended Ambition scenario is subject to uncertainty given local opposition.

⁴ Except where otherwise stated, all levelised costs in this chapter are for plant operational from 2030, under a 10% discount rate and DECC central fuel and carbon prices. These estimates are based on Mott Macdonald (2010) UK Electricity Generation Costs Update, <http://www.decc.gov.uk/assets/decc/statistics/projections/71-uk-electricity-generation-costs-update-.pdf>

⁵ CCC calculation based on DECC (2010) 2050 Pathways, http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/2050/2050.aspx. In order to convert capacity to generation, a 30% load factor was applied.

Figure 6.9: Estimated practical resource for UK renewables



Offshore wind generation has much more complex engineering aspects (e.g. relating to the salt-water environment), is at an earlier stage of deployment and is much more costly than onshore wind. However, there is a potentially important role for offshore wind given scope for cost reduction and the vast resource available in UK waters:

- **Economics of offshore wind:** Offshore wind is currently projected to be relatively expensive (e.g. 11 p/kWh rising to 13 p/kWh for sites in deeper waters, compared to 9 p/kWh for onshore wind and 7 p/kWh for new nuclear). However, there is likely to be scope for cost reduction (e.g. a recent UKERC report suggests that policy improvements, engineering developments and supply chain expansion could drive costs down to 10 p/kWh in the mid-2020s)⁶. We will consider future costs of offshore wind including scope for learning and cost reduction in detail in our renewable energy review, to be published in Spring 2011.
- **Scope for investment in offshore wind:** The resource potential for offshore wind in the UK is huge (Figure 6.9). If current ambition for 2020 can be delivered, there will be a supply chain in place to facilitate ramping up of investment in the 2020s, should this prove desirable.
- **Managing intermittency/reliability:** Generation from both onshore and offshore wind is intermittent (capacity factors are likely to be between around 25% and 45% with wind generation being variable and difficult to predict). Intermittency is manageable at levels of wind generation envisaged to 2020, but further analysis is required to assess the impacts of intermittency at much higher levels of offshore wind penetration and how these could be managed.

⁶ Based on the most optimistic scenario from UKERC (2010) *Great Expectations: The Cost of Offshore Wind in UK Waters*, <http://www.ukerc.ac.uk/support/tiki-index.php?page=Great+Expectations%3A+The+cost+of+offshore+wind+in+UK+waters>

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- Our analysis suggests that intermittency related to investments envisaged in the period to 2020 and further investments through the 2020s can be managed through a combination of flexible balancing generation, interconnection, storage and demand-side response (see Section 3 below) and that associated costs are not prohibitive.
 - However, for much higher levels of offshore wind, there is uncertainty over associated levels of intermittency (e.g. this is likely to increase with the level of offshore wind capacity) and options for managing this; we will provide a more detailed assessment in our renewable energy review.

Therefore onshore wind could make a useful contribution to sector decarbonisation in the 2020s, depending on the extent to which further resource is available to exploit. Development of the offshore wind option is desirable notwithstanding initial high costs; the current focus to demonstrate/deploy this option is appropriate, with future decisions on the precise role of offshore wind in a low-carbon generation mix depending on further evidence about costs and implications of intermittency.

Tidal range

Tidal range technologies make use of the height difference created by high and low tide to generate electricity, creating a differential in the water levels either side of a structure and then passing this water through turbines. The Severn barrage project offers the largest scope (up to 16-20 TWh/year) for tidal range generation in the UK (Figure 6.10).

- **Economics of tidal range:** Even at a social discount rate (e.g. 3.5% and declining over time as in HM Treasury's Green Book), tidal range is expensive relative to wind and nuclear generation (see costs including optimism bias in Figure 6.11). Although there is limited scope for learning and cost reductions under the current proposed design, there may be scope for cost reductions under alternative designs (Box 6.3).
- **Scope for investment in tidal range:** Given a project lead time of at least 13 years including planning and construction (but not habitat relocation), the earliest the proposed Severn barrage could become operational is 2023, beyond which it could contribute through an asset life of around 120 years. There is some potential to invest in tidal range elsewhere in the UK, with a total resource of 44 TWh/year (Figure 6.10).
- **Intermittency/security of supply:** Tidal range generation is intermittent but predictable in advance, suggesting the need for operation in conjunction with various flexibility options (see Section 3 below).

Given current uncertainties over the role of other low-carbon technologies, the Severn barrage could make a useful contribution to required sector decarbonisation. This would be the case if there are binding build constraints for other low-carbon technologies, or where these turn out to be relatively expensive. However, in order to proceed with this project, it would be important to demonstrate that it was cost-effective relative to alternative options, and that any environmental impacts were addressed.

Figure 6.10: Estimated potential annual energy output of UK tidal range resource

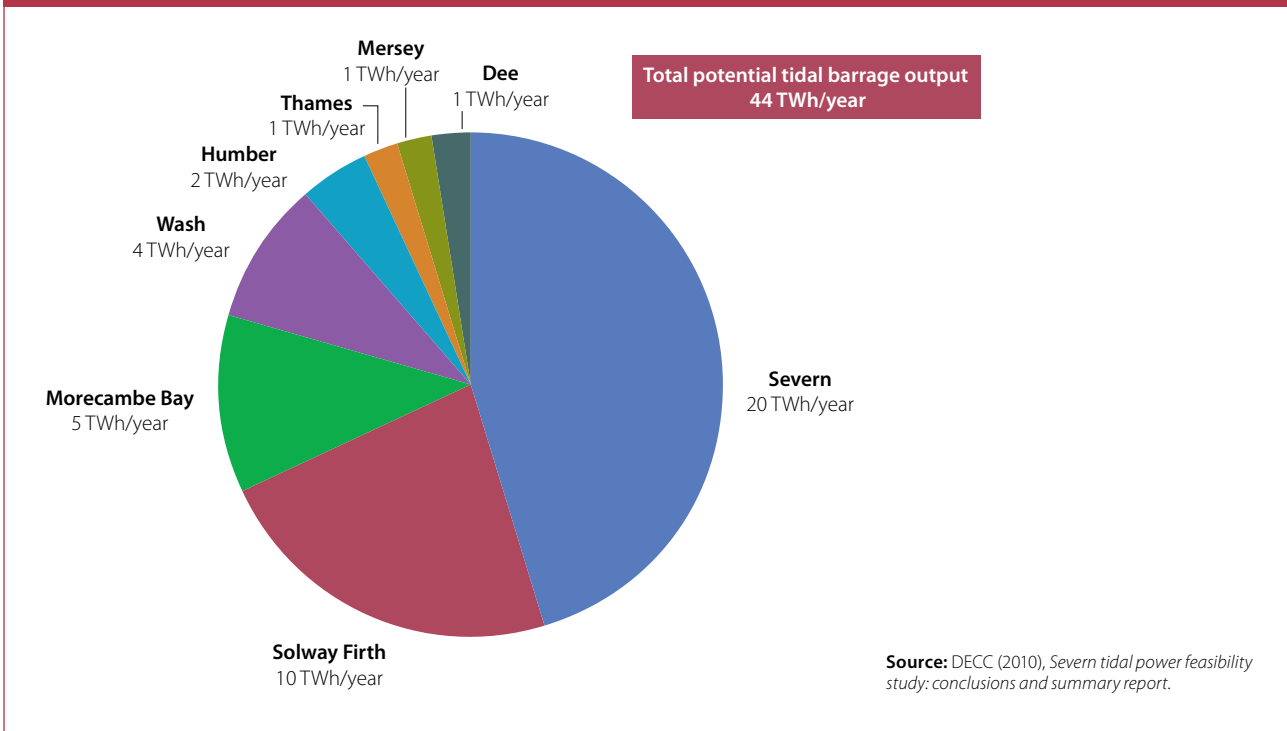
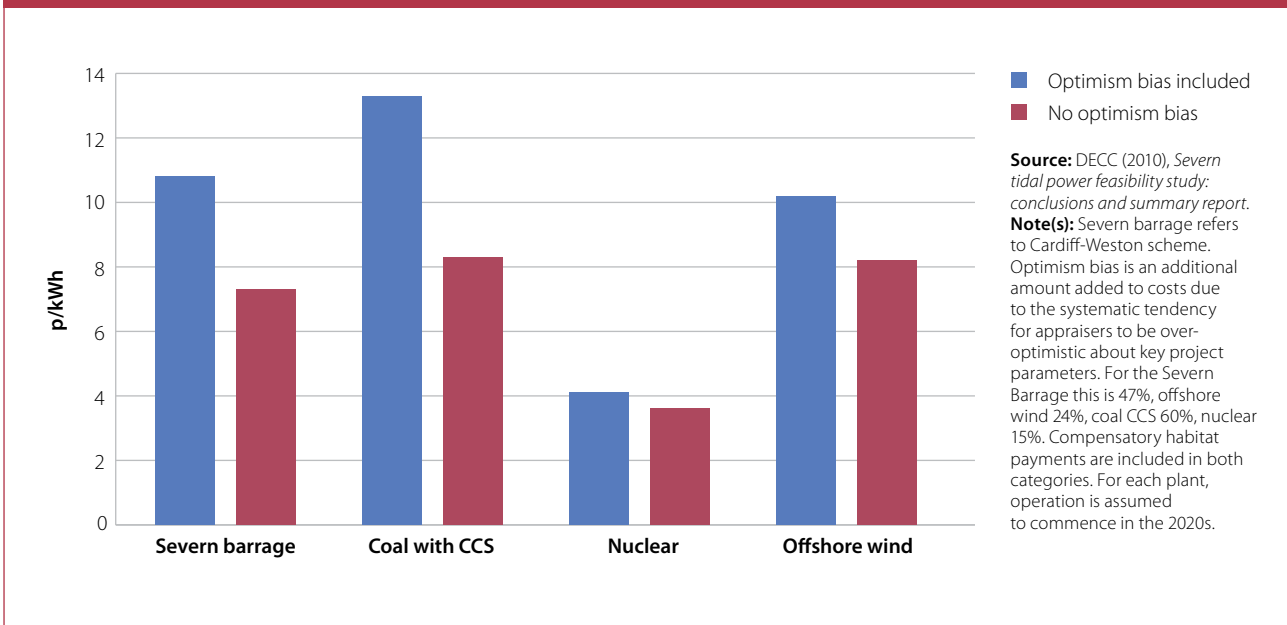


Figure 6.11: Estimated levelised costs of Severn barrage versus other low-carbon options at a social (3.5%) discount rate



Box 6.3: Future tidal range technologies

The Severn Embryonic Technologies Scheme was a £0.5 million fund from across government designed to develop more cost effective and less environmentally damaging alternatives to the conventional tidal barrage.

Two concepts investigated by the scheme are the Spectral Marine Energy Converter proposed by VerdErg and the Tidal Bar proposed by Atkins/Rolls Royce. The table below sums up the scheme's conclusions about these two proposals compared with the conventional barrage assessment

Table B6.3: Summary of potential tidal range technologies

Concept	Annual Output (TWh)	Capital cost (£bn)	Construction time (years)	Potential environmental impacts
Spectral Marine Energy Converter	8-12	10-17	7	18 km ² of bird habitat loss
Tidal Bar	17	17-24	11	9 km ² habitat loss
Conventional Cardiff-Weston Barrage	16	23-34	9	118-163 km ² habitat loss, significant loss of fish

Source: DECC (2010) *Severn tidal power feasibility study: conclusions and summary report*.

Both immature alternatives may offer reduced costs and environmental impacts compared to a conventional barrage. A tidal bar may also offer increased flexibility to the power system through its bi-directional turbines and requirement for a lower tidal range to operate.

Tidal stream and wave

Tidal stream generation exploits kinetic energy of tidal currents, whereas wave generation draws on energy in waves on or near the surface of the sea. Both types of technology are at an early stage of development, with relatively high costs compared to existing generation technologies. With cost reductions through the demonstration phase, both technologies could make a useful contribution to required decarbonisation in the 2020s, and add diversity to the generation mix:

- **Economics of tidal stream and wave.** The costs for wave and tidal stream when deployed at scale are highly uncertain:
 - DECC provide a range for costs of tidal stream in 2020 from 14-25 p/kWh, with scope for cost reduction through learning resulting in costs possibly falling to 8-17 p/kWh by 2050.
 - Wave could deploy in 2020 at 18-25 p/kWh, with scope for cost reduction to as low as 7-11 p/kWh by 2050⁷.
- **Scope for investment in tidal stream and wave.** There are currently plans to add up to 600 MW each of wave and tidal stream in the Pentland Firth in the period to 2020. Beyond this, there is considerable uncertainty about the long-term resources for wave and tidal stream. There is an ongoing controversy around the correct physical method for estimating the tidal stream resource, resulting in a wide range of estimates from 18-197 TWh per year,

⁷ Wave and tidal costs are from Ernst and Young, (2010) *Cost of and financial support for wave, tidal stream and tidal range generation in the UK*.

while the literature suggests that wave could make a practical contribution of 40-50 TWh per year⁸. In both cases, deployment at scale could be feasible from the mid-2020s depending on what demonstration projects reveal about costs and technical characteristics.

- **Intermittency/security of supply.** As with tidal range, generation from tidal stream is intermittent but predictable in advance. Output from wave is less predictable, but output from both technologies is largely uncorrelated to that of wind, and so both could add diversity to the generation mix. This would be desirable from a security of supply perspective, and could help contain the costs of intermittency associated with a high proportion of renewables on the system.

Given possible build constraints for other low-carbon technologies and the potential for cost reductions, there is a strong case for supporting demonstration of tidal stream and wave in order to develop an additional option for sector decarbonisation in the 2020s.

Biomass

The use of biomass for (dedicated and co-firing) power generation is well established in the UK, although its future role in the generation mix is uncertain given possible constraints on the supply of sustainable feedstock:

- Power generation from biomass co-firing with coal was 1.8 TWh in 2009, with scope to increase to around 7 TWh by 2020 (i.e. 10% of coal generation at this time could be met by co-firing). However, given that there is no role for unabated coal generation beyond the early 2020s, this type of co-firing will cease to be viable.
- There was 1.9 GW of dedicated biomass capacity on the system in 2009, comprising 1.1 GW landfill and sewage gas and 0.8 GW animal and plant solid biomass. Costs of dedicated biomass power generation are projected to be of the order 8-10 p/kWh for solid fuel and 5-10 p/kWh for biogas (e.g. landfill, sewerage, anaerobic digestion of wastes) in the 2020s, thus making it a competitive low-carbon generation option. This is reflected in the Government's National Renewable Energy Action Plan which projects installed capacity to reach 4.2 GW by 2020⁹.
- However, in the presence of binding constraints on sustainable biomass supply, the power sector may have to compete for available inputs with the transport and heat sectors. There are likely to be more options for decarbonising power than there are for niche transport and heat markets, suggesting limits for use in power generation (see Chapters 4-5). Assuming 7 TWh co-firing and the fulfilment of the government's ambitions for biomass in 2020, the biomass resource requirement could be around 100 TWh, although reducing to 2030 as co-firing decreases.

⁸ Offshore valuation Group (2010), *The Offshore Valuation: A valuation of the UK's offshore renewable energy resource*, <http://www.offshorevaluation.org/>

⁹ DECC (2010), *National Renewable Energy Action Plan for the United Kingdom*, http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/ored/uk_action_plan/uk_action_plan.aspx

Therefore any ongoing role for biomass generation is likely to require that this is in conjunction with CCS, either on dedicated plant or co-firing with fossil fuels, and in both cases offering scope for negative emissions. It follows from this that dedicated biomass plants should be built 'CCS ready', and that investments should proceed on the basis that there may be constraints on available biomass.

Geothermal

Geothermal energy exploits heat contained in or near the earth's crust. Although current capacity is limited to around 11 GW globally, the International Energy Agency (IEA) projects a potential share of around 3% in global electricity supply by 2050, reflecting relatively low costs:

- The IEA estimates that costs of geothermal generation currently range from 4-13 p/kWh for lower temperature resources and could fall to 5 p/kWh by 2030¹⁰. However these cost estimates are for Europe as a whole and it is not known whether they would apply at potential sites in the UK.
- Unlike wind and marine, geothermal is not intermittent, and would therefore be attractive from a system management perspective.

The UK resource of geothermal energy is concentrated in Cornwall where two demonstration projects are currently planned. Beyond this, the DECC *2050 Pathways* analysis suggests potential generation of up to 35 TWh per year by 2030 (i.e. 8% of total generation – Figure 6.9). However, given the early stage of development of the UK resource at present, the contribution from geothermal to sector decarbonisation through the 2020s is highly uncertain.

Solar

Solar PV could play an important role in global power sector decarbonisation, with the IEA estimating that this could generate around 11% of global electricity by 2050. However, the importance of this technology in the UK is unclear given relatively high costs:

- Solar PV is expected to cost around 28 p/kWh in 2020 for large applications (around 5MW) and 45 p/kWh for small residential-scale deployment¹¹, compared to around 7 p/kWh for nuclear and between 11-13 p/kWh for offshore wind.
- The UK resource is estimated at around 140 TWh/year, or 32% of total generation (Figure 6.9)¹².

Given the underlying economics, the contribution of solar PV to sector decarbonisation in the 2020s is likely to be limited, although a larger role is possible in the longer term if costs fall significantly. There is also a potential long-term role for the importing of concentrated solar power from sunnier regions (e.g. southern Europe and North Africa) via a 'super-grid'.

¹⁰ IEA (2010) *Renewable Energy Essentials: Geothermal*, http://www.iea.org/papers/2010/Geothermal_Essentials.pdf

¹¹ Element Energy (2009) *Design of Feed-In Tariffs for Sub-5MW Electricity in Great Britain*, www.decc.gov.uk

¹² DECC (2010) *2050 Pathways*.

(iii) Nuclear new build

Cost-effectiveness of new nuclear

Nuclear new build is highly likely to be a cost-effective form of low-carbon power generation:

- DECC's most recent analysis suggests that new nuclear generation could cost around 7 p/kWh by 2030 in a central case, compared to 7 p/kWh for unabated gas-fired generation (or 12 p/kWh for unabated gas generation when DECC's projected carbon price from 2030 (see Chapter 2) is included).
- The DECC analysis allows for waste and decommissioning costs, which account for a very small proportion of total costs in present value terms (Box 6.4).
- It also allows for recent projected cost increases, reflecting rising steel prices and exchange rate depreciation. According to these estimates, nuclear is the most cost-effective of the low-carbon technologies (Box 6.4).

Cost-effectiveness will depend on how nuclear is operated, with lower costs when operating as baseload plant, although operation at lower load factors may be viable:

- Nuclear is very capital-intensive, therefore average generation costs fall as output increases, and nuclear is most suited to operate as baseload plant.
- Although costs are very sensitive to load factors, until these fall to around 45% or below, the most recent evidence suggests that nuclear is more cost-effective than the alternative low-carbon plants (Figure 6.8).

Therefore nuclear could in principle make a cost-effective contribution to baseload and mid-merit generation, assuming an effective strategy for waste and decommissioning (Box 6.5), and with the specific role depending on the extent to which it can be deployed in a timely manner.

Box 6.4: Nuclear costs

Central estimates

Costs of 7 p/kWh are used for nuclear throughout this analysis. These are based on Mott Macdonald's analysis for DECC which looks specifically at generation costs in the UK context to 2030. This estimate is comparable to costs currently being incurred in Europe and to other published estimates:

- The Mott Macdonald analysis uses construction costs of \$4,140/kW, comparable to those currently being incurred for a third generation plant under construction in Finland (\$4,200/kW).
- The IEA's recent analysis estimates a generation cost for European plants of 7 p/kWh¹³.
- Parsons Brinckerhoff's published estimates puts nuclear between 6-9 p/kWh¹⁴.

'First of a kind' versus 'nth of a kind'

The first few plants of any type are likely to involve additional risks – e.g. around the application of new construction techniques and the management of new supply chains. These first plants are usually termed 'first of a kind' plants and are likely to be more costly than subsequent 'nth of a kind' plants.

We have used 'nth of a kind' costs throughout this analysis (for nuclear and other technologies). Although some additional costs may be incurred for the first few nuclear plants in the UK, these should diminish rapidly as development continues at scale. The following factors in particular may limit the number of plants that will incur 'first of a kind' costs:

- The Government is carrying out a Generic Design Assessment process which demands a high-level of design completion and justification prior to commencement of construction. This should limit the risk of modifications in the design being demanded during construction.
- A number of third generation pressurised water reactor nuclear plants (of the kind expected to be built in the UK) are being built around the world. Two are expected to come on-line in Europe (Olkilouto in Finland and Flamanville in France) by 2013, and several more are currently being built in Asia. The construction of these will have a positive impact on learning and supply chain development.

¹³ IEA (2010) *Projected Costs of Generating Electricity*. Based on average of costs for plants in Europe, converted at a \$/£ exchange rate of 1.6.

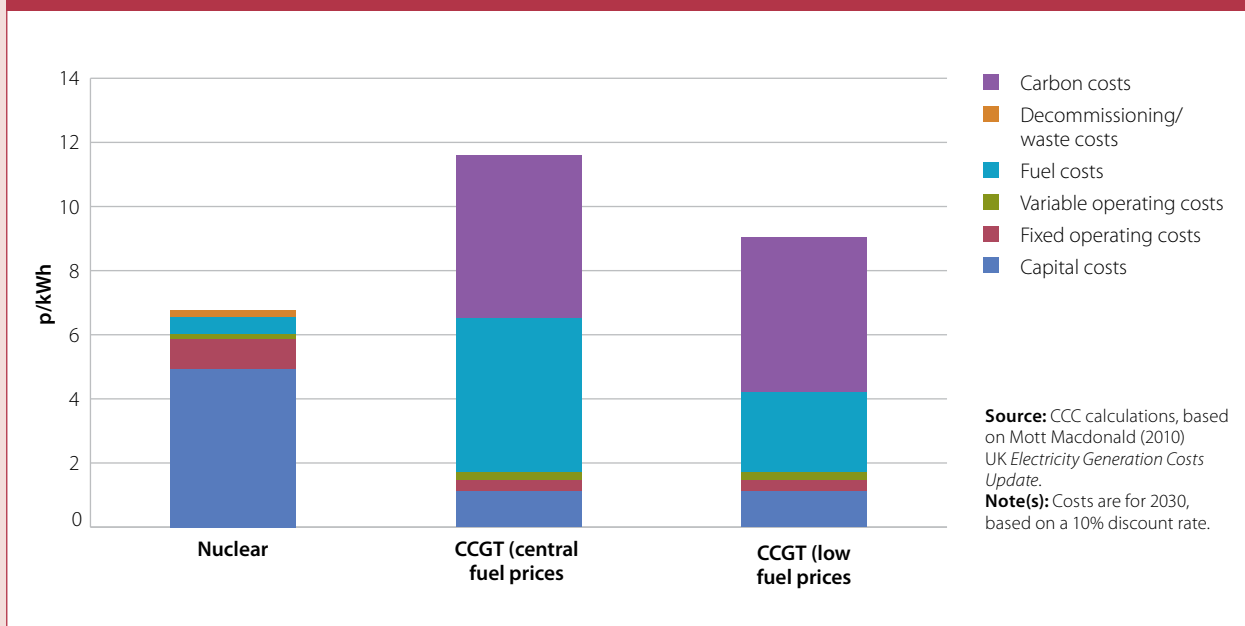
¹⁴ Parsons Brinckerhoff (2010) *Powering the Nation Update*, www.pbworld.co.uk/media.php?file=1148

Box 6.4: Nuclear costs

Key components of nuclear cost

The levelised cost of nuclear is dominated by capital costs (Figure B6.4). Capital costs contribute 5 p/kWh to the levelised costs, operating costs are relatively low (around 1 p/kWh), while decommissioning costs, including waste disposal costs, are significant but are projected to occur perhaps some 100 years after operations start, so become comparatively small in present value terms (around 0.2 p/kWh).

Figure B6.4: Estimated levelised cost for nuclear and CCGT (2030)



Recent rises in cost estimates

Cost estimates for nuclear have risen substantially in recent years, and were previously expected to be much lower than the 7 p/kWh used in the analysis presented in this chapter:

- Government analysis published in 2007 suggested a central cost of 4 p/kWh was appropriate, while a survey of market analysts in 2006 found a cost of 3 p/kWh was expected.¹⁵
- Parsons Brinckerhoff's estimates for nuclear costs have risen 40% since their 2008 publication (compared with rises of 20% for onshore wind, 25% for CCGT and 70% for offshore wind).

The recent rise in estimates is likely to be partly due to the fact that equipment prices for all the plants have risen sharply since 2006 (and this will disproportionately affect capital-intense plant such as nuclear), and also because higher than expected costs and longer construction periods have been incurred where third generation nuclear plants are actually under construction (e.g. in Finland).

¹⁵ DTI (2007), *Nuclear power generation cost benefit analysis*, <http://webarchive.nationalarchives.gov.uk/tna/+http://www.dti.gov.uk/files/file39525.pdf/>

Box 6.5: Nuclear waste

Nuclear power produces three main types of radioactive waste which require careful disposal.

- High Level Waste (HLW), generates heat and is highly toxic. It is converted to solid form using a treatment process called 'vitrification' and subsequently requires long term deep storage for thousands of years. If not reprocessed into new fuel, spent fuel generates heat and requires similar secure disposal to that of HLW.
- Intermediate Level Waste (ILW) includes fuel cladding, reactor components and radioactive sludge arising from historic and current operations. ILW is currently stored at nuclear sites pending eventual disposal.
- Low Level Waste (LLW) includes protective clothing, laboratory equipment, paper towels and gloves as well as concrete rubble from decommissioning. LLW is only slightly radioactive and is currently mostly buried at a depository at Drigg, West Cumbria.

The government expects in the absence of alternative proposals that the proposed new nuclear reactor designs will operate on a 'once-through' fuel cycle, meaning that spent fuel is not reprocessed. This spent fuel will require eventual deep disposal following a cooling period of up to 100 years after discharge from the reactor. The size of disposal facility required may be reducible through reprocessing of spent fuel, but this process has drawbacks in terms of increasing the risk of proliferation (since it produces plutonium which could be used in weapons) and producing some controversial discharges.

The Government announced in 2006 that it planned to dispose of higher activity radioactive wastes (HLW and ILW) in a Geological Disposal Facility (GDF), which is a deep underground repository. Such a GDF would be located at between 200 and 1000 metres below the ground and would aim to provide a high level of long-term isolation without future maintenance through a combination of natural and engineered barriers.

Globally, no GDF for spent fuel and HLW has yet been built, primarily because of public concern over safety and the consequent socio-political issues associated with the siting of repositories¹⁶. However there are plans to construct such facilities in Finland and Sweden by around 2020. The UK Government hopes that communities will volunteer to host a GDF in return for a variety of direct and indirect benefits, such as employment and investment in local infrastructure. No specific timeline has yet been set out and the government recognises that finding a site and building a repository could take many decades. In the meantime, waste from new nuclear power is expected to be stored on the site of new power plants, while the majority of legacy waste will continue to be stored at Sellafield in Cumbria. The revised Nuclear National Policy Statement states that the government is currently developing a timeline for the implementation of geological disposal for publication later this year and will provide annual reports to Parliament on progress towards this.

The impact of new nuclear build on the size of GDF required for legacy wastes is shown in the table below.

Table B6.5: Nuclear waste per GW of new plant: impact on size of GDF required

	Increase in the area required for spent fuel	Increase in the area required for ILW and LLW
Additional underground area required for the geological disposal of nuclear waste from 1 GW new build over that already required for legacy wastes.	6%	<1 %

Source: CCC calculations based on DECC (2009) *The arrangements for the management and disposal of waste from new nuclear power stations: a summary of evidence*.

¹⁶ IEA (2010) *Energy Technology Perspectives*, <http://www.iea.org/techno/etp/index.asp>

Timeline for deployment of nuclear generation

Project lead times for nuclear new build are long, requiring around two years for development (supply chain development, contract letting, etc.) and five years for construction. Given current projects under development, the first new nuclear plant in the UK could come on the system in 2018, with deployment of more than one plant a year potentially possible from the early 2020s:

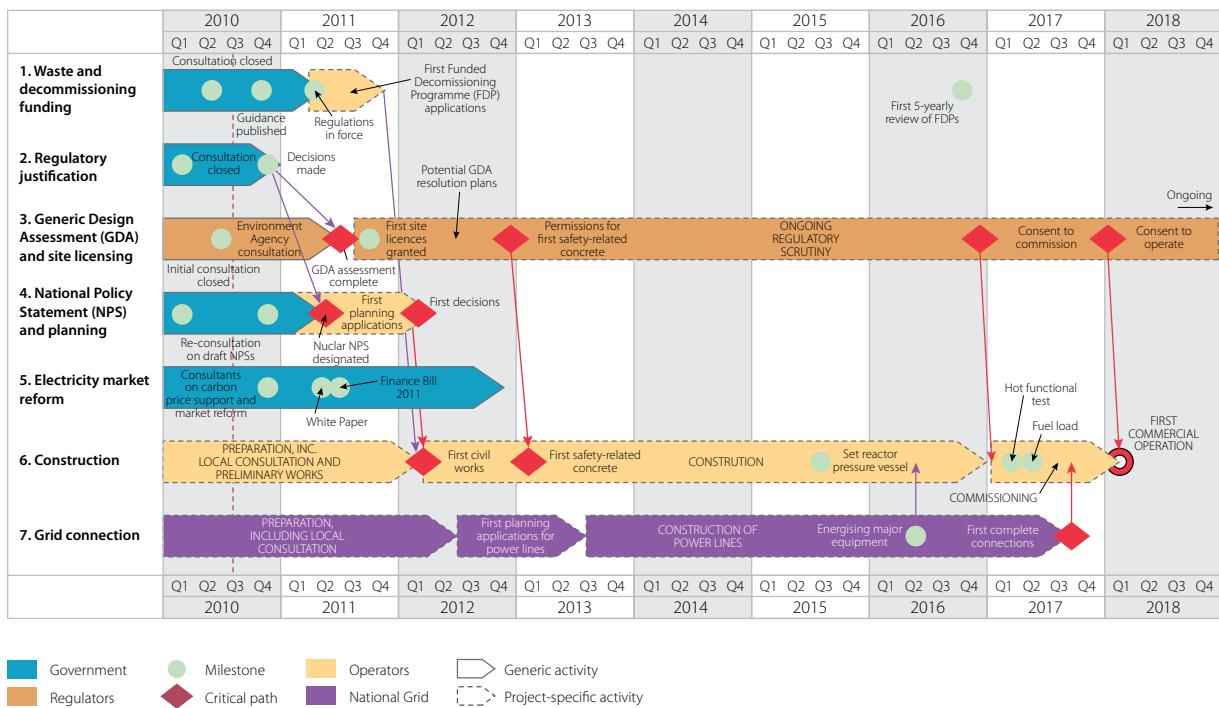
- There are several nuclear projects in the pipeline, with the decision to proceed with the first investments due in 2011. Given project lead times of around seven years, this would result in the first new plant becoming operational in 2018.
- Various planning and regulatory approvals will be required if investment is to proceed according to this schedule. DECC's proposed timeline for achieving these in order for the first reactor to commence operation in 2018 is shown opposite (Figure 6.12).
- Given progress on the first investment, deployment of more than one plant a year would be feasible from the early 2020s, based on investment decisions made from 2013; we discuss the pace of investment that may be both desirable and feasible in Section 4 below.

Contribution to security of supply

As a supplier of reliable baseload power, nuclear can make a crucial contribution to a technically secure and diverse low-carbon power system. Though the uranium required to fuel new nuclear plants will need to be imported, globally uranium is relatively plentiful. Identified global reserves are expected to last 100 years based on current requirements and it is available from countries where geopolitical risk of supply interruption is limited: currently 18 countries produce uranium¹⁷.

¹⁷ DECC (2010) *The Justification of Practices Involving Ionising Radiation Regulations 2004*, http://www.decc.gov.uk/assets/decc/consultations/proposedregulatoryjustificationdecisionsnewnuclearpowerstations/1_20091106131525_e_@_justificationpracticescondoc.pdf

Figure 6.12: DECC's indicative timeline for first new nuclear power stations



(iv) Coal CCS

Cost-effectiveness of coal CCS

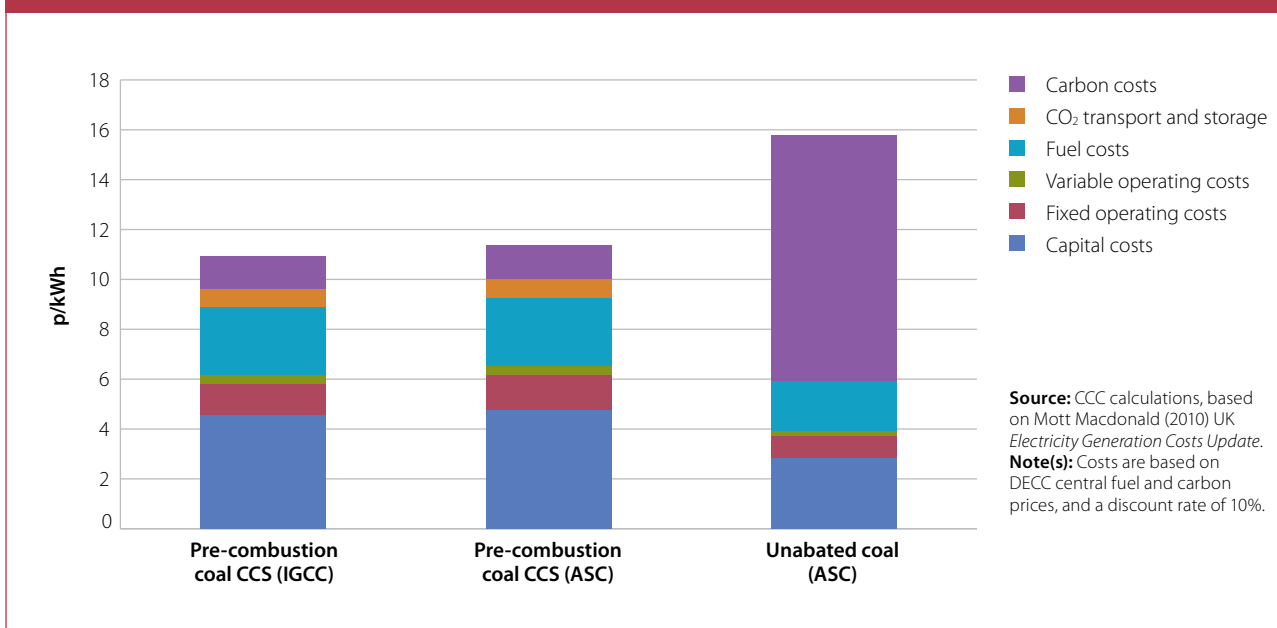
Coal CCS technology is currently entering the demonstration stage. Whilst the various component parts of the technology have been demonstrated, these have not been demonstrated together at scale. Coal CCS could play an important role in maintaining the diversity of the low-carbon mix in the UK, and is likely to be of key importance internationally, given the abundance of cheap coal and the coal-intensive power sectors in some developing economies.

The most recent evidence on coal CCS costs suggests that this has the potential to be a cost-effective low-carbon technology, particularly when operating as baseload plant:

- DECC's most recent analysis assumes a cost for coal CCS of 11 p/kWh¹⁸ for a plant commencing operation in 2030, operating at baseload (Figure 6.13).
- Coal CCS is a capital-intensive technology and is therefore most suited to running at high load factors.

¹⁸ These cost apply for CCS applied to both advanced super critical (ASC) coal plants and integrated gasification combined cycle (IGCC) coal plant.

Figure 6.13: Estimated levelised cost for coal CCS (2030)



- Although current cost estimates suggest that coal CCS may be more costly than nuclear, it has the potential to increase the total amount of low-carbon capacity on the system given build constraints for other technologies, to add diversity, and to reduce costs in a world with low coal prices and high nuclear costs.

The key challenge now is to demonstrate coal CCS and resolve uncertainties over costs and technical performance; following demonstration there will be a better evidence base against which to judge the extent to which CCS should be rolled out as part of wider sector decarbonisation.

Beyond demonstration, there is a longer-term question over residual emissions from coal CCS:

- While CCS can radically reduce the emissions from coal generation, the expected CO₂ capture rate of around 90% means that there would be residual emissions in the region of 100 gCO₂/kWh. This emissions intensity may be inconsistent with required sector decarbonisation by 2050.
- However, given technological improvements and expected increases in carbon prices over the period to 2050, it is reasonable to assume that capture rates may improve significantly beyond 90% in the long term, on a cost-effective basis.
- Co-firing of biomass with coal in CCS plants may also be useful in reducing these residual emissions in order to ensure that CCS power generation can also make an important contribution to meeting the 2050 target.

Coal CCS may therefore be regarded as a near-zero carbon technology when co-firing with sustainable biomass, which reinforces the argument for early demonstration of this promising technology.

Timeline for roll-out of coal CCS

The Government is committed to proceed with up to four CCS demonstration projects, which could feasibly come onto the system by 2016; a demonstration programme of this scale and timeframe is crucial in order to increase options and manage costs/risks of required power sector decarbonisation through the 2020s.

The current proposal is that there will be a rolling review based on evidence from demonstration projects here and in other countries, starting in 2016 and reporting by 2018. If this review were to find that CCS is viable, and to introduce appropriate supporting arrangements, it is likely that further investment (retrofit of part-fitted plant in the demonstration projects, and new plant) could become operational from the early 2020s, whether as part of a second demonstration phase or a deployment phase.

Beyond that, analysis commissioned by us from Pöyry Energy Consulting in 2009 suggests that up to 18 GW investment in CCS through the 2020s may be possible¹⁹. This would depend on its viability being proven in demonstration projects in the 2010s, support arrangements, and CCS infrastructure being in place. Coal CCS therefore has a potentially important role in contributing to required sector decarbonisation through the 2020s (see Section 4 below).

Contribution to security of supply

Coal CCS would add to the diversity of a low-carbon generation mix. Given the UK's domestic resource and abundant coal supplies from countries where geopolitical risk is limited, it would therefore enhance security of supply. Coal can also be stored easily, enabling considerable amounts of strategic storage to be in place.

(v) Gas CCS

Cost-effectiveness of gas CCS

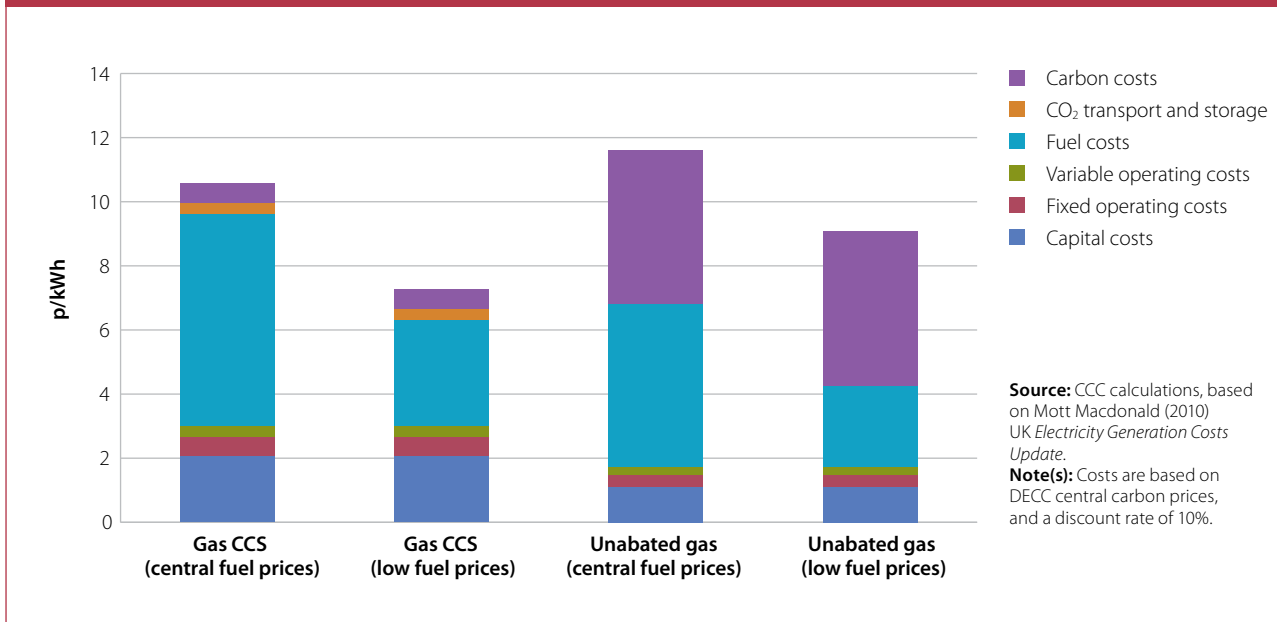
As with coal CCS, gas CCS is also currently at the demonstration stage, with considerable uncertainty over potential costs, which is compounded by uncertainty over future gas prices.

However, our analysis suggests that gas CCS is potentially competitive with coal CCS in a central fossil fuel price world, with a significant cost advantage when operating at low load factors and/or in a low gas price world (Figure 6.14). It also has the advantage of substantially lower residual CO₂ emissions than coal (e.g. 50 gCO₂/kWh rather than 100 gCO₂/kWh):

- **Central gas price world.** DECC's central case projection assumes a gas price of 76 p/therm in 2030, compared to today's price of 40-50 p/therm. DECC's most recent analysis suggests a gas CCS cost of around 11 p/kWh at this central gas price (including carbon costs) and operating at baseload, i.e. similar to the costs of coal CCS (Box 6.6) and below the cost of unabated gas (Figure 6.14).

¹⁹ Poyry Energy Consulting (2009) *Carbon Capture and Storage: Milestones to deliver large-scale deployment by 2030 in the UK*, http://downloads.theccc.org.uk/Poyry_-_CCS_Timelines_and_Milestones_for_CCC_2009_final.pdf

Figure 6.14: Estimated levelised cost for gas CCS (2030)



- **Flexible generation.** Continuing with DECC’s central case gas price assumption, gas CCS is particularly attractive when operating flexibly given its relatively low capital-intensity. For example, at a load factor of 40%, we estimate a gas CCS cost of around 14 p/kWh, compared to 18 p/kWh for coal CCS and 14 p/kWh for nuclear (Figure 6.8). Flexible operation of some plant will be required, given increasing levels of intermittency, and increasing seasonal demand from electric heating (see Chapter 5).
- **Low gas price world.** There is the possibility that potentially abundant supplies of unconventional gas will result in considerably lower gas prices (e.g. 35 p/therm in 2030 as projected in DECC’s low gas price scenario – Box 6.7). At this gas price, the cost advantage of gas CCS against coal CCS (at central coal prices), operating as baseload plant is around 4 p/kWh, increasing further to 8 p/kWh when operating flexibly at a 40% load factor.
- **CCS retrofit.** This could be an attractive option for existing CCGT plant, particularly when the alternative is to operate unabated at low load factors. Analysis that we commissioned from Element Energy suggests that around 20 GW of plant currently on the system would be suitable for retrofit in the 2020s, together with any plant added over the next decade (Box 6.8).
- **Co-firing.** Residual emissions from gas CCS could be offset through co-firing with biomethane. Scope for co-firing with larger proportions of biomethane offers the possibility that this could be a significantly negative-emissions technology.

Gas CCS is therefore potentially competitive, and could be applied both to new plant, and to 30-35 GW of plant likely to be on the system by 2020 (either currently existing plant, or plant due to be added to the system over the next decade).

Given its potential competitiveness and applicability in the UK (and globally, in the scenario where unconventional gas is cheap and abundant), we recommended to the Government

in June 2010 that gas CCS should be demonstrated under the four proposed CCS projects. In November 2010, the Government accepted the recommendation to include gas-fired plant within the competitive process to select the second, third and fourth CCS demonstrations.

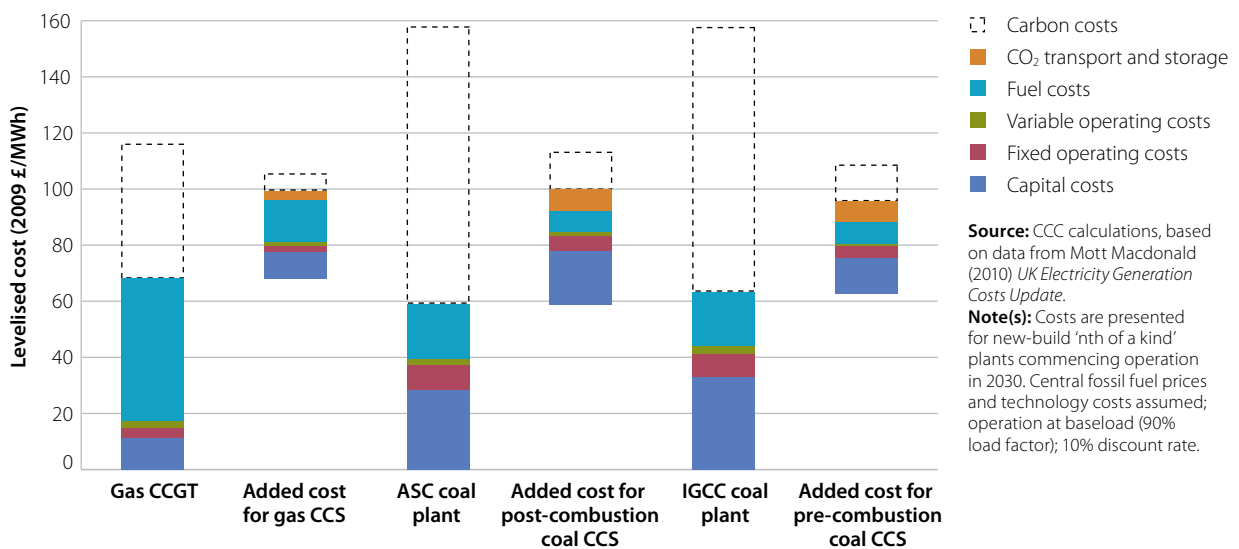
Box 6.6: Economic characteristics of gas CSS vs. coal CCS

Recent estimates from Mott Macdonald of the costs of baseload generation from coal CCS and gas CCS plants suggests that these costs are very similar at around 11 p/kWh in 2030, under assumed carbon prices and DECC's central fossil fuel price assumptions.

As we highlighted in our report to Parliament in June 2010, while the cost per tonne of CO₂ abated via application of CCS to coal plants appears to be lower than that for gas, the incremental cost per kWh of adding CCS is lower for gas than for coal. This discrepancy is due to the lower carbon-intensity of gas generation.

Given the need to decarbonise electricity supply, the appropriate comparators for fossil fuel CCS plants are not their unabated equivalents but rather other forms of low-carbon electricity generation. For this reason, the appropriate metric is the cost per kWh of low-carbon electricity generated, rather than the cost per tonne of CO₂ relative to an unabated fossil fuel plant.

Figure B6.6: Incremental costs of adding CCS to gas- and coal-fired plants (2030)



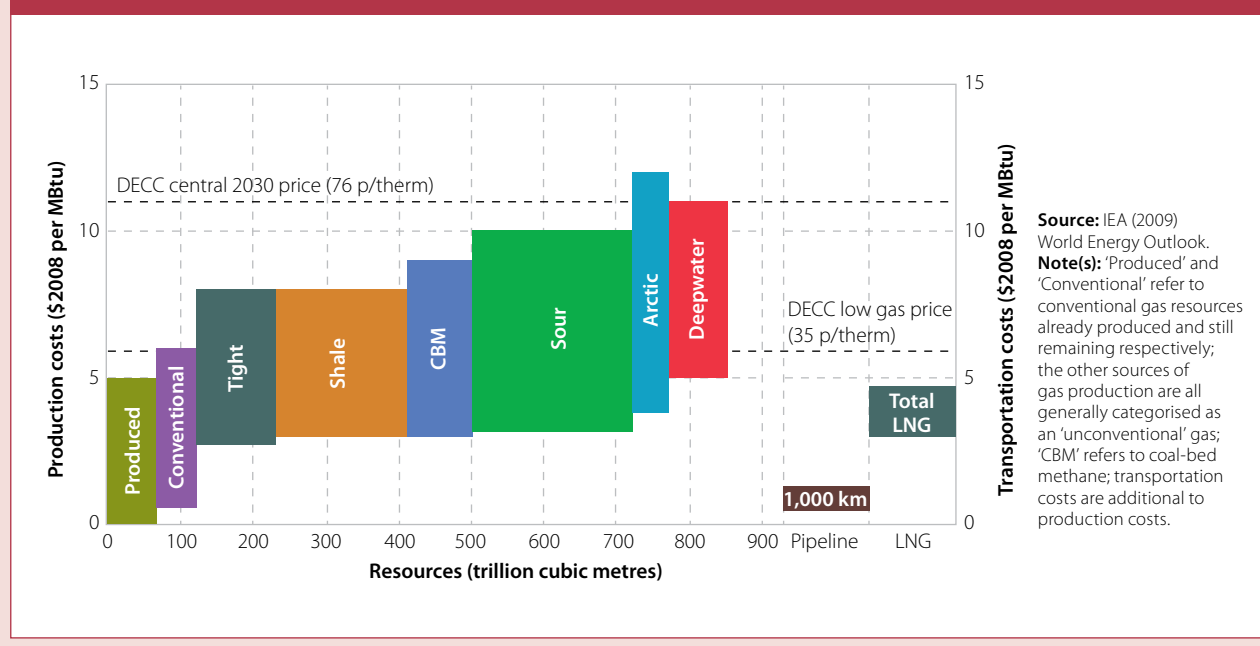
Box 6.7: Unconventional gas

The emergence of unconventional gas supplies, particularly in the North American market, has led to the prospect of a possible new 'dash for gas' in some regions of the world. While shale gas – one form of unconventional gas – has been exploited in North America for several decades, it is the recent advances in information technology and horizontal drilling techniques that have reduced costs to a point where they could have a major influence on energy systems in a number of regions.

Drilling for unconventional gas requires considerable amounts of water – and accompanying wastewater disposal – as well as access to land for drilling operations. Therefore it is possible that in many areas unconventional gas will not be exploited, due to space constraint or environmental regulations. Nevertheless, it is likely that gas markets even in these areas would be affected by the large-scale exploitation of unconventional gas resources in other regions, due to the interconnectedness of regional gas markets via shipping of LNG and long-distance pipeline transportation.

The International Energy Agency has estimated the scale of unconventional gas resources and the range of costs of production. These suggest that the gas price of 76 p/therm in 2030 under the central fossil price scenario is towards the high end of the range of supply costs, while DECC's lowest price of 35 p/therm and the current price of 40-50 p/therm are closer to the middle of this range.

Figure B6.7: Sizes and costs of conventional and unconventional resources of natural gas



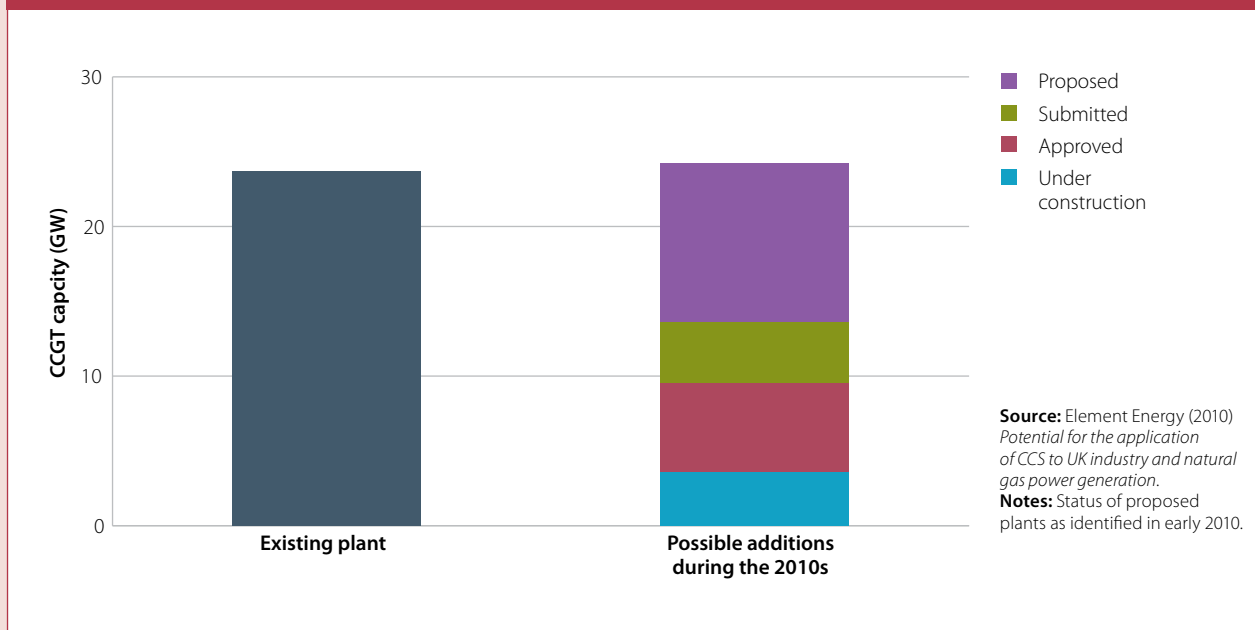
Box 6.8: Possible capacity of unabated gas (CCGT) on the power system in 2020

There is already a considerable amount of gas-fired CCGT capacity on the power system, much of which was built during the 'dash for gas' in the 1990s. As this plant is fairly new, it is unlikely that a significant number of plants will be retired before 2020. We commissioned Element Energy to look at the potential for application of CCS to gas-fired power generation in the UK. As part of this work, they indicated that 20 GW of the existing 24 GW of CCGT capacity currently on the system is potentially suitable for CCS retrofit.

In addition to this existing capacity, there is around 24 GW of new unabated gas capacity either under construction, consented but not yet under construction or going through the planning system. All of this potential new capacity is required to be 'CCS ready'. However, it is unlikely that all of these proposed plants will be built – this will depend on the extent to which renewable generation can fill the gap left by (largely coal) plant retirements, as well as the evolution of demand. In turn, demand depends on the long-term impact of the recession, improvements in energy efficiency (e.g. in appliances) and the extent of behaviour change.

However, even in the event of achieving the renewables target and demand being on the low side by 2020, it is likely that we will need some new gas-fired capacity in the period to 2020, given the large amount of capacity retiring during the 2010s. Our modelling assumption is that there will be around 35-40 GW of unabated gas CCGT capacity on the system in 2020.

Figure B6.8: Existing and possible new gas CCGT capacity



Timeline for roll-out of gas CCS

If the 2018 review were to find that CCS is viable, and were to introduce appropriate supporting arrangements, roll-out for the early 2020s would be feasible on new and existing plant:

- Given a 5- to 6-year lead time for gas CCS projects, a second phase of investment beyond the first demonstration could start from the early 2020s.
- Similarly, CCS could be added to existing capacity from the early 2020s. The limiting factor in rolling out retrofit is likely to be build constraints rather than the level of gas capacity on the system suitable for retrofit in the 2020s.

The potential to roll out gas CCS at scale on this schedule provides scope for this technology to contribute to required sector decarbonisation through the 2020s (see Section 4 below).

Contribution to security of supply

As with coal CCS, gas CCS would add to the diversity of a low-carbon generation mix. Its full security of supply impact would depend on development of the global gas markets and the extent to which this is characterised by geopolitical risk and price volatility, with these being less problematic in a shale gas world.

(vi) Overview of low-carbon generation technologies

Our analysis of low-carbon technologies leads us to three broad conclusions:

- **Cost-effectiveness:** There is a range of low-carbon technologies – nuclear, CCS, and some renewables – that are likely to be cost-effective by the 2020s, operating both as baseload and mid-merit plant (Figure 6.15). There may still be a cost penalty for some technologies (e.g. offshore wind). But given the uncertainty about future costs and the availability of new technologies such as CCS, there is a strong argument for continuing to develop these technologies, especially where the UK’s resource potential is large. Which technologies become cost-effective in practice will become clearer as technologies are demonstrated and deployed, and more information about costs and performance is revealed.
- **Scope for investment:** Significant investments in onshore and offshore wind are expected over the next decade with scope for increased investment during the 2020s depending on relative cost and build constraints for other technologies. Nuclear could be added to the system from 2018, with scope for large-scale investment from the early 2020s. Given demonstration of CCS in the mid 2010s, this technology could be rolled out on existing and new fossil fuel plant starting in the first half of the 2020s, with scope for investment in

Figure 6.15: Estimated levelised cost of generation technologies at baseload and mid merit

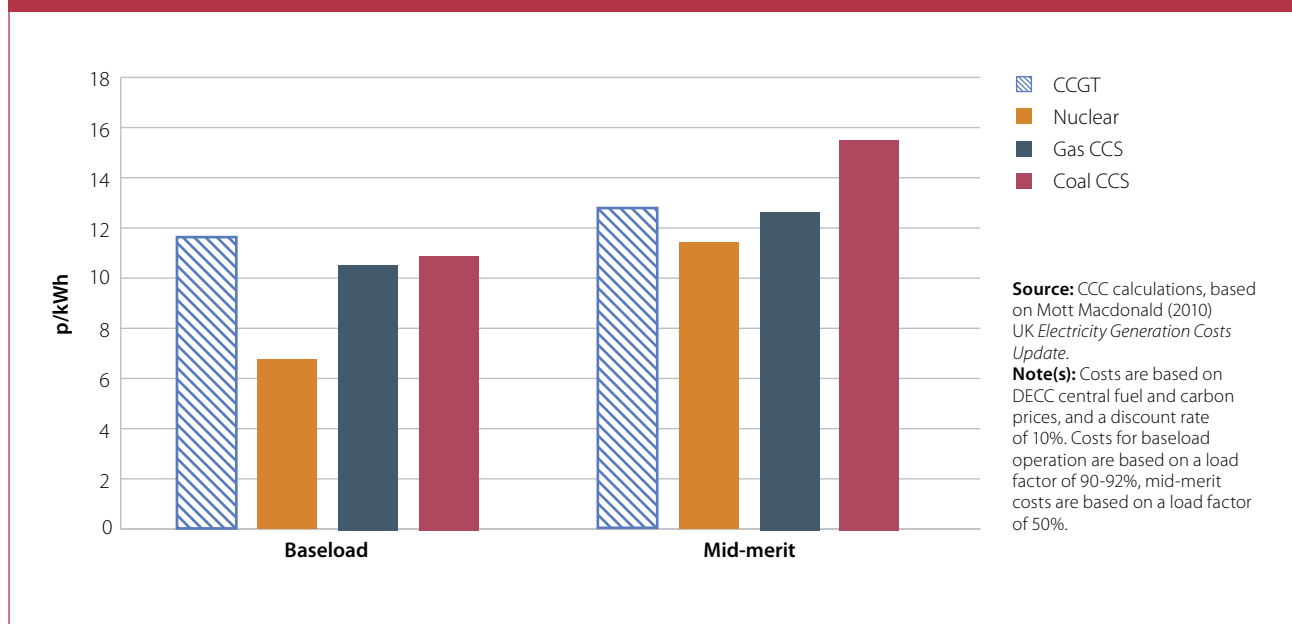
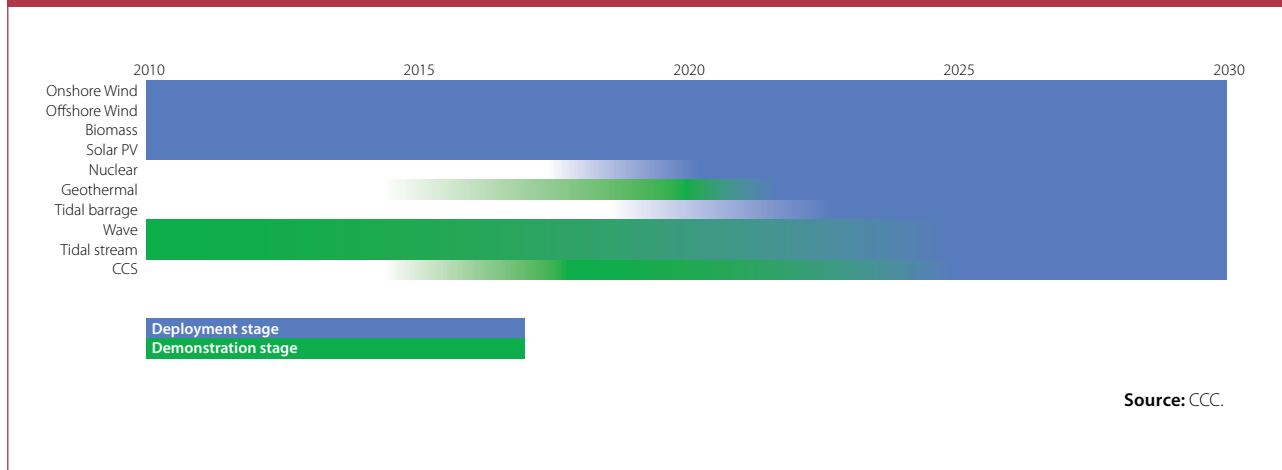


Figure 6.16: Illustrative timeline for roll out of technologies (2010-2030)



marine and geothermal generation also from this time. Therefore whilst scope for adding low-carbon technologies in the period to 2020 is limited, the full range of technologies could potentially contribute to required decarbonisation through the 2020s (Figure 6.16).

- **Security of supply:** Where low-carbon technologies are intermittent, this can be managed such that reliability is not undermined (see Section 3). Low-carbon technologies can increase diversity of the generation mix, and reduce reliance on imported gas (which is subject to price volatility, and may come from countries where there is geopolitical risk of supply interruption), thereby improving security of supply.

3. Options for increasing flexibility of the power system

The need for flexibility

Electricity is difficult to store, and so supply and demand for electricity must largely be balanced at each point in time; currently the needs of a largely inflexible demand side are met by a relatively flexible fleet of thermal fossil fuel plant.

The power system in the 2020s will be characterised by increasing levels of intermittent generation and more variable demand, implying a greater need for flexibility. At the same time increasing amounts of low-carbon plant will reduce flexibility (Box 6.9):

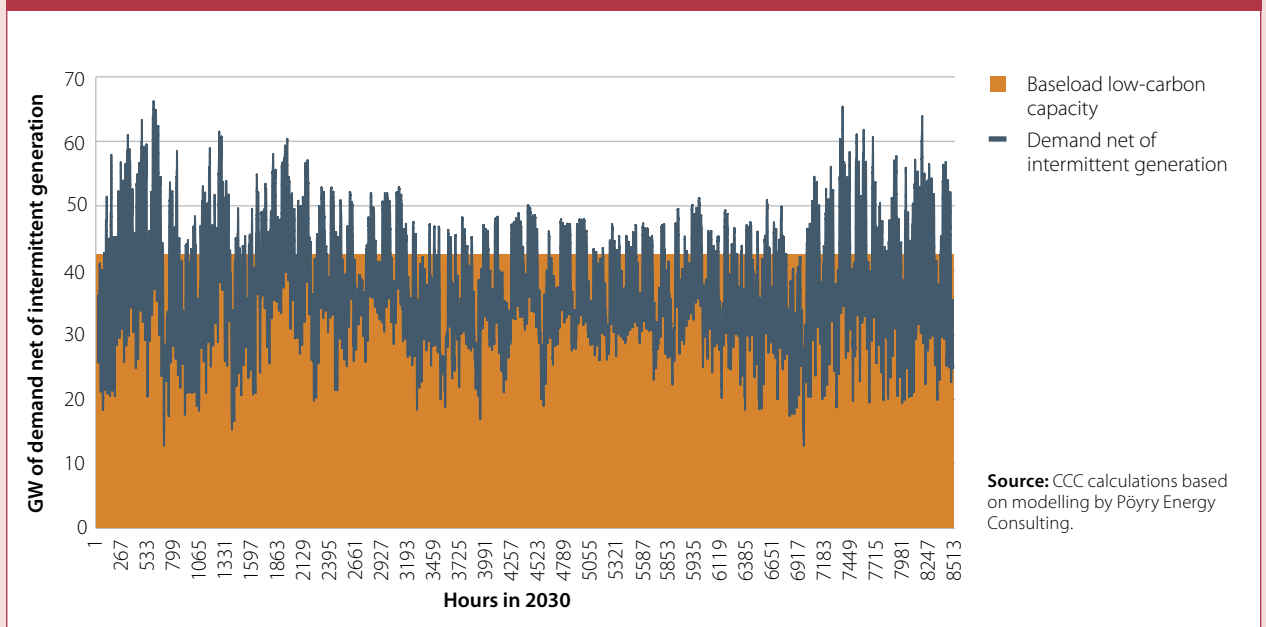
- The need for flexibility will increase as more intermittent wind generation is on the system – wind is variable, volatile and difficult to forecast.
- Decarbonisation will also increase the level and the variability of demand, through the electrification of heat and transport. In particular, demand for electricity from the heat sector could add significantly to the need for flexibility by increasing the variability, seasonality and peakiness of electricity demand.

- Low-carbon plant such as nuclear and coal CCS are less economically and technically flexible than conventional plant, being both more capital-intensive (and therefore more sensitive to the load factors at which they are run) and less able to ramp their output up and down (e.g. they have higher minimum stable generation levels and longer on and off times).

Box 6.9: Demand net of intermittent renewables

Figure B6.9 shows demand net of intermittent generation (based on observed patterns in 2001, and scaled up to 2030 levels) against the estimated low-carbon capacity needed to substantially decarbonise the power system in 2030. This shows that given variations in wind and demand, the required supply from all other generation fluctuates hour by hour across the year. In the absence of additional measures to add flexibility to the demand or supply sides, much of the low marginal cost generation from the low-carbon capacity could not be exploited.

Figure B6.9: Illustrative baseload low-carbon capacity and demand net of wind without additional flexibility (2030)



Options for flexibility

We commissioned Pöry Energy Consulting to identify and characterise options to increase flexibility on the system to 2030. Pöry compared the cost, emissions and security of supply impacts of a range of options falling into three main categories (Box 6.10):

- Operating low-carbon generation more flexibly.
- Importing flexibility from interconnection and bulk storage.
- Active management of demand from heating and transport.

Pöry found that there are many possible sources of low-carbon flexibility, which vary in terms of speed, duration, cost, reliability and magnitude of response:

- **Demand-side response:**

- Facilitating demand-side response through the roll-out of smart technologies and tariffs could provide a key source of within-day flexibility, e.g. to respond to swings in wind generation occurring over the course of several hours and to help smooth the daily pattern of demand. The main demand segments that will shift will be transport and heat; without the electrification of these sectors the potential to shift demand will be small.
- Demand-side response can also provide some between-day flexibility, e.g. from electric vehicles with lower use patterns. The ability of plug-in hybrid electric vehicles (PHEVs) to switch to using petrol or diesel can also help in extended periods of low wind.

- **Increased interconnection:** Increased interconnection with north-west Europe is not a substitute for domestic low-carbon capacity but can increase flexibility by allowing trading of electricity to exploit differences in the extent to which wind is blowing or in demand between the UK system and surrounding countries. Interconnection will have the potential to provide flexibility over several days, e.g. to help with prolonged periods of high or low wind.
- **Increased storage:** Bulk storage, such as pumped storage, can be used both to provide fast response and to help provide flexibility over several days (providing supply at times of peak daily demand rather than continuously over the whole period).
- **Low-carbon generation:** Over longer timescales (e.g. to meet seasonal fluctuations in demand) generation capacity is the main option which can provide flexibility, suggesting that investment in some lower capital cost low-carbon plants such as gas CCS may be desirable if they are more cost-effective than other low-carbon technologies at lower load factors.
- **Peaking plant:** A need for some fossil-fuelled peaking plant (e.g. unabated open-cycle gas turbines) is likely to remain, though the need is greatly reduced by increased demand-side response and interconnection. The extremely low load factors of these plants mean their emission impacts are likely to be small.

Virtually all of the packages assessed reduced CO₂ emissions and generation costs, whilst maintaining the level of system security. Investment in all of the above measures will be key to managing a decarbonised system.

Policy implications

Government will have an important role supporting investment in flexibility:

- **Infrastructure:** It will be important for Government to continue with its planned roll-out of smart grids and smart meters (Box 6.11). Options for investment in interconnection and storage should also be assessed.

- **Market arrangements:** It is crucial that the market arrangements maintain signals for investment to invest in supply- and demand-side technologies best able to respond to fluctuations in net demand; in the context of broader market reforms there may therefore be benefits to preserving price signals in the current wholesale market both to encourage investment in flexible plant and demand-side response, and a need for a capacity mechanism to secure peaking capacity and storage (see Section 5).

Box 6.10: Options for low-carbon flexibility

We commissioned Pöyry Energy Consulting to carry out a detailed quantitative assessment of options to add flexibility to the system.

The project assessed a range of flexibility options against four reference cases representing decarbonised power systems in 2030 and 2050. The results presented here all apply to a 2030 decarbonised power sector, with substantial electrification of heat and transport. More detail on the project, and the set of results across all four counterfactuals can be found in the full report on our website²⁰.

Flexibility packages:

The packages of flexibility assessed are set out in Table B6.10a. In all scenarios, security of supply was held constant, and any residual need for flexibility was met by unabated plant.

Table B6.10a: Flexibility packages

Generation	Generation	Demand	Interconnection and storage
Flexible generation	'Real-time' flexibility is provided by nuclear and CCS	Ex-ante time of use tariffs smooth demand	No change over reference case (3 GW of interconnection to north-west Europe and 1 GW to Ireland, 2 GW of storage).
Imported flexibility	As in reference with some additional CHP flexibility	Ex-ante time of use tariffs smooth demand	Total interconnection reaches 2 GW with Ireland, 6 GW with north-west Europe, and 2.5 GW with Norway.
Active demand side	No change over reference (minimum 48 hours on/off time for nuclear and 24 hours for coal CCS and minimum stable generation of 50% for nuclear and 70-90% for CCS)	Smart technologies facilitate a real-time response from demand	No change over reference case (3 GW of interconnection to North West Europe and 1 GW to Ireland, 2 GW of storage).

Source: Pöyry Energy Consulting (2010), *Options for low-carbon power sector flexibility to 2050*.

²⁰ Pöyry Energy Consulting (2010), *Options for low-carbon power sector flexibility to 2050*.

Box 6.10: Options for low-carbon flexibility

Modelling

The quantitative assessment was based on the outputs of Pöyry's wholesale electricity model Zephyr, which captures the interaction between variable supply and variable demand. In this project, Zephyr was used to simulate the dispatch of each unit on the GB system for each hour of the day, optimising least-cost dispatch of plant, taking account of costs and technical constraints on plant operation.

- **Wind and demand patterns:** Nine iterations representing wind, availability and demand profiles for the years 2000-2008 were run for each year modelled.
- **Costs:** Fuel and carbon prices were based on DECC's central projection, while technology costs were based on estimates from an early draft of Mott Macdonald's analysis for DECC (which are close to the finalised estimates).

Results

Generally, the flexibility packages reduced costs and CO₂ emissions, with the following caveats:

- Carbon-intensity was generally much lower than in the reference cases for all combinations of counterfactuals and flexibility packages. The one exception was in the active demand scenario for a 2030 system with electrification. In this scenario, demand side response is so effective at reducing peak demand net of wind that it reduces the space for low-carbon new entry. This is a transitional issue, by 2050 this package lowers emissions.
- Generation costs fall due to the flexibility measures. However, the impact on overall system costs is less clear:
 - There will be additional costs from smart technologies, but these should not all be attributed to flexibility, given the wider benefits which they can deliver.
 - There is a large degree of uncertainty over some of these costs, such as distribution costs.

The results are summarised below in Table B6.10b.

Table B6.10b: Key results for 2030

	Carbon-intensity (gCO₂/kWh)	Security of supply (expected lost load as a % of total generation)	Generation cost (£bn)
Reference case	89	0.0004%	45
Flexible generation	71	0.0005%	43
Imported flexibility	64	0.0003%	43
Active demand side	97	0%	42

Source: Modelling by Pöyry Energy Consulting for the CCC

Box 6.11: Smart grids

What is a smart grid?

A smart grid is an electricity network which makes use of information and communications technologies, enabling more dynamic 'real-time' flows of information on the network and more interaction between suppliers and consumers. An important element of a smart grid is a 'smart meter' which will allow display of energy usage data in real time and remote or automated control of energy usage by suppliers and consumers.

Currently, the transmission network is to a large degree 'smart' but the distribution networks are still largely 'not smart', uni-directionally moving electricity from the transmission system to consumers and delivering flexible supply in response to variable but unresponsive demand.

Why is a smart grid desirable?

A smart grid could play a major role in facilitating the decarbonisation of the electricity system by:

- Reducing the requirement for greater peak generation capacity by enabling consumers to shift non time-critical demand to non-peak times.
- Reducing the requirement for extensive transmission and distribution grid reinforcement by enabling better usage of existing networks.
- Improving outage management and investment optimisation by improving the information available to network companies.
- Allowing large amounts of small-scale, intermittent renewables to be connected at the distribution grid level, possibly by amalgamating them into single "Virtual Power Plants."

What is Government doing?

In 2009 Government published *Smarter Grids: the Opportunity* which outlined some of the developments which may be required in order to provide a more flexible system. It also launched a Smart Grid Demonstration Fund which is offering £6 million for demonstration of smart grid technologies. Another key fund in this area is Ofgem's Low Carbon Network Fund which offers £500 million for large-scale trials of smart grid technologies between 2010 and 2015.

The Government is now consulting on a Smart Metering Implementation Programme which seeks to roll out a smart meter to every home in Great Britain by 2020 or earlier and to ensure business and the public sector have 'smart or advanced energy meters suited to their needs'²¹.

Key components of the proposals include:

- Suppliers will be required to provide an 'In-Home Display' which will show usage information for gas and electricity in pounds and pence and in kilowatt-hours. Electricity usage will be updated every five seconds.
- Meters will allow supply to be controlled remotely.
- Communication to and from smart meters in the domestic sector will be managed by a new "Central Data Communications Entity" to be operating by autumn 2013.

²¹ DECC (July 2010) *Smart Metering Implementation Programme: Prospectus*.

4. Scenarios for power sector decarbonisation

We now develop a set of scenarios for power sector decarbonisation; we use these to underpin our economy-wide analysis in Chapter 3, where we consider which of the scenarios will deliver carbon budgets, and where we conclude that very aggressive power sector decarbonisation is likely to be required through the 2020s. Given this assessment, we then consider implications for reform of the current electricity market arrangements (Section 5) and other implications for the first three budget periods (Section 6).

Constructing scenarios for sector decarbonisation

We develop our scenarios in four steps:

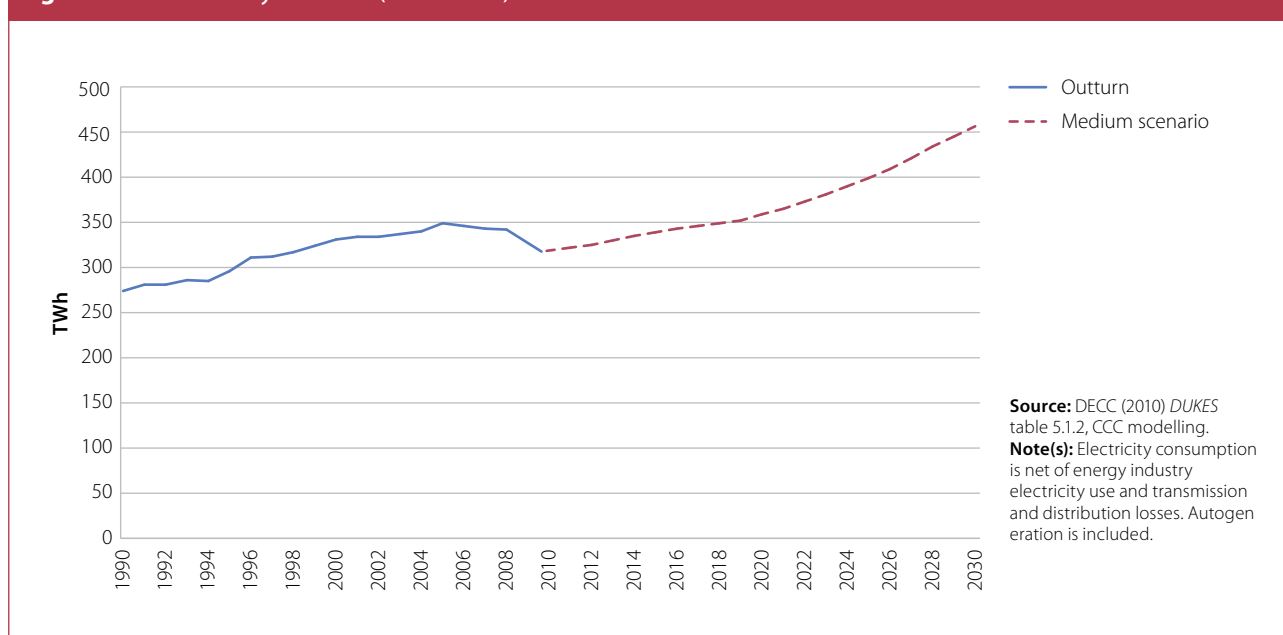
- We first project future demand from existing sectors.
- We then project demand from new sectors, namely electric vehicles and heat.
- Next we project a reference emissions scenario against which abatement scenarios can be benchmarked.
- Finally we set out three abatement scenarios under which there are varying levels of investment in low-carbon generation.

Demand projection for existing sectors

The starting point for our scenarios is to project demand from existing sectors:

- We use the DECC energy model to project demand increases based on increasing population, household numbers, personal income and business activity.

Figure 6.17: Electricity demand (1990-2030)



-
- We do not model a range of scenarios for demand from existing sectors, but recognise that departure from our projections would imply adjustment at the margin to investments in our abatement scenarios below.

Electrification of heat and transport

We then add in projections for extra demand due to electrification of transport and heat, based on our analysis in Chapters 4 and 5:

- Demand from electric vehicles is up to 43 TWh in 2030 compared to demand from other sectors of around 360 TWh (i.e. electric vehicles could add 12% to demand in 2030).
- Demand from electric heat pumps is up to 51 TWh in 2030 (i.e. electric heat could add 14% to demand from existing sectors in 2030).

Reference emissions scenario

Our reference emissions projection is constructed based on the following assumptions about demand and investment in new power capacity:

- We assume that investment to replace capacity that is retired and to meet demand growth flows to unabated gas-fired generation.
- In this scenario, total emissions are broadly flat through the 2020s, resulting in average emissions intensity of around 250 gCO₂/kWh in 2030.

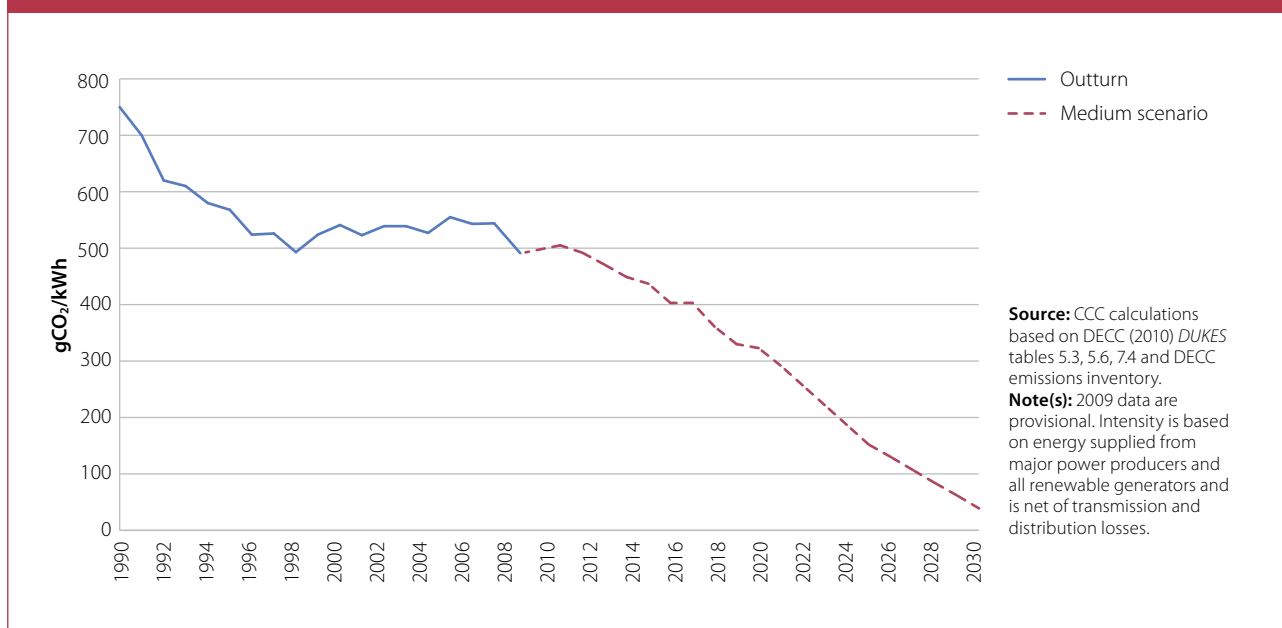
Abatement scenarios

Our abatement scenarios (Table 6.1) are based on different demand scenarios above, including energy savings from improved energy efficiency in lighting and appliance design based on our previous analysis of opportunities in this area (see Chapter 5). Low-carbon investment is added to the system where this is cost-effective given the projected carbon price and subject to build constraints. The scenarios are constructed using Pöyry power sector models (Box 6.12).

- **Low investment scenario.**
 - This scenario represents investment in a world where there is very limited demand growth from electric vehicles and heating, and there are tight constraints on the build rates of low-carbon plant.
 - In this scenario, 21 GW of low-carbon generation is added to the system through the 2020s²².
 - This results in emissions of 52 MtCO₂ in 2030, by which time average emissions have fallen to around 130 gCO₂/kWh.

²² Intermittent technologies are adjusted in this figure by the difference between their average availability and the availability of non-intermittent plants in order to put all plants an equivalent GW basis. GW are presented in this way throughout this chapter, unless otherwise indicated.

Figure 6.18: Emissions intensity of electricity (1990-2030)



- **Medium investment scenario.**

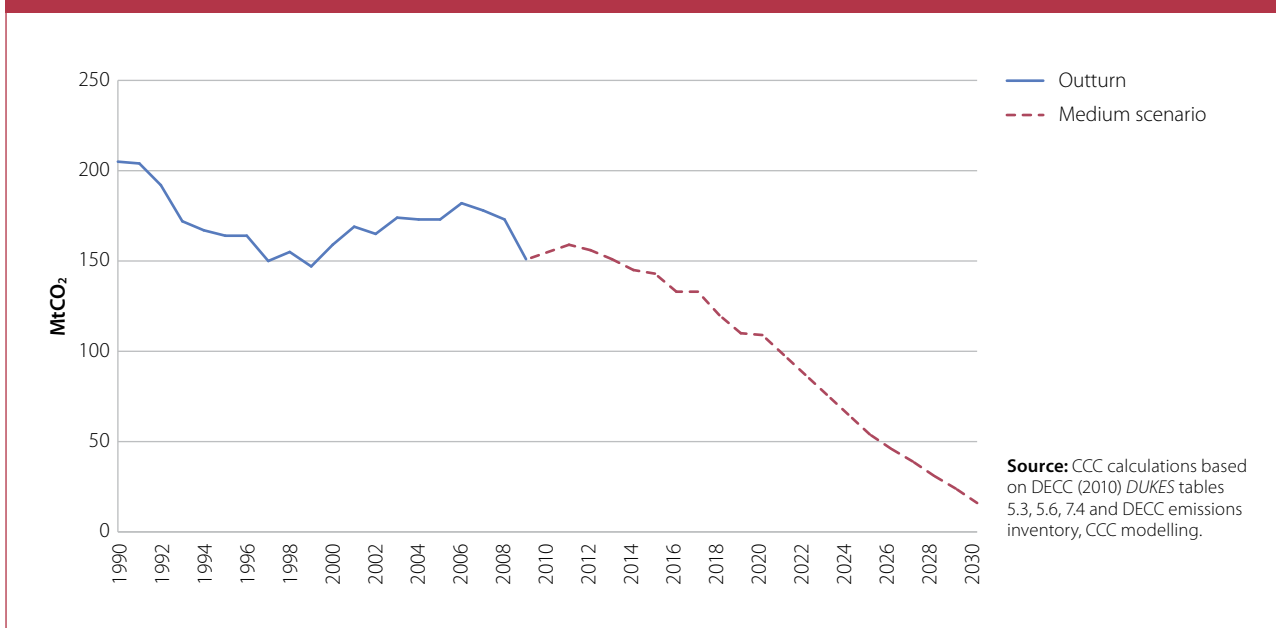
- This scenario reflects cost-effective investment in a scenario where there is demand growth from vehicles and heat as in our medium scenarios for these options (60% of new cars and vans are pure electric or plug-in hybrid by 2030, and heat pumps account for around 40% of total heat in buildings, see Chapters 4 and 5).
- We relax build constraints in this scenario, such that plant is added to the system whenever this is cost-effective (i.e. if it can provide electricity at a lower cost than the alternative of building/running a gas-fired or coal-fired plant and paying the carbon price to cover the resulting emissions).
- Investment in this scenario includes the addition of 36 GW of low-carbon capacity to the system in the 2020s.
- This results in emissions that are 16 MtCO₂ in 2030, and average emissions of around 50 gCO₂/kWh²³.

- **High investment scenario.**

- This scenario represents cost-effective investment where there is high demand from electric vehicles and heat (pure electric cars and vans and plug-in hybrids reach penetration of 85% in 2030 and a further 10% of new cars run on hydrogen fuel cells, and electric heat accounts for 55% of total heat in buildings, see Chapters 4 and 5).
- Investment includes the addition of 37 GW low-carbon capacity to the system through the 2020s.
- Resulting emissions are 13 MtCO₂ in 2030 and average emissions are around 40 gCO₂/kWh.

²³ Emissions intensity in our Medium scenario is 38 g CO₂/kWh excluding autogeneration and 52 g CO₂/kWh including autogeneration.

Figure 6.19: CO₂ emissions from power stations (1990-2030)



Box 6.12: Modelling approach

The scenarios were based on a number of model runs of Pöyry's wholesale electricity model Zephyr, which captures the interaction between variable supply and variable demand. The following key assumptions were employed in the analysis:

- **Costs:** Technology costs are based on Mott Macdonald's recent analysis for DECC (central, 'nth of a kind' and using 10% discount rate). DECC's central projections for fuel and carbon costs were used.
- **Technologies:**
 - A capacity mix consistent with achievement of the Extended Ambition scenario was assumed for 2020 (i.e. two new nuclear plants, and 27 GW of wind, and 4GW of other renewables – on a nameplate basis).
 - Offshore wind then was built throughout the 2020s to keep renewables at 30% of total generation.
 - An additional 5 GW of CCS was built after 2025, on top of the demonstrations assumed to be built by 2020. It was assumed that CCS coal could be retrofitted in all scenarios, but CCS gas retrofit was only available in the high scenario.
 - Additional nuclear and CCS were then built up to levels cost-effective under a carbon price.
 - Total interconnection reaches 6 GW with north-west Europe, 2.5 GW with Norway and 1.9 GW with Ireland. Bulk storage capacity remains at current levels.
- **Demand:** Demand assumptions were based on a reference case modelled using the DECC energy model, and bottom-up analysis of the heat, transport and residential sectors (see Chapters 4 and 5). The responsiveness of demand was based on the flexibility analysis carried out by Poyry for the CCC (Box 6.10)
- Adjustments were made to the results of all scenarios to exclude autogeneration, and to include costs and emissions from Northern Ireland²⁴.

²⁴ Detailed modelling was not carried out on the Northern Irish power system. An assumption was made that the emissions intensity could fall to 100 gCO₂/kWh by 2030 (higher than in the UK average), and that generation and infrastructure costs consistent with the UK average would be incurred.

Table 6.1: Abatement scenarios

	Low abatement	Medium abatement	High abatement
Demand from heat in 2030 (TWh)	24	51	51
Demand from transport in 2030 (TWh)	15	30	43
Build of low-carbon plant 2021-2030 (GW)	21	36	37
Emissions in 2030 (MtCO ₂)	52	16	13
Emissions intensity in 2030 (gCO ₂ /kWh, including autogeneration)	134	52	40

Source: CCC calculations based on modelling by Pöyry Energy Consulting for the CCC

Technologies to deliver scenarios

Given uncertainties over technical and economic characteristics of the various low-carbon technology options, we do not attempt to set out a precise technology mix which would deliver our investment scenarios. This is something which will become clearer over time, and is best determined once market mechanisms reveal more about the relative costs of the available technologies (see Section 5 below).

However, given current and expected stages of technology development, it is possible to give a high-level characterisation, and to draw out implications for the extent to which current build constraints may need to be addressed (see below).

Our starting point is to reiterate that there is no role for investment in coal plant without full CCS to come on the system beyond 2020, and only a limited role for unabated gas plant (e.g. running at low load factors in balancing intermittent generation). If there were to be investment in either form of unabated fossil fuel capacity for baseload generation, required sector decarbonisation would not be achieved.

Turning to low-carbon technologies, CCS is unlikely to be demonstrated until 2015 at the earliest, and a decision on CCS roll-out is unlikely to be taken until 2018 under the current framework; given this timeline, it is unlikely that further (new or retrofit) CCS capacity beyond the current demonstration projects would come on the system much before the early to mid 2020s.

Therefore delivery of our power sector decarbonisation scenarios would require early investment in nuclear and wind generation, with diversification to CCS and possibly marine and geothermal generation depending on what demonstration projects or increased deployment reveal about these technologies.

In order that new nuclear generation comes on to the system in 2020, and given project lead times, a decision to proceed with investments would have to be made around 2013 (and 2014 for investments to come on the system in 2021, etc.). The likely result of failure to make early decisions would be investment in gas-fired generation (where project lead times are shorter), which would be risky from a low-carbon perspective given technical and economic uncertainties around gas CCS which will remain through 2013 and beyond.

Build constraints

The average annual low-carbon capacity addition in our Medium and High investment scenarios is 3-4 GW. Whilst this is more than has been added in the UK, there are other countries where this build rate has been sustained over a number of years, and the UK has previously added coal-fired capacity at a comparable rate:

- There has been limited investment in new power capacity in the UK in recent years following a period of heavy investment in gas-fired generation in the 1990s, when 19 GW were added to the system over a 9-year period, and in coal generation in the 1960s and 1970s when 28 GW were added over a 8-year period.
- Going forward, it is envisaged that around 10-15 GW of unabated gas-fired generation will be added to the system in the period to 2020, together with around 1.5 GW of CCS demonstration plants, and 3 GW of nuclear and 23 GW of wind (on a nameplate basis).
- In France during the 1980s there was addition of 48 GW of new nuclear capacity over a 10-year period.

We have not done any analysis of current industrial capacity to construct low-carbon generation in the UK. We note concerns raised (e.g. by the Institution of Mechanical Engineers) about the current industrial capacity of the UK to deliver required low-carbon investments over the next decades. It is clear that there is a limit to how much industrial capacity can be expanded in the short term, therefore constraining the ability to add significantly more low-carbon generation than is currently envisaged over the next decade.

However, beyond the near term, there is scope to increase industrial capacity in order to deliver priority investments. Given acceptance of the path required to meet carbon budgets, it will be important within energy and industrial policy to consider capacity to deliver required low-carbon investments at a pace already achieved in other countries, and the possible need to use available policy levers to support industrial capacity expansion. With appropriate policies, current industrial capacity constraints should not be prohibitive in terms of required investments through the 2020s.

Planning scenario

Given long project lead times it is important to plan early for emissions reductions in the 2020s. This raises a question over which of the scenarios above it is appropriate to plan for; this in turn requires balancing risks of under and over-investment in low-carbon capacity.

Our assessment is that the Medium scenario represents the appropriate balance of risks:

- The Medium scenario develops options likely to be important on the path to 2050, and delivers investment in mature low-carbon technologies up to cost-effective levels given our best estimate of future demand, cost and carbon prices.
- It is consistent with our preferred economy-wide scenarios for electric vehicles and heat (see Chapter 3) and is therefore appropriate as part of a coordinated approach across sectors.
- Planning for the Medium scenario would keep the High scenario in play (e.g. the pace of investment could be accelerated if new information suggests that the High scenario is appropriate).
- The Low scenario is not optimal (i.e. it does not fully exploit cost-effective opportunities for investment in low-carbon generation), and would result in addition of unabated gas plant to the system that would later become stranded. Given that build constraints in this scenario can potentially be addressed, the aim should be to deliver a more ambitious pace of decarbonisation.

Therefore our focus in costing power sector decarbonisation and considering incentives to drive this is the Medium scenario.

Scenario costs and investment requirements

Notwithstanding the uncertainties on technology choice, we have developed an illustrative generation mix in order to assess costs and investment requirements. Specifically, we assume that:

- Nuclear capacity is added at a rate of 2-2.5 GW annually.
- Renewable generation accounts for at least 30% of total generation, with a higher share depending on the extent of cost reductions for offshore wind over the next decade.
- CCS retrofit of unabated coal occurs by 2025, with further additions of CCS capacity (coal and gas) at the rate of at least 1 GW per year between 2025 and 2030.

We estimate the additional cost of delivering the Medium investment scenario through this illustrative mix against a counterfactual where there is no carbon constraint and no carbon price, and therefore where investment flows to a portfolio of unabated coal and gas generation capacity (Table 6.2):

- Given a nuclear marginal abatement cost close to zero in 2030 relative to this counterfactual, and marginal abatement costs of £168/tCO₂ for offshore wind, £163/tCO₂ for coal CCS and

£122/tCO₂ for gas CCS, the cost of delivering the central investment scenario in 2030 would be around 0.4% of GDP²⁵.

- Under DECC's highest fuel prices costs are substantially lower at 0.2% of GDP, while under low fuel prices they rise to 0.7% of GDP.
- With investment costs of the order £3 billion/GW for nuclear, £7 billion/GW for offshore wind (adjusted for annual availability to be on the same basis as non-intermittent technologies), £2 billion/GW for coal CCS and £1 billion/GW for gas CCS, the central scenario would require around £100 billion of investment in total through the 2020s, not including investment in transmission and distribution.

Table 6.2: Costs of the Medium scenario

	Central	Low fossil fuel prices	High fossil fuel prices	Low capital costs (25% lower)	High capital costs (25% higher)
Total costs relative to the counterfactual, including transmission and distribution as a % of 2030 GDP	0.4%	0.7%	0.2%	0.2%	0.7%
Absolute investment costs 2021-2030 (£bn)	94	94	94	70	117

Source: CCC calculations based on modelling by Pöyry Energy Consulting for the CCC

Required progress from 2030 to 2050

Delivering the Medium investment scenario to 2030 (i.e. adding 3-4 GW of low-carbon capacity per year to the system through the 2020s) would position the UK power sector well for a wide range of possible requirements by 2050 (Figure 6.20):

- By 2030, the power sector would be largely decarbonised, with a potential requirement to continue building low-carbon capacity at up to around 3 GW per year between 2030 and 2050, depending on the additional demand implied by electrification of other sectors (e.g. electricity supply may need to increase by between 40% and 160% by 2050 from today's levels).
- There is potentially a wider range of low-carbon technologies available for deployment in the 2030s compared to the 2020s. By this time, various renewable technologies, coal and gas CCS could be ready for commercial deployment.
- It is realistic that there could be a European super-grid by 2050 which would help manage intermittent generation and facilitate imports of generation from technologies such as concentrated solar power.

The precise set of investments should be determined as uncertainties are resolved, preferably through new electricity market arrangements designed to select least-cost combinations of low-carbon technologies.

²⁵ These should be compared to the discounted value of the DECC carbon price in 2030, which is around £125/tCO₂ at a 10% discount rate and around £150/tCO₂ at a social discount rate of 3.5%.

Figure 6.20: Power sector emissions in the context of UK greenhouse gas emissions (1990-2030, 2050)

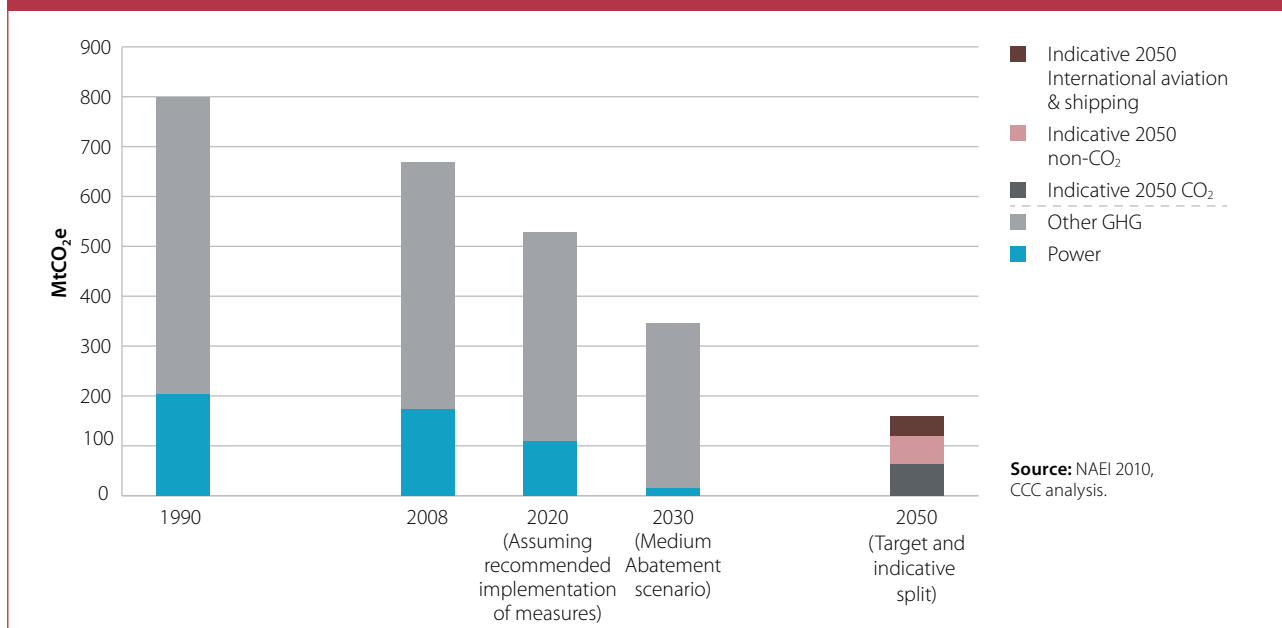
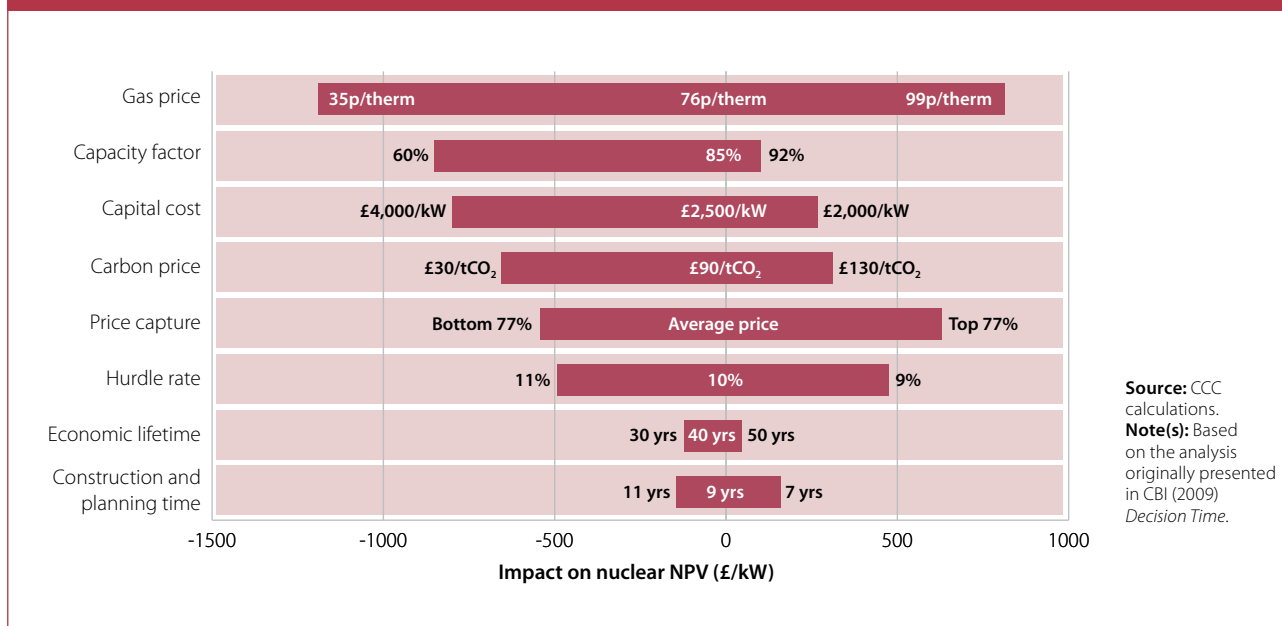


Figure 6.21: Relative importance of uncertainties faced by nuclear investors



5. Implications for reform of the current electricity market arrangements

Risks for investment under current market arrangements

In our 2009 report to Parliament we highlighted risks under current market arrangements for investment in low-carbon generation:

- Current market arrangements were designed to ensure efficient dispatch of existing plant, and to encourage investment in gas-fired, rather than low-carbon, generation.

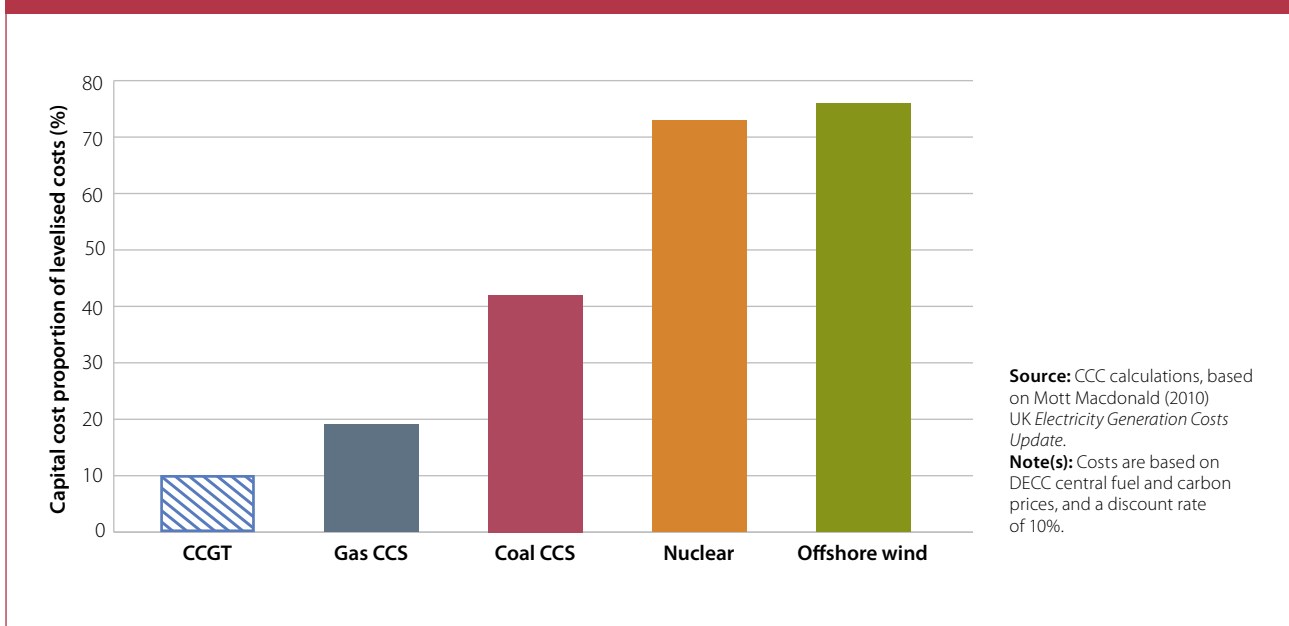
- The current arrangements mean that investment in low-carbon generation is subject to risks arising from fluctuations in carbon prices, gas prices, and electricity prices as well as from uncertainties relating to future electricity demand growth (peak and baseload due to development of new electric heat and vehicle markets, see Figure 6.21). These risks are not faced to the same degree by investors in (unabated) gas-fired plant, as CCGT plant is less capital-intensive and is hedged against the impact of the gas price on the electricity price (Figure 6.22 and 6.23).
- As a result of these risks, the cost of capital is likely to be significantly higher for investments in low-carbon generation. This is particularly problematic given the high capital-intensity of low-carbon generation options, creating the danger that there will be inadequate investment in low-carbon capacity, and escalating electricity prices as the carbon price rises. In our 2009 report, we showed that the result could be investment in unabated gas-fired generation and rising electricity prices through the 2020s (Table 6.3).

We contrasted this with the imperative to decarbonise the power sector through the 2020s, and suggested that this showed a divergence between private and social risks: given the set of private risks under current market arrangements, the key decision for investors is whether to invest in low-carbon generation; the decision for society is not whether to invest, but which forms of low-carbon generation to invest in (Box 6.13).

Table 6.3: Investment and prices under current market arrangements, relative to requirements under medium scenario

	Current market arrangements	Required under Medium scenario
Low-carbon investment 2021-2030	7 GW	36 GW
Emissions intensity in 2030 (gCO ₂ /kWh)	220 gCO ₂ /kWh	c. 50 gCO ₂ /kWh
Wholesale price (p/kWh)	12 p/kWh	Wholesale price will depend on market arrangements

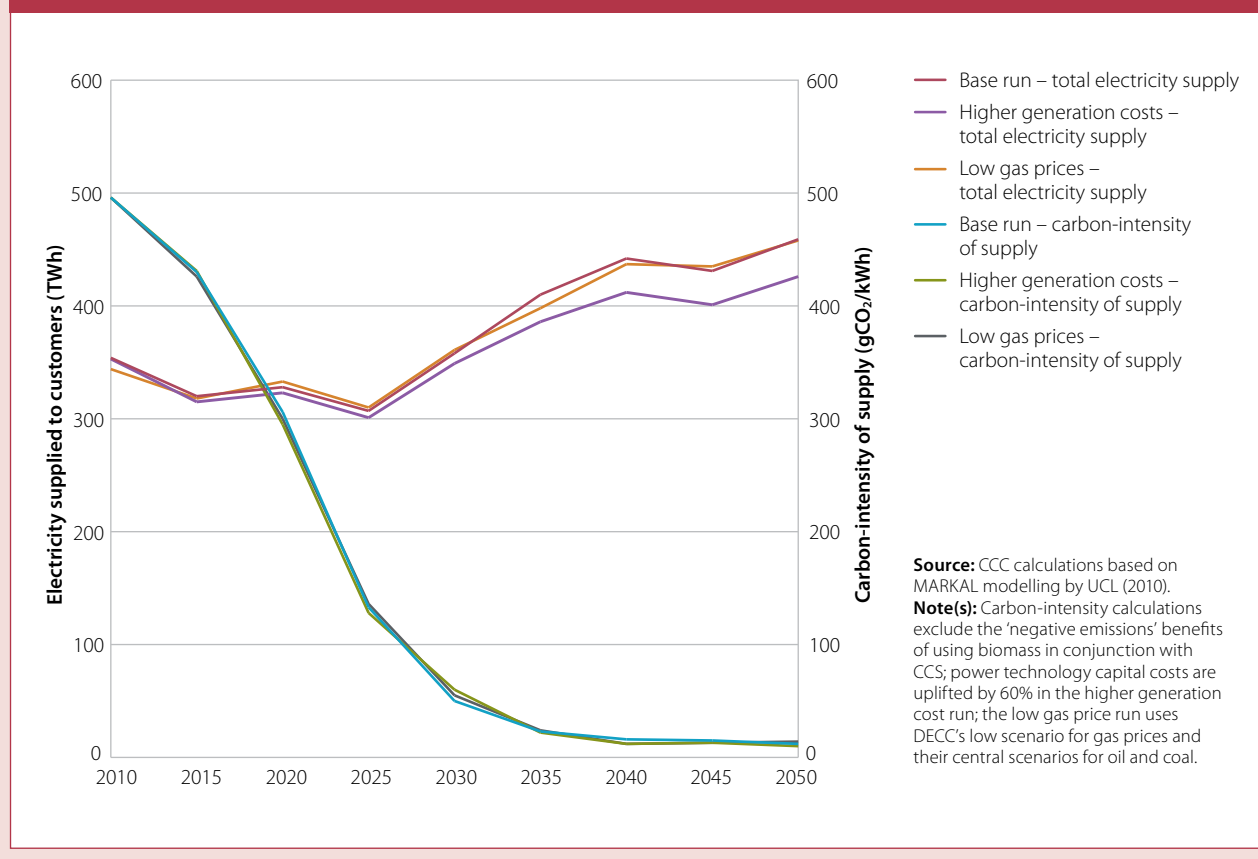
Figure 6.22: Estimated capital costs as a percentage of levelised costs (2030)



Box 6.13: Power sector decarbonisation is robust a range of scenarios for cost

MARKAL modelling shows that the need to decarbonise the power sector is robust to a range of scenarios. The key results do not change, even if power sector technology costs are higher than expected or fossil fuel costs are lower (Figure B6.13).

Figure B6.13: The cost-effective path to 2050 is robust to power sector costs



Options to address risks

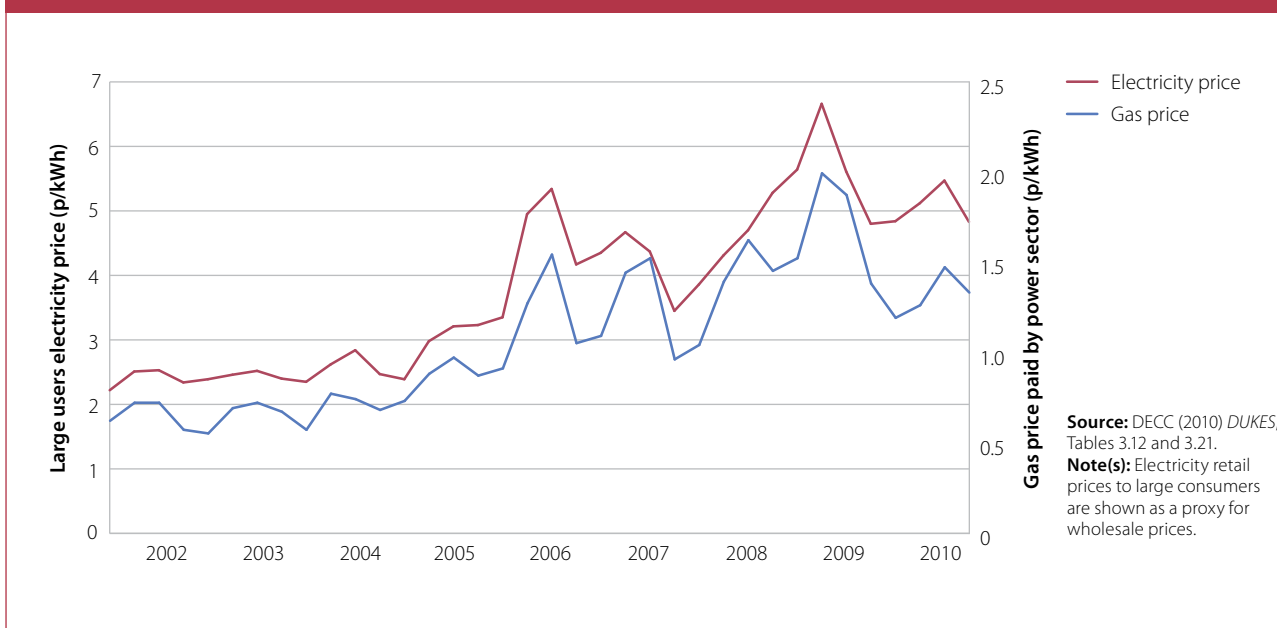
We therefore recommended that reform of the current electricity market arrangements should be seriously considered to better align private and social risks. We suggested three possible approaches to improve the investment climate for low-carbon generation consistent with energy policy objectives to maintain security of supply and affordability (Figure 6.24):

- Strengthening of the carbon price, for example through a carbon price floor.
- Providing more confidence about the price paid to low-carbon generation, for example, through low-carbon tariffs.
- Ensuring investment in low-carbon generation, for example, through tendering of long-term contracts.

Choosing between options: reducing political, regulatory and exogenous risks

In determining which of the options for securing required investments in low-carbon is most desirable, the key point is that where investors are required to bear more risk, this will be reflected in a higher cost of capital.

Figure 6.23: Correlation of electricity price and gas price (2001-2010)



Although there are strong arguments for investors to bear risks which they can manage (e.g. construction costs), they have limited scope to manage the various political, regulatory and other exogenous risks that we have identified in the context of low-carbon investment (Table 6.4).

Table 6.4: Private and social risks		
	Private management of risk	Social management of risk
Carbon price	A political risk which the private sector is not well placed to manage; the private sector will invest in gas-fired generation, or charge a premium for low-carbon investment.	Given policy levers, Government is able to mitigate risk.
Gas price	The private sector manages risk by investing in gas-fired generation. However, given limited scope for future investment in unabated gas capacity, the private sector will charge a premium for low-carbon investment when exposed to gas price risk..	Gas price risk is irrelevant (i.e. costless) to non-fossil generation for a society committed to decarbonisation, as investment in gas-fired plant is not a substitute for low-carbon investment.
Demand volatility	The private sector limits investment in new capacity/invests in gas-fired generation when faced with demand volatility/electricity price risk. This will become more pronounced with increasing amounts of intermittent generation. Investment in low-carbon capacity will be at a premium and an investment shortfall is likely.	There is a very limited cost from possible over-investment in low-carbon capacity (e.g. a slightly high reserve margin for a limited period has a small cost impact when spread across consumer base).
New demand	The private sector is unlikely to add capacity for markets that do not exist at the time investment decisions made (i.e. electric vehicles and heat); therefore an investment shortfall is likely when investors are exposed to this demand uncertainty.	Government has policy levers to manage electric vehicle and heat market development and therefore demand risk.

Source: CCC.

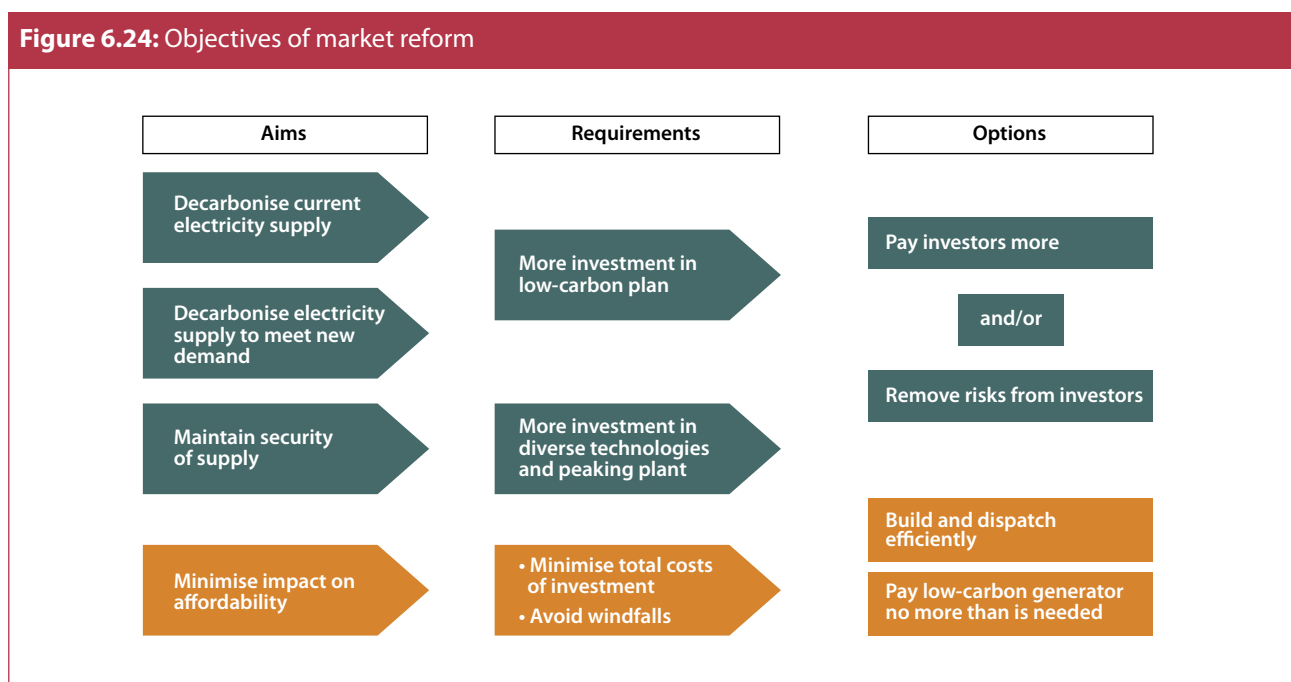
Therefore where these risks are left with investors, the result would be either that levels of investment are reduced, or that investments are forthcoming but at a high cost.

Faced with the risks imposed by the current market arrangements, Government policy can either seek to reduce risks, or subsidise to offset risks:

- The risk reduction strategy entails providing low-carbon developers with certainty in advance about the price at which they can sell given quantities of electricity, removing the risks created by fluctuating carbon, gas and electricity prices and demand uncertainty, thus reducing the cost of capital while still leaving the private sector with all construction and operational risks.
- The subsidy strategy entails leaving the low-carbon generators with price and quantity risks and a high cost of capital, but providing enough subsidy to offset this disadvantage.

Reducing risks is the optimal public strategy given that the private risks faced by investors do not correspond to the social risks of the investments, and can therefore be removed by the Government from the private sector at limited cost to itself or consumers, resulting in lower electricity prices than the subsidy strategy.

- Specifically, Government is well placed to manage risks around carbon price and future electric vehicle and heat demand, and gas price risk is not relevant for non-fossil technologies in a society committed to decarbonisation (Table 6.4).
- Analysis for the Committee by Redpoint Energy suggests that a strategy of reducing risks could lower the weighted average cost of capital by up to 3 percentage points. This could reduce the cost of decarbonising the power sector by around £5 billion annually by 2030.



Therefore, new market arrangements should provide an appropriate return on investments required to decarbonise the power sector through the 2020s, which does not depend on fluctuations in the gas and carbon prices or on realisation of uncertain and policy-induced demand from electric vehicles and heat.

Given a competitive process to ensure alignment of prices and costs, reallocating risks would deliver required investment at lowest cost to the consumer. Although tendering contracts for new capacity has been limited in the EU, this is widely used to support investment globally (Table 6.5).

Table 6.5: International examples of auctions for long-term electricity supply			
Country and date of auctions	Quantity auctioned	What auctioned?	Who are the buyers and sellers?
Brazil (2005-)	57 GW new capacity including 18 GW large hydro and 6 GW other renewables in technology specific auctions	15-30 year energy supply contracts	Distribution companies buying from generators
Chile (2006-)	37 TWh/year	15 year energy supply contracts	Distribution companies buying from generators
Peru (2006-)	3 GW capacity and 1 TWh/year renewable energy in technology specific auctions	8-12 year energy supply contracts	Distribution companies buying from generators
Mexico (1998-)	11 GW	Long-term power purchase agreements	State energy company buying from independent energy companies
PJM (US, 2007-)	129 GW firm capacity, 7 GW demand response, 1 GW energy efficiency for 2012/13	Capacity and demand resources (demand response and distributed generation) guaranteed for dispatch over the course of one year	System operator purchasing from generation companies

Mechanisms to reduce risks

Tendering of long-term contracts for low-carbon capacity commensurate with required decarbonisation through the 2020s could allocate risks appropriately while providing the discipline of price competition, including allowing new players to enter the market. It would provide most confidence that required investments will be delivered at least cost to the consumer (Figure 6.25):

- The long-term contracts tendered could take a number of forms, including: (i) Low-Carbon Contracts for Differences around the fluctuating electricity wholesale price, which could preserve positive aspects of the existing market arrangements (e.g. by providing a signal for appropriate location of wind farms and investment in system flexibility, and ensuring efficient dispatch), or (ii) Power Purchase Agreements/low-carbon tariffs in a separate low-carbon market (Box 6.14).
- Either option would ensure that low-carbon investors faced certain future prices for electricity delivered. Both could include capacity payments to ensure revenues cover sunk costs across different scenarios for growth in demand from electric vehicles and heat.
- Investors could be current players in the energy market or new players currently unable to enter the market given its vertically integrated structure.
- Both options could allow flexibility to respond to new information. The quantity of capacity to be tendered could be adjusted in the light of developing estimates of future required demand.
- Annual tendering for new slices of future capacity would ensure that prices tendered reflected latest assessments of construction and operating costs.
- While administered low-carbon feed-in tariffs (set by Government rather than through a tendering process) could also remove the future price and revenue risk faced by low-carbon generators, they would provide less certainty over investment outcomes and less pressure to deliver low costs to consumers. Such feed-in tariffs might be set either too high, resulting in unnecessarily high electricity prices, or too low, resulting in underinvestment. While modelling by Redpoint for DECC²⁶ has suggested that administered feed-in tariffs could be a more cost-efficient way to incentivise low-carbon generation than the Renewable Obligations device, tendering for future low-carbon electricity delivery would achieve the same risk reduction benefits while maintaining the discipline of price competition.

²⁶ Implementation of EU 2020 Renewable Target in the UK Electricity Sector: Renewable Support Scheme, <http://webarchive.nationalarchives.gov.uk/+/http://www.berr.gov.uk/files/file46778.pdf>

Box 6.14: What a low-carbon contract for difference might look like

Contracts for Differences are standard in power markets (e.g. they were used in the England and Wales market in the 1990s).

A Contract for Difference effectively guarantees the price paid for wholesale electricity by setting a strike price. If the wholesale price is higher than the strike price, the generator pays the difference between these two prices to the contract counterparty; if the strike price is lower than the wholesale price, the contract counterparty pays the difference to the generator.

A Low-Carbon Contract for Difference would make payments contingent on capacity being declared available.

- For capacity that is dispatched, the Low-Carbon Contract for Difference would function in the same way as its standard counterpart (i.e. payments would be made depending on the difference between the electricity wholesale price and the strike price in the contract).
- For capacity that is not dispatched, there would be no payments based on differences between the wholesale price and the strike price; there would be a capacity payment made to the generator in order to cover sunk costs.
- The wholesale price and the strike price could be defined in a way so as to encourage plant availability and to provide signals for investment in plant to enhance fleet diversity and flexibility (e.g. by making the strike price technology rather than plant-specific, and defining the wholesale price as the daily average).

Tendering of Low-Carbon Contracts for Differences would be on the basis of levelised cost comparisons, with bids including levelised costs and capacity payments.

Contract length could be commensurate with loan tenor for debt finance and/or asset life.

Mechanisms providing limited confidence and raising costs

Other mechanisms that rely on subsidy rather than risk reduction would not provide confidence over required investment and would be unnecessarily expensive:

- Carbon price strengthening without long-term contracts would result in escalating electricity prices in line with the increasing cost of unabated gas-fired generation. It is likely that carbon price strengthening would result in continued portfolio investment including in unabated gas-fired generation, and would deliver economic rents to low-carbon generators. Therefore carbon price strengthening should be a complement to more radical reforms based on tendering long-term contracts (e.g. it could have a similar role to an Emissions Performance Standard in signalling a limited scope for coal generation in the 2020s; and in providing signals on the choice between low-carbon technologies with different emissions intensities); see Chapter 2 for a more general discussion of carbon price strengthening.
- Extension of the current Renewables Obligation to cover all low-carbon generation may work, but at an unnecessary cost to electricity consumers, since the premium price paid to low-carbon generators will need to be high enough to compensate for the risks they still face (Box 6.24); similar arguments apply to other mechanisms based on paying a premium to low-carbon generation (e.g. low-carbon capacity payments over and above the wholesale price in the current electricity market).

Figure 6.25: Performance of market reform options

	Long-term contracts for low-carbon plant	Administered feed-in tariffs	Premium on top of electricity price	Carbon price underpin alone
Deliver low carbon investment to meet current demand	High confidence	High confidence	High confidence	High confidence
Deliver low-carbon investment to meet new demand from heat and transport	High confidence	Some confidence	Some confidence	Some confidence
Maintain security of supply	High confidence	Some confidence	Some confidence	Some confidence
Minimise impact on affordability	High confidence	Some confidence	No confidence	No confidence

■ No confidence
■ Some confidence
■ High confidence

Source: CCC.
Note(s): In order to provide full confidence on maintaining security of supply, long-term contracts for low-carbon plant may need to be supplemented by mechanisms to encourage investment in peaking plant.

- Capacity mechanisms applicable to all types of generation (whether high- or low-carbon) may have a useful complementary role to play in securing balancing and peaking capacity, but will not ensure a shift to low-carbon generation alone, and could result in inappropriately high levels of unabated gas-fired generation in the system. A specific low-carbon capacity obligation could complement other incentives, for example, requiring energy companies to contract for capacity at the level required for sector decarbonisation.
- An Emissions Performance Standard alone would be unlikely to deliver low-carbon investment at the scale required, but could have a role in conjunction with tendering of long-term contracts for low-carbon capacity.²⁷

The Energy Market Review

Government’s Energy Market Assessment (EMA) was launched in December 2009 and reported back alongside the March 2010 Budget. The EMA concluded that current market arrangements are not fit for purpose to deliver required low-carbon investments and considered five possible reforms at a high level.

Of the reforms considered, the EMA concluded that neither carbon price strengthening alone nor a single-buyer model would provide an appropriate enduring solution, but committed to looking at the following three measures in more detail:

- Additional incentives for low-carbon generators above the carbon price (e.g. a low-carbon obligation, premium feed-in tariffs or contracts for difference on the electricity price).
- Regulation to directly limit high-carbon generation (e.g. legislation to directly limit investment in unabated fossil fuel plant, or a requirement to accompany each GW of investment in unabated fossil fuel plant with a certain amount of low-carbon investment).

²⁷ Redpoint Energy (2009), *Decarbonising the UK Power Sector*, http://downloads.theccc.org.uk/docs/FINAL%20Decarbonising%20the%20GB%20power%20sector_v1.pdf

-
- Long-term payments to low-carbon generators to provide revenue certainty (e.g. fixed feed-in tariffs, competitive tendering for low-carbon generation or regulation of an appropriate return).

A consultation setting out the Government's preferred options is due to be published in December 2010 with the aim of following it with a White Paper in Spring 2011.

We will respond to DECC's consultation in early 2011.

6. Other implications for the first three budgets

The analysis in this chapter reinforces the need to implement existing Government policy in a number of areas:

- **Nuclear generation.** In order that large-scale investment from the early 2020s is feasible, the enabling framework (e.g. National Policy Statement, justification etc.) should be progressed so that the first new plant comes onto the system as planned in 2018.
- **Coal and gas CCS.** Timely demonstration of coal and gas CCS based on completing the first competition and proceeding with the second competition is crucial in order to develop this option for roll-out from the first half of the 2020s. Further improvements to the framework for investment in CCS include clarification of financing arrangements beyond the demonstration stage, and introduction of an Emissions Performance Standard.
- **Renewable generation.** An ambitious programme of investment in wind generation and demonstration of marine and geothermal generation is appropriate both to reduce emissions, and to develop these options for roll-out. In order that investment proceeds, key elements of the enabling framework remain to be tested (e.g. the planning regime for onshore wind generation), and complementary investments to ease bottlenecks in the power transmission network are required.
- **Demand-side response.** The current plan to roll out smart meters by 2020 and to deploy a smart grid will support demand response, and facilitate the use of car batteries as a form of storage. There are a number of challenges associated with ensuring this roll-out harnesses demand-side response relating to encouraging and enabling consumer engagement, developing and demonstrating new technologies and adapting the regulatory framework and business models.

There are a number of areas where further evidence is required:

- **Network impacts from electric vehicle and heat market development.** It is currently uncertain the extent to which development of these markets will require investments in electricity distribution and transmission networks. For example, there are scenarios where implications from increased electric car penetration would be limited based on overnight charging, with larger implications in scenarios where there is daytime charging or increased electricity demand in the peak due to electric heating. Further assessment is required to better identify these impacts, in order that required investments can be incorporated in energy companies' broader investment programmes.

-
- **Interconnection benefits.** Our analysis suggests that increased interconnection could be potentially beneficial in addressing demand volatility. However, we have not carried out a detailed cost-benefit analysis of specific options. More detailed analysis is required to ensure that projected benefits outweigh costs, following which new projects should be developed as appropriate.
 - **Industrial capacity.** We have highlighted the need for significantly increased investment in low-carbon power generation. Whilst this would appear to be feasible based on what has been achieved in other countries historically, it is not clear what gap currently exists in the UK as regards industrial capacity, though some organisations have raised concerns²⁸. Further assessment is required to identify the gap, together with remedial measures that may be required in addition to creation of demand for low-carbon generation and expected market response.
 - **Smart grid.** Our analysis suggests that smart grids could greatly help in managing increased intermittency and more peakiness of demand in the system.

Given this evidence, it will be important to develop economy-wide scenarios for decarbonisation through the 2020s, drawing out implications for the power sector and using these to frame both technology support over the next decade and beyond, and the introduction of new market arrangements under which there is tendering of long-term contracts for low-carbon capacity.

²⁸ For example, The Institute of Mechanical Engineers (2010) *Nuclear Build: A Vote of No Confidence*.

7. Key findings



Share of total UK emissions from power generation.

28%

The carbon intensity of power will need to fall from around 500 g/kWh today to 50 g/kWh by 2030.

50
gCO₂e/kWh

97% of electricity should be generated by low-carbon sources in 2030, compared to 26% now.

97%

Low-carbon capacity needs to be added to the system in 2020s – a mixture of nuclear, renewables and CCS.

30-40
GW

DECC will consult on options for market reform.

December
2010

The power sector will need to almost completely decarbonise by 2050.

Zero
Carbon
by 2050

Chapter

7



1. Agriculture emissions in the period to 2020
2. Options for reducing emissions from agriculture through best practices and technology
3. Opportunities for reducing emissions through reduced food waste and changed diets
4. The role of land use, land-use change and forestry (LULUCF)
5. Policies to support agriculture and LULUCF emissions reduction
6. Scenarios for agriculture and LULUCF to 2030
7. Implications for the first three budget periods
8. Key findings

Chapter 7: Reducing emissions from agriculture and land use, land-use change and forestry

Introduction

In this chapter we consider options for reducing emissions arising from agriculture and land use, land-use change and forestry activity.

The UK inventory estimates that agriculture emissions in 2008 amounted to around 48 MtCO₂e or 8% of total UK greenhouse gas emissions. Emissions have fallen from 61 MtCO₂e in 1990, mainly due to reduced activity as a result of reform of the EU Common Agricultural Policy. The Government is aiming to reduce agriculture emissions by around 3 MtCO₂e in England over the next ten years (a similar level of ambition in the devolved administrations would deliver an additional 1.5 MtCO₂e). Without further abatement beyond this ambition, agricultural emissions would account for a high share of allowed emissions in 2050 (e.g. around 28%). This would be unsustainable given emissions from other difficult to reduce sectors (e.g. aviation, shipping, and industry). Therefore it will be important to continue to reduce the emissions intensity of agricultural production in the 2020s.

On a net basis, the land use, land-use change and forestry (LULUCF) sector absorbed 2 MtCO₂ in 2008. Going forward, LULUCF is forecast to revert to a net emitter of emissions due to a decline in the historical forest planting rate.

In this chapter we consider options for reducing emissions through the 2020s from agriculture and LULUCF including:

- Options for agriculture to reduce emissions from soils, livestock and manures through the uptake of best practices and new technologies.
- More radical supply-side options (e.g. introduction of biotechnological options such as GM, changes to agricultural systems).
- Scope for reducing CO₂ emissions from energy use on farms (e.g. from farm vehicles).
- Opportunities for reducing emissions through reducing food waste and rebalancing diets.
- Role of afforestation in reducing net LULUCF emissions.

Our aim is to identify promising options for further consideration and to develop scenarios for agriculture and LULUCF emissions reductions through the 2020s. We build these into economy-wide scenarios which underpin our advice on the level of the fourth carbon budget (see Chapter 3).

The key messages in this chapter relating to agriculture are that:

- The scale of the opportunities to reduce agriculture emissions is more uncertain than in other sectors of the economy. Even the precise scale of emissions is uncertain, due to incomplete understanding of both the science and of the current mix of farming practices.

Moreover the extent to which specific technically feasible abatement opportunities can in fact be achieved and reflected in the UK's greenhouse gas inventory is complicated by the difficulties of monitoring either changes in farming practices or changes in actual resulting emissions. Further analysis is required to reduce uncertainties and to identify policy levers which can increase certainty of implementation.

- Analysis suggests that there is a technically feasible abatement opportunity of 4-14 MtCO₂ by 2030, through the uptake of best practices and technologies to reduce N₂O emissions arising from soils and CH₄ emissions arising from livestock and manures.
- In addition there is scope for abatement through reducing energy use on farms (e.g. through use of low-emissions engines and alternative fuels and technologies).
- Given the difficulties of ensuring attainment of technically feasible abatement, we have assumed that 5 MtCO₂e of this reduction can be achieved in the Medium Abatement scenario (in addition to the 4.5 MtCO₂e assumed for the UK between now and 2020). This will deliver a 12% reduction by 2030 relative to 2020 levels, and a reduction of 18% relative to today's levels.
- This assumed pace of reduction is significantly lower than in other sectors of the economy, and if further reductions could not be achieved by 2050, agriculture would then account for 40 MtCO₂e out of the total 160 MtCO₂e target. Combined with emissions in other difficult to reduce sectors (industry direct emissions, aviation and shipping) this level of agricultural emissions would make the 2050 target extremely difficult and perhaps impossible to attain.
- In addition, the vast majority of measures that we assume under the Medium Abatement scenario are available at negative cost (i.e. can save money for farmers). All the measures are less than our projected economy-wide carbon price and should therefore form part of a least-cost emissions path for the overall economy.
- It is therefore essential that work continues to identify further reduction opportunities beyond those which we have assumed for the fourth budget. To achieve these further reductions might require:
 - The development of stronger policy levers to ensure the attainment of technically feasible and uncontroversial abatement opportunities (e.g. reduced use of nitrogen fertiliser via better application techniques) while at the same time mitigating any competitiveness risks.
 - Novel technologies, including potentially controversial ones, such as the use of GM technology.
 - Changes in consumer behaviour, such as via reductions in food waste, or via a changed mix of diets, with reduced consumption of carbon-intensive foods.
 - Our assessment of emissions reduction from diet rebalancing raises broader questions about production- versus consumption-based emissions accounting approaches, which we believe it would be useful for the Committee to investigate in detail, both as regards agriculture and more generally.

The key messages relating to LULUCF are that:

- Available land use and land-use change options, mainly increasing the number of trees, could absorb up to 3 MtCO₂ in 2030. This would require initiation of forest planting programmes today to deliver estimated abatement potential.
- For LULUCF, we use a range of abatement of 1-3 MtCO₂e in our economy-wide scenarios.

We set out the analysis that underpins these messages in seven sections

1. Agriculture emissions in the period to 2020
2. Options for reducing emissions from agriculture through best practices and technology
3. Opportunities for reducing emissions from agriculture through reduced food waste and changed diets
4. The role of land use, land-use change and forestry (LULUCF)
5. Policies to support agriculture and LULUCF emissions reduction
6. Scenarios for agriculture and LULUCF emissions to 2030
7. Implications for the first three budget periods

1. Agriculture emissions in the period to 2020

Current agriculture emissions

The UK agriculture inventory estimates current agricultural emissions to be around 48 MtCO₂e or 8% of total greenhouse emissions (Figure 7.1).¹

- These mainly comprise nitrous oxide (N₂O) emissions from the use of fertiliser on soils (54%) and methane (CH₄) emissions from enteric fermentation, a process related to digestive systems of cattle and sheep (38%) (Figure 7.2).
- Estimated emissions fell by 21% between 1990 and 2008 (Figures 7.3 and 7.4) – mainly reflecting changes in agricultural activity:
 - Livestock numbers fell as a result of Common Agricultural Policy (CAP) reform, which decoupled subsidies from production.
 - The quantity of fertiliser applied to agricultural lands fell, particularly on pasture land, reflecting lower stocking densities.
 - There is some evidence of improved efficiencies in livestock production and nitrogen use efficiency, neither of which may be wholly captured in the UK GHG inventory.
- In 2008, N₂O and CH₄ emissions from agriculture accounted for 47% of all non-CO₂ emissions (Figure 7.5).

¹ This figure includes crown dependencies which are not covered by the UK Climate Change Act.

Figure 7.1: GHG emissions from agriculture in the context of total UK emissions (2008)

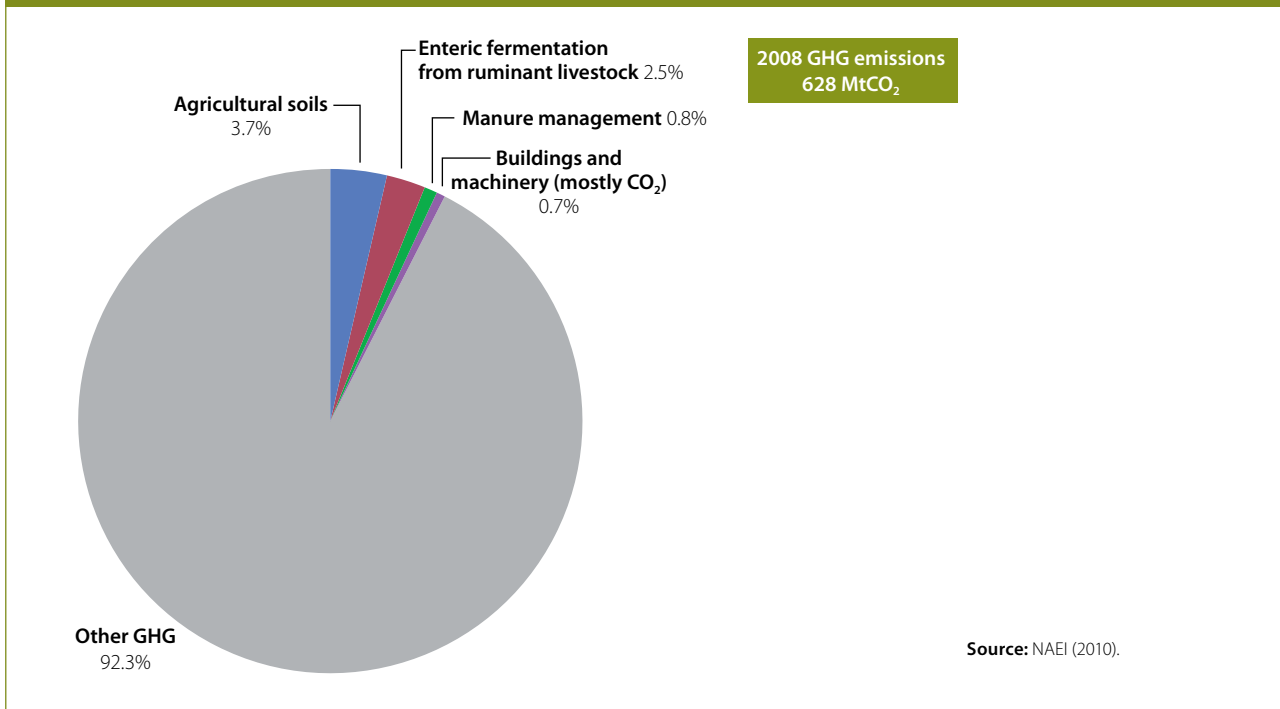
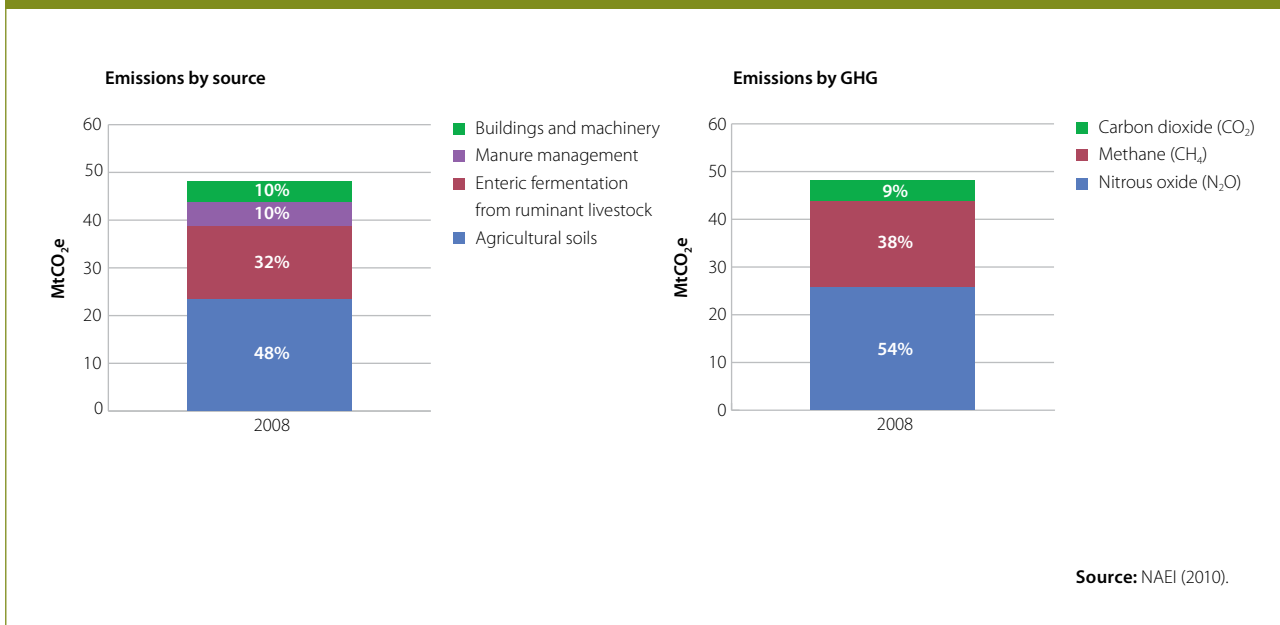


Figure 7.2: Agriculture emissions (2008)



- Agriculture is also responsible for CO₂ emissions arising from the use of machinery (e.g. tractors) and consumption of fuel in farm buildings. Agricultural CO₂ emissions accounted for 0.8% of UK CO₂ emissions in 2008.

Estimates of agricultural emissions include significant uncertainties:

- In the UK inventory agriculture emissions estimates are calculated by multiplying a measure of activity by an ‘emissions factor’ (the amount of emissions associated with that activity).

Figure 7.3: Agriculture emissions by source (1990-2008)

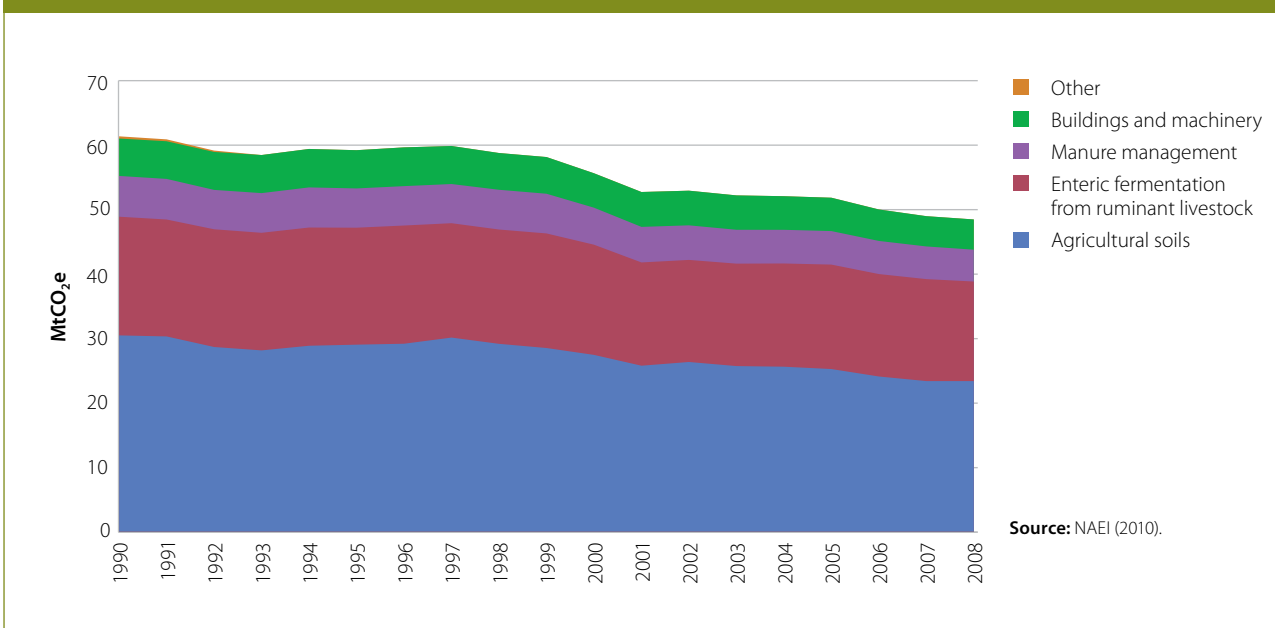
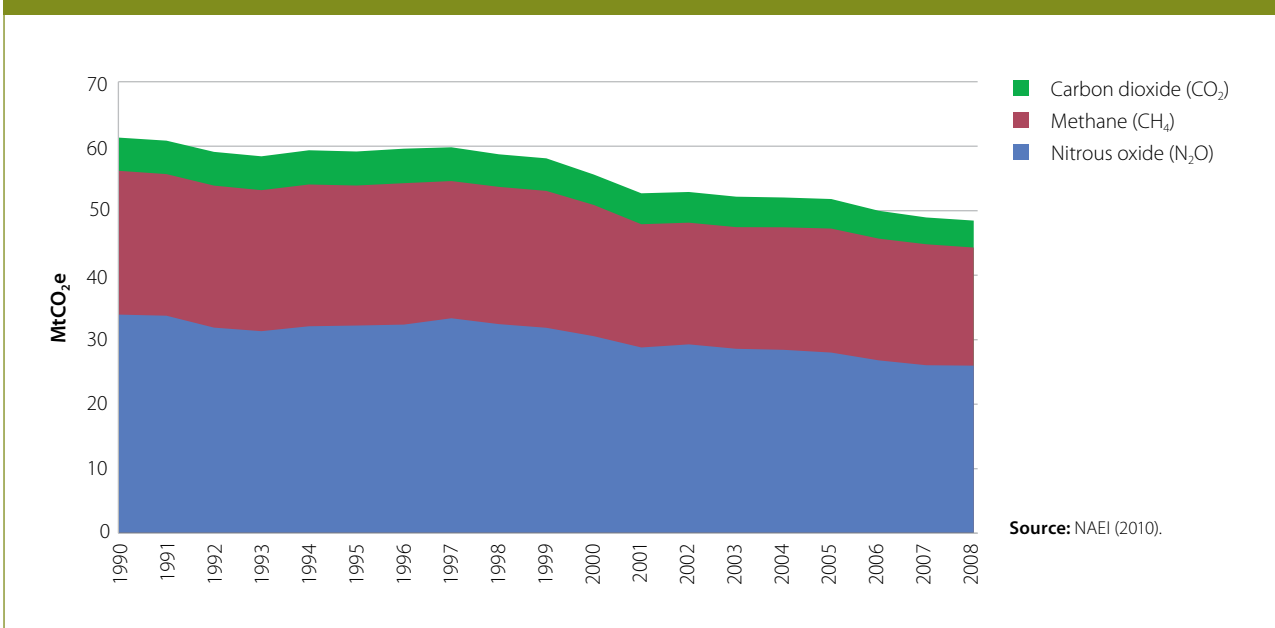


Figure 7.4: Agriculture emissions by GHG (1990-2008)



- Uncertainty about past and current agricultural activity is unlikely to be higher than in other sectors. However, uncertainty in emissions factors is likely to be much larger than compared to other sectors. Emissions factors represent generic world or regional averages, but these may not be appropriate for UK conditions as emissions are heavily influenced by variable elements such as climate and soil quality as well as farming practices.²
- If the uncertainties in emissions estimates are taken into account, agriculture could account for between 2% to 13% of all UK emissions.

² The UK inventory for agriculture is at present calculated using default IPCC emissions factors in the absence of better country-specific emissions factors. The Government has committed to investing in the agriculture evidence base to better understand and measure emissions from biological systems and develop a more accurate inventory that can reflect mitigation activities.

Figure 7.5: Agriculture share of non-CO₂ emissions (2008)

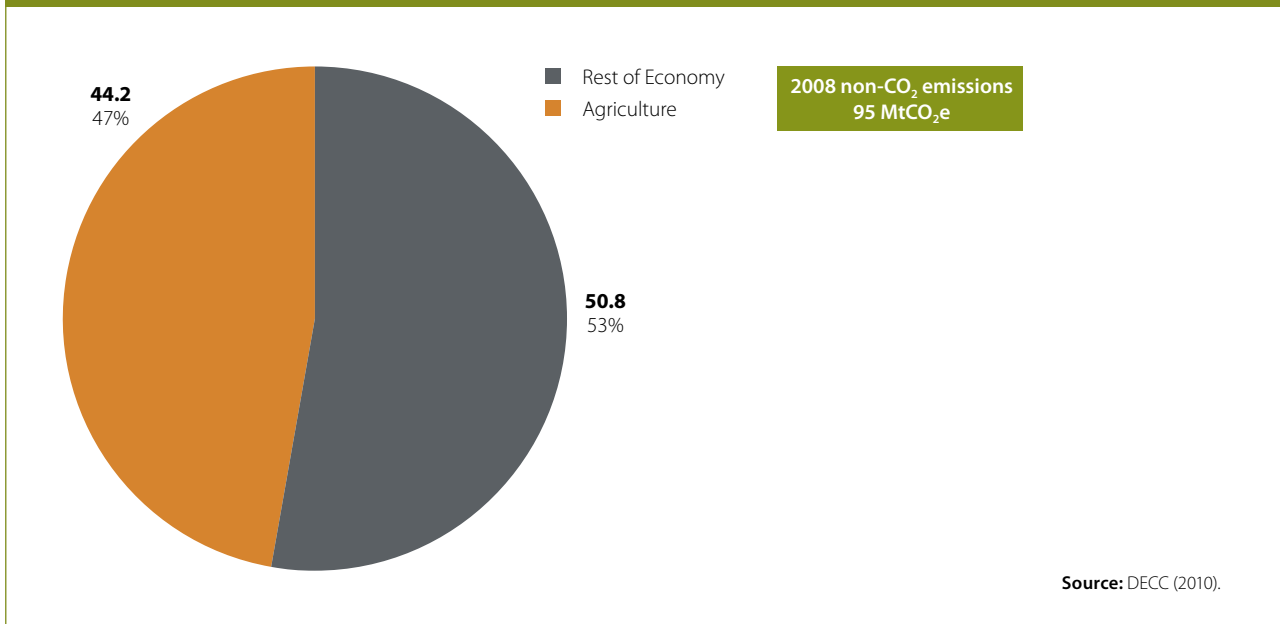
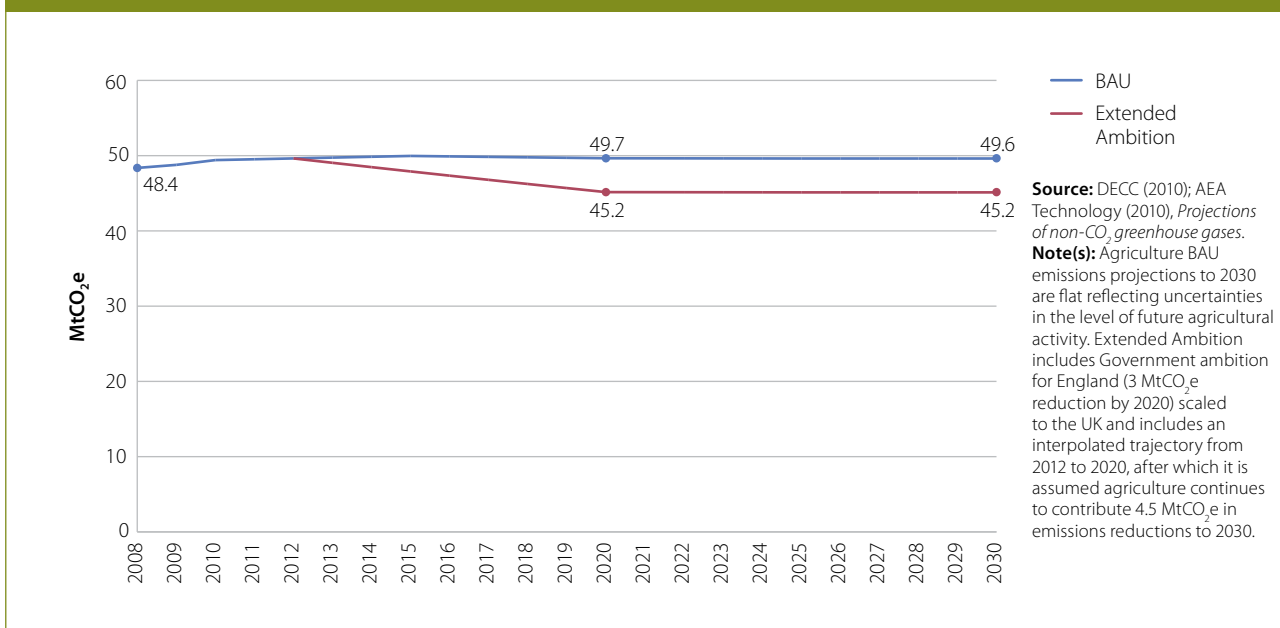


Figure 7.6: Agriculture emissions reference projections (2008, 2020, and 2030)

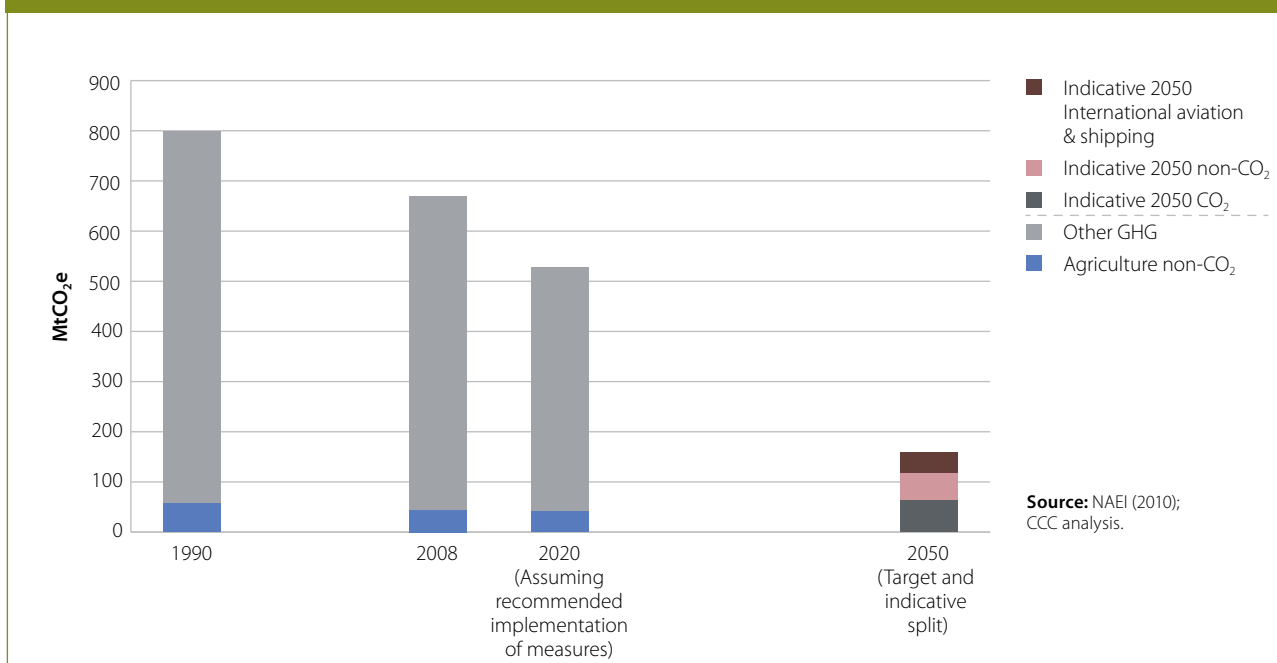


Projected emissions in 2020

Agriculture emissions are projected by the Government to be at 50 MtCO₂e in 2020 under ‘business as usual activity’ (BAU). This figure reflects forecasts for livestock and crop production and is slightly higher than the current emissions level of 48 MtCO₂e (Figure 7.6). Analysis in our 2010 Progress Report to Parliament suggested that there is scope for 5-12 MtCO₂e reduction in UK agriculture emissions by 2020 (a 27-39% reduction from 1990 levels). This is through a range of cost-effective soils, livestock, and manure management measures (<£40/tCO₂e), of which the majority are available at negative cost (i.e. they would save money for farmers).

The previous Government committed, in its Low Carbon Transition Plan (LCTP), to reduce emissions from agriculture in England by 3 MtCO₂e in 2020. We scale this up to 4.5 MtCO₂e

Figure 7.7: Agriculture sector emissions in the context of UK greenhouse gas emissions (1990-2020, 2050)



at the UK level on the basis of analysis conducted by the Scottish Agricultural College. This is around 40% of the maximum technical potential we identified in our 2010 Progress Report to Parliament. An industry action plan, developed by the Climate Change Task Force (a joint collaboration between agriculture industry groups) identified measures to deliver the LCTP emissions reduction, and proposed an approach to delivery based on provision of information, advice and voluntary action.

Given the high levels of uncertainty over future emissions, both as regards business as usual emissions and the emissions impact of abatement measures, we recommend that the focus of policy effort should be on implementing measures and on developing a more robust evidence base to better identify current farming practice and resolve uncertainties over abatement potential. In this chapter, as in other sectoral chapters, we start by defining an emissions entry point in 2020, from which we develop emissions scenarios through the 2020s. In line with the previous Government’s LCTP ambition, we assume that UK agriculture emissions are reduced by 4.5 MtCO₂e in 2020. Therefore we assume that emissions fall from the Government’s business as usual projection level of 50 MtCO₂e in 2020 to 45 MtCO₂e (i.e. around 10% of UK emissions allowed under the intended budget of 450 MtCO₂e in 2020 – Figure 7.7). With no further change, agriculture emissions would account for 28% of total allowed emissions under the 2050 target (160 MtCO₂e) in the Climate Change Act.

Reference emissions projection to 2030

Our agriculture reference projections to 2030 are again based on the Government’s business as usual projections net of abatement targeted in the period to 2020:

- Government projections assume that baseline agricultural emissions will increase slightly going forward, from the current level of 48 to just under 50 MtCO₂e in 2025, reflecting forecasts for livestock and crop production.

- Netting out 4.5 MtCO₂e from the BAU projections to 2025 gives agriculture emissions of 45 MtCO₂e (of which 41 MtCO₂e are non-CO₂ emissions).
- In the absence of formal projections to 2030, we assume flat emissions between 2025 and 2030 (Figure 7.6).

We now consider scope for emissions reduction from this reference case in the period to 2030, and set out scenarios based on different assumptions about abatement in Section 6.

2. Options for reducing emissions from agriculture through best practices and technology

We divide our analysis of scope for on-farm agriculture emissions reduction into non-CO₂ and CO₂ abatement, and now consider each category in turn.

(i) Measures to reduce on farm non-CO₂ emissions

Currently identified scope for emissions reductions from soils and livestock measures

Analysis by the Scottish Agricultural College (SAC)³ has guided our assessment of abatement potential. The SAC analysis considers a range of measures to reduce emissions from soils and livestock including:

- more efficient use of nitrogen fertilisers,
- breeding livestock for improved genetics, fertility and productivity,
- improvements in livestock feed efficiency and use of dietary additives,
- improved manure management and anaerobic digestion.

The analysis found a range of 8.6 to 18.9 MtCO₂e of abatement potential from the above measures at a cost of less than £70/tCO₂e (i.e. our projected carbon price for 2030, see Chapter 2), by the end of the third budget (2022) (Figure 7.8):

- The range reflects uncertainties relating to the baseline against which the measures are applied; the technical effectiveness of abatement measures; and whether some measures would be permitted under future regulatory regimes (Box 7.1).
- Of the maximum 18.9 MtCO₂e:
 - 14.3 MtCO₂e is available at negative cost and therefore represents an opportunity for farmers to increase their competitiveness whilst reducing the emissions intensity of production
 - 14.5 MtCO₂e is available at a cost of less than £40/tCO₂e
 - All of the abatement potential is available at a cost less than our 2030 projected carbon price of £70/tCO₂e (see Chapter 2 for our carbon price projections).

³ Scottish Agricultural College et al. (2010), *Review and update of UK marginal abatement cost curves for agriculture*.

Figure 7.8a: Agriculture MACC maximum technical potential, pessimistic case (2022)

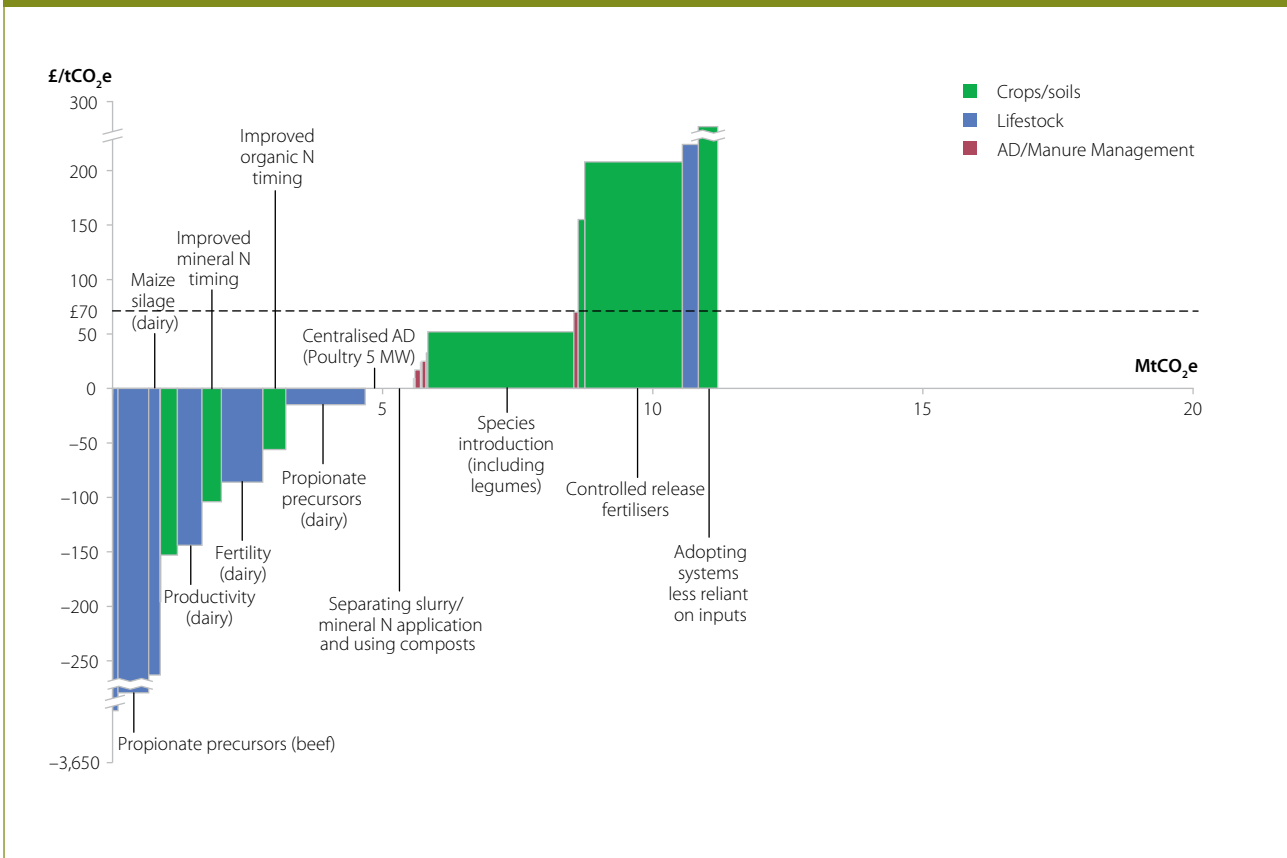
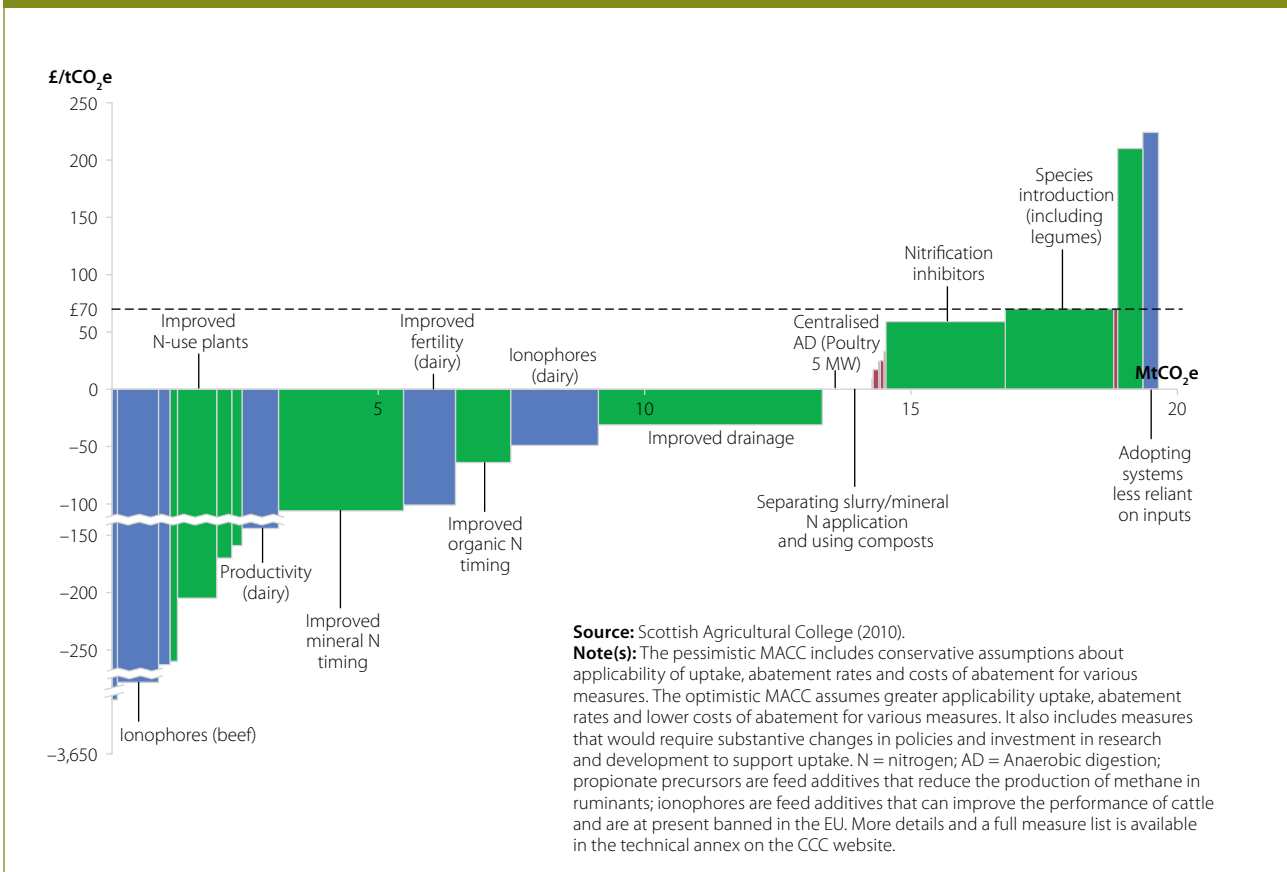


Figure 7.8b: Agriculture MACC maximum technical potential, optimistic case (2022)



Source: Scottish Agricultural College (2010).
Note(s): The pessimistic MACC includes conservative assumptions about applicability of uptake, abatement rates and costs of abatement for various measures. The optimistic MACC assumes greater applicability uptake, abatement rates and lower costs of abatement for various measures. It also includes measures that would require substantive changes in policies and investment in research and development to support uptake. N = nitrogen; AD = Anaerobic digestion; propionate precursors are feed additives that reduce the production of methane in ruminants; ionophores are feed additives that can improve the performance of cattle and are at present banned in the EU. More details and a full measure list is available in the technical annex on the CCC website.

Therefore the analysis suggests scope for additional technical abatement of 4-14 MtCO₂e through the 2020s over and above the 4.5 MtCO₂e reduction that is assumed in the LCTP (scaled to the UK).

Box 7.1: Uncertainties in the Agriculture MACCs

The SAC MACC analysis identifies technical potential ranging from 8.6-18.9 MtCO₂e by 2022. The range indicates a pessimistic and optimistic set of assumptions, which reflect a number of uncertainties. These include:

- Baseline uncertainty as to the present state of farming practice. For example, the extent to which farmers are already implementing measures or the amount of additional land to which a measure can be applied.
- Technical uncertainty or the ability of measures to deliver identified potential given current evidence and/or timelines required to test and deploy options. For example, nitrification inhibitors, which slow the rate of conversion of fertiliser ammonium to nitrate, need to be adequately tested under UK conditions to establish their efficacy.
- Regulatory uncertainty. For example, the use of ionophores in livestock (which inhibit the production of methane from enteric fermentation) is at present illegal within the EU.

We assume that the technical potential identified in the MACCs is inclusive of abatement targeted in the LCTP, or 3 MtCO₂e within England by 2020 which scales to 4.5 MtCO₂e at the UK level. The residual abatement is calculated by netting off 4.5 MtCO₂e, resulting in 4 to 14 MtCO₂e in additional abatement available by 2022 (which is also available throughout the 2020s).

The ability to unlock additional technical potential depends upon resolving the uncertainties described above. For some measures, such as anaerobic digestion and nutrient management practices, there is greater confidence in their ability to deliver emissions reductions. Other measures require further testing under a variety of UK conditions. Still others require resolution of other issues (e.g. trade-offs between other objectives of farming including animal welfare and biodiversity). The level of confidence in MACC measures given remaining uncertainty is summarised below.

Table B7.1 Confidence in MACC measures given remaining uncertainty

Category	Measure(s)	Confidence	2022 Abatement Potential (MtCO ₂ e)	
			Pessimistic	Optimistic
Nutrient management	Improved timing of fertiliser application, avoiding excess application, etc.	Medium	1.2	4.2
Soil management	Drainage	Low	0.0	4.2
	Reduced tillage	Low	0.3	0.3
Nitrification inhibitors		Low	0.0	2.2
Using more nitrogen-efficient plants	Improved nitrogen-use plants	Medium	0.0	0.7
	Species introduction	Medium	2.7	2.0
Livestock breeding	Improved genetics in beef/dairy; improved fertility in dairy	High	1.3	1.8
Livestock feeding	Propionate precursors for beef/dairy	Medium	2.0	0.0
	Ionophores for beef/dairy	Low	0.0	2.4
	Use of maize silage for dairy	Medium	0.2	0.2
Anaerobic digestion	Pigs and poultry farm units	High	0.6	0.6
Manure management	Covering lagoons & slurry tanks	Medium	0.2	0.2
Total			8.6	18.9

Source: Scottish Agricultural College (2010), *Review and update of UK marginal abatement cost curves for agriculture*, Table E.6.

Additional measures identified in the Scottish Agricultural College analysis

The SAC analysis considered a broader set of options to reduce emissions from crops and soils activity, and from livestock than those appearing in the final MACCs. It prioritised MACC mitigation measures based on relative costs, abatement potential, technical feasibility and acceptability to industry.

SAC acknowledged, however, that costs for other measures that were screened from the MACCs could decrease and that new options will become available over time as result of targeted research and technological development. These additional measures could include:

- Wider measures to improve soil management (e.g. residue management and waste management to improve soil structure and sequester carbon).
- Improved cattle health through reductions in endemic disease.
- Alternative dietary energy sources for ruminants (e.g. increasing high starch concentrates) to reduce the production of methane in ruminants or to improve animal yields.
- Other scales and types of anaerobic digestion systems that may become cost-effective, depending on incentives and future market prices.
- Increased use of nitrogen efficient crop varieties, including the potential use of genetically modified (GM) organisms (Box 7.2).
- Adopting alternative production systems e.g. mixed farming (Box 7.3).

Thus a range of management and technological options (including unanticipated technologies) could provide additional abatement. This would require research effort and funding, and be subject to regulatory barriers, public acceptability and trade-offs between low-carbon and other objectives (e.g. animal welfare) being addressed.

Box 7.2: The potential for biotechnology in agriculture mitigation

The MACC analysis considers various biotechnological options for reducing emissions from agriculture, including introducing crops which use nitrogen more efficiently, thus reducing the amount of fertiliser required and associated N₂O emissions. In the longer term, additional biotechnological options for mitigating agriculture emissions may also involve use of genetic modification (GM) technology to improve nitrogen use efficiency and confer nitrogen fixing capabilities to cereal crops.

There is potential to improve nitrogen use efficiency in plants by traditional breeding and GM methods. In breeding programmes, desired traits are introduced by crossing plants from related varieties or species and selecting individuals with the desired characteristic. These can then be developed into new varieties. Traditional breeding programmes can have long lead-times due to constraints in developing and selecting new varieties. For instance it can take ten years or more to develop crops with the desired characteristics. Biotechnological approaches such as marker-assisted breeding and selection can be used to significantly speed up this process and are likely to be used increasingly in plant breeding programmes.

GM-based approaches to improving nitrogen use efficiency would involve the introduction of novel genes, either from the same species or from another species, into a plant. While to date there has been little success in engineering improved nitrogen use efficiency, it has been argued that GM approaches may deliver faster results than conventional breeding programmes.

Box 7.2: The potential for biotechnology in agriculture mitigation

A longer-term option to reducing fertiliser use in agriculture is developing crops (e.g. cereals) that can convert nitrogen gas, abundant in the atmosphere, into a usable form. This 'nitrogen fixing' capability is already present in legume crops (e.g. clover and beans). These crops have nodules on their roots that contain bacteria, which carry out the fixing process. Legume crops are used in some farming systems to provide nitrogen through crop rotation. Enabling other crop plants to fix nitrogen may require the use of GM technology. In last year's *Reaping the Benefits* report, the Royal Society notes that if engineering of nitrogen fixation in non-legume crops is possible, it is a long-term development (over 10-15 years away) and would require significant investment in research and development.

The use of GM has been controversial in the EU and to date there has been limited commercial cultivation of GM crops in the region. Future use would require resolution of consumer acceptability issues, both around understanding the science of GM as well as safety concerns.

It is also noted that GM crop development has predominantly been driven by the private sector, while public funding for agricultural research and development has declined over the past 20 years. Going forward, and as we identified in our July 2010 report *Building a low-carbon economy: the UK's innovation challenge*, innovation within agriculture should be a priority given the early stage of development of key agri-biotechnologies and the potential importance of these options for meeting carbon budgets and for addressing other issues (e.g. feeding a growing global population).

The Royal Society has called for an inclusive approach to considering new technologies in food production systems where no techniques or technologies should be ruled out before the risks and benefits are assessed. We similarly recommend that the Government consider the full set of agri-biotechnological options, including both traditional and GM approaches, in developing longer-term approaches to reducing emissions from agriculture.

Source: Royal Society (2009), *Reaping the benefits – Science and the sustainable intensification of global agriculture*; J. Piesse and C. Thirtle (2010), *Agricultural R&D, technology and productivity*, Phil. Trans. R. Soc; B. Collard and D. Mackill (2008), *Marker assisted selection: an approach for precision plant breeding in the twenty-first century*, Phil. Trans. R. Soc; Pathak et al (2008), *Molecular physiology of plant nitrogen use efficiency and biotechnological options for its enhancement*, Current Science.

Box 7.3: The role of changed agricultural systems in mitigation

While most agricultural systems will inevitably lead to net emissions of greenhouse gases, farming systems are characterised by different mixes of inputs and practices, with differing implications for GHG emissions. Key farming systems relevant to UK production include:

- Conventional farming, which tends to be more intensive and is characterised by mechanisation and the use of synthetic inputs such as chemical fertilisers and pesticides.
- Precision farming, which involves use of spatially explicit information on soils (e.g. via GPS, sensors, and information management tools) to target inputs of nutrients and optimise nutrient supply, thereby minimising potential losses.
- Mixed farming, which combines arable and livestock production and can be effective at closing the nutrient cycle (e.g. animal wastes can be returned more easily to arable fields as fertiliser).
- Organic farming, which avoids use of synthetic fertilisers or pesticides, relying instead on organic fertilisers and crop rotation to promote soil fertility.
- Agro-forestry, which combine arable and/or livestock production with trees, relying on interactions between both to offer environmental benefits, including carbon sequestration.

In considering the relative emissions impacts of farming systems, it is important to note the following:

- There exist as many differences in farming practices within the same system as there exist across systems. Thus under any given farming system there is likely to be great variation in emissions.
- Specific management practices are not discrete and can be adopted across farming systems.
- Changing farming systems often hinges on factors such as land quality and location.

Box 7.3: The role of changed agricultural systems in mitigation

- Calculating the emissions intensity of a given farming system depends on the method employed:
 - Emissions arising from organic systems may be smaller on a per-hectare basis, due to reduced fertiliser inputs and extensive grazing methods, but emissions arising from conventional farms may be smaller when calculated on a per unit of product basis, as conventional yields are typically higher than organic yields.
 - Mixed farming systems may close the nutrient cycle, saving in upstream fertiliser and transport emissions, which are not currently captured in the agriculture MACCs.
 - Organic and agro-forestry systems can play an important role in absorbing and sequestering soil carbon, which would not be captured within the UK agriculture inventory.

If the goal is to maximise production on available land, intensive production may be beneficial from a GHG perspective, but may be associated with other environmental and animal welfare trade-offs. Given global land constraints and concerns around enhancing food security for a growing population, there is an increasing call for the sustainable intensification of global food production systems, defined as achieving higher yields from the same area of land without severely impacting the environment. This underscores the need, in developing policies to reduce emissions from agriculture, to examine trade-offs and interactions between delivering emissions reduction and other objectives of the farming sector (including productivity, animal welfare, biodiversity, air and water quality, etc.).

(ii) Measures to reduce on-farm CO₂ emissions

Farms currently emit around 4 MtCO₂ (i.e. in addition to 44 Mt of other GHGs) due to mobile machinery and stationary combustion:

- Emissions from mobile machinery (e.g. arising from diesel use in tractors, combine harvesters, mowers, sprayers and balers) are currently around 3.6 MtCO₂, with scope for reduction through use of efficient engine technology and alternative vehicle fuels.
- Emissions from stationary combustion (e.g. of natural gas for space heating in farm buildings) are currently around 0.5 MtCO₂, with scope for reduction through use of high-efficiency and biomass boilers.

AEA analysis currently commissioned by Defra suggests that there is cost-effective opportunity to reduce on-farm CO₂ emissions associated with mobile machinery and stationary combustion by 2030. Given the earlier stage of analysis we do not reflect this opportunity in our scenarios for agriculture emissions (see Section 6 below) and economy-wide emissions scenarios (see Chapter 3) but will revisit this abatement potential at a later stage.

3. Opportunities for reducing emissions through reduced food waste and changed diets

Our analysis to date has focused on changing farming practices and using new technologies as they relate to crops, soils and livestock to reduce emissions from agriculture. We now consider potential opportunities offered through changes in consumer behaviour as they impact agriculture production emissions.

Reducing food waste

Our analysis of scope for reducing non-CO₂ emissions from waste (Chapter 3, Box 3.8) includes emissions reduction from diverting food waste from landfill. However, diverting food waste does not avoid emissions associated with production and distribution of food, and therefore additional emissions reductions are available where waste can be reduced.

Currently around 16 million tonnes⁴ of total UK food and drink is wasted:

- 8.3 million tonnes are wasted by households
- 3.6 million tonnes are wasted in the retail sector and the supply chain
- 4 million tonnes are wasted elsewhere, such as in schools, the hospitality sector, and agriculture; although these waste stream estimates require further analysis
- Of the 8.3 million tonnes wasted by households, 5.3 million tonnes or around 15% of total food and drink purchased is waste that could be avoided through the introduction of good practices
- Total emissions associated with this avoidable food waste (5.3 Mt) are estimated to be 20 MtCO₂e on a consumption basis⁵, with UK agriculture emissions from soils and livestock accounting for around 6.5 MtCO₂e (32%) of this
- The associated annual cost is of the order £12 billion in total, equivalent to around £480 per household.

Analysis by WRAP suggests that up to half of avoidable household food and drink waste (or 2.7 Mt) could be prevented through simple measures including information-provision and engagement with retailers, brands, local authorities and householders to encourage reduced food waste. If this level of reduction in food waste were to be achieved the corresponding emissions reduction could be up to 10 MtCO₂e on a consumption basis:

- 3.2 MtCO₂e could result from savings in agricultural production, although it is difficult to estimate the likely impact of food waste reduction measures on agricultural emissions. For example, better planning, storage, and packaging may reduce household purchase of food, but it is not clear whether this would result in a corresponding reduction in agricultural production (e.g. the food and drink sector could export more products).
- 1.2 MtCO₂e could result from avoided landfill emissions due to not purchasing food that would otherwise be wasted and end up in landfill. This is additional to waste abatement potential in Chapter 3 which does not include diversion of household food waste from landfill.

Notwithstanding challenges in changing behaviour to addressing this opportunity, it is available at negative cost (i.e. saves households money) and social research evidence suggests people are keen to reduce waste.⁶ Therefore policy effort in this area is worthwhile.

⁴ WRAP (2010), *Waste arisings in the supply of food and drink to households in the UK; updated following personal communication with WRAP.*

⁵ WRAP (2009), *Household Food and Drink Waste in the UK*; This figure includes contributions from the relevant elements of the food and drink sector including agriculture, manufacture, packaging, distribution, retail, transport to the home, storage and preparation in the home and waste treatment and disposal (net of emissions associated with exports).

⁶ Owen, L., Seeman, H., and Prince, S (2007), *Public Understanding of Sustainable Consumption of Food: A report to the Department for Environment, Food and Rural Affairs*; WRAP (2010), Results of Courtauld Commitment Phase I.

Reducing emissions through changed diets

Varying carbon intensity of different foods

In our 2008 Report we presented evidence, based on life-cycle analysis of GHG emissions arising from food products, which showed the relatively higher carbon intensity of red meat products. This reflects the inefficiency of sheep and cows at processing food, and emissions arising from their digestive processes (Figure 7.9):

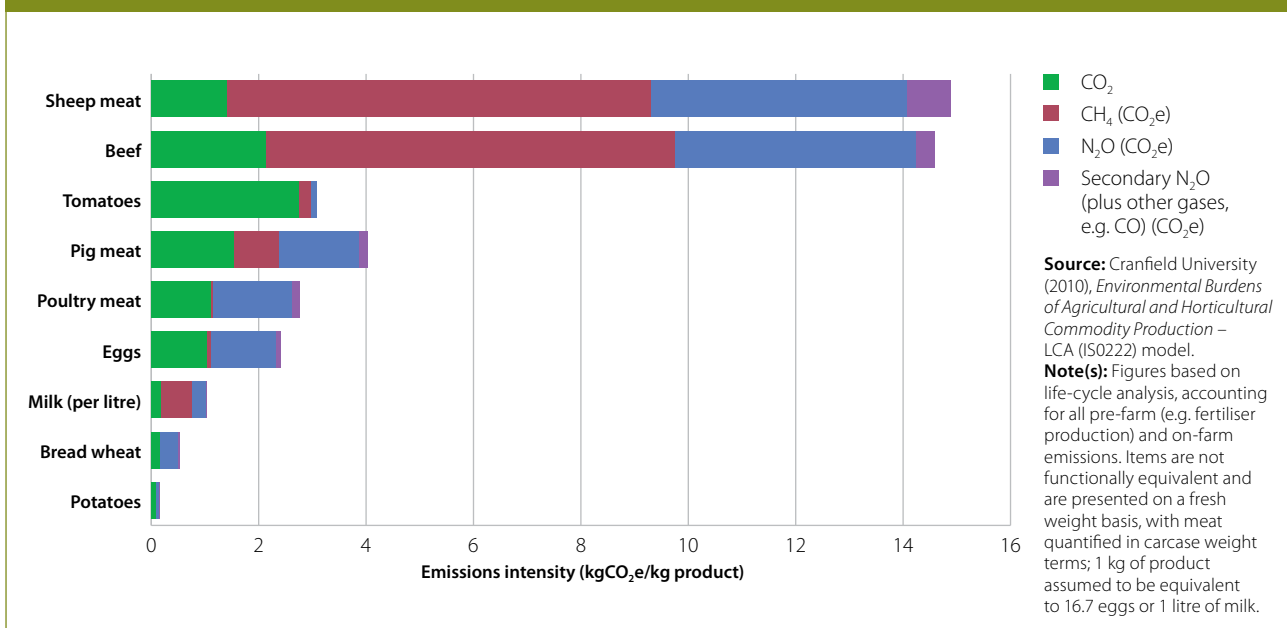
- Cows require 15.6 kg and sheep require 27.7 kg of feed (concentrates, grass, and barley), to produce 1 kg of meat. This may be compared to pigs and chicken, which require 4.2 kg and 3.1 kg respectively for each kg of meat.⁷
- Cows and sheep are ruminant animals, feeding on grass and digesting this through a process called enteric fermentation, giving rise to significant methane emissions.

In effect, cows and sheep require relatively high amounts of grass and feed, producing large amounts of methane, which has a much higher Global Warming Potential than CO₂ (around 25 times).

We suggested in the 2008 report that rebalancing diets towards less emissions-intensive foods could therefore reduce emissions. We recommended that this should be considered to meet the 2050 target, subject to a number of issues around land-use impacts, nutritional content of diet, and emissions accounting being addressed:

- Ruminants convert grass (which cannot be digested by other animals) into food (e.g. meat and dairy) and use grassland that in some cases cannot be used for other purposes (e.g.

Figure 7.9: Estimated GHG emission intensities of different food products



⁷ Cranfield life-cycle assessment (LCA) model (2010); Estimates are averages across several possible breeding and finishing systems in the UK; Cranfield University (2010), *The effect of changes in UK food consumption patterns on land requirements and greenhouse gas emissions*, Table 11.

for arable crop production and/or forestry). Therefore changing diets requires increased production of substitute commodities (e.g. crops for human consumption) and as a result could lead to land-use change and related emissions (e.g. release of soil carbon) both domestically and abroad.

- Food products have different nutritional characteristics and cannot be treated as direct substitutes. Therefore any change in diet would have to deliver adequate nutritional content.
- Food products (and feed inputs) are both imported and exported, so any change in UK food consumption may not impact UK food production and emissions. This is an issue given the accounting framework under the Climate Change Act, which is based on production rather than consumption emissions. It raises the possibility that changed diet would not contribute to meeting carbon budgets, notwithstanding any global benefits that this would give rise to. It reflects a broader issue around production-versus consumption-based accounting approaches to emissions, to which the Committee will give future consideration.

New analysis of emissions impacts of changed consumption

We commissioned Cranfield University to assess scope for emissions reduction through consumption change, including impacts on land-use change and emissions, by addressing three key questions:

- Can UK land support a reduction in the consumption of meat/dairy products and an increased production of substitute goods?
- What are the net GHG emissions and land-use impacts of this change (including soil carbon releases/sequestration, feed production impacts, and N₂O and CH₄ emissions)?
- If the UK cannot wholly support consumption change, what are the international implications GHG emissions (land-use and GHG impacts)?

The analysis uses three illustrative scenarios with different degrees of consumption change away from red and white meat and dairy products⁸:

- **Scenario 1:** A 50% reduction in livestock product supply balanced by increases in plant commodities
- **Scenario 2:** A shift from red (e.g. beef and sheepmeat) to white (pigs and poultry meat), with no overall reduction in livestock consumption
- **Scenario 3:** A 50% reduction in white meat supply balanced by increases in plant commodities

Each scenario would provide comparable levels of energy, protein and fat supply as current average UK consumption patterns (Table 7.1). In general there are likely to be health benefits from reducing excessive animal protein intake (Box 7.4) although further work is required to determine the health impacts of low-carbon diets for other groups of nutrients.

⁸ The Cranfield study refers to red meat as ruminant (beef and sheep) and white meat as monogastric (pig and poultry) whilst acknowledging pigmeat is not strictly defined as white meat in nutritional terms.

Table 7.1: UK average macronutrient levels as affected by consumption change scenarios

Scenario	Energy Supply (kcal/day)			Protein supply (g/day)	Fat supply (g/day)
	Livestock products	Non-livestock products	Total		
Baseline: Average UK consumption patterns (2004)	957	2334	3291	103	128
Scenario 1: 50% reduction in animal products	482	2843	3325	89	111
Scenario 2: Switch from ruminant (beef/sheep) to monogastric (pigs/poultry) products	956	2334	3290	105	120
Scenario 3: 50% reduction in monogastrics products (pigs/poultry)	843	2471	3314	97	125

Source: Cranfield University (2010), *The effect of changes in UK food consumption patterns on land requirements and greenhouse gas emissions*.

Notes: The consumption scenarios relate to the flows of food commodities entering the food system (e.g. production plus imports net of exports). The macronutrient levels are derived using integrated FAOSTAT data sets for the energy, protein and fat content of various food commodities supplied in the UK.

Box 7.4: Nutritional and public health impacts of consumption change

The consumption change scenarios analysed in the Cranfield study involve significant changes to average UK food consumption patterns that may appear unlikely or extreme today. However there are likely to be nutritional and public health benefits from reduced consumption of livestock products.

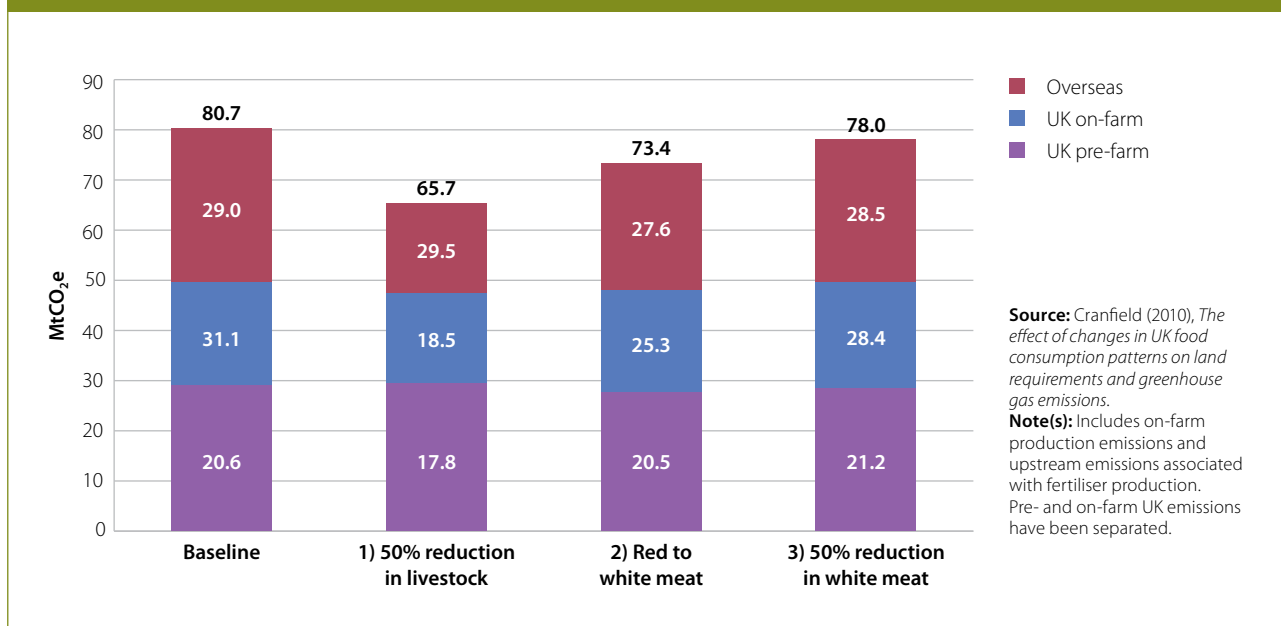
The Food Standards Agency's 'eatwell plate' depicts the types and proportions of foods recommended for a healthy and well-balanced diet. Meat, grouped with fish, beans and other alternatives, and dairy, is part of the recommended balanced diet (although it is recommended that individuals eat moderate amounts, choose lower fat versions, and use smaller quantities of meat in dishes). While there have been positive changes in UK diets over the last 15 years, reflecting a general move towards healthier consumption patterns, UK consumers are, on average, not consuming diets in line with dietary targets and guidelines:

- UK households consume animal protein in excess of what is recommended by reference nutrient intake levels, with animal protein comprising a larger share of intake. The UK Scientific Advisory Committee on Nutrition has recommended that individual consumption of red and processed meat should not rise and that high consumers should consider a reduction with the aim of reducing the risk of colorectal cancer.
- Average per capita fruit and vegetable consumption, while increasing, remains below the recommended level of five portions per day.
- Intake of saturated fat, of which excessive consumption is linked with cardio-vascular and coronary heart disease, exceeds recommendations in all age groups (foods high in saturated fat are often more processed, and thus may also have greater life-cycle emissions associated with refrigeration, heating and reheating, etc.).

Notwithstanding concerns about vulnerable people (e.g. children, elderly and lower socioeconomic groups), the above suggests that there are potential health, in addition to GHG emissions, benefits of dietary change away from livestock products and processed foods, which could be brought about by diets moving more in line with healthy eating guidelines. Further analysis of the nutritional impacts of low-carbon diets, particularly in consideration of impacts to micronutrients (e.g. iron) is required.

Source: Scientific Advisory Committee on Nutrition (2008), *The Nutritional Wellbeing of the British Population*; J. Kearney (2010), *Food consumption trends and drivers*, Phil. Trans. R. Soc.

Figure 7.10: Agriculture GHG emissions associated with current UK consumption patterns and consumption change scenarios



The Cranfield analysis shows that all scenarios result in direct emission reductions, with more significant reductions in scenarios with reduced red meat and dairy consumption (Figure 7.10).

- **Scenario 1:** Direct emissions associated with UK agricultural production would fall by 13 MtCO₂e within the UK, or by 40% from estimated current levels⁹; emissions arising abroad related to supporting UK consumption patterns would increase slightly by 2%.
- **Scenario 2:** UK emissions would fall by 6 MtCO₂e, or by 19%; emissions abroad would fall by 5%.
- **Scenario 3:** UK emissions would fall by 3 MtCO₂e, or by 9%; emissions abroad would fall by 2%.

Therefore on the basis of direct emissions impact, diet change has a potentially useful contribution to make to meeting carbon budgets. However, it is also necessary to account for land-use impacts before asserting that this is unambiguously the case.

Land-use impacts

The study calculates that currently around 21 million hectares of land (14.6 million hectares within the UK and 6.4 million hectares overseas) are required to support current UK food consumption patterns, with the bulk of this land accounted for by livestock production (Figure 7.11):

- Grassland accounts for around 60% of total land used to support UK food consumption, with the vast majority of this (around 85%) in the UK. Approximately 40% of total grassland within the UK was determined to have some arable potential (i.e. suitable for purposes other than grazing).

⁹ Cranfield's LCA model includes both upstream emissions associated with fertiliser production as well as on-farm emissions. Both emissions sources are presented in Figure 7.10.

Figure 7.11: Domestic and overseas agricultural land used to support current UK consumption patterns

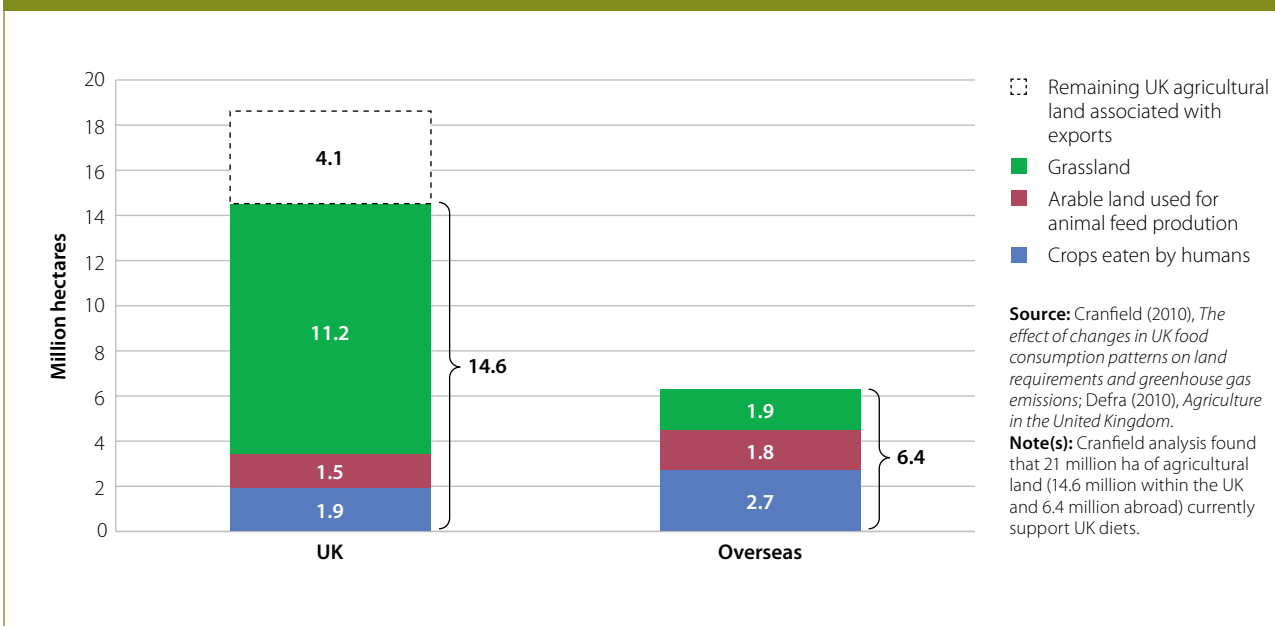
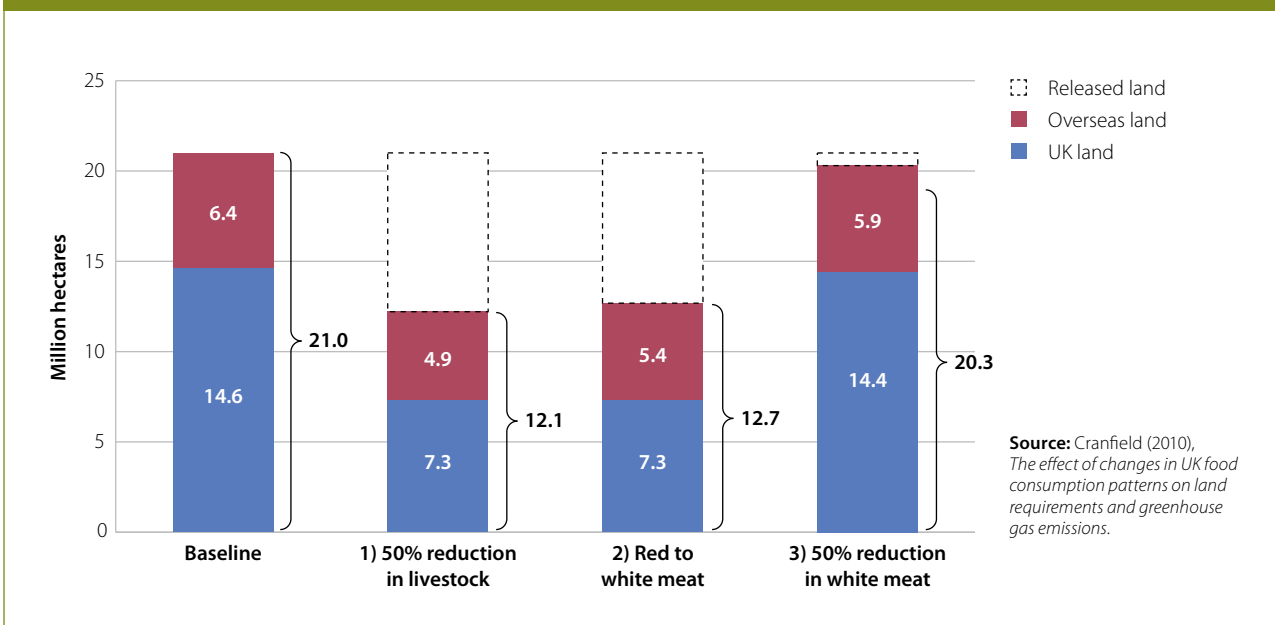


Figure 7.12: Agricultural land requirements under consumption change scenarios



- Arable land used to grow feed for livestock accounts for around 16% of total land, with roughly equal amounts in the UK and overseas.
- Around 22% of total land is used for growing crops for human consumption, with the majority of this (around 60%) overseas.

In considering land-use impacts, it is important to recognise that sheep and cows are inefficient processors of food compared to chickens and pigs. Therefore reduced consumption of red meat and substitution for more white meat (and crops for consumption by humans) is likely to free up land. This is borne out in the Cranfield analysis, which suggests that diet

change could free up to around 40% of land used (both domestically and overseas) to support current UK food consumption (Figure 7.12):

- **Scenario 1:** UK land requirements fall by 50% and overseas land requirements by 24%
- **Scenario 2:** UK land requirements fall by 50% and overseas land requirements by 15%¹⁰
- **Scenario 3:** UK land requirements do not change but overseas land requirements fall by 8%

The potential emissions impact of *changing* land use within UK farming to support changed diets (e.g. release of soil carbon from converting land) depends on how freed-up land is used. For example, depending on its quality, land released from growth of crops for animals can be used to grow crops for humans with limited emissions impact.

The emissions impact of *converting* land released from the scenarios again depends on how this land is used. Scenario 1, for example, estimates that 7.3 million hectares could be freed up within the UK of which 0.3 million hectares is arable land and 2.4 million hectares is grassland with some arable potential. Freed-up land could be used for:

- **Extensification of livestock production:** Released grassland could be used more extensively for beef, sheep, and dairy production by using clover to fix nitrogen rather than synthetic fertilisers. Extensification could result in an additional saving of up to 1.7 MtCO₂e through fertiliser reductions.¹¹ Under this management option, some of the positive aspects of livestock could be maintained (e.g. use of crop residues and food waste as feed, use of lowest quality land, and reduced stocking densities continuing to provide ecosystem services at desired levels).
- **Increasing food production:** All potentially tillable land could remain cultivated or be converted to arable land to increase food production for export, which may be required given increasing global population. Similarly all grassland could continue in animal production for export. Agriculture production emissions would increase as would land-use change emissions associated with conversion of freed-up land to arable land.
- **Bioenergy production:** Released arable land could be used for increasing the growth of feedstock for bioenergy.
- **Forestry:** Agriculture land could be converted to forestry, managed for sequestering carbon or for substituting fossil fuel use in other sectors (e.g. biomass and building materials).
- **Other purposes,** such as house-building.

Some of these purposes potentially generate wider environmental and biodiversity benefits as well as economic benefits. Other purposes (e.g. house-building) could, depending upon the specific nature of the land, impose additional environmental costs. In reality, land use allocation and decisions are determined by numerous factors, including economic forces,

¹⁰ Pig and poultry production depends on feed crops, which compete directly with land used to grow crops for human consumption. While under this scenario the overall release of arable quality grassland exceeds the increased land required to grow feed crops for pigs/poultry, it is important to note that UK demand for overseas land to grow feed crops would increase relative to baseline levels.

¹¹ Emissions savings associated with upstream fertiliser production and on-farm N₂O emissions.

regulatory regimes and by the location and underlying characteristics and qualities of the land in question.

The recent Foresight Land Use Futures Project¹² finds that current UK policies do not take into account the ecosystem services provided by land and suggests a set of interventions to address this. While not explicitly considering the potential role and consequences of dietary change on land use, the report concludes that policies are needed to make better use of the land across the UK for climate change mitigation and for supporting the transition to a low-carbon economy (as well as managing the impacts of changing climate, Box 7.5).

Summary of emissions impacts through changed consumption

The Cranfield analysis shows that there is clear scope for emissions reduction due to changed consumption, and net of any emissions due to land-use change. For example, under Scenario 1, UK and overseas emissions associated with agricultural production to support UK consumption could be reduced by around 20% (and agricultural land used to support UK consumption could be reduced by 40%). This is in contrast to our previous cautious approach, where we suggested that emissions reduction from consumption change may be limited due to impacts of land-use change.

We do not explicitly reflect the potentially significant opportunity for direct and land-use related abatement from diet change into our agriculture emissions scenarios (Section 6 below). However we recommend that the Government should consider encouraging a less emissions intensive diet alongside other motivators (i.e. nutrition benefits). We consider policies to encourage dietary change in Section 5.

Box 7.5: Impacts of climate change on UK agriculture

The impact of climate change on UK agriculture is likely to be mixed. There will be increased yields of some crops and the possibility to grow new crops, however there will be risks from new pests and diseases, water shortages and reduced soil quality.

Some of these impacts may be apparent by the 2020s; however the natural variability of UK climate from year to year may be just as important as the long-term warming trend from greenhouse gas emissions over this timescale. For example, UKCP09 projections suggest that by the 2020s, summer mean temperature could increase between 0.5°C and 2.5°C and summer precipitation could change between -25% and +10%, while recent climate has shown annual variations of a similar magnitude. Beyond the 2020s, however, we are committed to continued (and potentially much greater) long-term change.

Source: Met Office Hadley Centre observation datasets, <http://hadobs.metoffice.com/hadcet/>.

¹² The Government Office for Science (2010), *Foresight Land Use Futures Project Final Project Report*.

4. The role of land use, land-use change and forestry (LULUCF)

Emissions from LULUCF activities are made up almost entirely of emissions from the conversion of land to cropland and settlements, which are largely offset by land converted to forestry and grassland.

- CO₂ is released from soils and biomass due to land being converted to cropland, tillage practices and from forests following harvesting of wood.
- Conversely, 'sink' emissions arise from converting land to pasture or forestry from other uses. This helps to remove CO₂ from the atmosphere through increases in forest and organic matter in soils, and avoidance of degradation of these stores.

Emissions trends and projections

On a net basis, the LULUCF sector absorbed 2 MtCO₂ in 2008 (Figure 7.13). Net emissions have moved from increasing marginally, to reducing marginally the UK's total emissions between 1990 and 2008. From 2013 onwards, LULUCF is forecast to revert to a net emitter due to a decline in the historical planting rate.¹³ LULUCF emissions projections to 2030 are not currently available (Figure 7.14).

In our 2008 report, we suggested that there is emissions reduction potentially available for this sector. We recommended that the UK Government and the devolved administrations should consider how the policy framework might be developed to unlock this potential and/or provide additional biomass supply as part of a broader forestry and land use strategy.

LULUCF abatement options – forestry

There are two key options for emissions reduction through forestry:

- Sequestration, whereby more trees are planted, removing and storing carbon from the atmosphere; this is a one-off measure, offering scope for reducing emissions until a forest reaches saturation point, beyond which no further carbon is absorbed.
- Substitution, such that biomass produced in the forestry sector can substitute for fossil fuels in other sectors (e.g. biomass for heat and energy and building materials); this allows ongoing emission reductions given that biomass crops do not reach saturation point.

Analysis by the Forestry Commission suggests that there is significant scope for emissions reduction through planting more trees (e.g. up to 3 MtCO₂e in 2030, and 5 MtCO₂ in 2050) (Box 7.6). This is reflected in planned tree planting programmes in Scotland and Wales and which we reflect in our emissions scenarios.

We also note scope for increasing biomass production in the UK, which we include in our scenarios for power, transport, and buildings and industry emissions. Our scenarios for transport, heat and power in the 2020s assume around 300 TWh of primary energy use. Analysis by E4tech¹⁴ suggests around 250 TWh of resource could be produced in the UK,

¹³ This may also reflect, in part, the cyclical nature of emissions from forestry and the method by which emissions are reported in the LULUCF inventory.

¹⁴ E4tech for DECC (2009), *Biomass supply curves for the UK*.

Figure 7.13: LULUCF emissions (1990-2008)

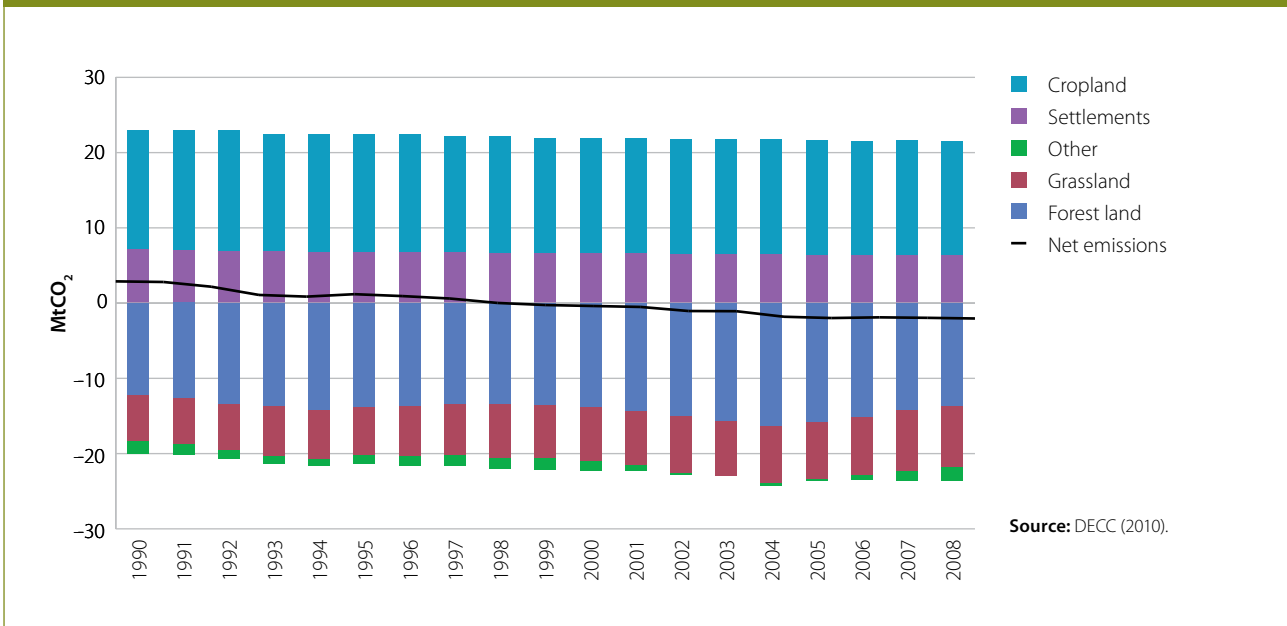
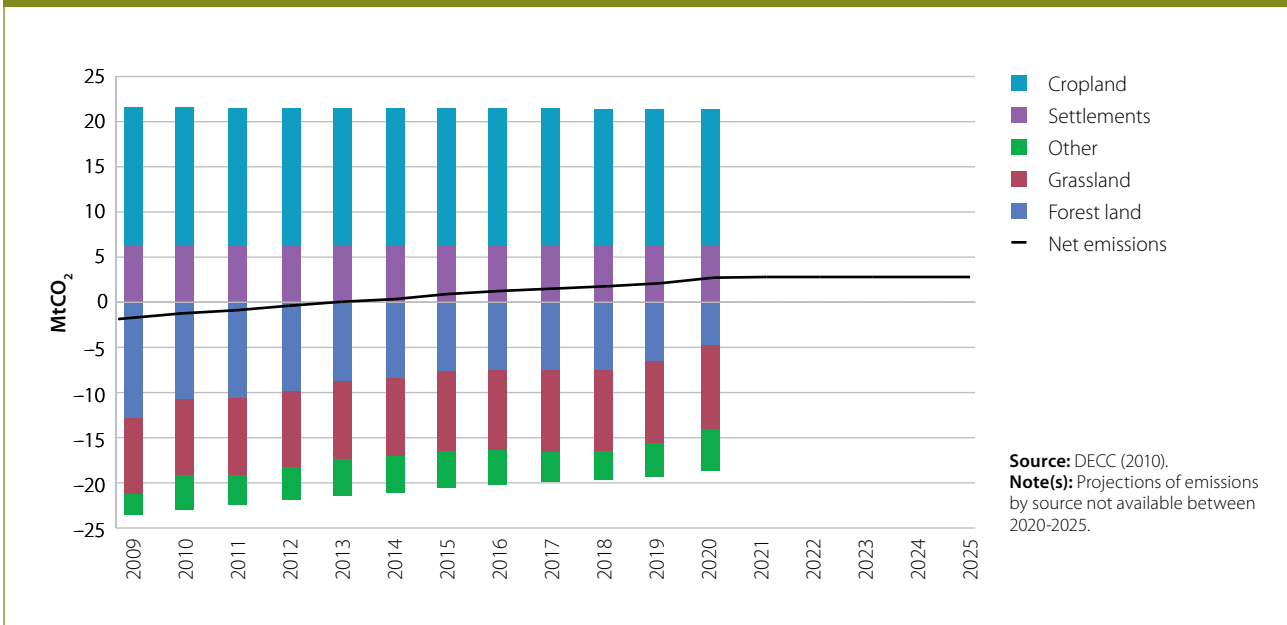


Figure 7.14: LULUCF emissions projections (2008-2025)



mainly from wastes, manures, and residues, but including up to 85 TWh from energy crops and forestry, with an implied land take of approximately 1.2 million hectares. We will consider further scope for increasing UK biomass production in the context of our Bioenergy Review to be published at the end of 2011.

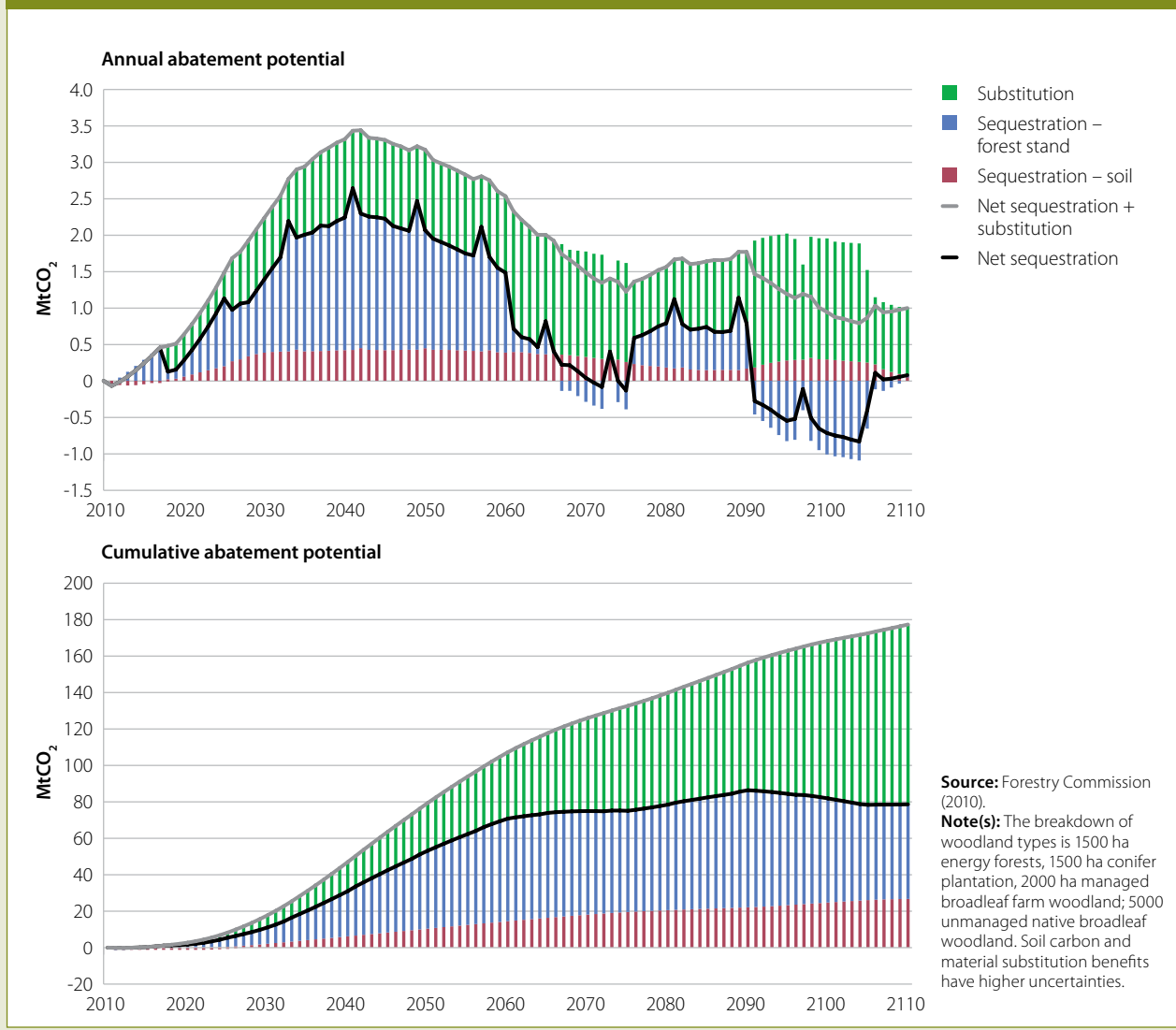
Box 7.6: Forestry Commission Read Report on Forestry

The Forestry Commission's Read Report on Forestry (November 2009) considers various forestry mitigation options and concludes that afforestation, or greater woodland creation, offers the greatest abatement opportunities in the medium to long term. The report examines two illustrative scenarios for a 15-year woodland creation programme that could deliver additional abatement potential through sequestration of carbon in soils and forest biomass and substitution for fossil fuels occurring in other sectors at a cost less than £70/tCO₂e:

- A 10,000 hectare per year woodland creation programme could cumulatively remove 53 MtCO₂ from the atmosphere through sequestration by 2050, rising to 80 MtCO₂ if biomass products were used to displace fossil fuels. This would result in an annual abatement level of 1 MtCO₂ being absorbed in 2030 and 2 MtCO₂ in 2050 (Figure B7.6).
- A 25,000 hectare per year programme could cumulatively remove up to 130 MtCO₂ through sequestration and 200 MtCO₂ in total including substitution by 2050. This would result in an annual abatement level of 3 MtCO₂ being absorbed in 2030 and 5 MtCO₂ in 2050.

The land requirements implied in the above scenarios is 150,000 – 375,000 hectares (at present UK forests encompass 2.8 million hectares). The report notes a range of additional unvalued benefits from forestry, with potential benefits in helping the UK adapt to climate change.

Figure B7.6: Estimated emissions abatement potential from a 15-year 10,000 ha woodland creation programme



LULUCF abatement options – agriculture and other land management practices

Various land management practices can sequester carbon although it is not clear whether such practices result in additional abatement and thus whether they offer true additional mitigation potential¹⁵:

- Crop residues, manures and biosolids:
 - Application of crop residues, manures and biosolids can retain soil carbon, but are generally applied to land under baseline conditions and as such the additional mitigation benefits are unclear.
 - However, incorporating organic wastes such as paper crumble can be considered genuine additional carbon storage against baseline conditions.
- Reduced tillage: There is uncertainty regarding the effect of reduced tillage of agricultural soils on net GHG emissions (i.e. this practice would reduce the release of stored carbon but can increase the rate of oxidation of methane from the atmosphere).
- Biochar:
 - This is produced through the partial combustion of biomass (e.g. biofuels crops, straw or wastes) in limited oxygen.
 - The potential benefits of applying biochar to soils include a permanent increase in soil carbon, stabilisation of other soil carbon, suppression of other GHGs (e.g. N₂O emissions), and enhanced fertiliser-use efficiency.
 - These effects have yet to be widely demonstrated in the UK context although recent field-scale trials have indicated modest benefits.
 - There are potential risks associated with biochar production and use, including life-cycle emissions arising from combustion, land-use implications from sourcing biomass to produce biochar, and damage to soils.
- On-farm woodland planting: Trees in field boundaries, for example, can provide additional abatement, if permanent, or if managed for biomass.

Given uncertainties, we do not include any emissions reduction from these measures in our emissions scenarios, but will return to some of the issues above in our forthcoming Bioenergy Review.

¹⁵ Food Climate Research Network, Soil carbon sequestration workshop, January 2010.

LULUCF abatement options – peat restoration and reducing horticultural use of peat

Peat soils are organic soils that have accumulated in waterlogged conditions over thousands of years, and currently store around 5,500 Mt of carbon in the UK. When in good condition, peat soils sequester carbon from the atmosphere, but when degraded or damaged they can become net carbon sources, as well as release other greenhouse gases (methane and nitrous oxide). Carbon release from peat is estimated to have been at least 1.5 MtCO₂ in 2008, and possibly significantly higher (Box 7.7).

There is an opportunity to reduce peat emissions in future through less use of peat in horticulture (and therefore reduced peat extraction), and the restoration of degraded and damaged peatlands (i.e. raising the water table and re-establishing peat-forming vegetation).

However, the scale of quantifiable abatement potential in this area is uncertain, and emission reductions would not be well captured in the UK emissions inventory. Therefore our approach is to highlight the need for further work in order to better understand the scale of the opportunity, and to recommend that inventory measurement of peat emissions is revisited in order to accurately reflect emissions and emission reductions, so that any future progress in this area can contribute to meeting carbon budgets.

Box 7.7: Emissions and abatement from peat soils

Of the 10,000 Mt of carbon stored in UK soils, 55% are locked up in peat lands. UK peat soils have been degraded over time due to intensive agricultural practices (e.g. drainage, burning, over-grazing and cultivation), extraction for horticultural purposes and industrial emissions. There is some scientific uncertainty about current emissions arising from peat soils although it is generally felt that the LULUCF inventory underestimates emissions from peat. According to the UK inventory, emissions associated with peat soils were equivalent to 1.4 MtCO₂ in 2008:

- 1.1 MtCO₂ from historic drainage of lowland fen
- 0.3 MtCO₂ from extraction for horticulture use

Other analysis suggests that the figure is much higher. A recent study by Natural England finds that the majority (~75%) of England's peatlands are in a degraded condition and as such total emissions are likely to be of the order of 3 MtCO₂. Emissions arising from the drainage of peat lands located in the UK uplands are not covered in the LULUCF inventory because of lack of data.

In addition to mitigation benefits, peat restoration may also be an important adaptation measure, as the impacts of climate change may accelerate carbon losses from degraded peatlands in the future (through changes in soil moisture, water regimes and warmer temperatures), while providing a range of co-benefits, including improved water quality, reduced downstream flood risk and enhanced biodiversity.

Source: Natural England (2010), *England's peatlands: Carbon storage and greenhouse gases*.

5. Policies to support agriculture and LULUCF emissions reduction

Many of the options to reduce emissions from agriculture and LULUCF in the longer term would require marked departures from current policies. Given the long lead-time to 2030 there should be scope for technological advancement and the development of stronger policies to support behavioural change to reduce agricultural emissions. For LULUCF, long planning horizons mean that early action is required to deliver abatement potential.

Policies to support reduced emissions from soils and livestock

We have set out our assessment of policies to support greater uptake of soils and livestock measures in our 2010 Progress Report to Parliament, and we provide a summary here for completeness.

We have considered five policy options:

- **Voluntary agreements:** agreements between industry and the government to reduce emissions. Voluntary agreements are often backed up by the threat of legally binding rules or stringent monitoring and enforcement systems.
- **Information provision:** providing better information and advice to farmers on best practice to reduce GHG emissions, and developing a better understanding of emissions reduction opportunities by getting better information about the baseline state of farming practices.
- **Grants, subsidies, charges, levies and taxes:** encompassing a wide mix of incentives and penalties to encourage low-carbon farming, implemented at either the EU or UK level. For example, the EU Common Agricultural Policy, which is up for revision in 2013, could be reformed to link subsidies and incentives more closely to environmental objectives, including climate change mitigation. In addition, there is the possibility of an EU-wide carbon tax which could be extended to agriculture. Any UK charges, levies or taxes would have to address concerns about competitiveness impacts (e.g. through taxing at point of sale rather than upstream).
- **Cap and trade scheme:** placing a price on GHG emissions from agriculture and providing incentives to encourage farmers to find efficient ways to lower their emissions. To the extent that there are competitiveness concerns these could be addressed through issuing free allowances or recycling revenues.
- **Direct regulation:** introducing emissions standards or limits from agricultural practice or restricting/requiring certain farming practice.

The industry-led approach should strengthen incentives to action. However, stronger levers may be required, particularly to deliver more expensive measures.

In its response to our 2010 Progress Report the Government acknowledged that the industry-led approach will be supported by other policies, such as the EU Nitrates Directive and the UK Nitrate Action Programme or CAP reform, which could generate greenhouse gas emission benefits. The Government will need to consider whether further policy strengthening is

required, particularly to encourage uptake of more expensive measures. It has committed to undertake a review in 2012 of progress made under the GHG Action Plan, which should consider the range of options for Government intervention to supplement industry action, in the event that the current voluntary approach does not deliver in full. This should include action at EU level since changes to the CAP provide a potential way to minimise any competitiveness impacts on UK agriculture.

We further note the potential role of environmental benchmarking, or comparing industry performance against good practices to promote efficiency improvements. Benchmarking is proving effective in other sectors, and is a big component of the Carbon Reduction Commitment where the use of performance league tables and mandatory reporting (ranking of performance in published tables) could provide reputational incentives to organisations to improve energy efficiency. Some food retailers are at present driving efficiency improvements in farming across energy, fertiliser and feed inputs through use of benchmarking tools. While not the full solution to promoting greater uptake of mitigation measures, benchmarking is likely to be effective for unlocking cost-saving measures.

Policies to encourage food waste reduction

Policies to reduce food waste include raising consumer awareness and working with the food industry to reduce food waste in the supply chain. WRAP has found initial success in reducing household waste through information campaigns and changes in retail environments (e.g. through focus on better storage and pack/portion sizes). Going forward, there is scope for further engagement with the food industry to reduce food waste (e.g. through improved demand forecasting and changes to contractual arrangements).

Policies to encourage changed diet

As for supply-side abatement, there is a range of potential policy options to encourage diet change, from awareness-raising to providing financial incentives:

- **Awareness-raising.** Progress has been made on developing guidelines for determining the carbon footprint of goods and services including food, although there are complexities relating to trade-offs between objectives (e.g. carbon and wider environmental, or animal welfare). The effectiveness of awareness-raising will depend on the extent to which people care about their carbon footprint, and whether this translates into action. Evidence suggests a likely limited response based on current attitudes and behaviours (Box 7.8); elsewhere in the food sector, evidence suggests that there has been some, but not comprehensive, response to health labelling and promotion of healthy foods.
- **Retail and supply chain leadership and/or agreements.** Retailers are examining opportunities to reducing emissions embedded in their products and the role of labelling in promoting alternatives to carbon intensive food. Given that UK grocery market share is concentrated amongst a small number of retail players, there should be scope for industry and government to work together to promote low-carbon food.

- **Choice editing.** Government and/or industry could influence the choices made by consumers by offering products with lower carbon intensities (e.g. smaller portion sizes, ready-made meals and sandwiches with lower meat content).
- **Introducing a carbon tax on food.** This would reflect the relative carbon content of different products and therefore provide a strong signal about full costs (resource and carbon) for consumer decisions (Box 7.9). It could be introduced at UK or EU levels. If a carbon price were introduced, risks relating to other objectives (e.g. affordability of basic foodstuffs, availability of nutritional substitutes, impacts on vulnerable groups) would need to be addressed. Emissions leakage could be avoided if levies were placed on goods at the point of sale. Carbon taxes on food could require retailers to know the footprint of all suppliers, which would require standardisation of footprinting methodologies.

From a general perspective, and based on experience in other sectors (e.g. uptake of simple energy efficiency measures) awareness-raising, whilst useful as a complement to other levers, is unlikely to result in deep cuts alone. Retail and supply chain leadership agreements could be useful (e.g. as in the case of phasing out incandescent light bulbs), but have again had limited impact in reducing emissions more generally (e.g. as regards purchase of efficient appliances). Therefore we recommend that the full range of measures, from awareness-raising to introduction of a carbon price for food, are seriously considered by Government in order to deliver the significant emissions reduction potential that we have identified on a pathway to 2050.

Box 7.8: Role of carbon labelling in influencing consumer behaviour

A number of UK food companies and retailers have in recent years chosen to voluntarily carbon label their own branded products. Some have worked with the Carbon Trust, using standardised methodologies, to calculate the carbon footprints of selected products, and have committed to reducing emissions over two years. While the primary role of labelling to date has been to provide incentives to companies to document and manage their supply chain emissions, researchers have examined the likely impact of carbon labelling on consumer behaviour, which reveals the following:

- Few people think about the environment when shopping
- Most shoppers take little notice of nutrition labels and would be no more likely to read carbon labels
- Many would not be willing to pay a premium for a carbon-labelled product, although labelling may be effective if the lower-carbon product is cheaper than a substitute
- Those who try to base purchasing decisions on environmental and ethical factors have limited understanding of how shopping relates to carbon emissions
- Many are puzzled by the use of grams (e.g. gCO₂/pack) as a measure of emissions
- People question the technical reliability of carbon labelling and some are cynical about the motives of companies that provide labelling

If carbon labelling is adopted more widely, surveyed individuals have recommended that approaches should be standardised across the food industry and should function to remove the most emissions-intensive products from shelves. Shoppers should also be provided with better context as to what the information means and should be directed towards lower-carbon alternatives.

Source: Tyndall Centre Manchester (2009), *Carbon Labelling: Public Perceptions of the Debate*, Report to the Sustainable Consumption Institute, University of Manchester.

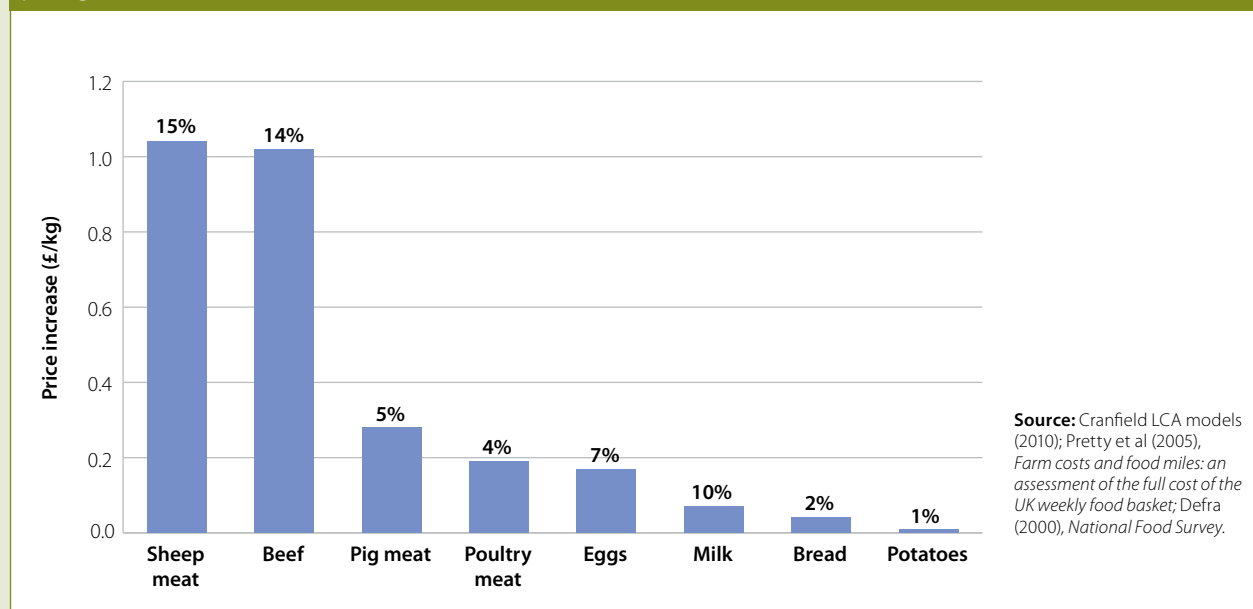
Box 7.9: The GHG impact of introducing a carbon tax on food

Changing diets is a controversial issue but one that could be effective at reducing the emissions and land-use impact of agriculture. Taxes have been effective in other sectors to change consumer behaviour (e.g. fuel duties have been shown to be powerful levers to affect choice of car and fuel use) and may also be an efficient instrument to reduce agricultural emissions. We consider below the emissions impact of introducing a carbon consumption tax on GHG intensive food commodities, using the following data sources:

- Life-cycle assessment data on the emissions intensities of food products (Cranfield University LCA model – Figure 7.9)
- Published demand price elasticity data for key food products (Defra (2000), *National Food Survey*)
- Typical UK weekly food basket and expenditures (Pretty et al., 2005)

The possible impact of a carbon price of £70/tCO₂e in 2030 on the price of key food commodities is summarised in Figure B7.9 below.

Figure B7.9: Potential increase in food prices as a result of a carbon tax, 2030 (based on average emissions per kg of food)



A static high-level assessment suggests that a carbon price of £70/tCO₂e in 2030 could result in a direct emissions reduction of around 1.3 MtCO₂e (or a 6% reduction in emissions from the basket of goods considered). We have not conducted in-depth analysis to calculate the impact of substitution towards other food products, given a lack of specific data on cross-price elasticities. However the relatively lower emissions intensities of substitute products (e.g. cereals and vegetables) suggests an overall net reduction in GHG emissions is possible:

- A recent study (Wirsenius, Hedenus and Mohlin, 2009) finds a carbon tax of €60/tCO₂ on animal food products could reduce EU agricultural emissions by 7%, even while accounting for the emissions impact of substitute products.
- The Cranfield analysis (Section 3 above) finds that consumption change away from livestock products and towards plant-based substitutes results in a net reduction in GHG emissions (even while accounting for land-use change effects).

The above calculations are presented for illustrative purposes but suggest that carbon taxes on food could be an effective lever to curb emissions from agriculture in the long term.

Source: J.N. Pretty et al. (2005), *Farm costs and food miles: An assessment of the full cost of the UK weekly food basket*; Defra National Food Survey (2000); Cranfield LCA model (2010), Defra Research Project ISO0205; Wirsenius, Hedenus and Mohlin (in press), *Greenhouse gas taxes on animal food products: Rationale, tax scheme and climate mitigation effects*, *Climatic Change*.

Policies to encourage afforestation

Given long lead-times, encouraging abatement from afforestation will require a planned rather than reactive approach. In addition to existing regulatory powers, including the issuance of felling licenses and planning consents, policy options to support such an approach include:

- Encouraging private financing (e.g. through recognition of forestry projects in corporate reporting guidelines).
- Fiscal incentives, such as grants or tax incentives to encourage businesses or individuals to plant more trees.
- Changes to building regulations which encourage the use of wood in construction and which indirectly increase the demand for forestry products, some of which may come from UK forests.
- Research to reduce the future risks and to manage existing outbreaks of pests and diseases, including the development of appropriate and effective interception and monitoring systems to prevent the introduction of pests and pathogens.

6. Scenarios for agriculture and LULUCF to 2030

We now bring together our assessment of opportunities to reduce agriculture and LULUCF emissions:

- These reflect soils and livestock measures identified by the Scottish Agricultural College in the MACC analysis, excluding measures where SAC suggested there was a lower degree of confidence given remaining uncertainty.
- They include scope for emissions reduction from LULUCF.
- We do not explicitly include abatement from reducing on-farm CO₂ emissions, more radical supply-side options, avoided food waste, and rebalancing of diet; we regard these as options for additional abatement, or substitutes for other abatement in our scenarios should this not ensue.

Our scenarios result in a range of agriculture emissions from 38 to 41 MtCO₂e in 2030 (i.e. 21% to 15% below current levels – Figure 7.15).

- Our Low Abatement scenario includes:
 - All the measures in the pessimistic MACC, excluding measures where there is a lower level of confidence. This delivers 8.3 MtCO₂e (or 3.8 MtCO₂e in additional abatement relative to the 4.5 MtCO₂e identified in the LCTP).
 - Agriculture emissions in this scenario are 41.3 MtCO₂e in 2030.
 - Afforestation, which could deliver at least 1 MtCO₂,¹⁶
- Our Medium Abatement scenario includes:

¹⁶ We include abatement potential from LULUCF in our scenarios, but account for potential emissions reduction from afforestation in our economy-wide CO₂ scenarios (Chapter 3).

- The centre of the range for cost-effective emissions reductions provided by the Low and High Abatement scenarios. This delivers 9.9 MtCO₂e (or 5.4 MtCO₂e in additional abatement from agriculture during the 2020s); the vast majority of measures are available at negative cost (i.e. can save money for farmers) and all measures cost less than £70/tCO₂e.
- Agriculture emissions in this scenario are 39.7 MtCO₂e in 2030.
- Afforestation, which could deliver at least 1 MtCO₂e.
- Our High Abatement scenario includes:
 - All measures in the optimistic MACC, excluding all low confidence measures. This delivers 11.6 MtCO₂e (or 7.1 MtCO₂e in additional abatement).
 - Agriculture emissions in this scenario are 38.0 MtCO₂e in 2030.
 - Afforestation, which could deliver up to 3 MtCO₂e.

We reflect these scenarios in our Low, Medium and High Abatement economy-wide scenarios in chapter 3.

We provide the above scenarios as indicative trajectories for agriculture but recognise the high level of uncertainty over future emissions, both as regards business as usual emissions and the emissions impact of abatement measures. As uncertainties are resolved over time, we will revisit abatement potential in agriculture in the context of its contribution to the fourth carbon budget.

Figure 7.15: Abatement potential under agriculture scenarios (2008-2030)

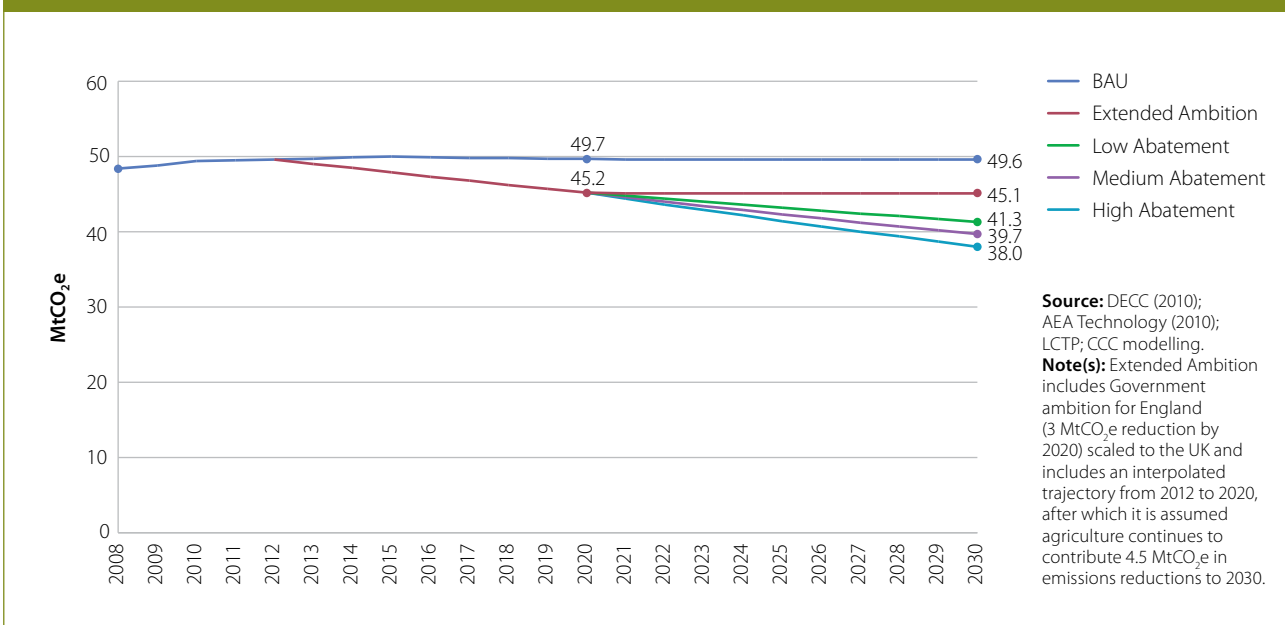
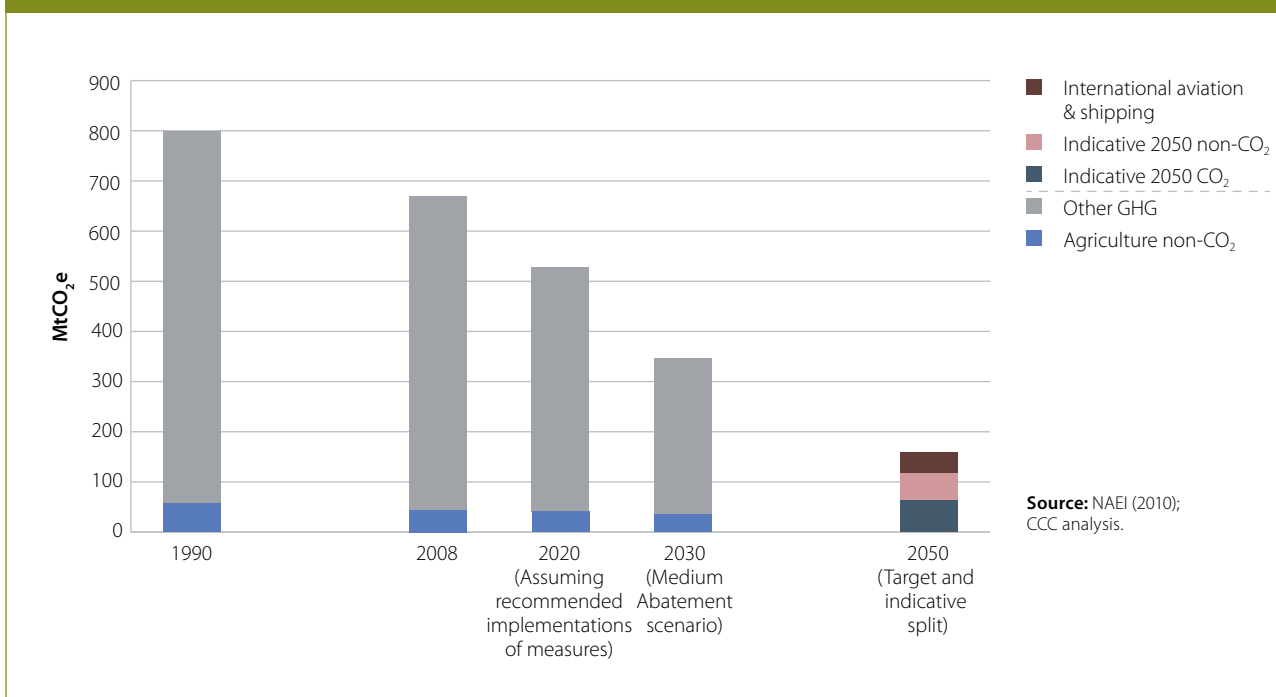


Figure 7.16: Agriculture sector emissions in the context of UK greenhouse gas emissions (1990-2030, 2050)



Path from 2030 to 2050

Under the Medium Abatement scenario, agricultural emissions are 40 MtCO₂e in 2030. Abatement options for further reductions from agriculture after 2030 include:

- Plant breeding and alternative approaches to cropping
- Further improvements to livestock feed efficiency through diets and/or use of additives and vaccinations to reduce enteric methane emissions
- Further improvements to livestock efficiency through breeding and health measures
- Improving soil management and carbon
- Precision farming
- Nitrification inhibitors
- Demand-side measures (e.g. reduced food waste and consumption change)

Given the very clear need for further agriculture emission reductions beyond 2030 on the path to 2050, these options should be explored further with research and development support provided as required. Failure to further reduce agriculture emissions would risk making the 2050 target unattainable. (Figure 7.16)

7. Implications for the first three budget periods

To deliver emission reductions from agriculture outlined in this chapter, there are a number of implications for action in the first three budgets:

- Implement measures to 2020 as targeted by the Government and industry in the GHG Action Plan
- Resolve uncertainties in agriculture, including:
 - The measurement of emissions via an improved Agriculture GHG Inventory
 - Estimated abatement potential from soils and livestock measures, both as regards the state of current farming practices and the emissions impact of measures
- Explore abatement potential from more radical options through research and technological development
- Consider the full range of policies to support further emission reductions, including:
 - For supply-side abatement, ranging from voluntary to EU-level to other approaches
 - For demand-side abatement (e.g. reducing waste along food chain and encouraging rebalancing of diets), ranging from information-provision to taxes

For LULUCF activities to contribute to emissions reduction in the fourth budget, the implications for action in the first three budgets are as follows:

- Resolve uncertainties in LULUCF activities including:
 - Afforestation: improve understanding and monitoring of soil carbon emissions and emissions savings from fossil fuel substitution
 - Agricultural land management practices: identify soil carbon sequestration practices that offer true additional mitigation potential
 - Peat soils: bring evidence together to understand the scale of the opportunity around peatland restoration/management
- Consider policies to support LULUCF activities, including the role of economic incentives, grants, and markets to promote private investment in woodland creation.

8. Key findings



Agricultural emissions currently 8% of the UK total.

8%

If left unabated beyond 2020, agriculture will account for 28% of permitted 2050 emissions.

28%

Possible to reduce 2030 emissions by 18% from current levels.

18%

Agricultural abatement potential in 2020s.

5.0
MtCO₂e

Share of abatement potential that also increases farmers profits.

70%

Potential agricultural GHG emissions in 2030.

40
MtCO₂e

Abatement potential in 2030 from forestry, if planting starts today.

1
MtCO₂e



Chapter 8



- A. Wider economic and social considerations
- B. Differences in national circumstances
- C. Key findings

Chapter 8: Wider economic and social considerations and differences in national circumstances

Introduction and key messages

In this chapter we set out our analysis of impacts from meeting the fourth budget. We consider the range of impacts listed in the Climate Change Act in two sections:

- A. Wider economic and social considerations, including impacts for competitiveness, the fiscal balance, security of supply and fuel poverty
- B. Differences in circumstances across the devolved administrations

We considered these aspects in detail in our 2008 report, where we concluded that the various risks could be mitigated through appropriate policy tools.

In this report we update our earlier analysis and consider high level impacts through the 2020s. We reach a similar set of conclusions to those in our 2008 report.

Our key messages are:

- **Competitiveness impacts** are currently mainly addressed through issuing of free allowances in the EU ETS. Competitiveness risks in the 2020s will depend on a future international agreement, and the extent to which this results in binding carbon constraints and equal carbon prices for competing firms. Where competitiveness concerns remain, these could be addressed through sectoral agreements or border levelling.
- **Fiscal impacts:** In the period to 2030 fiscal rebalancing will be needed to maintain both incentives and revenues; absent rebalancing, fiscal impacts from meeting the fourth carbon budget are likely to be small and manageable.
- **Security of supply** risks due to increasing levels of intermittent power generation through the 2020s can be managed through a range of flexibility options including demand side response, increased interconnection and flexible generation. Decarbonisation of the economy will reduce the reliance on fossil fuels through the 2020s and thus help mitigate any geopolitical risks of fuel supply interruption and price volatility.
- **Fuel poverty** is currently a problem which should be addressed through targeted energy efficiency improvement and other instruments such as social tariffs. The impact of meeting the first three carbon budgets on fuel poverty is broadly neutral, given the offsetting effects of energy efficiency improvements and rising energy prices. Measures to meet carbon budgets in the 2020s can help to address fuel poverty in some cases (e.g. solid wall insulation and low carbon heat) and need not exacerbate it (e.g. if power sector decarbonisation takes place within a framework of new market arrangements).

-
- **Devolved administrations.** Significant abatement opportunities exist at the national level across all of the key options (i.e. renewable electricity, energy efficiency, low carbon heat, more carbon efficient vehicles, agriculture and land use). We project scope to reduce direct emissions in the devolved administrations by around 48% in Scotland, 36% Wales and 49% in Northern Ireland given active policy support from the national governments.

A. Wider economic and social considerations

We now consider the following wider economic and social impacts of meeting the fourth carbon budget and driving down emissions through the 2020s:

1. Competitiveness impacts
2. Impacts for the fiscal balance
3. Security of supply impacts
4. Fuel poverty impacts

1. Competitiveness impacts

Recap of our 2008 report

Competitiveness impacts are a potential issue where energy-intensive firms subject to a carbon price compete in global markets with firms not subject to a carbon price. In this situation profits could be eroded, and at the extreme, production may relocate to regions with weaker emission constraints (i.e. emissions would leak from the UK, staying at the same level or increasing internationally).

In our 2008 report we presented detailed analysis of potential competitiveness impacts for meeting UK carbon budgets in the context of the EU's 2020 package. This showed that there are risks of leakage for a limited number of sectors subject to a combination of a high energy cost share within total costs and significant exposure to international trade, and accounting for less than 1% of GDP. The impacts of leakage could be pronounced in certain areas with significant impacts for the local economy (e.g. iron and steel in Wales).

We considered three key levers for mitigating competitiveness risks:

- **Global sectoral agreements:** bringing all firms within a specific sector into a global agreement.
- **Free allocation of emission allowances:** issuing of free allowances to energy intensive firms within the EU ETS.
- **Border levelling:** introduction of border tariff adjustments reflecting the carbon content of imported or exported goods, in order to levelise carbon costs across regions.

We argued that a global agreement is the first-best solution and border levelling is in principle relatively attractive given perverse consequences from free allowance allocation. However,

for practical purposes the EU have decided to grant free allowances. Whilst not ideal, the EU approach should mitigate competitiveness impacts for firms in the EU ETS in the period to 2020.

Competitiveness impacts in the 2020s

A rising carbon price through the 2020s would increase costs, particularly for energy-intensive firms, and could increase competitiveness risks if firms in other countries are not subject to the same carbon price.

The extent to which there will be a uniform carbon price facing all competing firms will depend on the nature of a future international deal and the way in which carbon markets develop:

- Where all countries are subject to emissions reduction targets, and where these translate to binding caps and/or carbon prices at the industry level, firms in all regions would be subject to carbon prices and competitiveness risks would therefore be minimised.
- Full mitigation of competitiveness risks would require integration of regional carbon markets or similar carbon constraints across countries such that there is uniform global carbon price.

At the moment there is a great deal of uncertainty of the nature of an international deal for the 2020s, both as regards the global pathway and financing arrangements for emissions reductions to deliver this pathway (see chapter 2).

Where a future deal results in caps for some but not all countries and/or where regional carbon markets are not integrated, the same options for mitigating competitiveness risks in the period to 2020 would be available in the 2020s (i.e. sectoral agreements, free allocation of allowances, border levelling). Given these options, any competitiveness issues could be addressed and do not provide a rationale against legislating an ambitious fourth carbon budget.

Going forward, we will monitor developments in the international framework as part of annual progress reports to Parliament, and will consider how emerging carbon markets and emissions reduction targets may impact on UK competitiveness in the context of carbon budgets.

2. Impacts for the fiscal balance

Recap of our 2008 report

In our 2008 report we focused on the most significant fiscal impacts, both positive and negative, likely to arise as a direct result of the policies used to pursue carbon budgets in the period to 2020:

- Positive impacts on the fiscal balance included increased revenues from auctioning of EU ETS allowances.
- Negative impacts included likely reductions in revenue from transport (fuel duty and Vehicle Excise Duty) and purchase of offset credits.

-
- The net impact could be either positive or negative depending on how EU ETS auctioning progresses.

Overall, we concluded that any net negative impacts would be of a small order of magnitude relative to the total fiscal envelope and would therefore be manageable.

Fiscal impacts of meeting the fourth carbon budget

We have extended the analysis in our 2008 report to cover emissions scenarios for the 2020s and have focused on the most significant likely fiscal impacts. Additional impacts on the fiscal balance may arise from a range of policies which we have not addressed in detail due to uncertainties in policy design going forward (e.g. the Carbon Reduction Commitment (CRC), Green Investment Bank, and/or any additional instruments required in aviation). Our approach is based on the current fiscal framework; we show that the order of magnitude of any negative impact on the fiscal balance is likely to be small relative to total revenues. This should be manageable particularly given scope for significant rebalancing over the next two decades to maintain revenues.

EU ETS revenues

Revenues will increase over the next decade as the proportion of EU ETS allowances auctioned increases. By 2020 UK revenues under the EU 20% package could be £2 billion to £3.5 billion, with the upper figure representing full auctioning of the UK's allowance allocation and the lower if 40% were allocated for free in line with current plans¹.

Going beyond 2020, there are three revenue drivers:

- Revenues will increase as the proportion of auctioning increases (assuming that this is not 100% by 2020).
- Revenues will fall as the EU ETS cap tightens. At a minimum under current EU ETS legislation (20% package) the cap will continue to tighten through the 2020s on a straight line from the path to 2020, although a more stringent cap is likely to be required (see chapter 2, Box 2.3).
- The price of carbon will increase (e.g. we assume to a global price of £70/tCO₂ in 2030, see chapter 2).

Assuming the EU ETS cap is tightened (i.e. consistent with a 30% package and further reductions thereafter), we estimate that the combination of these factors could result in annual EU ETS revenues for the UK of £3 billion to £8.5 billion by 2030². This range reflects the potential cap in 2030 (see chapter 2, Box 2.3) and the proportion of auctioned allowances, with the lower figure reflecting auctioning levels in 2020 and the higher figure reflecting full auctioning. The introduction of a carbon price underpin (chapter 2) would strengthen confidence and provide a lower bound for these revenue streams going forward.

¹ The European Commission is currently finalising their plans for free allocation. This is an indicative figure based on historical shares of emissions and assuming 100% auctioning in the power sector.

² This reflects direct revenues, assuming the UK's share of EU ETS allowances is around 10%. Actual revenues to the Exchequer would be lower to the extent that businesses eligible to pay Corporation Tax treat their allowances as a tax deductible expense.

Transport revenues

Currently, annual fuel duty and VED receipts are around £26 billion and £6 billion respectively. Fuel duty accounts for 5% of total tax receipts and VED 1%.

Under an unchanged fiscal regime, meeting the fourth carbon budget in the way that we have recommended would result in reduced revenues due to improved efficiency of conventional vehicles and increased penetration of electric vehicles in the 2020s (see chapter 4):

- Average fleet efficiency would improve
 - from 135g/km in 2020 to 91g/km in 2030 for conventional and plug-in hybrid cars
 - from 180g/km in 2020 to 126g/km in 2030 for conventional and plug-in hybrid vans
- Electric and plug-in hybrid penetration of the fleet would increase to 31% (cars) and 29% (vans) by 2030, of which only plug-in hybrids would pay fuel duty, and this only on longer journeys.

The total revenue impact of these changes would be up to around £10 billion:

- Fuel duty revenues would fall by up to £3 billion in 2030 relative to our reference emissions projection (see chapter 4).
- VED revenues would fall very substantially by 2030 since almost all new cars, as well as the fleet average, would be more efficient than the current threshold for zero rating; the total impact could be up to £7 billion. However, this could be offset by adjusting VED banding in line with vehicle efficiency improvement.

These effects illustrate the need for fiscal rebalancing in the period to 2030. Given that UK roads are likely to become increasingly congested over time, one option which should be seriously considered is the introduction of road pricing, which would have environmental, economic and fiscal benefits (see our 2009 Progress Report).

If road pricing is to be introduced, our analysis suggests that this should be in addition to, and not instead of, fuel duty. The reason for this is that early reduction of fuel duty would encourage increased travelling and emissions which would more than offset the environmental benefits of road pricing. In addition, reduction of fuel duty would also undermine incentives for purchase of electric cars.

Credit purchase

Under our Global Offer budget (chapter 3), provision is made for the purchase of up to 35 MtCO₂ credits by the Government in order to meet the difference from the Domestic Action budget. At a price of £45/tCO₂ this would represent an exposure to the Exchequer of up to around £2 billion in 2025.

Overall fiscal impact in the fourth budget period

Under the current fiscal framework by 2030 the net impact would be negative, with revenue reductions from the transport sector and the cost of credit purchase outweighing increased revenues from EU ETS auctioning.

The order of magnitude of any negative fiscal impacts through the 2020s relative to total revenues is likely to be small (e.g. 1% to 2%) and with adjusted VED banding and full auctioning of EU ETS allowances impacts could be broadly neutral or even positive.

To the extent that further rebalancing is necessary or desirable in the 2020s (e.g. the Government has committed to increase the proportion of tax revenue accounted for by environmental taxes), key options for consideration should include a carbon price underpin, new/revised taxes to reduce aviation emissions, and congestion charging to reduce road emissions.

3. Impacts on security of supply

Carbon budgets will have an impact on two aspects of security of supply:

- Technical security of supply (or reliability) – the degree of certainty that energy supply will be available immediately when consumers want it. This is mainly an issue in the power sector.
- Geopolitical and economic security of supply – 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 is an issue in power, heat and transport.

Technical security of supply

Reducing emissions in the 2020s will increase the challenges for maintaining technical security of supply in the power sector:

- The challenge of balancing supply and demand at each point in time will increase as more intermittent wind generation is on the system – wind is variable, volatile and difficult to forecast.
- Low-carbon plant such as nuclear and CCS are less economically and technically flexible than conventional plant, and thus less able to respond to fluctuations in intermittent generation and demand.
- Electrification of heat will increase the variability, seasonality and peakiness of electricity demand.

However, analysis we commissioned from Pöyry Energy Consulting suggests that technical security of supply can be maintained in a radically decarbonised power system in 2030, while ensuring costs of power sector decarbonisation do not rise above 0.4% of GDP, through a range of flexibility options such as measures to facilitate demand-side response, increased interconnection or flexible generation.

To ensure that technical security of supply is not compromised it will be important to accompany increased investment in low-carbon generation with the following measures:

- The planned roll-out of smart grids and smart meters, which will help to effectively engage opportunities on the demand side.
- New electricity market arrangements which facilitate investment in options for flexibility.
- It will also be important to ensure that the transition to new market arrangements is managed in a way that ensures that an investment hiatus does not occur during the transitional period as new arrangements are introduced in the early 2010s.

Geopolitical security of supply

Concerns about geopolitical security of supply may ease somewhat depending on whether large supplies of shale gas come to market in the next years.

Where security of supply remains a concern, this would be addressed through emissions reductions in the 2020s reducing the need for imported fossil fuels:

- Increased electrification in the context of a decarbonised power sector and energy efficiency improvements will reduce reliance on fossil fuels in the transport and heat sectors.
- Low-carbon technologies in the power sector will reduce reliance on fossil fuels, and a diverse mix of low-carbon technologies in the power sector will protect against increases in costs or technical difficulties with any one technology. The same is true of biomass and biogas in industry.
- Electricity market reform can shield consumers from electricity price fluctuations, which otherwise would be driven by volatile gas and carbon prices.

4. Impacts on fuel poverty

Fuel poverty drivers

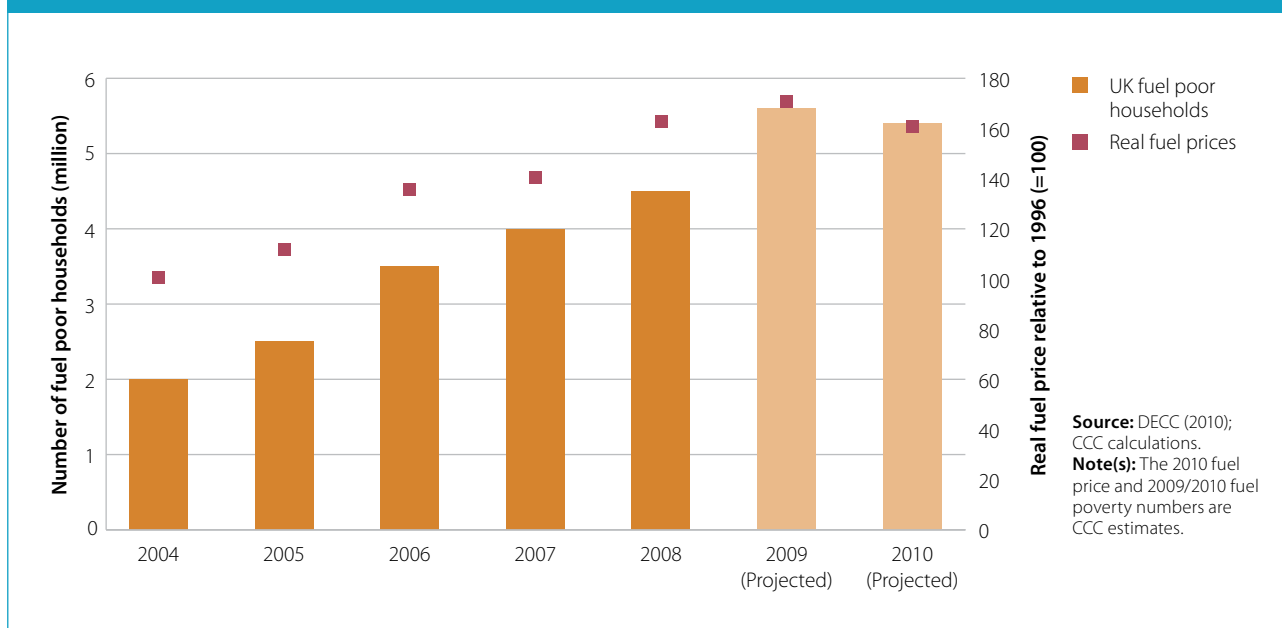
Fuel poverty is driven by levels of energy prices, energy consumption, energy efficiency and household income. Therefore, the fuel poverty impacts from meeting carbon budgets work in two offsetting ways:

- Fuel poverty increases due to higher energy prices to support low carbon power generation.
- Fuel poverty is mitigated by support for energy efficiency measures (e.g. loft and cavity wall insulation) and potentially also by the deployment of low carbon heat.

Fuel poverty to 2020

In our 2008 report, we suggested that higher energy prices in 2020 were broadly offset by energy efficiency improvements such that there would be a similar number (3.5 million, based

Figure 8.1: Fuel poverty and fuel prices (2004-2010)



on the Government’s estimates for 2006) of households in fuel poverty at the end of the third budget period as before the first budget period.

Since the publication of the 2008 report, rising energy prices have resulted in a significant increase in the number of fuel poor. The Government’s most recent estimate is that there were 4.5 million fuel poor households in 2008, with a projection that this is likely to have risen to 5.4 million in 2010 (Figure 8.1), and with more pronounced fuel poverty in the devolved administrations (Box 8.1).

Box 8.1 Regional variations in fuel poverty

A household is said to be in fuel poverty if it needs to spend more than 10 per cent of its income on fuel to maintain an adequate level of warmth. Fuel poverty is modelled on DECC energy prices data and housing condition surveys in the four nations. While England, Wales and Northern Ireland use broadly similar methodologies, Scotland uses a more stringent interpretation of a satisfactory heating regime for pensioners, the long-term sick and the disabled.

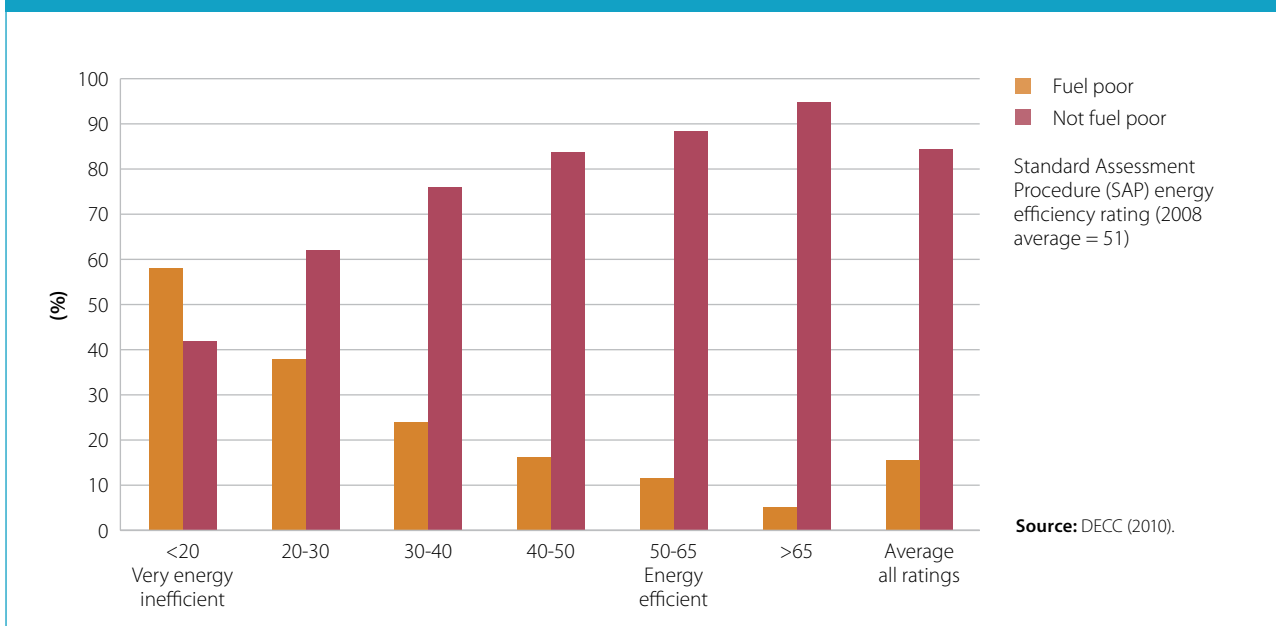
Latest estimates of numbers in fuel poverty are:

UK	Scotland	Wales	Northern Ireland
15.6% (2008)	33% (2008)	26% (2008)	34.2% (2006)

There are a number of regional variances in the factors that drive fuel poverty, in particular household income and connection to the gas grid:

- **Household income:** on average, gross disposable annual household income per head in Scotland (£14,301), Wales (£13,073) and Northern Ireland (£13,260) is below the UK average (£14,872)
- **Off-gas properties:** The devolved administrations have higher proportions of properties that are off the gas grid and thus are generally more expensive to heat. While in England only 9% of properties have no gas connection, in Northern Ireland around 75% are off-grid, while in Scotland and Wales the figures are 21% and 16% respectively.

Figure 8.2: Percentage of fuel poor versus non-fuel poor households and energy efficiency of housing England, 2010)



Going forward, gas and electricity prices to 2020 are expected to rise faster than in our 2008 report, and household income growth is likely to be lower than previously envisaged. Therefore the number of fuel poor at the end of the third budget period is likely to be significantly higher than we projected in 2008, although not as a consequence of meeting carbon budgets.

This issue can and should be addressed through energy efficiency improvements and other measures, such as social tariffs and income transfers (e.g. winter fuel payments). In this respect, while the 2010 Spending Review cut the budget of the main energy efficiency programme for the fuel poor in England (Warmfront) by two-thirds, the Government also announced a new mandatory social price support and a new Supplier Obligation to provide fuel poverty mitigation from 2013.

Fuel poverty impacts of meeting the fourth carbon budget

Through the 2020s there are opportunities for meeting carbon budgets that at the same time can help ease fuel poverty, through measures to reduce energy bills and low carbon heat:

- **Energy efficiency improvement.** Improving the insulation of older, especially solid-walled, properties through the 2020s could significantly benefit fuel poor households.
 - There are higher levels of fuel poverty among those living in poorly insulated properties (e.g. in England 40% of the fuel poor live in houses with an energy efficiency rating below 40 (Figure 8.2). Typically this means solid walls, single glazing and no gas boiler).
 - A recent report³ for Peabody Housing Association suggests that at current energy prices, solid wall insulation can reduce the prevalence of fuel poverty by about 50%.

³ http://www.peabody.org.uk/media/7071502/peabody_carbon_reportoct09.pdf

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- In our Medium Abatement scenario we assume that almost half of all solid-walled properties will be insulated by 2030.
 - Targeted support mechanisms for fuel poor households will be necessary to allow them to take up solid wall insulation which has high upfront costs.
 - **Electricity market arrangements.** New arrangements to reduce the risks (and therefore costs) of low carbon plant and to break the link between rising carbon prices and electricity prices would limit the fuel poverty impacts of power sector decarbonisation through the 2020s (see chapter 6). Without such new arrangements, electricity prices would rise through the 2020s in line with a carbon price increasing to £70/tCO₂, with additional price increases to cover the costs of low carbon generation.
 - **Low carbon heat.** We envisage significant penetration of low carbon heat through the 2020s, with the possibility of investment in district heating (see chapter 5). Given rising fossil fuel prices, low carbon heat options and district heating can offer cost savings relative to conventional gas or oil boilers:
 - Low carbon heat options are particularly cost-effective in off-grid homes, primarily in rural areas. These homes have a higher incidence of fuel poverty (e.g. in England 25% of rural households are fuel poor). Our analysis suggests that up to half of off-grid homes could have their heat demand met by low carbon heat options such as heat pumps and biomass boilers.
 - However, running costs (in particular for heat pumps) depend on correct sizing, installation and efficient operation. Complementary measures such as post-installation technical support are thus particularly important for fuel poor homes to ensure cost savings.
 - While low carbon heat will be cost-effective from a social perspective, low income homes are likely to require financial support to cover capital costs which will remain higher than for conventional boilers.

Therefore fuel poverty programmes which include targeted mechanisms for energy efficiency and low carbon heat, together with ongoing social tariffs/income transfers should mitigate any incremental fuel poverty impacts from meeting carbon budgets through the 2020s.

B. Differences in national circumstances

Our approach to assessing differences in national circumstances through the 2020s involves three steps:

1. Derive a reference emissions projection to 2030 for each of the devolved administrations that takes into account, as far as possible, differences in current and projected trends across the devolved administrations.
2. Present the results of analysis carried out for the 2020s and the period of the fourth budget on abatement opportunities across a range of sectors, highlighting where particular opportunities and challenges exist for the devolved administrations.
3. Put these together to provide indicative scenarios for the 2020s.

1. Current and projected emissions

Current emissions

The latest greenhouse gas inventory for the devolved administrations is for 2008 and shows higher shares of emissions relative to population and GDP shares (Figure 8.3):

- Emissions in Scotland of 53.7 MtCO₂e account for around 9% of total UK emissions, relative to the Scottish share in UK population of around 8% and in UK GDP of around 8%.
- Emissions in Wales of 49.5 MtCO₂e account for around 8% of total UK emissions, relative to the Welsh share in UK population of around 5% and in UK GDP of around 4%.

Figure 8.3: Greenhouse gas emissions in the devolved administrations as proportion of UK total (2008)

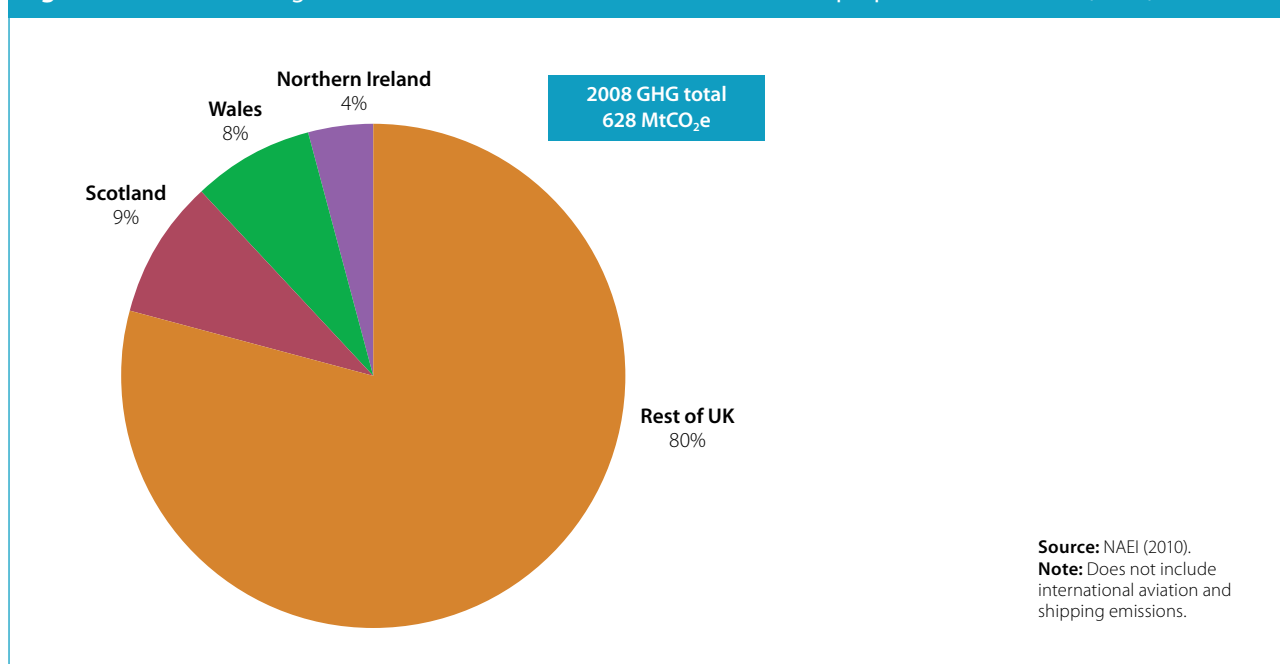
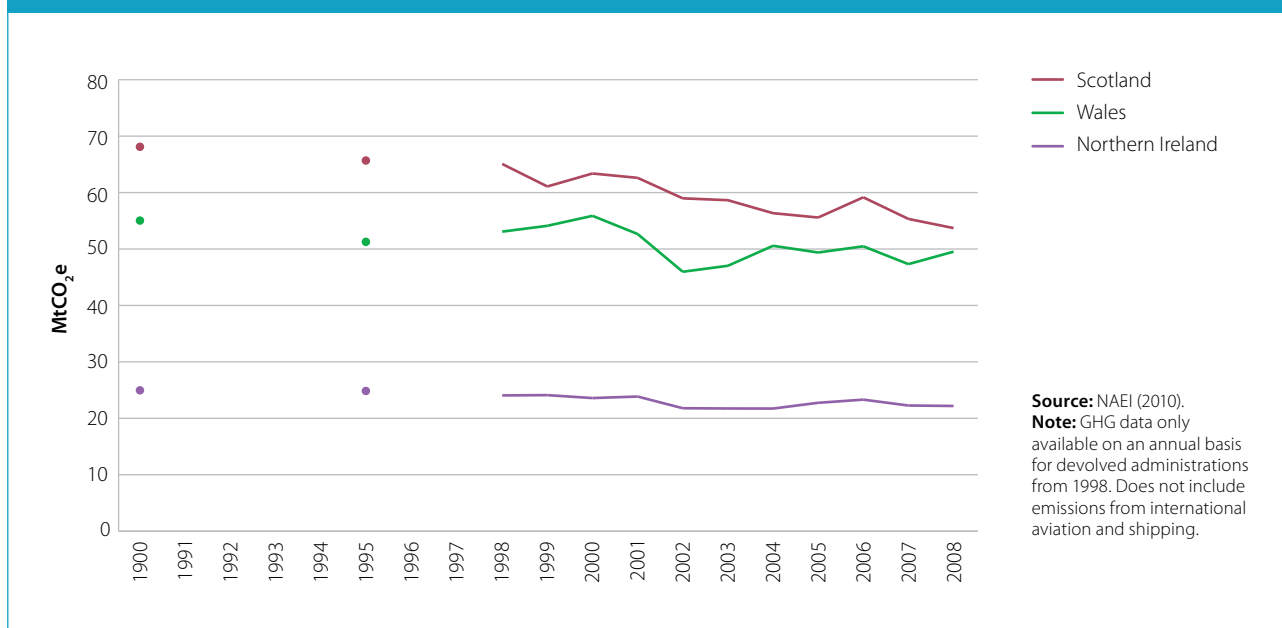


Figure 8.4: Greenhouse gas emissions from 1990 to 2008, Scotland, Wales and Northern Ireland



- Emissions in Northern Ireland of 22.2 MtCO₂e account for around 4% of total UK emissions, relative to the Northern Irish share in UK population of around 3% and in UK GDP of around 2%.

Emissions trends since 1990 vary between the devolved administrations (Figure 8.4):

- Emissions have fallen since 1990 by 21% in Scotland, 10% in Wales and 11% in Northern Ireland.
- Over the last 5 years to 2008, emissions have fallen by an average of 1% in Scotland and 0.4% in both Wales and Northern Ireland each year over that period.
- The latest year of data available for the devolved administrations is for 2008 (showing falls of 2.9% in Scotland and 0.4% in Northern Ireland, and a rise of 4.7% in Wales due mainly to a coal-fired power station coming back on to the system). Therefore it is not yet possible to assess the full impact of the recession in 2009 as we did for the UK as a whole (where emissions fell 8.6% in 2009). However, 2009 macroeconomic data for the devolved administrations suggests similar falls in emissions will have occurred.

Projected emissions to 2020

Under our Extended Ambition scenario, emissions in the devolved administrations fall 21% in Scotland, 13% in Wales and 27% in Northern Ireland by 2020 from 2008 levels (Box 8.2 and Figure 8.5).

Box 8.2 Deriving emissions projections for the devolved administrations

Our methodology follows that of our 2008 report:

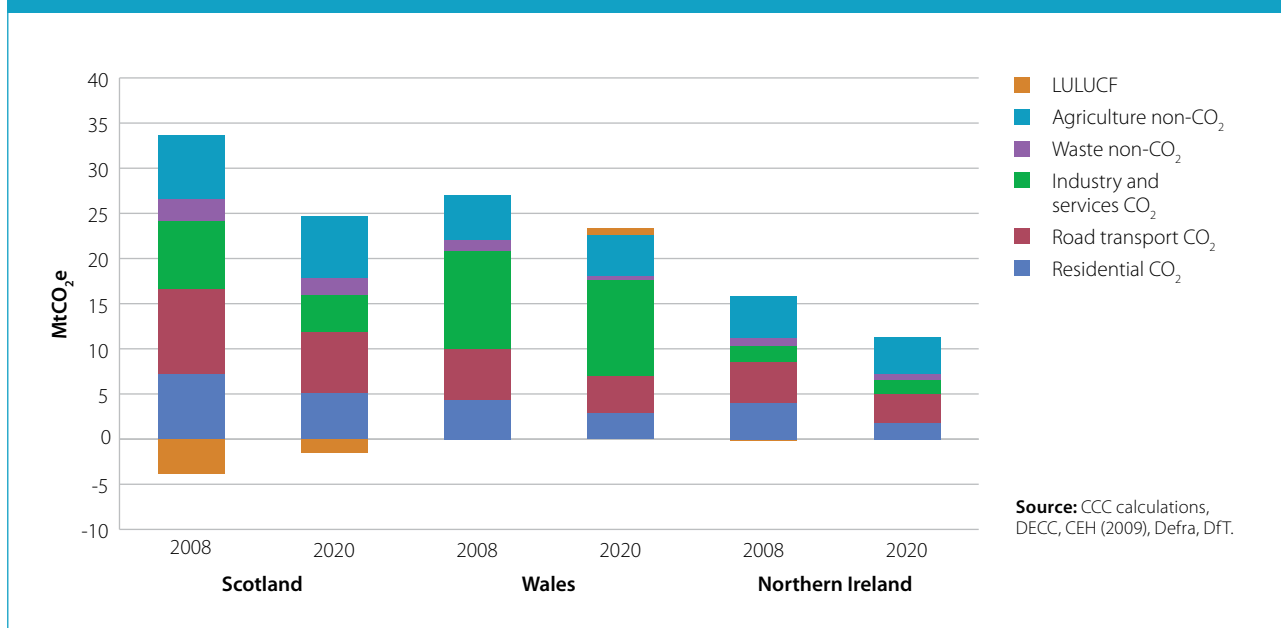
- Residential and industry and services CO₂ emissions are derived from the DECC Energy Model forecasts of UK energy demand using nation-specific fuel consumption shares and forecast trends in number of households and economic circumstances across each nation.
- This does not account for potential future variations in demand for energy or varying shares of abatement that may be achieved in the devolved nations (for example through nation specific implementation of measures to reduce carbon intensive energy consumption), or in the fuel mix (for example if the gas grid was extended in Northern Ireland).
- Road transport (cars, vans, HGVs and buses) emissions projections are produced from the DfT National Transport Model for Scotland and Wales, while Northern Ireland's are emissions estimated on the basis of road transport fuel consumption.
- Emissions from land use, land use change and forestry are produced separately for each UK nation by the Centre for Ecology & Hydrology, currently projected to 2020.
- Projections for non- CO₂ gases are published separately for the devolved administrations (latest published October 2009). These are currently published to 2025, therefore we have assumed a flat trend thereafter to 2030.

Estimates of abatement potential from detailed sector models are netted from these reference projections. These emissions projections exclude the power sector, industrial process, and transport sectors other than road.

There is a similar pattern of abatement potential in devolved administrations as in the UK, but with the following key differences:

- Residential sector emissions could fall by around a third in Scotland and Wales and by up to half in Northern Ireland compared to just over a quarter in the UK as a whole
- The combination of a high share of energy intensive industries combined with limited abatement potential is reflected in the lower overall projected fall in Wales' emissions to 2020
- Agriculture abatement is more pronounced, given the higher share of agriculture emissions in devolved nations.

Figure 8.5: Devolved administration reference emissions in the Extended Ambition scenario to 2020



The actual entry point to the 2020s will in part depend on the actions and policies developed towards meeting devolved administration targets covering this period (Box 8.3).

Box 8.3 Devolved Administration emissions reductions targets to 2020

Each of the devolved nations has set their own targets for emissions reductions over the next decade:

- Scotland has legislated a 42% cut in 2020 relative to 1990 covering all greenhouse gases and emissions, including international aviation and shipping. On the latest baseline year data available this requires Scotland's net greenhouse gas emissions to reduce to 40.7 MtCO₂e in 2020.
- Wales has set a target to reduce all greenhouse gases by 40% by 2020 against a 1990 baseline, which suggests emissions will have to fall to just under 33 MtCO₂e in 2020.
- Northern Ireland is aiming to reduce greenhouse gas emissions by 25% below 1990 levels by 2025. Although there are no annual or interim targets currently set, to achieve the 25% cut by 2025 on steady path of emissions reductions from now suggests emission should be around 20 MtCO₂e in 2020 compared to just over 22 Mt CO₂e now.

Projected emissions to 2030

Disaggregating the UK reference projection to 2030⁴ suggests emissions falls between now and 2030 of 26% in Scotland, 14% in Wales and 33% in Northern Ireland; this projection assumes no additional abatement effort beyond 2020 (Figures 8.6, 8.7 and 8.8)

⁴ These projections exclude LULUCF as current projections are only available for devolved administrations to 2020.

Figure 8.6: Reference projection to 2030 – Scotland

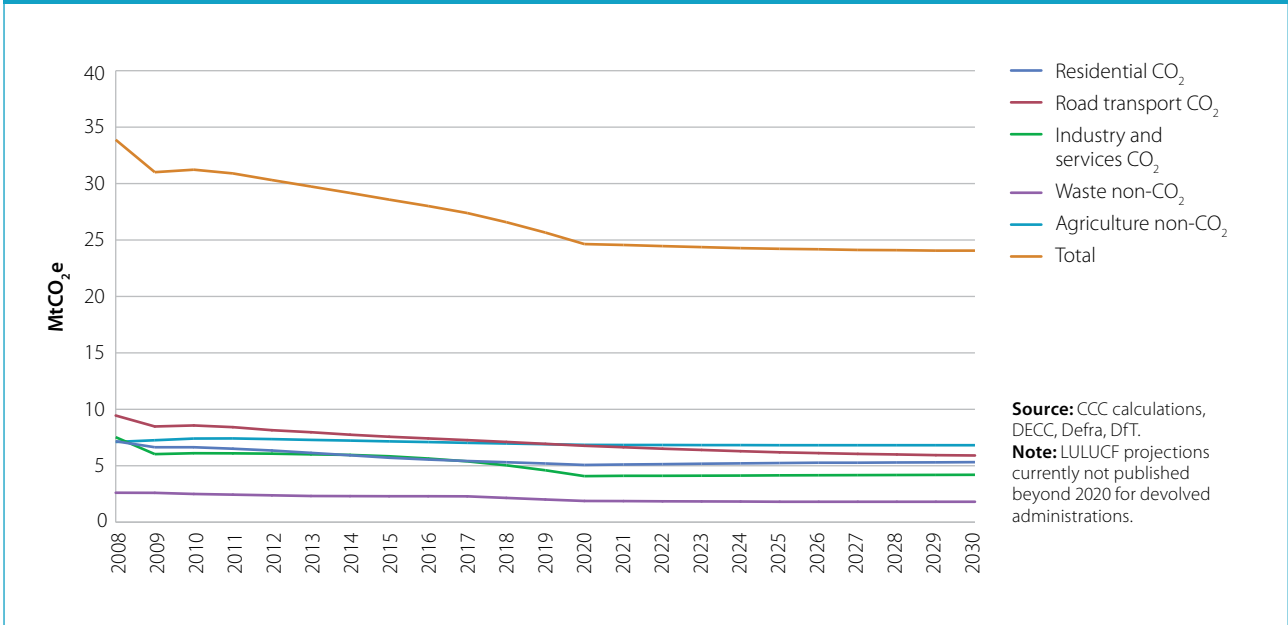


Figure 8.7: Reference projection to 2030 – Wales

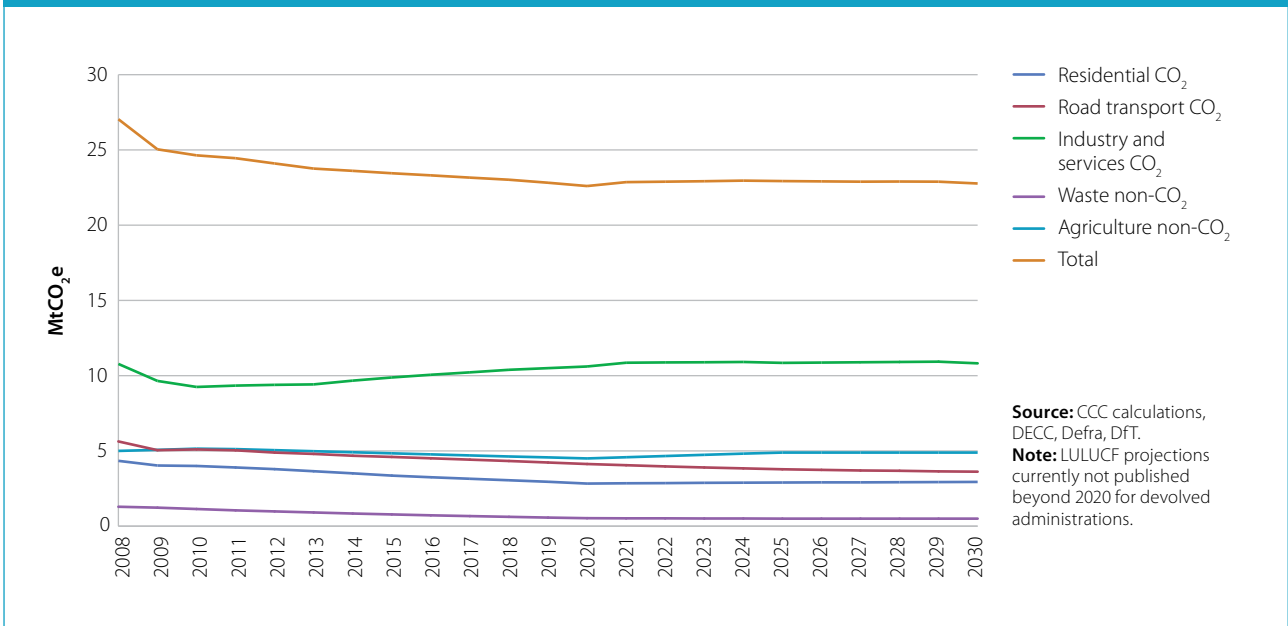
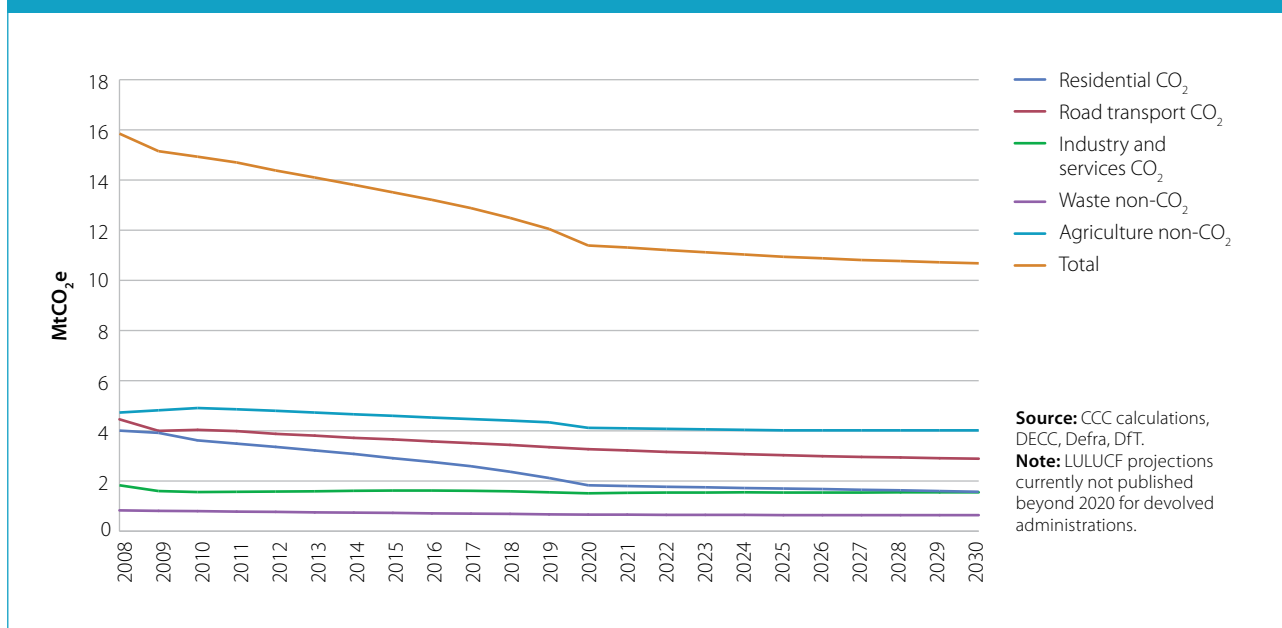


Figure 8.8: Reference projection to 2030 – Northern Ireland



2. Abatement opportunities through the 2020s

In developing emissions reduction scenarios for the devolved administrations, the next step is to consider abatement opportunities across the key emitting sectors. Following this, we net our estimates of feasible emissions reductions from the reference emissions projection. A cross-cutting point is that delivering feasible emissions reductions will require new policies, both at the UK and devolved levels, given the balance of reserved and devolved powers.

Although we do not include the power sector in the reference emissions projection, or abatement scenarios, we briefly discuss the potential contribution to decarbonising the UK's power sector from the devolved nations, given the significant resource potential in each area.

Power sector

Much of the UK renewable electricity resource potential lies in the devolved administrations (e.g. potential resource in Scotland amounts to 40% of Britain's offshore wind, 80% of wave, and 50% of tidal resource).

Although only a small amount of this resource has been exploited to date, there are significant investments in the pipeline and ambitious targets in place:

- **Scotland** produced around 40% of the UK's total renewable electricity generation in 2009. Leases awarded so far indicate 1.6 GW of wave and tidal energy could be deployed in the Pentland Firth and Orkney Waters by 2020. In addition, offshore wind sites with around 11 GW of potential capacity have been granted commercial leases in Scottish Territorial Waters and Round 3 Crown Estate licensing rounds. The Scottish Government recently increased its target for renewable electricity consumption from 50% to 80% in 2020 on the path to meet 100% of Scotland's electricity demand from renewables through the 2020s.

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- In **Wales** renewable electricity generation accounted for around 6% of the UK total, including 10% of generation from wind in 2009. Around 600 MW of offshore wind capacity has received planning approval, with the Welsh Assembly Government aiming to add up to 20 GW of renewable capacity in the period to 2025, which would generate twice the current level of demand.
 - **Northern Ireland** accounted for 4% of the UK's renewable electricity generation in 2009 and almost 10% of wind generation. Demonstration of tidal energy is continuing in the waters of Strangford Lough. The Northern Ireland Executive has set a target to generate 40% of electricity from renewable sources by 2020.

Given the resource potential and ambitious targets, the devolved administrations have an important role to play contributing to required UK power sector decarbonisation through the 2020s (see chapter 6). The extent of this contribution will depend on a range of factors including the economics of renewable technologies and the enabling framework which we will consider further in our renewable energy review, to be published in Spring 2011.

Buildings: Energy efficiency and low carbon heat

There is potential in the devolved administrations for emissions reductions from both energy efficiency and low carbon measures through the 2020s:

- At the UK level, we have highlighted scope in the residential sector for ongoing insulation of solid walls through the 2020s. This opportunity exists also at the national level, particularly in Scotland where the proportion of households with solid walls is around 25%, and in Wales, where the proportion is around 20%.
- Zero carbon homes and buildings regulations will make a useful contribution to emissions reductions, although these will impact on only a small proportion of the total buildings stock in 2030.
- Detailed analysis of potential for low carbon heat at the UK level (see chapter 5) also included analysis of opportunities at the level of the devolved administrations in residential and non-residential buildings. This analysis suggests substantial scope for emissions reductions from low carbon heat in the devolved administrations (e.g. 3 MtCO₂, 2 MtCO₂ and 1.3 MtCO₂ in Scotland, Wales and Northern Ireland respectively). Northern Ireland has a relatively higher share of low carbon potential in the residential sector, reflecting the widespread absence of gas and the high proportion of the population using coal and oil for heating compared to the UK as a whole.

Industry

Our analysis suggests that over 90% of cost effective industry emissions reductions from short pay-back energy efficiency improvement will be achieved in the period to 2020. Emissions reductions in the traded sector over this period will occur disproportionately across the devolved administrations reflecting different industry shares in total emissions (e.g. the share of

CO₂ emissions covered by EU ETS in Scotland is around 55%, with a share of 63% in Wales and 36% in Northern Ireland, compared with 50% UK wide).

In the 2020s, there are significant opportunities for additional abatement (see chapter 5), including:

- For low carbon heat, there is scope for emissions reductions potential up to 1.6, 1 and 0.5 MtCO₂ in Scotland, Wales and Northern Ireland respectively, including from increased penetration of biomass and biogas in industry
- For CCS, our analysis suggests significant potential for carbon capture across a number of sites in Scotland and Wales. Although we do not anticipate these would be deployed until later in the 2020s, earlier deployment could ensue depending on capital investment cycles, market conditions, technological developments etc. We therefore include early deployment of industry CCS in our high scenario. The Scottish Government is exploring the potential for carbon capture for storage under the North Sea with the aim of moving from demonstration to deployment through the 2020s.

Our analysis of additional abatement options in the carbon-intensive industry sectors⁵ suggests there is potential by 2030 for:

- In Scotland, an additional 0.3 MtCO₂ with particular opportunities in the cement sector.
- In Wales, a further 1.5 MtCO₂, the majority of which is concentrated in the iron and steel sector.
- In Northern Ireland, 0.2 MtCO₂, primarily in the cement sector.

Transport

The main opportunities for reducing transport emissions through the 2020s are more efficient conventional vehicles, increased penetration of electric and plug in hybrid vehicles, and biofuels. However there are also important demand-side measures, such as the promotion of 'Smarter Choices', eco-driving, and developing cycling infrastructure, for which devolved administrations control the relevant policy levers. Disaggregating potential across these key options suggests significant scope at the level of the devolved administrations in 2030, over and above abatement already achieved through Extended Ambition measures to 2020:

- Scotland – additional potential abatement of around 1.0 MtCO₂
- Wales – additional potential abatement of around 0.6 MtCO₂
- Northern Ireland – additional potential abatement of around 0.5 MtCO₂

⁵ A further 0.4Mt CO₂ and 0.7 MtCO₂ abatement potential was identified in the refining sector in Scotland and Wales respectively, however this sector is not part of the industry baseline here and we exclude this from the scenario developed for devolved administrations.

Agriculture and land use

Agriculture is particularly important in the economies of the devolved administrations, reflected in this sector's share of emissions of 14%, 11% and 23% in Scotland, Wales and Northern Ireland respectively, compared to 8% for the UK as a whole.

There is significant potential for emissions reductions through a range of soils and livestock measures, which are being explored in each devolved nation:

- The Scottish Government has outlined over 0.3 MtCO₂e abatement potential in 2020 from policies aimed at improving efficiency and developing renewable energy
- The Welsh 'Glastir' programme supports farmers to develop sustainable land management approaches and encourages on-farm renewable energy generation
- The Northern Ireland Executive is consulting on a range of measures to reduce emissions including better livestock management and optimising renewable energy and fuel efficiency on farms.

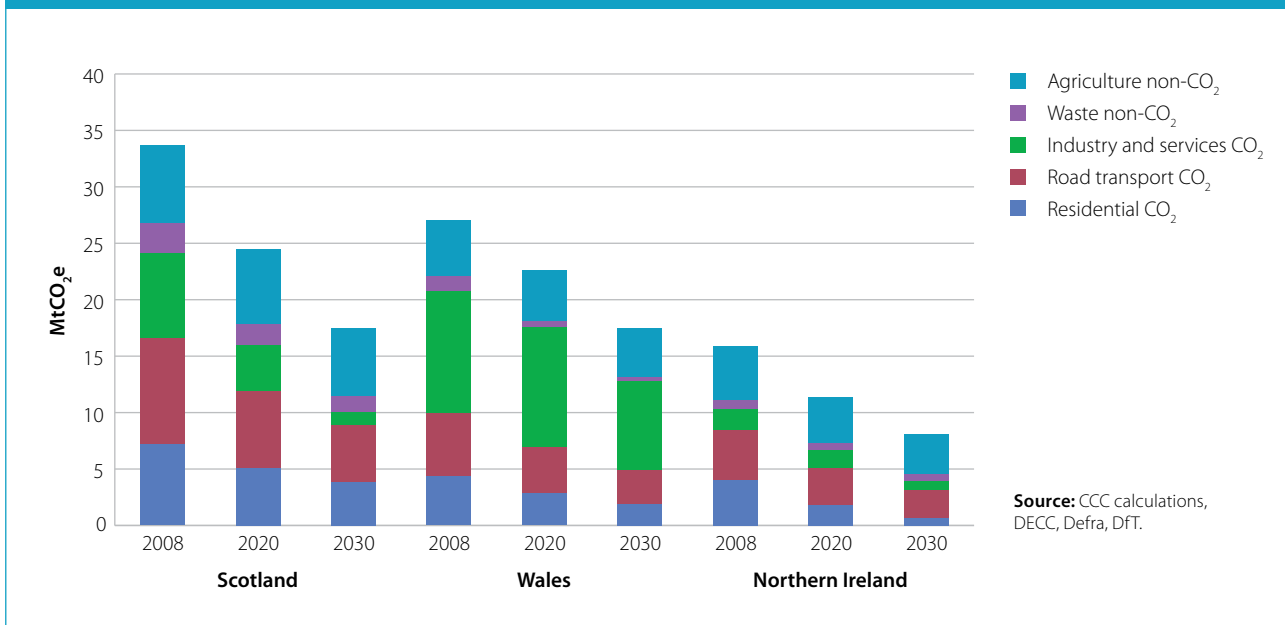
Beyond 2020 our Medium Abatement scenario suggests that in agriculture there is around 10 MtCO₂e emissions reduction potential available in the UK as a whole in 2030 at a cost of less than £70/tCO₂ (see chapter 7). Analysis of the potential at the devolved administration level suggests:

- A range of potential abatement between 1.2 and 1.7 MtCO₂e in Scotland, 0.9 and 1.2 MtCO₂e in Wales, and 0.9 and 1.1 MtCO₂e in Northern Ireland.
- A Medium scenario of around 1.4, 1.1 and 1.0 MtCO₂e reduction in 2030 in Scotland, Wales and Northern Ireland respectively. This abatement potential forms a higher share of overall abatement in devolved nations than in the UK as a whole, and is in line with their higher shares of agriculture emissions.
- However, any abatement already achieved in 2020 should be netted from the 2030 figures.

In addition there are opportunities for reducing emissions through devolved administration approaches to land use and forestry:

- Scotland has a significant proportion of the UK's carbon store in its peat soils. The importance of protecting and managing this is highlighted in the Scottish Government's land use strategy consultation. Targets to increase the carbon sink impact of forests require 10,000 hectares of woodland creation per annum by 2015, with potential to increase this to 15,000 hectares being considered.
- The Welsh Assembly Government is seeking to increase woodland creation rates to 5,000 hectares per annum and is considering a range of other land use measures.
- In Northern Ireland, the Department for Agriculture and Rural Development consultation proposals to reduce emissions include measures for locking in carbon in soils and peatlands and in new and existing woodlands.

Figure 8.9: 2008 emissions, 2020 reference projection, and 2030 medium scenario – Scotland, Wales and Northern Ireland



3. Scenarios for emissions in the devolved administrations

We now bring together our reference emissions projections and our assessments of abatement potential and set out indicative emissions scenarios for the devolved administrations through the 2020s. Our analysis suggests that in total there is potential to reduce direct emissions in the sectors analysed by around 48%, 36%, and 49% by 2030 in Scotland, Wales and Northern Ireland in the Medium Abatement scenario, compared to 2008 (Figure 8.9). We will use this analysis to help inform our advice on targets on emissions reduction in Scotland in 2011.

4. Developing options to reduce emissions at the national level

In each of the key areas, deep cuts in emissions through the 2020s from the abatement options above will require action now to develop options, both at the UK and at the national levels:

- New policies will be required to support energy efficiency improvement in the period to 2020 and beyond.
- Government support will be required for development of markets for low carbon heat and electric vehicles.
- Government financial and other support will be required if renewable electricity resource potential is to be exploited.
- New policies will be required to encourage farmers to reduce emissions.

Given the balance of reserved and devolved powers, there will often be an important role for the UK in driving emissions reductions. However, the devolved administrations have a crucial role to play, ensuring that appropriate incentives are in place to encourage implementation of measures where cost effective potential is available.

C. Key findings



Competitiveness risks: proportion of UK GDP from energy and trade-intensive sectors in 2020.

<1%

Possible EU ETS fiscal revenues generated in 2030.

Up to
£8.5bn

Neutral

Impact on fuel poverty of meeting carbon budgets to 2020.

2020 target for emissions reduction in Scotland from 1990 levels.

42%

2020 target for emissions reduction in Wales from 1990 levels.

40%

2025 target for emissions reduction in Northern Ireland from 1990 levels.

25%

Future work of the Committee

The Committee has a number of deliverables in 2011-12 either required under the Climate Change Act or requested by Government:

- **Review of renewable energy ambition.** This was commissioned by the new Government as set out in the Coalition Agreement document and subsequent commissioning letter. We will assess the role of renewable energy in meeting carbon budgets to 2030 and beyond, also drawing out any further implications for actions and ambition over the next 10 years. We will report back in spring 2011.
- **Advice to the Scottish Government** on the following:
 - **Scottish cumulative emissions budget.** This will draw out implications from the analysis of the UK's fourth budget and advise on a cumulative emissions budget for Scotland covering the period to 2050.
 - **Second batch of Scottish targets (2023-27)** and on limits to carbon unit use (2013-2017)
 - **Progress in reducing emissions** in line with legislated targets
- **Advice to the Welsh Assembly Government** on climate strategy and progress reducing emissions
- **Third annual progress report to Parliament.** This will review progress reducing emissions as GDP returns to growth. It will include assessments of emissions trends, progress implementing measures against our framework of leading indicators, and progress meeting policy milestones to drive the required step change in the pace of emissions reduction. It will be published in June 2011.
- **Advice on use of offset credits to meet the second carbon budget.** This advice is required no later than June 2011 under the Climate Change Act.
- **Review of international shipping emissions.** The Committee has already provided a high-level assessment of international shipping emissions in the context of giving advice on the 2050 target. Further more detailed work is required to underpin advice on inclusion of shipping and aviation in carbon budgets (see below).
- **Review of sustainable bioenergy.** Various forms of bioenergy – biomass, biogas, biofuels – may have a role in reducing emissions (e.g. in power, heat, surface transport, aviation, shipping). However, there is uncertainty as regards the level of availability of sustainable bioenergy given rising food demand and other sustainability constraints (e.g. water, biodiversity). Given resource constraints, there is also a need for further work on the best use of bioenergy (e.g. between sectors and applications). The review will aim to provide an in-depth assessment on these issues and the role of bioenergy in delivering carbon budgets.

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- **Advice on inclusion of international aviation and shipping in carbon budgets.** This advice is required under the Climate Change Act. The Committee previously recommended that international aviation and shipping should be in the 2050 target, and that international aviation should be reflected in decisions on carbon budgets. The Government implicitly accepted this advice, both in adopting the 2050 aviation target, and in its modelling of pathways to 2050. However, a formal decision on whether the net carbon account should be defined to include international aviation and shipping is required in 2012 under the Climate Change Act, following advice from the Committee. This will build on high-level advice on inclusion of aviation and shipping as part of the broad work on the fourth carbon budget.
 - **Second progress report on adaptation.** The Adaptation Sub-Committee (ASC) will use the emerging outputs from the UK Government's climate change risk assessment and the first set of adaptation reports from infrastructure providers to provide a further assessment of the UK's progress on adaptation, with a focus on developing indicators of preparedness and more in-depth analysis in one or two priority areas for early action (land use planning and infrastructure). The report, planned for July 2011, will also contain the ASC's statutory advice on the preparation of the climate change risk assessment.

Glossary

Adaptation

Adjustment of behaviour to limit harm, or exploit beneficial opportunities, arising from climate change.

Aerodynamic fairings

Aerodynamic fairings are additional add on's to trailers and cabs that help reduce aerodynamic drag, reducing fuel consumption. They may be retrofitted to tractors and trailers to give significant emissions reduction. A large number of different fairings are available giving variable benefits.

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.

Battery Electric Vehicle (BEV)

A vehicle that receives all motive power from a battery.

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.

Biomethane

Pipeline quality methane of biological origin (effectively renewable natural gas), generally produced either by cleaning up the biogas that results from anaerobic digestion or via a 'methanation' process to produce methane from the synthesis gas resulting from biomass gasification.

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 emissions reduction within the scheme by trading units which correspond to quantities of abatement.

Capacity payment

Payment to energy supplier for providing a guaranteed level of capacity over a period of time.

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.

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 (CO₂e) 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 (CO₂e) 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 price

The price at which 1 tCO₂e can be purchased. We use projections for the carbon price as a comparator for judging cost-effectiveness of potential emissions reduction measures.

Carbon Reduction Commitment (CRC)

A mandatory carbon reduction and energy efficiency scheme for large non-energy intensive public and private sector organisations. CRC will capture CO₂ emissions not already covered by Climate Change Agreements and the EU Emissions Trading System and started in April 2010.

Carbon sink

An absorber of carbon (usually in the form of carbon dioxide). Natural carbon sinks include forests and oceans.

CERT

Carbon Emissions Reductions target. *See Supplier Obligation.*

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 objective

To keep central estimates of global mean temperature change as close to 2 degrees as possible, and to limit the likelihood of temperature change above 4 degrees to very low levels.

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.

Coalition Agreement

The coalition's programme for government, setting out agreements between the parties on various issues. Released in May 2010.

Coefficient of performance

The amount of heat a heat pump produces compared to the total amount of electricity needed to run it.

Co-firing

Combustion of two different materials at the same time.

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)

The simultaneous generation of heat and power, putting to use heat that would normally be wasted. This results in a highly efficient way to use both fossil and renewable fuels. Technologies range from small units similar to domestic gas boilers to large scale CCGT or biomass plants which supply heat for major industrial processes.

Contract for Difference

Form of hedging on the future price of a commodity in which a strike price is pre-specified. Payments are made between counterparties depending on the difference between the strike price and the market price at the time.

Contrail

Condensation trail (i.e., white line-cloud often visible behind aircraft).

Copenhagen Accord

The document that delegates of the 15th Conference of Parties to the UNFCCC agreed to 'take note of' in December 2009. The text endorsed the continuation of the Kyoto Protocol, but is not legally binding.

Credits

Carbon credits purchased in international carbon markets, generally corresponding to 1 tCO₂e per credit. Also referred to as 'carbon units' in the Climate Change Act. It is not clear how carbon markets will develop by the 2020s. Therefore, where we refer to credits for the 2020s these could be allowances purchased in schemes such as the current EU ETS, or offset credits from project-based schemes (e.g. such as those generated under the Kyoto treaty's project-based flexibility mechanisms, Joint Implementation and Clean Development Mechanism).

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.

Domestic Action budget

Our proposed Domestic Action budget (for 2023-27) reflects our assessment of feasible abatement in the UK through the 2020s that is cost-effective and/or necessary on the path to 2050. It should be legislated in the first instance, with the aim to deliver it through domestic emissions reduction (i.e. without relying on credits).

Drivetrain

The group of components in a motor vehicle that generate power and deliver it to the road surface.

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.

Electric vehicle

Vehicle capable of full electric operation fuelled by battery power driven by an electric motor. These include battery electric (BEV), plug-in hybrid electric (PHEV) and hydrogen fuel-cell vehicles.

Electrolysis

The use of electricity to split water into its constituent parts: hydrogen and oxygen.

Energy intensity

A measure of total primary energy use per unit of gross domestic product.

Enteric fermentation

Fermentation process that takes place in the digestive systems of ruminant animals (e.g. cattle and sheep) to break down hard-to-digest grassy materials, leading to the release of methane.

EUA

European Union Allowance. Units corresponding to one tonne of CO₂ which can be traded in the EU ETS.

European Commission

Executive arm of the European Union.

European Union Emissions Trading Scheme (EU ETS)

Cap and trade system covering the power sector and energy-intensive industry in the EU.

Extended Ambition scenario

Emissions reduction scenario for measures to 2020, developed in our 2008 report and updated in our 2009 and 2010 progress reports. We recommended that the measures in this scenario should be implemented given the need to prepare for the 2050 target and the relative cost-effectiveness of many of the measures.

Feed-in-tariffs

A type of support scheme for electricity generators, whereby 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 either in gasification or reforming processes.

Fluorinated Gases (F-gases)

Family of greenhouse gases containing fluorine. Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF₆) are used in industrial processes, refrigeration and air conditioning. They have a high global warming potential.

Flywheel hybrid

A hybrid vehicle that uses a high speed carbon fibre flywheel that stores and releases energy from/to the vehicle driveline. The flywheel stores energy, while braking for example, releasing it to supplement or temporarily replace the engine output. The technology has been used in F1 racing cars.

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%. Their use is currently 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. Their use in vehicles generates electricity as required from hydrogen stored in the fuel tank.

Fuel Duty

A tax on petrol and diesel. In Nov 2010, the UK tax was £0.58 per litre for petrol and diesel.

Fuel Poverty

A household is said to be in fuel poverty if it needs to spend more than 10 per cent of its income on fuel to maintain an adequate level of warmth.

Gasification

Process in which the solid energy-containing materials are subjected to high temperatures in the presence of small amounts of oxygen. Instead of full combustion, this breaks down the material into an energy-rich 'synthesis gas', which typically contains a mixture of hydrogen, carbon monoxide, carbon dioxide and various other hydrocarbons. This mixture can then be used to generate electricity and/or heat or to produce other forms of energy such as methane, biodiesel (via the Fischer-Tropsch process) or pure hydrogen

Geothermal energy

Geothermal energy exploits heat contained in or near the earth's crust, either for electricity production or to extract usable heat.

Global Offer budget

Our Global Offer budget (for 2023-2027) represents an indicative UK contribution to a global pathway consistent with our climate objective. It shows that the UK should be prepared to go beyond the Domestic Action budget in the context of a global deal, with the option to deliver the extra effort through credit purchase or increased domestic effort.

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

DECC's Global Carbon Finance model, developed to look at the costs to different countries of moving to a low-carbon global economy, and the international financial flows and implied carbon prices this might generate.

Green Deal

The Green deal is the Coalition Government's initiative to support the implementation of energy efficiency measures to households and businesses without needing to meet any upfront costs.

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.

Gross disposable annual household income

The amount of money available to households after taxes, National Insurance, pension contributions and interest have been paid.

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 (1,000 million tonnes).

Heat pumps

Can be an air source or ground source heat pump to provide 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).

Hybrid Vehicle

A vehicle powered by an internal combustion engine and electric motor that can provide drive train power individually or together. E.g. Toyota Prius.

Hydrocarbon

A chemical compound comprised of hydrogen and carbon atoms, often of fossil fuel origin. Examples include methane, crude oil and oil products (e.g. petroleum, diesel and kerosene). Hydrocarbons release CO₂ upon combustion.

Intended budget

As proposed in our 2008 report, the Intended budget (2008-2022) corresponds to the UK share of an EU 30% 2020 target. We recommended it should be enacted in the context of a global deal to reduce 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.

Interim budget

As proposed in our 2008 report, the Interim budget corresponds to the UK share of an EU 20% 2020 target. This is the current set of legislated budgets.

Ionophores

Feed additives that can improve the performance of cattle. They are currently banned in the EU.

Joule

The standard international unit of energy. Related units are: Kilojoule (KJ) = 1000 Joules, Megajoule (MJ) = 1 million Joules, and Gigajoule (GJ) = 1 billion Joules.

Kilowatt-hour (kWh)

A unit of energy, equal to the total energy consumed at a rate of 1,000 watts for one hour. Related units are: Megawatt-hour (MWh) = 1,000 kWh, Gigawatt-hour (GWh) = 1,000 MWh and Terrawatt-hour (TWh) = 1,000 GWh. The kilowatt-hour is equal to 3.6 million joules.

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 (CO₂), methane (CH₄), nitrous oxide (N₂O), sulphur hexafluoride (SF₆), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

Levelised cost

Lifetime costs and output of electricity generation technologies are discounted back to their present values to produce estimates of cost per unit of output (e.g. p/kWh).

Life-cycle assessment

Methodology used to quantitatively assess the environmental performance (e.g. emissions) of a product or service from its cradle to grave.

Lightweighting

An option to reduce fuel consumption of vehicles by reducing the vehicle weight.

Liquefaction

Process for turning a gas into a liquid by cooling it to below its boiling point.

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.

Low Carbon Transition Plan (LCTP)

White paper from the Department of Energy and Climate Change (DECC) published in 2009.

Marginal Abatement Cost Curve (MACC)

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.

Medium abatement scenario

The scenario for emissions reduction measures through the 2020s that is our best estimate of the appropriate level of ambition to currently plan for.

Methane (CH₄)

Greenhouse gas with a global warming potential of 20 (1 tonne of methane corresponds to 20 tonnes CO₂e). Arises in the agriculture sector from the digestive systems of ruminant animals (e.g. cattle and sheep) as well as in manures.

Mitigation

Action to reduce the sources (or enhance the sinks) of factors causing climate change, such as greenhouse gases.

MtCO₂

Million tonnes of Carbon Dioxide (CO₂).

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.

Nitrification inhibitors

Chemical additives that slow the rate of conversion of fertiliser ammonium to nitrate and reduce the chances for nitrogen loss.

Nitrous oxide (N₂O)

Greenhouse gas with a global warming potential of 300 (1 tonne of nitrous oxide corresponds to 300 tonnes of CO₂e). Arises naturally in agricultural soils through biological processes and is influenced by a variety of soil and nutrient management practices and activities (e.g. synthetic fertiliser application).

NO_x

Oxides of nitrogen, defined as the sum of the amounts of nitric oxide (NO) and nitrogen dioxide (NO₂).

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

See credits.

Ofgem (Office of Gas and Electricity Markets)

The regulator for electricity and gas markets in Great Britain.

Ozone

A greenhouse 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.

Peaking plant

Electricity generation plants that run only at times of peak demand or troughs in supply from other sources.

Plug-in hybrid Electric Vehicle (PHEV)

A vehicle that receives motive power from both a battery and a secondary source (e.g. an internal combustion engine). The battery will generally be charged in the same way as that in a BEV, but all electric range will be more limited (e.g. 40 rather than 100 miles).

Power Purchase Agreement

Agreement to purchase some pre-specified quantity of energy over a specified future time period.

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.

Propionate precursors

Feed additives that reduce the production of methane in ruminants.

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.

Radiative forcing

A measure of the atmospheric warming or cooling effect of various climate drivers such as solar radiation, 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 in a given year, relative to the balance during pre-Industrial times.

Reforming

Process that converts hydrocarbons such as methane into a mixture of hydrogen and carbon monoxide. This mixture can then be used to produce other forms of energy such as biodiesel (via the Fischer-Tropsch process) or pure hydrogen. Around 95% of global production of industrial hydrogen is produced via reforming of hydrocarbons.

Renewable Heat Incentive (RHI)

Will provide financial assistance to producers (householders and businesses) of renewable heat when implemented in June 2011.

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.

Reserved powers

Policy areas governed by the UK Government. Also refers to 'excepted' matters in the case of Northern Ireland.

Sequestration

The process of removing CO_2 from the atmosphere and capturing it, particularly in biomass and soils.

Shale gas

A form for natural gas resource that has traditionally been categorised outside mainstream 'conventional' sources. Recent developments in drilling techniques have now enabled it to be produced at a cost potentially competitive with more conventional sources of natural gas, for example in the US.

Smart grid

A smart grid is an electricity network which makes use of information and communications technologies (ICTs), enabling more dynamic 'real-time' flows of information on the network and more interaction between suppliers and consumers.

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 real time information that could help them use less energy.

Smarter Choices

Measures that 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 Tariffs

Discounted energy tariffs for those who find it difficult to heat and light their homes.

Solar photovoltaics (PV)

Panels that generate electricity from daylight.

Solar water heating

Solar technology which uses the warmth of the sun to heat water to supply hot water in buildings.

Standard Assessment Procedure (SAP)

Measures that 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.

Super-grid

An electricity transmission system, mainly based on direct current, which could potentially facilitate the transmission across Europe and beyond of large-scale power generation from remote areas to centres of consumption.

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 2012.

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.

Turbocharging

A type of forced induction system, which compresses the air flowing into a petrol or diesel combustion engine, squeezing more air into a cylinder, then allowing more fuel to be added. A turbocharged engine produces more power overall from each explosion in each cylinder, improving the power-to-weight ratio of the engine. One advantage is that it reduces fuel consumption without compromising engine performance.

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 100g CO₂/km).

Vulnerable household

Households with children, the elderly, sick or disabled which, because of their additional heating requirements are deemed vulnerable to fuel poverty.

Abbreviations

ASHP	Air Source Heat Pump
BEV	Battery Electric Vehicle
CAD	Centralised Anaerobic Digestion
CAP	Common Agricultural Policy
CCA	Climate Change Agreement
CCC	Committee on Climate Change
CCGT	Combined-Cycle Gas Turbine
CH₄	Methane
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power
CLG	Department for Communities and Local Government
COP	Coefficient of Performance
CRC	Carbon Reduction Commitment
CRU	Climatic Research Unit at University of East Anglia
CRDPs	Carbon Budget Reduction Delivery Plans
DA	Devolved Administration
DECC	Department for Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
DfT	Department for Transport
DUKES	Digest of UK Energy Statistics
EAP	Equal Annual Percentage
EC	European Commission
ENSG	Electricity Network Strategy Group
EU ETS	European Union Emissions Trading System
EUA	European Union Allowance
FIT	Feed-in Tariff
GDA	Generic Design Assessment

GHG	Greenhouse Gas
GHGAP	Agriculture Industry Greenhouse Gas Action Plan
GLOCAF	Global Carbon Finance Model
GSHP	Ground Source Heat Pump
GVA	Gross value added
HGV	Heavy goods vehicle
ICAO	International Civil Aviation Organisation
IEA	International Energy Agency
IMO	International Maritime Organisation
IPC	Infrastructure Planning Commission
IPCC	Intergovernmental Panel on Climate Change
LCA	Life-cycle assessment
LCTP	Low Carbon Transition Plan
LULUCF	Land use, land use change and forestry
MACC	Marginal Abatement Cost Curve
MARKAL	MARKet ALlocation Model
MPP	Major Power Producer
N₂O	Nitrous oxide
NAEI	National Atmospheric Emissions Inventory
NG	National Grid
NTS	Non-Traded Sector
OFGEM	Office of the Gas and Electricity Markets
OFTO	Offshore Transmission Owner
PHEV	Plug-In Hybrid Electric Vehicle
RHI	Renewable Heat Incentive
SMEs	Small & Medium Enterprises
UNFCCC	United Nations Framework Convention on Climate Change
VED	Vehicle Excise Duty

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