

Meeting the UK aviation target – options for reducing emissions to 2050

Committee on Climate Change
December 2009



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Chairman's Foreword

In our December 2008 report we presented an initial analysis of aviation emissions. We concluded that these will become an increasingly significant share of total emissions, both because aviation emissions will increase over time and because total allowed emissions will fall. We showed a scenario where the UK's 80% emissions reduction target could be achieved by keeping aviation emissions in 2050 around current levels together with deep cuts in other sectors. In this scenario, aviation emissions would account for around 25% of all allowed UK emissions of Greenhouse Gases in 2050.

In January 2009, the Government decided both to expand Heathrow airport, and to set a target that UK aviation emissions of CO₂ in 2050 should not exceed 2005 levels. The Committee was asked to advise on options for reducing emissions below business as usual to meet the target and on the implications for aviation expansion in the 2020s.

This Report sets out our advice on the implications of the aviation target. It analyses the potential to reduce the carbon intensity of air travel through technological improvements in airframe and engine design, through operational efficiency improvements and through the use of sustainable biofuels. The more rapidly carbon intensity can be reduced, the greater is the extent to which aviation demand can increase while still meeting the emissions target. The report also explores the likely impact of a carbon price on demand and the potential reduction from modal shift to high-speed rail and the use of videoconferencing.

The Report finds that there is potential for aviation demand to increase while still meeting the Government's target – in the most likely scenario, a 60% increase in demand is allowed. Higher increases might be possible if technological progress and the development of sustainable biofuels were more rapid than currently envisaged, but it is not prudent to base current policy on the assumption that speculative future technological breakthroughs are achieved.

It is important to note, moreover, that the allowable demand increase is far below that which would result if demand were unconstrained by carbon prices or limits on airport capacity. Deliberate policies to limit demand below its unconstrained level are therefore essential if the target is to be met.

The allowable overall level of demand increase could be compatible with a range of different approaches to capacity expansion at specific airports, and it is not the role of the Committee to address the other factors which should determine the balance of demand between different airports. The policies pursued, should however be consistent with a total demand increase limited to at most 60% by 2050.

We will publish further analysis of the role of aviation in carbon budgets, and an assessment of any global aviation deal coming out of Copenhagen in our progress report to Parliament in June next year and in our advice on the UK's fourth budget in December.

The Committee and the Secretariat have delivered this report in the context of what has been a very busy year and a challenging work programme for the year ahead. On behalf of the Committee I would like to thank the Secretariat for their excellent support and dedication.



The Committee on Climate Change



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 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.



Dr Samuel Fankhauser

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



Professor Michael Grubb

Professor Michael Grubb is Chairman of the international research network Climate Strategies. He is also senior research associate at Cambridge University and holds a visiting professorship at Imperial College.



Sir Brian Hoskins

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



Professor Julia King

Professor Julia King became Vice-Chancellor of Aston University in 2006, having previously been Principal of the Engineering Faculty at Imperial College, London, before that she held various senior positions at Rolls-Royce plc in the aerospace, marine and power business groups. In March 2008 she delivered the 'King Review' that examined vehicle and fuel technologies that, over the next 25 years, could help to reduce carbon emissions from road transport.



Lord John Krebs

Lord Krebs is an internationally renowned scientist and Principal of Jesus College, Oxford University and also chair of the Adaptation Sub-Committee. He sits in the House of Lords as an independent cross-bencher and is currently chairing an enquiry by the Science and Technology Select Committee into Nanotechnology and Food.



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 the Director at the Policy Studies Institute (PSI). He has also acted as Launch Director for the Low Carbon Vehicle Partnership and was Director of the Economic and Social Research Council's Global Environmental Change Programme.



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Other members of the CCC secretariat that contributed to the report: Mark Bainbridge, Swati Khare-Zodgekar, David Joffe, Eric Ling, Nina Meddings, Claire Thornhill and Emily Towers.

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

Executive summary

In January 2009 the Government decided to support a third runway at Heathrow Airport, committing to an expansion of allowable Aircraft Traffic Movements (ATMs) at Heathrow from 480,000 to 605,000 per annum. Alongside this decision, the Government set a target that CO₂ emissions from UK aviation in 2050 should be at or below 2005 levels. It therefore asked the Committee 'to assess scope for [emissions] reductions, including from improvements in technology and the effects of appropriate policy levers; and the implications of further aviation expansion beyond 2020'. In addition it signalled that in 2020, the Government would ask the Committee to advise on whether a further expansion of Heathrow allowable ATMs (from 605,000 to 702,000) was or was not compatible with achieving the 2050 target.

UK aviation CO₂ emissions in 2005 were estimated to be 37.5 MtCO₂ on a bunker fuels basis. This report therefore sets out the Committee's assessment of the actions required to ensure that UK aviation CO₂ emissions in 2050 do not exceed 37.5 MtCO₂, and in particular assesses the maximum increase in demand from current levels which is likely to be consistent with this target given current best estimates of future technological progress. If the target were to be achieved, aviation emissions would account for around 25% of the UK's total allowed emissions under the economy wide 80% cut in 2050 relative to 1990 included in the Climate Change Act.

In making our assessment, we start by projecting the possible growth of demand and emissions if there were no carbon price constraining demand and if no limits were placed on airport capacity expansion. We then consider scope for reducing emissions relative to reference projections through carbon prices, modal shift from aviation to rail/high-speed rail, substitution of communications technologies such as videoconferencing for business travel, improvements in fleet fuel efficiency, and use of biofuels in aviation. We conclude by setting out scenarios for aviation emissions to 2050 encompassing the range of options for reducing emissions, comparing emissions in 2050 with the target and considering how any gap might be closed.

The report also notes the potential implications of non-CO₂ aviation effects on global warming. The scale of such effects is still scientifically uncertain, and the effects are not covered by the Kyoto Protocol, the UK Climate Change Act or the Government's aviation target. The Committee notes the likely need to account for these effects in future global and UK policy frameworks, but we do not propose a specific approach in this report. Our assessment of required policies is therefore focused on the target as currently defined – keeping 2050 UK aviation CO₂ emissions to no more than 37.5 MtCO₂.



The key messages in the report are:

Projected demand growth

- **In the absence of a carbon price and with unconstrained airport expansion, UK aviation demand could grow over 200% between 2005 and 2050:**

- Demand for aviation has grown by 130% over the past 20 years in a context where GDP has increased by 54% and air fares have fallen significantly.
- Given forecast real income growth of around 150% in the period to 2050, and absent a carbon price or capacity constraint, we project that demand could grow by over 200% from the 2005 level of 230 million passengers annually to 695 million passengers in 2050.

- **A rising carbon price and capacity constraints could reduce demand growth by 2050 to 115%:**

- Specifically, this would result from a carbon price rising gradually to £200/tCO₂ in 2050, together with limits to airport capacity expansion envisaged in the 2003 Air Transport White Paper (i.e. with expansion at Edinburgh, Heathrow, Stansted, and then no further expansion).

Modal shift and videoconferencing

- **There is scope for a useful contribution to achieving the 2050 target through modal shift from air to rail and increased use of videoconferencing:**

- There is scope for significant modal shift to rail/high-speed rail on domestic and short-haul international routes to Europe, which could reduce aviation demand by up to 8% in 2050.
- There is uncertainty over scope for substitution of videoconferencing for business travel. We reflect this in a conservative range from very limited substitution to a reduction of 30% in business demand in 2050.
- Together modal shift and videoconferencing could result in a reduction in emissions of up to 7 MtCO₂ in 2050.

Improvements in fleet fuel efficiency

- **Fleet fuel efficiency improvement of 0.8% annually in the period to 2050 is likely given current technological trends and investment intentions**

- The Committee's current expectation is that improvement in fleet fuel efficiency of 0.8% per annum in the period to 2050 is achievable through evolutionary airframe and engine technology innovation, and improved efficiency of Air Traffic Management and operations.
- This pace of improvement would reduce the carbon intensity of air travel (e.g. grams of CO₂ per seat-km) by about 30%.

- There would be scope for further improvement (i.e. up to 1.5% per annum) if funding were to be increased and technology innovation accelerated.

Use of biofuels in aviation

- **Concerns about land availability and sustainability mean that it is not prudent to assume that biofuels in 2050 could account for more than 10% of global aviation fuel:**

- It is likely that use of aviation biofuels will be both technically feasible and economically viable.
- However, there will be other sectors which will compete with aviation for scarce biomass feedstock (e.g. road transport sector for use in HGVs, household sector biomass for cooking and heating, power generation for co-firing with CCS technology).
- And it is very unclear whether sufficient land and water will be available for growth of biofuels feedstocks given the need to grow food for a global population projected to increase from the current 6.7 billion to around 9.1 billion in 2050.
- Biofuel technologies that would not require agricultural land for growth of feedstocks (e.g. biofuels from algae, or biofuels grown with water from low-carbon desalination) may develop to change this picture but must be considered speculative today.
- Given these concerns, it is not prudent today to plan for high levels of biofuels penetration. We have assumed 10% penetration in our Likely scenario.

Aviation non-CO₂ effects

- **Aviation non-CO₂ effects are likely to result in global warming and will therefore need to be accounted for in future international and UK frameworks. This may have implications for the appropriate long-term UK aviation target:**

- The UK Government's aviation target excludes these additional non-CO₂ effects, consistent with international convention and the UK Climate Change Act, as they do not derive directly from emissions of Kyoto gases.
- Aviation non-CO₂ effects are however almost certain to result in some additional warming, but with considerable scientific uncertainty over their precise magnitude.
- It will therefore be important, as scientific understanding improves, to account for aviation non-CO₂ effects in the future international policy framework and in the overall UK framework for emissions reduction.
- The implications for appropriate emissions reduction across different sectors of the economy are unclear, but some further reduction in aviation emissions may be required. This will be relevant when considering expansion of aviation capacity in the 2020s.



Achieving the aviation emissions target

- **Given prudent assumptions on likely improvements in fleet fuel efficiency and biofuels penetration, demand growth of around 60% would be compatible with keeping CO₂ emissions in 2050 no higher than in 2005:**

- In our Likely scenario, assumptions on improvement in fleet fuel efficiency and biofuels penetration result in annual carbon intensity reduction of around 0.9%.
- The cumulative reduction of around 35% in 2050 provides scope for achieving the target with around 55% more Air Traffic Movements (ATMs). With increasing load factors over time this could allow for around 60% more passengers than in 2005.
- Given currently planned capacity expansion and with a demand response to the projected carbon price and to some of the opportunities for modal shift, demand could grow around 115% between now and 2050.
- Constraints on demand growth in addition to the projected carbon price would therefore be required to meet the 2050 target.

- **Future technological progress may make more rapid demand growth than 60% compatible with the target, but it is not prudent to plan on the assumption that such progress will be achieved:**

- It is possible that improvements in fleet fuel efficiency will progress more rapidly than currently anticipated, and/or that the prospects for sustainable biofuels will become more favourable over time.
- Unless and until emerging evidence clearly illustrates that this is the case, however, it is prudent to design current policy around a maximum demand increase of 60%.

- **A 60% increase in total UK demand could be consistent with a range of policies as regards capacity expansion at specific airports:**

- The maximum increase in ATMs compatible with the emissions target is around 3.4 million per year in 2050 compared to around 2.2 million per year in 2005.
- Total current theoretical capacity at all airports in the UK is around 5.6 million ATMs but demand cannot be easily switched between different geographical locations and capacity utilisation differs hugely between for instance 97% at Heathrow and well below 50% at some smaller airports outside the top ten.
- Optimal capacity plans at specific airports therefore need to reflect factors other than total national demand levels, and it is not the Committee's role to assess such factors.

- The combination of different policies (e.g. tax and capacity plans) should however be designed to limit total demand increase to a maximum of around 60%, until and unless technological developments suggest that any higher figure would be compatible with the emissions target.

We summarise the analysis that underpins these messages in 6 sections:

1. Aviation demand trends and projections
2. Reducing emissions through modal shift and videoconferencing
3. Reducing emissions through improvements in fleet fuel efficiency
4. Scope for use of biofuels in aviation
5. Non-CO₂ climate effects of aviation
6. Meeting the UK's 2050 aviation target

Throughout the report, we assume that UK action is in the context of an international agreement which limits aviation emissions in all countries:

- Action at the European level is required in order to avoid leakage from UK airports to hubs in other Member States.
- Action at a global level is required in order to constrain aviation emissions in a way that is consistent with achieving broader climate change objectives.

The Committee's September 2009 recommendations to Government on an international deal are summarised in Box ES.1.

Box ES.1 The Committee on Climate Change's advice on a framework for reducing global aviation emissions

Capping global aviation emissions

- Aviation CO₂ emissions should be capped, either through a global sectoral deal or through including domestic and international aviation emissions in national or regional (e.g. EU) emissions reduction targets.
- Ideally all aviation CO₂ emissions would be capped. However, an interim phase where the cap applies to all departing and arriving flights in developed countries with exemptions for intra-developing country flights may be necessary.
- The level of emissions reduction ambition under any international agreement should be no less than that already agreed by the EU (i.e. developed country net emissions in 2020 should be no more than 95% of average annual emissions from 2004-2006).



Box ES.1 continued

Auctioning allowances in cap and trade schemes

- Emissions allowances under a cap and trade scheme should be fully auctioned so as to avoid windfall profits for airlines that would ensue under free allowance allocation.
- Aviation auction revenues are one of a number of possible sources for funding of adaptation in developing countries that should be agreed as part of a global deal in Copenhagen.
- Significant R&D that is urgently required to support innovation in the aviation industry should be considered in the context of a global deal for aviation, and funded from aviation auction revenues or other sources.

Emission reductions within the aviation sector

- Emissions trading will be useful for an interim period in providing flexibility to achieve cost-effective emissions reductions, subject to the caveat that the carbon price in any trading scheme should provide strong signals for appropriate demand management and supply side innovation.
- The aviation industry should also plan however, for deep cuts in gross CO₂ emissions relative to baseline projections (e.g. for developed country aviation emissions to return to no more than 2005 levels in 2050), which will be required as a contribution to meeting the G8's agreed objective to reduce total global emissions in 2050 by 50%.

Non-CO₂ effects of aviation

- Non-CO₂ effects of aviation must be addressed as part of any international framework through commitment to a schedule for introduction of appropriate policy instruments (e.g. covering NO_x, cirrus and contrails). Given current scientific understanding, early introduction of measures to reduce NO_x emissions may be feasible and should be seriously considered.

1. Aviation demand trends and projections

Aviation demand has increased in the UK by around 130% since 1990, from 104 million passengers flying in 1990 to 238 million passengers in 2008, in a context where income has increased by 54% and average fares have fallen by around 50% between 1997 and 2006.

Within this aggregate growth, there have been significant increases in demand for both short-haul and long-haul flying (Figure ES.1):

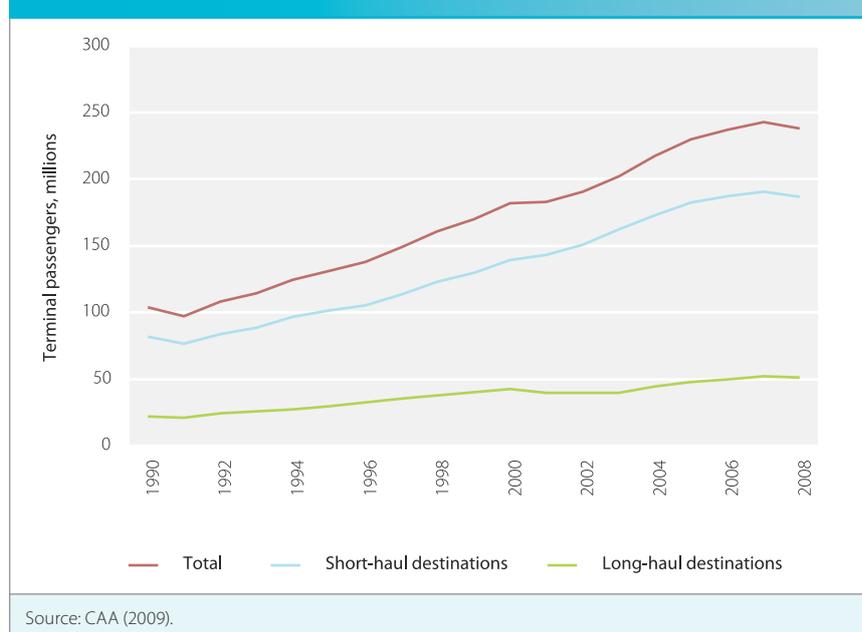
- Short-haul demand has increased by 128% from 82 million to 187 million passengers per year.
- Long-haul demand has increased by 133% from 22 million to 51 million passengers per year.

Both leisure and business travel have grown but the growth of leisure has been particularly dynamic:

- Leisure demand has increased by 185% from around 63 million to 180 million passengers per year.
- Business demand has increased by 70% from around 35 million to 60 million passengers per year.

Survey data suggests that around 50% of the UK adult population travels by plane annually and that likelihood of flying is closely related to income. Amongst people who fly the average number of flights per year also varies significantly by income, with those on incomes of more than £60,000 per annum flying on average just under four times per year, and those on less than £20,000 flying two times per year. Income elasticity of demand is thus high, both as between income groups and over time.

Figure ES.1 UK aviation demand since 1990





Emissions growth has been slightly less than demand growth (e.g. 120% compared to 130%) over the period 1990 to 2007. Three main factors account for this difference:

- Increasing load factors over time have reduced emissions growth relative to demand growth.
- Improvements in fleet fuel efficiency have also reduced emissions growth relative to demand growth.
- These effects have however been somewhat offset by relatively high demand growth in the long-haul segment, for which emissions per flight are relatively high, and which now accounts for around 70% of total UK aviation emissions (Figure ES.2).

Future demand is likely to grow rapidly as high income elasticity outweighs moderate price elasticity (Table ES.1).

Given an assumption of around 150% real UK GDP growth in the period to 2050, alternative projections for future demand suggest that (Figure ES.3):

Figure ES.2 Distribution of UK aviation emissions by distance in 2005

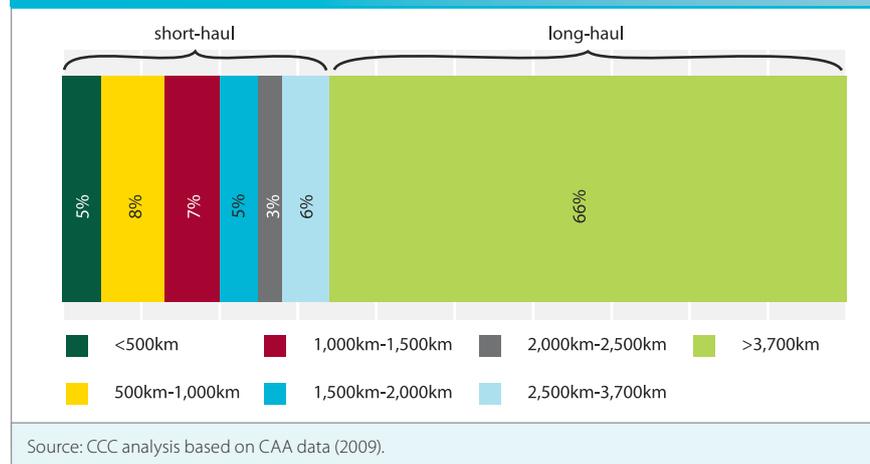
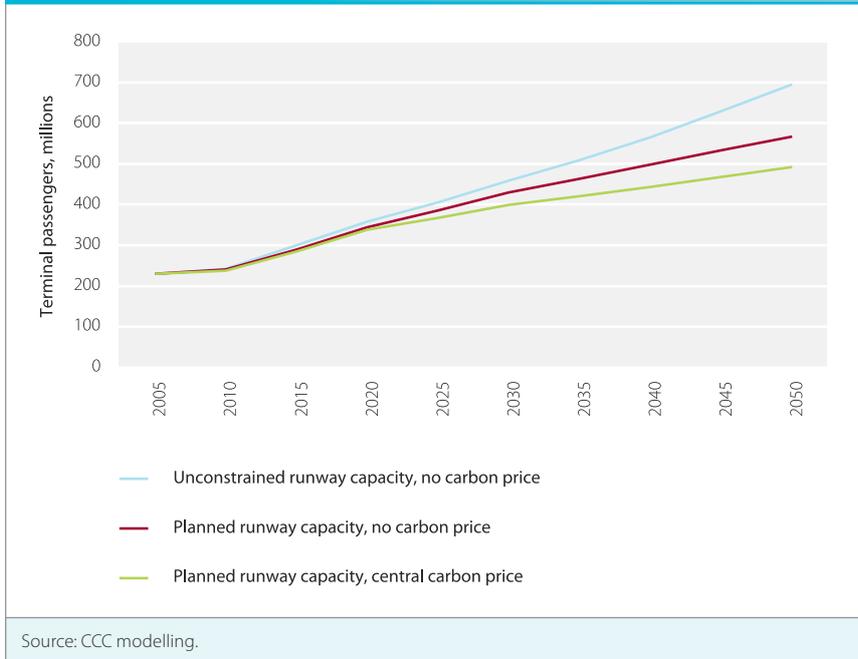


Table ES.1 DfT Elasticity estimates¹

	Price elasticities	Income elasticities
UK Business	-	1.4
UK Leisure	-1.0	1.5
Foreign Business	-	0.6
Foreign Leisure	-0.2	0.7

Source: DfT (2009).

¹ DfT could not identify a statistically significant relationship between business demand and air fares in their modelling. Nevertheless, estimates from the literature reviewed for the CCC by MVA Consultancy pointed to a small but non-zero price elasticity of -0.2. We have run sensitivities on our three core scenarios with this elasticity and the impact in 2050 is less than 1 MtCO₂ in all scenarios and therefore would not materially alter our conclusions.

Figure ES.3 Reference demand projections

- With no runway capacity constraints and no carbon price, demand would grow by over 200% by 2050 relative to 2005 levels (i.e. from 230 million passengers to 695 million passengers annually)
- With runway capacity at levels envisaged in the 2003 Air Transport White Paper (i.e. with new capacity at Edinburgh, Heathrow and Stansted) and no carbon price demand would grow by around 150% by 2050 relative to 2005 levels (i.e. from 230 million passengers to 570 million passengers annually)
- With runway capacity at levels envisaged in the Air Transport White Paper and under a central case carbon price (i.e. rising to £200/tCO₂ in 2050) demand would grow by 115% by 2050 relative to 2005 levels (i.e. from around 230 million passengers to around 490 million passengers annually).

In projecting emissions going forward, we translate our demand projections to estimates of Air Traffic Movements (ATMs) and then convert ATMs to emissions; we subsequently adjust emissions projections to reflect scope for improvement in the fuel efficiency of the fleet (see section 3 below).

With no runway capacity constraints and no carbon price, and if the carbon intensity of air travel remained unchanged (i.e. no technological progress) emissions would rise to just under 100 MtCO₂ in 2050. With planned capacity constraints and a central case carbon price, and with no technological progress, emissions would rise to around 74 MtCO₂ in 2050.



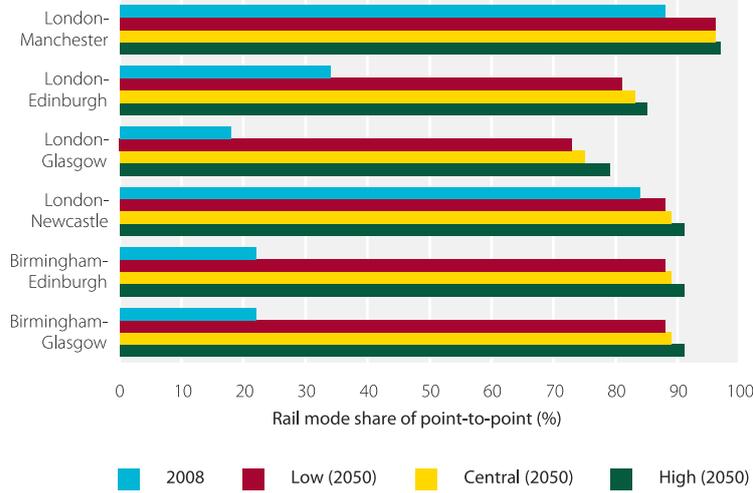
2. Reducing emissions through modal shift and videoconferencing

The scope for modal shift between aviation and rail/high-speed rail depends critically on route distance. Our analysis suggests that journeys up to 800km offer significant potential for substitution from aviation to high-speed rail. In particular, market shares of up to 90% on Anglo-Scottish routes, and 60% on short-haul routes (e.g. Amsterdam, Dusseldorf and Frankfurt) may be achievable in the context of a UK high-speed rail line and a fully integrated European high-speed network (Figure ES.4 a and b).

There is scope for considerable uptake of videoconferencing. However it is uncertain how far this will substitute for air travel, rather than resulting in a higher level of business interaction with travel patterns unchanged. Current best business practice suggests that videoconferencing can substitute for up to 30% of travel, but the largest reductions relate to within company communications and similar reductions may not be possible when travel is for meetings between firms. Further analysis of scope for videoconferencing to substitute for business travel would require comprehensive data on trip patterns including frequency with which business travellers fly, the purpose of their meetings (internal versus external), the number of meetings per trip, etc. Given current uncertainties, we assume a conservative range from very limited business travel substitution to a 30% reduction in business demand for air travel in 2050.

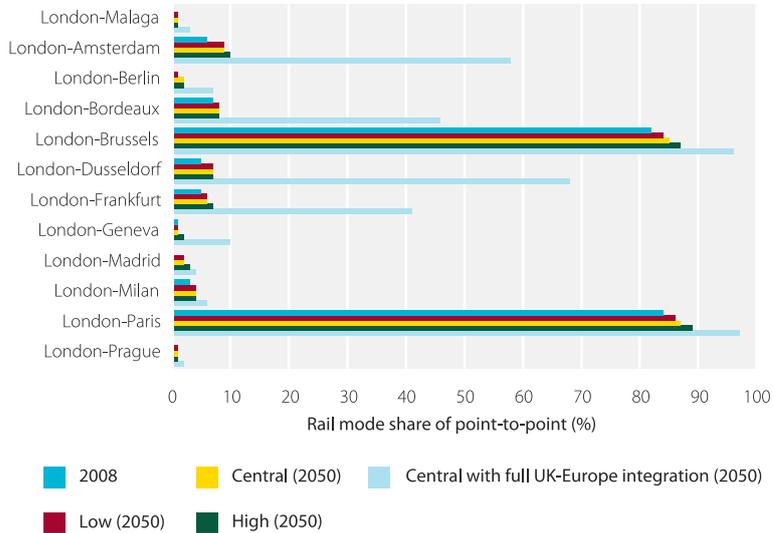
Overall our scenarios for modal shift and videoconferencing suggest a potential to reduce emissions by up to 7 MtCO₂ in 2050. Under a policy regime which involved constraints on capacity but which allowed demand to increase to fill the allowed capacity, some of this reduction would be offset by increases in other categories of demand (e.g. long-haul leisure). For this reason modal shift and videoconferencing effects show up as small on our charts illustrating emission scenarios assuming planned capacity constraints (see Section 6 below). Modal shift and videoconferencing will however have a significant role to play in delivering economic benefits and increased business efficiency, and as optimal responses to likely required policies (e.g. constraints on slot capacities focussed on routes where high-speed rail is an alternative, or carbon taxes which will fall heavily on more carbon intensive business class seats).

Figure ES.4a Projected rail mode share on selected domestic routes in 2050 (with new UK high-speed line)



Source: SDG (2009).

Figure ES4.b Projected rail mode share on selected routes from London to mainland Europe in 2050



Source: SDG (2009).



3. Reducing emissions through improvements in fleet fuel efficiency

Engine and airframe improvements could increase the fuel efficiency of new aircraft by up to 40% in the 2020s relative to new aircraft in 2005. Major manufacturers currently plan to introduce these improvements in new narrow-body aircraft families in the 2020s, with no firm plans to introduce new families for other market segments beyond the 2010s. Once introduced, these families will make up a small but increasing proportion of new aircraft entering the fleet, where the latter reflects turnover of the existing stock (e.g. around 4% annually) and increased demand. More radical technology innovation (e.g. blended wing aircraft) could offer significant potential for emissions reduction, although this would require as yet unplanned high levels of investment.

In addition to airframe improvement there is scope for efficiency improvement in Air Traffic Management (e.g. through flying direct routes at optimal heights and avoiding holding at airports) and operations (e.g. through maximising payload, reducing cabin deadweight and improving airport operations) which together could reduce emissions by up to around 13%.

We set out scenarios for improvement in annual fleet fuel efficiency the period to 2050 from 0.8% to 1.5% on a seat-km basis, with variation largely driven by assumptions on timing of new technology deployment. The low end of the range corresponds to deployment of evolutionary technology starting in the period 2025-2030 – the Committee's current expectation – with the high end reflecting earlier deployment and the introduction of more radical technologies.

4. Scope for use of biofuels in aviation

It is likely that use of aviation biofuels will be both technically feasible and economically viable, particularly in a world of increasing carbon prices. However, there is considerable uncertainty over sustainability of biofuels use in aviation.

Since sustainability constraints apply at a global level, we cannot assess sustainability by reference to the biofuels use of one country alone. The UK can only consider a major role for biofuels as sustainable if that role would be sustainable when applied globally. The Committee therefore believes that, for instance, the UK should only assess a 10% biofuels use in aviation as sustainable if we are confident that sustainable biofuels could account for 10% of total global aviation fuel use.

Key considerations relating to use of sustainable biofuels in aviation include demand for biofuels from other sectors, the need to feed an increasing global population, limited confidence about biofuels routes which do not require use of potential agricultural land, and the lifecycle emissions reductions from biofuels:

- International Energy Agency (IEA) scenarios for 2050 include use of biofuels in aviation, shipping, and road transport, with use of biomass for cooking and heating in developing countries, and in CHP generation or co-firing power generation in conjunction with CCS technology; 100% biofuels penetration in aviation together with use of biomass in other sectors as envisaged in the IEA scenarios could require 9.3 million km² of land for growth of feedstocks.
- Land and water availability should be considered in the context of global population which is projected to rise from 6.7 billion to 9.1 billion by 2050, with demand for food possibly increasing by more than 70% as people become richer². Whilst there are some optimistic estimates suggesting this food demand can be met with land to spare, these would require significant agricultural productivity improvement at a time of constrained use of carbon intense fertilisers, declining water resources and climate change impacts; given these uncertainties we cannot therefore be confident that there will be adequate land available for growth of biofuels feedstocks.
- Technological progress may make possible biofuels which would not require potential agricultural land or scarce water for growth of feedstock (e.g. biofuels from waste, forest residues, algae, or using desert land and water from low-carbon desalination processes). But there are significant uncertainties around the viability and/or the pace of development of these routes for biofuels production. It would not therefore be prudent to base current policy on the assumption these routes will make possible high levels of sustainable biofuels penetration in aviation.
- The emissions reductions actually achieved by using biofuels will depend on the emissions generated in their production and their direct and indirect impacts on land use. Biofuel feedstock production could for instance cause food production to shift to currently forested land, land with carbon rich soils, or less productive land where more intensive use of fertiliser is required. We have assumed an average emissions savings relative to fossil fuels of 50%.

Reflecting these considerations, our scenarios for biofuels penetration in aviation in 2050 range from 10% (Likely) to 30% (Speculative). Given uncertainty about whether the higher figures are compatible with sustainability, it is not prudent to base current policy on the assumption of a penetration rate above 10%. It is possible that over time more optimistic assumptions may become justified but these should only be used as a base for policy if and when there is clear evidence that all sustainability concerns have been addressed.

² The increase in demand for food will reflect not only increased population but also changes in diet, with a wide range of assumptions possible as to how far developing world diets will converge towards developed world resource intensive patterns (e.g. with higher proportion of meat and dairy). Estimates of total additional agricultural production required range from 50 to 100%.



5. Non-CO₂ climate effects of aviation

The Kyoto framework, the UK's Climate Change Act and the UK's 2050 aviation target all exclude aviation non-CO₂ effects since these do not derive from emissions of any of the six greenhouse gases covered by the Kyoto Protocol. It is highly likely however that the net impact of non-CO₂ effects – particularly contrails and other induced cloud formation – is to increase the global warming impact of aviation beyond that suggested by CO₂ emission alone (Figure ES.5).

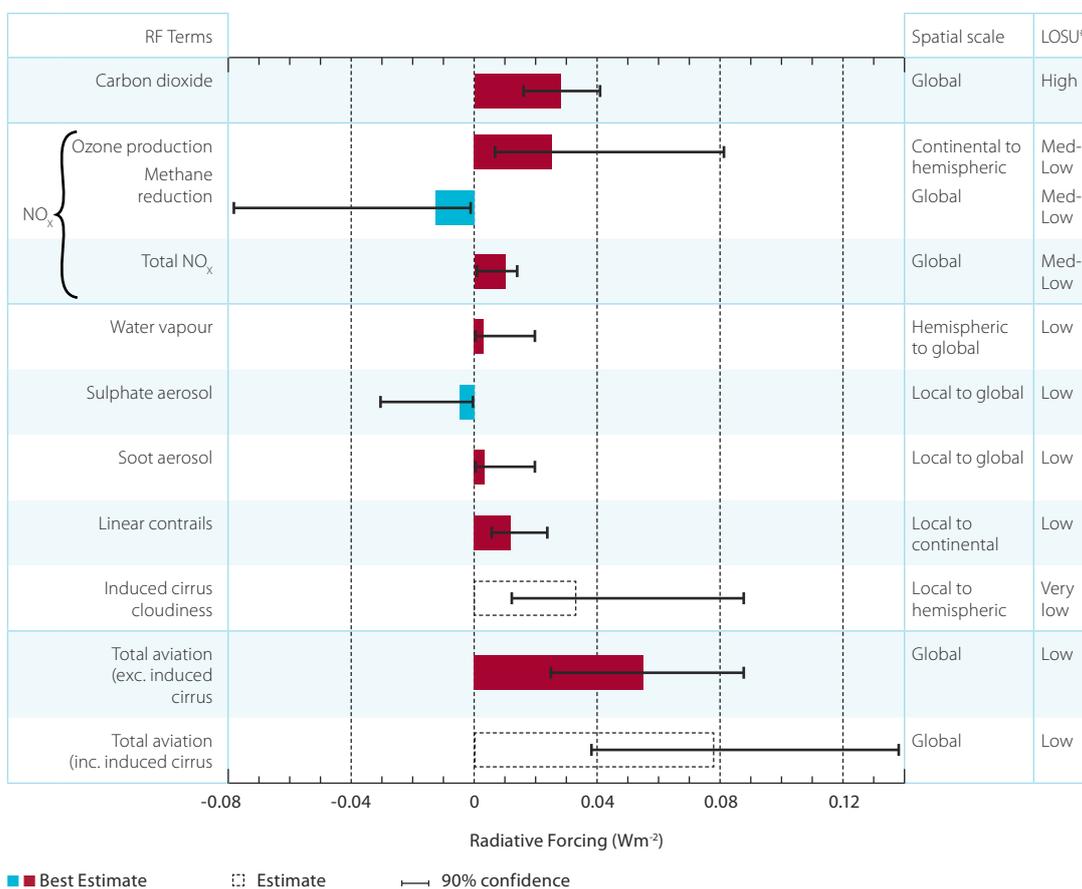
The precise scale of the additional impact is unclear and there are considerable scientific uncertainties still to be resolved, but it is highly likely that these non-CO₂ effects are significant. It will therefore be important that they are accounted for in future international policy frameworks and in the overall UK policy framework for emissions reduction.

While this report concentrates on the UK Government aviation target as currently expressed in terms of CO₂ alone, we therefore comment also on the possible implications of considering non-CO₂ effects. The inclusion of non-CO₂ aviation effects into the UK policy framework could be reflected in three different ways (or a mix of these ways):

- The total level of CO₂ equivalent emissions allowed in 2050 across all sectors of the economy could be increased to reflect the fact that the starting level of relevant emissions today is higher than previously assessed. This approach however may not be consistent with the overall climate change objectives which the Committee considered when it recommended the 2050 target which has now been adopted by Parliament.
- The aviation target could be restated to be that total aviation effects (CO₂ and non-CO₂ combined) should be no higher in 2050 than in 2005. This would be consistent with the Government's principle of returning aviation emissions to 2005 levels by 2050, but would require that other sectors of the economy to achieve even bigger reductions than those envisaged by the Committee in its first (December 2008) report.
- The aviation target could be adapted to include non-CO₂ effects with total CO₂ equivalent emissions (combining CO₂ and non-CO₂ effects) required to fall between 2005 and 2050 rather than simply not increase.

The most appropriate response is unclear and would need to reflect consideration of the different costs of achieving emissions reductions in different sectors of the economy, as well analysis of the latest scientific understanding of the global warming effects and the evolution of the international and European policy framework. Future work by the Committee, for instance our review in 2020 of further slot release at Heathrow, will need to take account of these considerations alongside latest information on the pace of the technology advances discussed in sections 3 and 4.

Figure ES.5 Aviation radiative forcing components in 2005



Source: Reproduced from Lee et al. (2009)³. Global average radiative forcing (in Watts per square metre, Wm²) in the year 2005 from global aviation. Bars are shown for each of the identified aviation effects, with total bars (with and without induced cloudiness) at the bottom. The right hand columns indicate the spatial scales over which these forcing effects operate and the level of scientific understanding (LOSU) regarding each forcing.
 Note: *Level of Scientific Understanding

³ Lee et al. (2009). 'Aviation and global climate in the 21st century'. *Atmospheric Environment*



6. Meeting the UK's 2050 aviation target

We have developed three scenarios which combine different assumptions about rates of change in respect to modal shift, videoconferencing, improvement in fleet fuel efficiency, and biofuels⁴:

- **Likely scenario:** This reflects demand reductions and carbon intensity reductions likely to be achieved given current policies, investment levels and the pace of technological advance.
- **Optimistic scenario:** This would require both:
 - A significant shift from current policy (e.g. in respect to high-speed rail), and an increase in the level of investment in new aircraft technologies and/or in the pace of fleet renewal as well as improvements in ATM and operations so as to make a 1.0% per annum improvement in carbon efficiency attainable.
 - Progress of biofuel technologies which would make it reasonable to assume that a 20% penetration was compatible with sustainability.
- **Speculative scenario:** This would require both technological breakthroughs and a significant increase in the pace of aircraft fuel efficiency improvements. In addition, it would require the development of sustainable biofuels which are currently speculative (e.g. biofuels from algae), or an evolution of global population, food demand and agricultural productivity which would make possible the sustainable and large scale use of current agricultural land and water to grow biofuel feedstocks. These developments are assessed today as very unlikely.

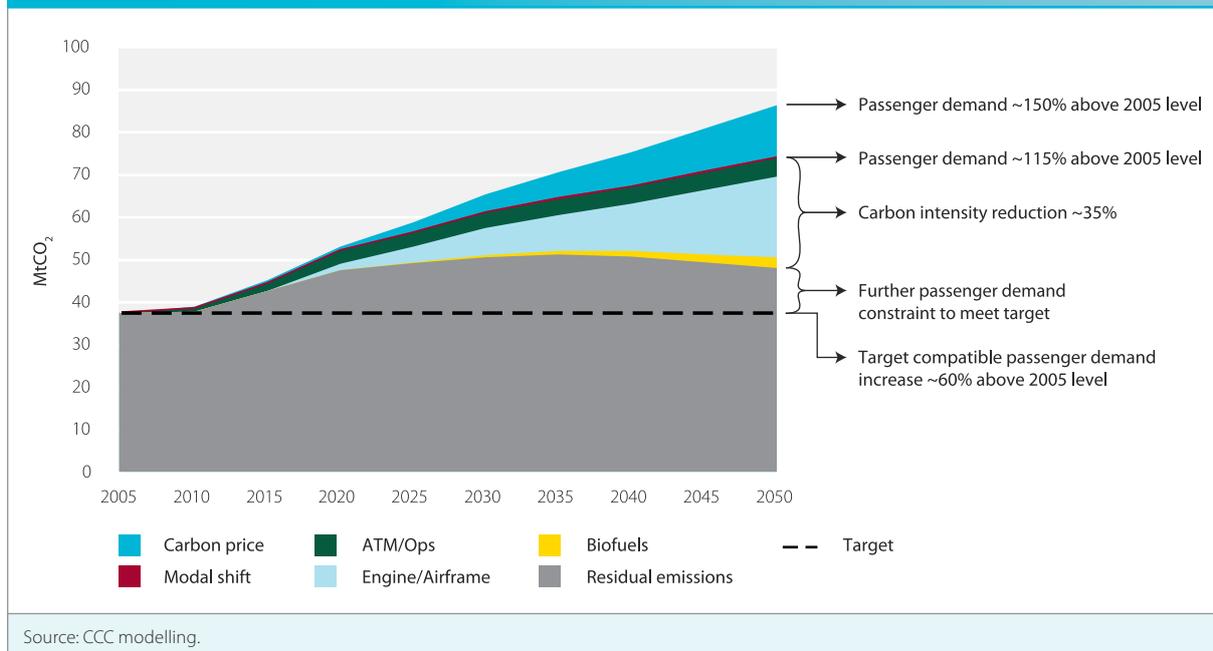
Meeting the target in the Likely scenario

In our Likely scenario we assume annual improvements in fleet fuel efficiency of 0.8% together with 10% biofuels penetration in 2050. This combination of improvement in fleet fuel efficiency and biofuels penetration implies a carbon intensity reduction of around 35% in 2050 relative to the reference projection (Figure ES.6). As a result an increase in ATMs of around 55% relative to 2005 levels would be compatible with the target of ensuring that 2050 CO₂ emissions did not exceed the 2005 level of 37.5 MtCO₂. Given increasing load factors over time, an increase in passengers of around 60% on 2005 levels by 2050 would be possible, taking total annual passenger numbers from 230 million to around 370 million. This would be equivalent to taking total passenger trips (one departure plus one arrival) from 115 million in 2005 to around 185 million in 2050.

This target-compatible demand growth of around 60% compares with the growth of over 200% which might result in a world where there were no capacity constraints and no carbon price.

⁴ These should not be compared with the Committee's Current, Extended and Stretch scenarios defined in the context of UK emissions excluding aviation, where there is less uncertainty about abatement potential and more policy levers are available at the UK level.

Figure ES.6 Likely scenario (planned capacity)



On the demand side, however, the Likely scenario incorporates the future capacity limits assumed by the 2003 Air Transport White Paper. It also allows for the impact of carbon price in line with our central projections (rising gradually to around £200/tCO₂ by 2050), and for some modal shift to conventional rail. These assumptions generate a demand growth of 115% relative to current levels by 2050.

Meeting the 2050 target that CO₂ emissions are no higher than 37.5 MtCO₂ is therefore likely to require policy measures to restrain demand which go beyond our central projected carbon price. The policy instruments which could achieve this restraint include a carbon tax on top of the forecast carbon price, limits to further airport expansion, and restrictions on the allocation of take-off and landing slots even where airports have the theoretical capacity available.

Meeting the target in other scenarios

In the *Optimistic* scenario, we assume 1.0% annual improvement in fleet fuel efficiency and 20% biofuels penetration in 2050. This combination of improvement in fleet fuel efficiency and biofuels penetration implies a carbon intensity reduction of around 45% in 2050. As a result it would be possible to increase ATMs by around 80% and passenger numbers by around 85% and still meet the target that CO₂ emissions should not exceed 37.5 MtCO₂ in 2050 (Figure ES.7). Passenger trips (one departure plus one arrival) could increase from 115 million in 2005 to around 215 million in 2050.



Given demand growth under this scenario of 115%, meeting the target would still require additional policy measures to constrain demand beyond those implied by the 2003 Air Transport White Paper and the central carbon price projection. But these additional measures would not need to be as restrictive as in the Likely scenario.

In the *Speculative* scenario, we assume annual improvement in fleet fuel efficiency 1.5% and biofuels penetration of 30% in 2050. The implied carbon intensity reduction is around 55% by 2050. This would make an increase in ATMs of around 125% and of passengers of around 135% compatible with meeting the target. The combination of already planned capacity limits, the demand response to the projected carbon price and opportunities for modal shift and videoconferencing, would produce a demand increase below this 135%. No additional policy measures would therefore be required to meet the target (Figure ES.8).

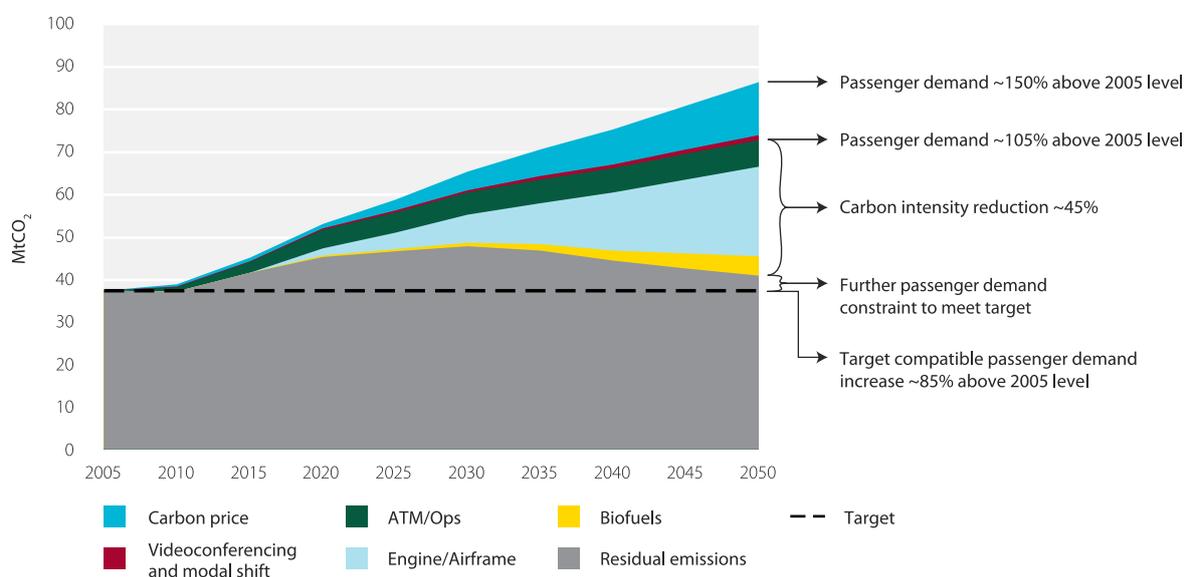
It should be noted however that even in this scenario the maximum demand increase compatible with the target (135% increase in passengers) is much lower than the increase which our projections suggest would occur in a world of no constraints (i.e. with no carbon price and unlimited airport expansion).

The high growth in aviation demand which would occur in an unconstrained environment illustrates the high value which people place on the opportunity to fly, in particular for leisure purposes. If the Optimistic or Speculative scenarios can be achieved, the number of flights compatible with meeting the 37.5 MtCO₂ target increases.

In considering the difference between scenarios, three aspects should be distinguished:

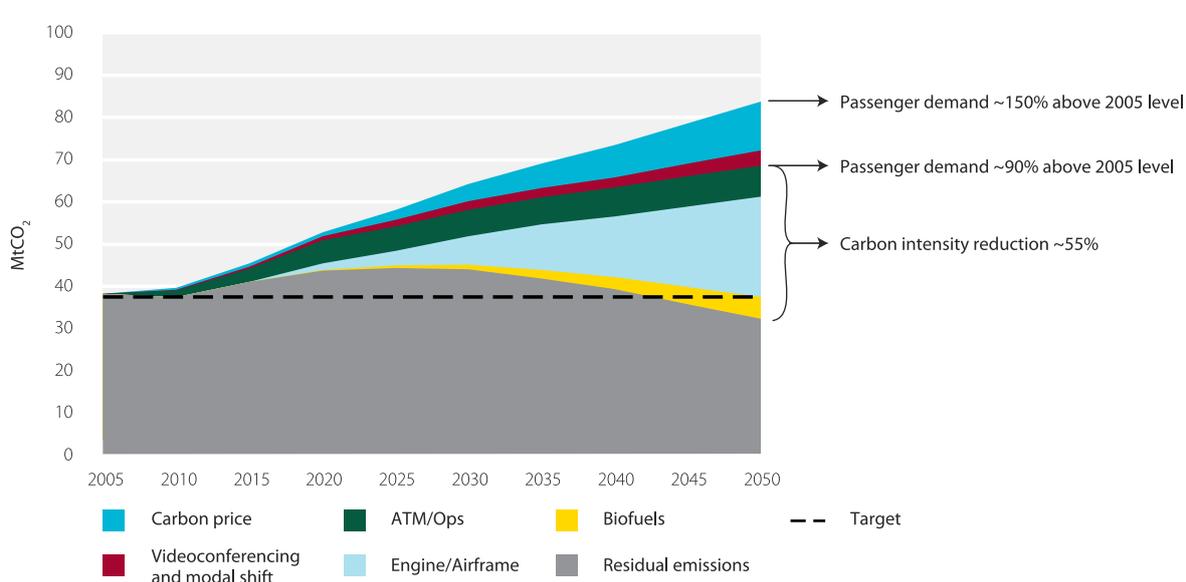
- Achieving greater modal shift to rail and greater use of videoconferencing does not increase the total target-compatible level of demand, but it makes it possible for more of that total to be devoted to other uses (e.g. long-haul leisure) where there are no alternatives to air travel. Investing in a new high-speed rail line and promoting full integration of UK and European high-speed networks can increase the potential for modal shift. Promotion of videoconferencing technologies could ensure higher levels of business travel substitution.
- Achieving more rapid fuel efficiency improvements directly increases target-compatible demand growth. It could be fostered through increasing investment in R&D, introducing regulatory limits on new aircraft CO₂ performance, exploring possible benefits from early scrapping of older aircrafts, and full implementation of SESAR and NATS initiatives on ATM efficiency improvement.

Figure ES.7 Optimistic scenario (planned capacity)



Source: CCC modelling.

Figure ES.8 Speculative scenario (planned capacity)



Source: CCC modelling.



- The higher the percentage of biofuels use which can be considered sustainable the greater the target-compatible demand increase. Here however it is not clear that higher investment will necessarily drive more rapid improvement, since there is inherent uncertainty about what progress can be achieved, and about the implications of population growth and food demand for land use. We therefore need to observe through time the development of speculative technologies, and trends in agricultural productivity and land availability. Governments could however encourage investment in those technologies most likely to be sustainable. And expanded use of biofuels will need to be underpinned by a global policy framework to mitigate the risks of harmful land-use changes resulting from the growth of biofuel feedstocks.

Several of these developments which might make possible more rapid demand increases than in the Likely scenario are ones over which the UK acting alone has only small influence. EU or broader international action would be required to accelerate the pace of improvement of fleet fuel efficiency and international action would be required to develop a framework to mitigate against risks of indirect land use impacts from biofuels.

The prudent assumption on which to base policy today is therefore that reductions in the carbon intensity of air travel will be limited to the reduction of around 35% achieved in the Likely scenario, implying a maximum allowable increase in ATMs of around 55% and a maximum demand increase of around 60%. If faster technology progress is in fact achieved this can be reflected in adjustments in policy over time.

Implications for airport expansion and slot allocation

The 2003 Air Transport White Paper proposed that there could be airport runway capacity expansions at Edinburgh, Heathrow and Stansted, but at no other airports. In January 2009, the Government decided in favour of a third runway at Heathrow and in favour of increasing slot capacity there from 480,000 to 605,000. It decided however, that any decisions on the allocation of further slot capacity (to the maximum theoretical potential of 702,000 with a third runway in place) should be subject to recommendations from the Committee on Climate Change in 2020 on whether further expansion then appears compatible with the target of restricting CO₂ emissions to a maximum 37.5 MtCO₂ in 2050. The Terms of Reference for this report in addition asked the Committee to consider 'the implications [for meeting the 2050 target] of further aviation expansion in the 2020s'.

The key implication from our analysis is that future airport policy should be designed to be in line with the assumption that total ATMs should not increase by more than about 55% between 2005 and 2050, i.e. from today's level of 2.2 million to no more than around 3.4 million in 2050. This constraint could be consistent with a range of policies as regards capacity expansion at specific airports.

Total current theoretical capacity at all airports in the UK is about 5.6 million ATMs which is already in excess both of today's actual ATMs and of maximum ATMs compatible with the 2050 target (Table ES.2a and b). But demand cannot be easily switched between different geographical locations, and there is a tendency for demand to concentrate at major hubs, given the advantages of inter-connection between different routes. As a result, capacity utilisation differs hugely between for instance, 97% at Heathrow and well below 50% at some smaller airports outside the top ten.

If demand was allowed to grow in line with the demand assumptions of the Likely scenario, with passenger numbers growing 115% there would be around 4 million ATMs by 2050. Our modelling suggests that an allocation of demand at this level would entail Heathrow operating at its maximum 702,000 capacity (with a third runway) with several other airports highly utilised (Table ES.2b). Our analysis suggests however total ATMs need to be restricted to a maximum of about 3.4 million in 2050, about 0.6 million below the level modelled in the Likely scenario.

Table ES.2a: Actual runway capacity and utilisation in 2005

Airport	Maximum runway capacity (ATMs, '000s)	Actual use (ATMs, '000s)	Capacity utilisation	Spare capacity (ATMs, '000s)
Heathrow	480	466	97%	14
Gatwick	260	248	95%	12
Stansted	241	166	69%	75
London City	73	60	82%	13
Luton	100	72	72%	28
Bristol	188	58	31%	130
Birmingham	186	111	60%	75
Manchester	276	213	77%	63
Glasgow	188	93	50%	95
Edinburgh	186	106	57%	79
<i>Other UK Airports</i>	3,400	568	17%	2,832
Total	5,577	2,160	39%	3,417

Source: CCC modelling.



Table ES.2b: Projected runway capacity, utilisation and target compatible ATMs in 2050 (Likely scenario assumptions)^{5,6}

Airport	Maximum runway capacity (ATMs, '000s)	Planned capacity, ATM distribution ('000s)	Capacity utilisation	Spare capacity (ATMs, '000s)
Heathrow	702	702	100%	0
Gatwick	260	260	100%	0
Stansted	480	317	66%	163
London City	120	120	100%	0
Luton	135	135	100%	0
Bristol	226	127	56%	98
Birmingham	206	206	100%	0
Manchester	500	449	90%	51
Glasgow	226	198	88%	27
Edinburgh	450	224	50%	226
<i>Other UK Airports</i>	<i>4,000</i>	<i>1,227</i>	<i>31%</i>	<i>2,773</i>
Total	7,304	3,965	54%	3,339
Target compatible ATMs		3,418		
Difference between the Likely scenario and target compatible ATMs		547		

Source: CCC modelling.

This restriction could be achieved through a range of different policies relating to taxes, capacity expansion or slot allocation at specific airports. Optimal decisions on specific airport capacity do not therefore mechanically follow from national aggregate demand, but need to reflect a wide range of other factors such as customer preference, alternatives to air travel, local environmental impact, competition between UK airports and continental hubs, and economic impacts both local and national. It is not the Committee's role to assess these factors.

The Committee's clear conclusion is however that the combination of future aviation policies (combining tax, capacity expansion and slot allocation decisions) should be designed to be compatible with a maximum increase in ATMs of about 55% between now and 2050, and that this should continue to be the policy approach until and unless technological developments suggest that any higher figure would be compatible with the emission target.

⁵ The ATM distribution is an indicative model output rather than a definitive view on the distribution in the Likely scenario.

⁶ Stansted utilisation and total demand may be higher in practice when suppressed demand is reallocated from other London airports.

Future work of the Committee on aviation

Further work on aviation emissions by the Committee over the next year will include:

- Assessing whether international aviation emissions should be included in carbon budgets given the final mechanisms agreed by the EU for allocating EU ETS allowances across Member States.
- Assessing the relative costs of emission reductions in different sectors of the economy (including aviation) within the context of the Committee's development of recommendations for the fourth budget period (2023-2027) which will be delivered in December 2010. This will entail consideration of the feasibility of reductions in other sectors sufficient to offset the fact that aviation emissions are likely to grow before falling back to the 37.5 MtCO₂ level.

Over the longer term the Committee will:

- Review any new evidence on improvement in fleet fuel efficiency, sustainable biofuels and aviation non-CO₂ effects and their implications for the maximum demand increase compatible with meeting the emissions target.
- In 2020 advise Government on whether release of the second tranche of slots from Heathrow capacity expansion (from 605,000 to 702,000) is then compatible with meeting the 2050 target.

The Committee's next annual report to Parliament in June 2010 will include an assessment of latest data on UK aviation emissions and will reflect any developments on international aviation policy resulting from the Copenhagen climate change summit.

Chapter 1

Background and methodology for the review of UK aviation emissions

In our December 2008 report¹, we set out a preliminary analysis of aviation emissions including emissions projections and scope for emissions reduction through innovation in engine, airframe and fuel technology. We concluded that global aviation emissions could account for a significant proportion of total allowed global emissions in 2050, and we argued that they should therefore be included in climate change strategies and policy frameworks. This would provide incentives for supply and demand side aviation emissions reductions, and ensure that total UK emissions are reduced in line with appropriate targets informed by climate science.

In January 2009, the Government set a target to reduce UK aviation emissions in 2050 back to 2005 levels or below. Together with a 90% cut in CO₂ emissions from other sectors, this would broadly achieve the economy-wide target in the Climate Change Act to reduce emissions by 80% in 2050 relative to 1990. The Government asked the Committee to undertake a review of the long-term path for UK aviation emissions, and to consider how the 2050 target could be met through technology improvement and the use of appropriate policy levers, accounting for implications of planned aviation expansion in the 2020s.

This chapter sets out the Committee's approach to the review, which comprises:

- Developing reference case demand and emissions projections
- Considering alternatives to air travel, namely modal shift from aviation to rail and increased use of communication technologies such as videoconferencing
- Assessing scope for emissions reductions through fuel efficiency improvements
- Assessing scope for emissions reductions through the use of sustainable biofuels
- Considering non-CO₂ effects of aviation
- Identifying potential gaps between emissions projections and the 2050 target, and setting out options for closing any gaps, including through explicit constraints on demand growth.

¹ Committee on Climate Change (2008). Building a low-carbon economy – the UK's contribution to tackling climate change. See: <http://www.theccc.org.uk/reports/building-a-low-carbon-economy>



The chapter is set out in three sections:

1. Key aviation messages in our December 2008 report
2. The Government's 2050 UK aviation emissions target
3. The Committee's approach to the review.

1. Key aviation messages in our December 2008 report

The analysis in our December 2008 report focused on three areas:

- (i) Projections of global aviation emissions
- (ii) Projections of UK aviation emissions
- (iii) Accounting for international aviation emissions under the Climate Change Act.

(i) Projections of global aviation emissions

Aviation emissions growth

We showed in our 2008 report that following ten years of 5% annual demand growth, global aviation emissions currently account for up to 2.4% of global total CO₂ emissions². We argued that there will be significant demand growth in the period to 2050 based on income growth in developed and developing countries.

The Committee considered, *inter alia*, the CONSAVE scenarios for aviation emissions under alternative assumptions about policies to constrain demand growth (Box 1.1). These showed that in a world with largely unconstrained demand growth, aviation emissions could account for 15-20% of total allowed CO₂ emissions in 2050 under global emissions reduction scenarios required to limit the risk of dangerous climate change (i.e. to cut global emissions by at least 50% in 2050 and reduce emissions to an average of just over 2 tCO₂e per capita)³.

The Committee argued, therefore, that it is essential that aviation should be covered by a policy framework which:

- (i) Ensures aviation faces an appropriate cost of carbon so as to provide an incentive both for supply side abatement and for demand constraint
- (ii) Ensures that the total level of emissions (i.e. from aviation and other sectors) is reduced in line with appropriate scientific targets.

² The percentage relates to aviation CO₂ emissions as a percentage of overall global CO₂ emissions (excluding emissions relating to land-use).

³ The preferred global emission scenarios in our 2008 report pointed to a range of 20-24 GtCO₂e by 2050. For a population of 9.2 billion, this translates to 2.1-2.6 tCO₂e per capita.

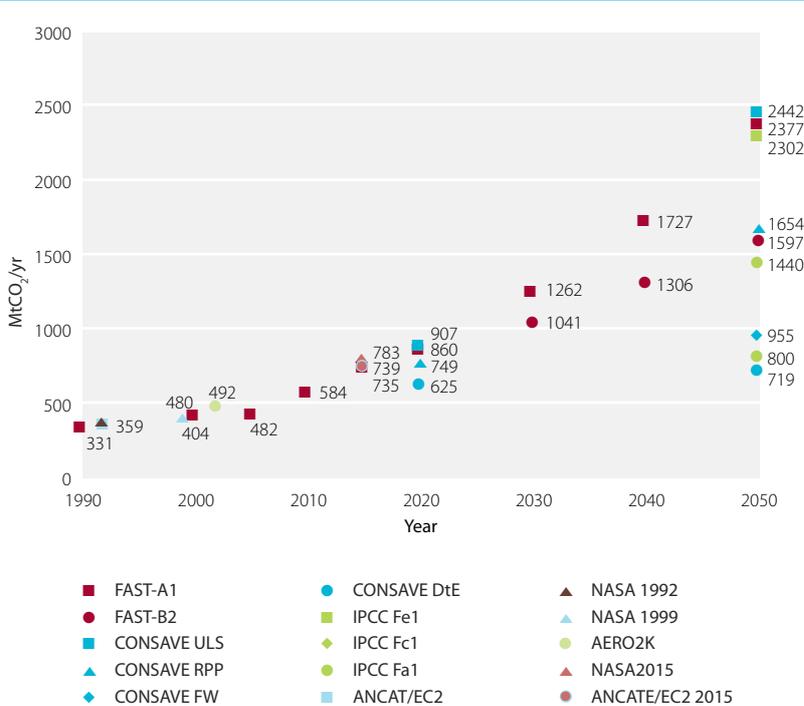
Box 1.1 Projections of global aviation emissions to 2050

There are many projections for global aviation emissions and this makes it hard to establish one 'business as usual' case. Projections vary widely, depending on the precise assumptions made about income convergence, traffic growth, fuel efficiency trend, the regulatory environment, consumer behaviour and on the scope of the study.

The CONSAVE scenarios (Figure B1.1) show four possible scenarios for the growth of global (domestic and international) aviation emissions. The scenarios range from 'Unlimited Skies' (ULS), which is comparable with an unconstrained demand scenario, but pressure on capacity at airports, to 'Down to Earth' (DtE), which would require strong policy action and regulation.

In a world without significant policy action at the global level, we are more likely to be on a path resembling the CONSAVE ULS scenario, which would result in 2.4 GtCO₂ from global aviation in 2050 under an assumption that fleet efficiency improves by 1.5% annually. Global CO₂ emissions from aviation at around these levels would, in 2050, account for 15-20% of all CO₂ emissions permitted under the CCC preferred global emissions reduction scenarios set out in the CCC's December 2008 report.

Figure B1.1 Global Aviation Emissions Scenarios (Including Consave)



Source: IPCC WG3 AR4, Fig. 5.6, (2007).

Emissions reduction through technology innovation

The CONSAVE 'Unlimited Skies' scenario highlighted in our 2008 report includes assumptions that the fuel efficiency of the global aircraft fleet will improve at an annual average rate around 1.5% in the period to 2050. This is contingent on new, efficient aircraft being introduced in the fleet and on efficiency improvements in Air Traffic Management (ATM) (e.g. by flying more direct routes, adopting different altitude profiles and reducing holding at airports) and operations (e.g. increasing load factors and the efficiency of airport operations).

The Committee commissioned work from QinetiQ to identify the scope for efficiency improvement. This study suggested that upper-bound evolutionary changes to airframe and engine technologies, together with changes in efficiency of ATM and operations could result in a new production aircraft in 2025 being 40-50% more fuel efficient than one produced in 2006 (on a passenger-km basis). This is broadly consistent with both the assumptions in the CONSAVE scenario and with industry targets. For example, efficiency targets for new aircraft set by the Advisory Council for Aeronautics Research in Europe (ACARE) aim for CO₂ emissions per passenger-km from a new aircraft to be 50% lower in 2020 than 2000.

It should be noted that these percentages refer to new aircraft that could be available for service at a certain date in the future; it would then take a relatively long time (given the long lifetime of aircraft) for these aircraft to be taken up in significant numbers and contribute to improving the average efficiency of the global fleet.

(ii) Projections of UK aviation emissions

Historic and projected aviation emissions

UK aviation CO₂ emissions have grown by over 50% in the past ten years due to increasing demand in both passenger and freight traffic (Figure 1.1); aviation CO₂ emissions now account for around 5% of total UK GHG emissions (Figure 1.2).

Figure 1.1 UK aviation demand and emissions 1996-2007

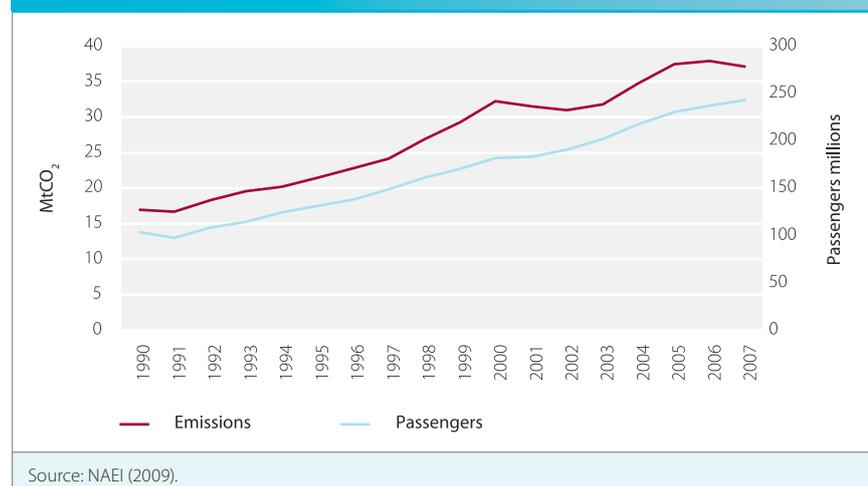
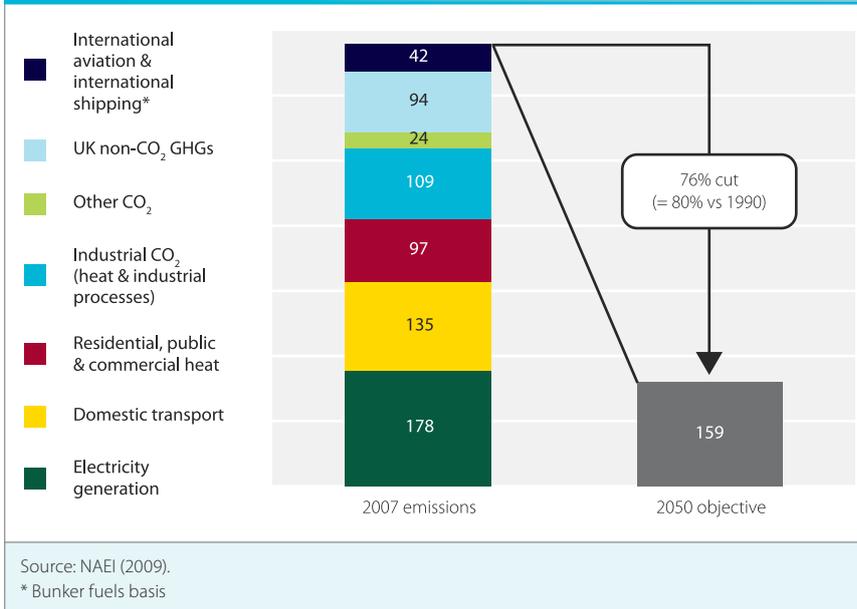
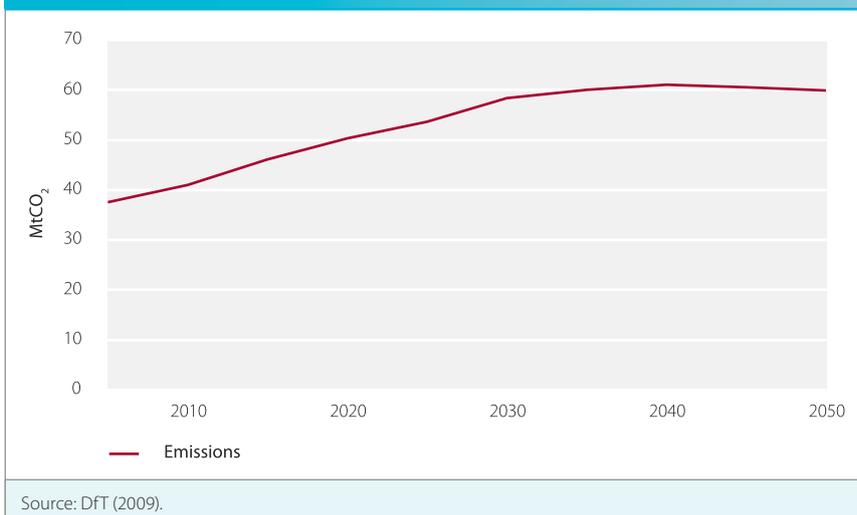


Figure 1.2 Breakdown of UK Kyoto GHG emissions by sector (MtCO₂)



Going forward, the Department for Transport's (DfT) central projections for UK aviation emissions published in January 2009 show emissions increasing from 37.5 MtCO₂ in 2005 to around 60 MtCO₂ by 2030, then remaining flat to 2050 (Figure 1.3). The projections are driven by demand growth which is accommodated with additional airport capacity before 2030, and improvements in the fuel efficiency of the fleet of the order 1% annually; the projections flatten out beyond 2030 due to a combination of continuing efficiency improvements, infrastructure constraints and market saturation. Under the projections, UK aviation emissions would account for around 35% of total allowed UK greenhouse gas (GHG) emissions in 2050 to meet an 80% emissions reduction target (i.e. 60 MtCO₂ from a total of around 160 MtCO₂e).

Figure 1.3 DfT central projections of aviation emissions growth to 2050



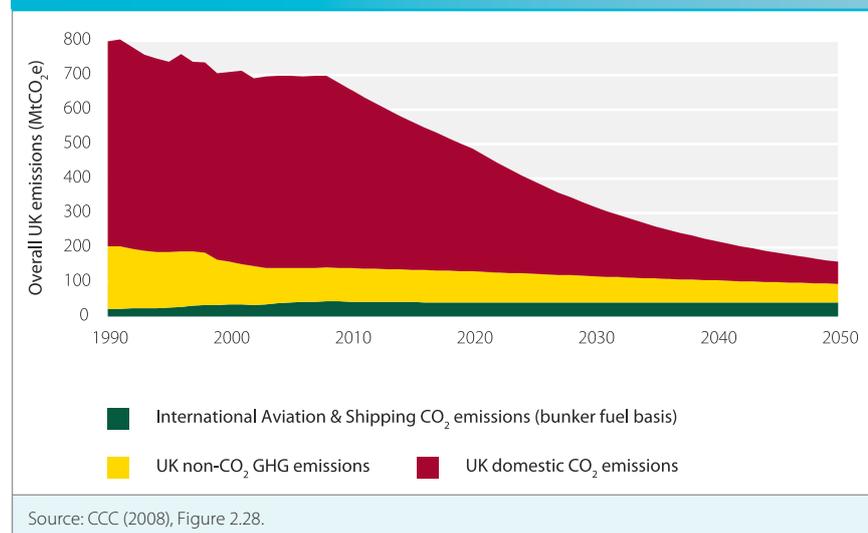
Economy-wide emissions reduction scenarios

Our 2008 report included a range of scenarios for achieving an 80% cut in economy-wide emissions. These typically included early energy efficiency improvement and decarbonisation of the power sector, with extension of low-carbon electricity to transport and heating from the 2020s.

Our analysis suggested that there should be limited reliance on purchase of offset credits to meet long-term targets given that these will become increasingly scarce/ expensive as all countries aim to achieve very challenging emissions reduction targets; it is therefore not prudent to plan that aviation will be a net purchaser of credits in the global market in 2050 and beyond.

We designed a scenario to show how the 80% target could be achieved across all sectors including aviation with very limited offset credit purchase. Specifically, we showed that if aviation emissions in 2050 were broadly equal to 2005 levels, if shipping followed the same pattern and if non-CO₂ emissions were reduced by 70% relative to 1990, then a 90% cut in CO₂ emissions from other sectors would achieve an 80% economy-wide cut (Figure 1.4).

Figure 1.4 Indicative path to the UK target of an 80% reduction in GHG emissions in 2050



The difference between allowed emissions on the path to 2050 and feasible emissions reductions for non-aviation sectors represents an indicative ceiling on aviation emissions over the next decades. This ceiling initially grows but begins to fall from around 2030 on the path to returning to 2005 levels in 2050 (Box 1.2).

However, the fact that there is a challenging emissions constraint in 2050 suggests that scope for growth in emissions on the path to 2050 may actually be limited given the long-lived nature of aviation assets (e.g. airports, planes, etc.); our focus in this report is therefore meeting the 2050 target rather than any possible increase on the path to 2050.

Box 1.2 Indicative ceiling for UK aviation emissions to 2050

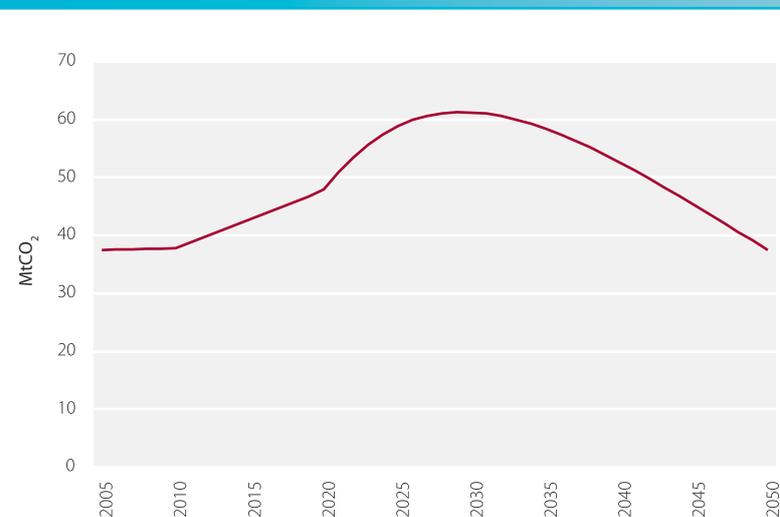
Figure B1.2 shows an illustrative emissions pathway for the UK aviation sector consistent with the 2050 aviation target, the overall, economy-wide target of reducing GHG emissions by 80%, and a set of assumptions about emissions reduction in other sectors of the economy.

The pathway was derived as follows:

- To 2020, aviation emissions are assumed to follow our Likely scenario (Box 1.5).
- In 2020, total emissions are defined by an economy-wide emissions reduction of 42% (the Committee's Intended budget) together with business as usual emissions in aviation and shipping.
- From 2020, economy-wide emissions are assumed to fall on an equal annual percentage reduction trajectory to an 80% reduction in 2050.
- The pathway for aviation is the residual of the economy-wide trajectory less emissions in other sectors; consistent with our December 2008 report, we have assumed that CO₂ emissions outside aviation fall on an equal annual percentage reduction trajectory to a 90% reduction in 2050, and non-CO₂ gases fall on an annual equal percentage emissions reduction to a 70% reduction in 2050.

The pathway shows some scope for emissions growth (e.g. peaking in 2029 with emissions 63% above 2005 levels) before returning to 2005 levels by 2050.

Figure B1.2 Indicative ceiling for UK aviation emissions



Source: NAEI (2009) and CCC calculations.

(iii) Accounting for UK aviation emissions under the Climate Change Act

In the context of providing advice on the level and scope of the first three carbon budgets, the Committee was required to consider whether international aviation should be formally included. The Committee's position was that international aviation should be part of climate strategy and would ideally be included in carbon budgets⁴.

In practice, however, the Committee identified a complexity arising from differences in appropriate emissions allocation methodologies and the proposed methodology for allocating EU ETS allowances:

- The United Nations Framework Convention on Climate Change (UNFCCC) Subsidiary Body for Scientific and Technological Advice (SBTA) has recommended that four methodologies for allocating aviation emissions be considered further: bunker fuels, nationality of airline, international departures/arrivals on an aircraft basis, international departures/arrivals on a passenger basis. Each of these methodologies allocates a similar percentage (7-8%) of total global international aviation emissions to the UK (Box 1.3).
- Within the EU ETS, however, the proposal at the time was that EU airlines would be administered by the Member State in which they were issued their operating licence, with non-EU airlines administered by the Member State which accounts for the largest proportion of their emissions. This could result in the UK administering allowances covering up to 60 MtCO₂ (i.e. significantly more than the 35 MtCO₂ under a bunker fuel methodology).

The Committee considered inclusion of international aviation in carbon budgets under two alternative allocation methodologies: administration under the EU ETS, and bunker fuel estimates. The Committee argued:

- Inclusion on the basis of EU ETS administration would not reflect the UK's actual aviation emissions and therefore would not be an appropriate basis for inclusion.
- Inclusion on a bunker fuels basis would be appropriate but potentially confusing given the existence of the EU ETS methodology.

The Committee therefore concluded that international aviation emissions should not for the time being be included in carbon budgets. They were reflected, however, in the Committee's advice, which proposed carbon budgets that, together with the EU ETS cap on aviation emissions, would be an appropriate contribution to required global emissions reductions over the first three budgets.

⁴ Domestic aviation is already explicitly included in carbon budgets as per the Kyoto Protocol reporting requirements.

Box 1.3 Alternative approaches to measure UK aviation emissions

Total UK aviation emissions comprise of domestic aviation emissions plus a UK share of international aviation emissions.

Domestic aviation emissions relate to internal UK flights and are reported in the National Atmospheric Emissions Inventory (NAEI) for the purposes of the UK emission reduction commitments. These emissions accounted for around 2.4 MtCO₂ in 2005, and are therefore a relatively small proportion (around 0.3%) of total UK GHG emissions.

There is a variety of possible ways of determining the UK share of international aviation emissions. Alternative methodologies recommended for further consideration by the UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA) include the following:

- **Bunker fuels:** Emissions from fuel used for international flights and sold in the UK would be attributed to the UK.
- **Airline nationality:** Emissions from British airlines would be attributed to the UK.
- **International departures and arrivals on an aircraft basis:** Emissions of out-bound flights from the UK would be attributed to the UK while emissions of the return flight would be attributed to the destination country.
- **International departures and arrivals on a passenger basis:** Emissions of out-bound flights from the UK, adjusted by a passenger-km index to reflect seat bandings of different flights, would be attributed to the UK.

On a 'bunker fuel basis' (which is reported as a memorandum item in the UNFCCC National Register), UK international aviation emissions were around 35 MtCO₂ in 2005.

In our December 2008 report, we illustrated that the alternative SBSTA methodologies for allocating international aviation emissions all lead to the UK being allocated a share of 7-8% of the global total.

Since the 2008 report was published, it has become clear to the Committee that the EU ETS methodology in the Directive (published in January 2009) actually suggests an approach to attribute emissions to individual Member States that may be consistent with methodologies recommended by the UNFCCC. Specifically, while the 85% of emission allowances to be freely allocated to airlines will follow the EU ETS administration rules, the revenues from auctioning the remaining 15% will be attributed to member countries on the basis of an all-departing/ third country arriving flights principle.

Given that the approach for allocating auction revenues from aviation inclusion in the EU ETS to Member States may be consistent with suitable methodologies for allocating aviation emissions (thereby reducing the potential for confusion), it is appropriate to reconsider inclusion of international aviation emissions in the UK carbon budgets.

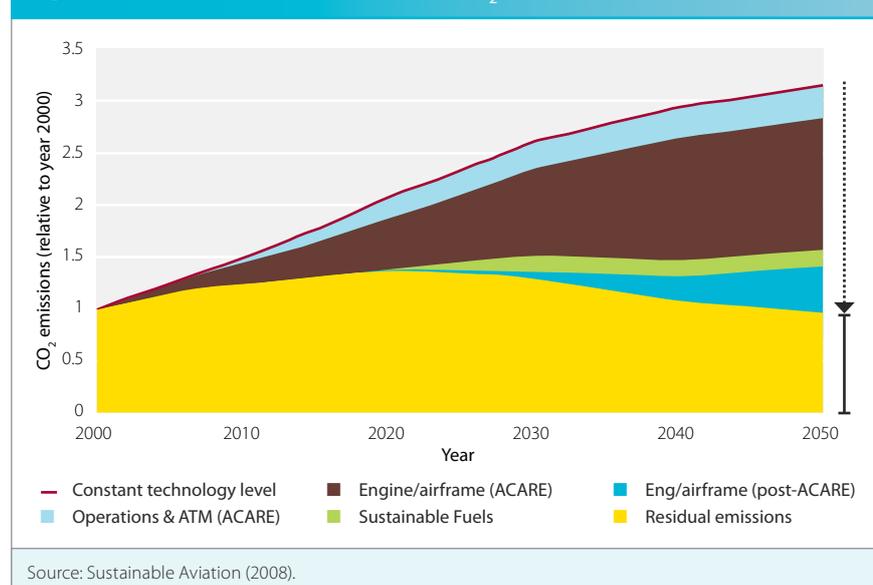
The Committee will reconsider the case for inclusion of international aviation emissions in carbon budgets as part of a wider legislative package covering the fourth budget and possible amendments to the first three budgets following the Copenhagen climate summit; the Committee's advice on the fourth budget will be published at the end of 2010, as required under the Climate Change Act.

2. The Government's 2050 aviation emissions target

In January 2009 the Government set a new target to reduce UK aviation emissions to 2005 levels or below in 2050 as part of its decision to support expansion of Heathrow. Two factors were important in determining this target:

- The Committee's 2008 report and the scenarios showing that reducing aviation emissions to around 2005 levels and cutting CO₂ emissions in other sectors by 90% would achieve the economy-wide 80% Kyoto GHG emissions reduction target.
- Analysis by Sustainable Aviation – a UK aviation industry group – showing how UK aviation emissions could be reduced back to 2000 levels in 2050 through a combination of ATM, engine and airframe innovation and use of biofuels (Figure 1.5)⁵.

Figure 1.5 The Sustainable Aviation CO₂ Roadmap



⁵ See: <http://www.sustainableaviation.co.uk/images/stories/key%20documents/sa%20road%20map%20final%20dec%2008.pdf>

The target is consistent with assumptions that it is prudent not to plan for net credit purchase by the aviation industry further out to 2050, and that other countries will be operating under similar constraints on aviation emissions:

- The fact that the target is set in terms of gross rather than net emissions (i.e. it relates to actual emissions rather than emissions net of purchase of credits from other sectors or from the international carbon markets) reflects an assumption that the supply of cheap credits will be exhausted over time and that it is therefore important for the aviation sector to focus on reducing its own emissions.
- The target would result in positive environmental impact if other countries were operating under similar constraints on aviation emissions; if this were not to be the case, demand and emissions would be displaced, at least to an extent, to other countries. It is reasonable to assume that other countries will be operating under similar constraints given the very challenging targets to reduce global emissions and achieve climate objectives in the period to 2050 and beyond.

The Committee was requested to carry out a review of aviation emissions⁶ focusing on:

- UK trends in aviation emissions
- The basis for measurement for the UK target for aviation emissions in 2050
- The scope for reductions, including from improvements in technology and the effect of appropriate policy levers; and the implications of further aviation expansion beyond 2020
- An appropriate structure and/or international target regime to support a global deal to reduce aviation emissions.

This report covers the first three areas. The Committee reported separately to the Secretaries of State for Transport and Energy and Climate Change on international aviation in September 2009 and made a set of recommendations for a global deal that would both constrain aviation emissions in a way consistent with meeting climate objectives, and avoiding leakage through a multilateral rather than unilateral approach (Box 1.4).

⁶ See: <http://hmccc.s3.amazonaws.com/2009-01-14%20Letter%20from%20Geoff%20Hoon.pdf>

Box 1.4 The Committee on Climate Change's advice on a framework for reducing global aviation emissions

Capping global aviation emissions

- Aviation CO₂ emissions should be capped, either through a global sectoral deal or through including domestic and international aviation emissions in national or regional (e.g. EU) emissions reduction targets.
- Ideally all aviation CO₂ emissions would be capped. However, an interim phase where the cap applies to all departing and arriving flights in developed countries with exemptions for intra-developing country flights may be necessary.
- The level of emissions reduction ambition under any international agreement should be no less than that already agreed by the EU (i.e. developed country net emissions in 2020 should be no more than 95% of average annual emissions from 2004-2006).

Auctioning allowances in cap and trade schemes

- Emissions allowances under a cap and trade scheme should be fully auctioned so as to avoid windfall profits for airlines that would ensue under free allowance allocation.
- Aviation auction revenues are one of a number of possible sources for funding of adaptation in developing countries that should be agreed as part of a global deal in Copenhagen.
- Significant R&D that is urgently required to support innovation in the aviation industry should be considered in the context of a global deal for aviation, and funded from aviation auction revenues or other sources.

Emission reductions within the aviation sector

- Emissions trading will be useful for an interim period in providing flexibility to achieve cost-effective emissions reductions, subject to the caveat that the carbon price in any trading scheme should provide strong signals for appropriate demand management and supply side innovation.
- The aviation industry should also plan, however, for deep cuts in gross CO₂ emissions relative to baseline projections (e.g. for developed country aviation emissions to return to no more than 2005 levels in 2050), which will be required as a contribution to meeting the G8's agreed objective to reduce total global emissions in 2050 by 50%.

Non-CO₂ effects of aviation

- Non-CO₂ effects of aviation must be addressed as part of any international framework through commitment to a schedule for introduction of appropriate policy instruments (e.g. covering NO_x, cirrus and contrails). Given current scientific understanding, early introduction of measures to reduce NO_x emissions may be feasible and should be seriously considered.

3. The Committee's approach to the review

The basis for measuring the UK aviation target

As already noted, the methodologies proposed by the UNFCCC for allocation of global aviation emissions to national levels – bunker fuels, nationality of airlines, departing flights – gives a broadly similar level of UK international aviation emissions. In our December 2008 report, we considered inclusion of international aviation emissions in carbon budgets on the basis of a bunker fuels methodology, given that this is the convention for measuring domestic aviation emissions in the UK's national emissions inventory, and international aviation emissions as a memo item in the UNFCCC National Register.

Going forward, it is likely that there may be scope for more precise measurement based on flight specific fuel consumption data. The Committee will consider further the appropriate methodology for measuring compliance with the UK's aviation emissions target, and whether there is evidence to suggest an alternative to bunker fuels may be appropriate, in the context of its advice about whether aviation should be included in carbon budgets.

Projecting emissions for comparison with the target

In order to understand how the 2050 target might be achieved, we have developed reference demand and emissions projections, and then explored scope for emissions reductions through modal shift from aviation to rail, increased use of videoconferencing as a possible substitute for business travel, improvement in the fuel efficiency of the fleet through evolutionary and more radical technology innovation, and the use of sustainable biofuels.

Based on these options, we have defined three core scenarios reflecting increasingly optimistic assumptions about technological developments and policy intensity (Box 1.5). We have considered the implications of these scenarios in relation to both CO₂ emissions and non-CO₂ effects of aviation. We have also assessed the extent of possible constraints to demand growth that may be required to close any gap to the 2050 target. We have done this drawing on in-house analysis, modelling commissioned from expert consultants, DfT analysis, and extensive discussions with aviation industry stakeholders. Specifically, we adopted the following steps:

- **Reference demand and emissions projections.** The Committee commissioned MVA to develop a model of UK aviation demand and emissions. We have used this to develop two types of reference scenarios:
 - A reference scenario with unconstrained demand growth, and an assumption of no improvement in fuel efficiency relative to the current situation. These represent a hypothetical worst case from a carbon perspective (e.g. because of scope for technology innovation that would reduce emissions) and show the scale of the challenge in terms of required emissions reductions to meet the 2050 target.

– A reference scenario which retains the assumption of no improvement in fuel efficiency but introduces a demand constraint in response to carbon prices reflected in the cost of air travel. In addition, we follow the DfT convention and model a capacity constrained system (e.g. expansion as envisaged in the 2003 Air Transport White Paper and recent announcements⁷, currently existing capacity only, etc.).

- **Modal shift to rail and increased videoconferencing:** The Committee commissioned SDG to assess scope for switch from short-haul (domestic and international) aviation to rail and high-speed rail. The analysis carried out by SDG does not attempt to quantify the costs and benefits (e.g. travel time savings) of investment in high-speed rail. It does however provide an estimate of the order of magnitude of the reduction in demand for flights that would ensue under plausible scenarios for modal shift, which we reflect in our emissions projections. Our analysis also includes scope for reduced air travel as a result of videoconferencing, which may become more attractive with technology innovation and increasing cost of air travel.
- **Fleet efficiency improvement through technology innovation:** We build on our work last year – which identified scope for a new production aircraft in 2025 to be 40-50% more fuel efficient than one produced in 2006 – using a hybrid top-down (fleet average) /bottom-up (new aircraft) approach to model improvements of fleet efficiency under a plausible range of scenarios. These range from what is achievable under the current framework to what is achievable but very unlikely and would require a significant shift in policy and investment. We then adjust the emissions factor reference projections to account for efficiency improvement scenarios, both as regards technology innovation and improved efficiency in Air Traffic Movements and operations.
- **Use of sustainable biofuels:** It is likely that large scale use of biofuels in aviation will be technically feasible. There are outstanding questions, however, about the sustainable production of biofuels and the quantity of sustainable biofuels that may be available for use in aviation. The Committee has developed a number of scenarios for sustainable biofuels use in global and UK aviation, given constraints on availability of land and other resources; our scenarios allow for emissions reductions from biofuels under alternative assumptions about the level of sustainable biofuels, their lifecycle savings, and the use of sustainable biofuels in aviation rather than other sectors.
- **Aviation non-CO₂ effects:** The UK aviation target relates to Kyoto GHGs, and therefore to CO₂ only; the core of this report focuses on aviation CO₂ emissions. The Committee has also reviewed the current scientific evidence based on non-Kyoto/ non-CO₂ effects (e.g. NO_x, contrails, etc.) and the

⁷ Specifically, in modelling capacity in line with current plans, we assume that additional runways will be built by 2030 at Heathrow, Stansted and Edinburgh and that more efficient use of existing runways at other airports will result in increased capacity.

implications of including these in the UK's emissions targets (e.g. the need for further CO₂ emissions reductions in aviation and/or further cuts in other sectors to achieve the UK's climate objective). The Committee is not proposing that aviation non-CO₂ effects should currently be included in the UK's aviation target. These effects are likely, however, to be significant, and should therefore be considered as part of any strategy for emissions reduction in aviation and more generally, with inclusion contingent upon better scientific understanding in the context of an internationally agreed approach. Aviation non-CO₂ effects are included in this report as an additional source of uncertainty when assessing how emissions targets for UK aviation may be achieved.

- **Options for addressing a potential gap:** Where a gap remains between emissions projections and the 2050 aviation target, this could be closed through a number of complementary options, including maximising the potential for demand reductions through modal shift to rail and videoconferencing, accelerating efficiency improvements and investing in the development of low-carbon fuels.
- **Explicit constraints on demand growth:** In the absence of a compelling case for any of the above routes the Government may need to consider explicitly constraining demand growth. We consider at a high level the order of magnitude of *target compatible* demand growth, and any implications for aviation expansion.

The remainder of the report sets out in detail the blocks of analysis above.

Box 1.5 Approach for dealing with uncertainty and developing scenarios in assessing options for meeting the UK's 2050 aviation target

A constant theme running through the analysis is that of the considerable uncertainty over UK aviation emissions projections due to:

- **Policy uncertainty:** For example, airport capacity expansion, development of a high-speed rail network in the UK and Europe, the framework for support of aviation R&D
- **Demand uncertainty:** For example, uncertainty about responses to changing incomes and prices, opportunities for modal shift to rail, opportunities for reducing the need to fly through technologies such as videoconferencing
- **Technology uncertainty:** For example, uncertainty relating to the pace of engine and airframe technology innovation, availability of land for growing biofuel feedstock, availability of biofuels which do not require significant amounts of land
- **Scientific uncertainty:** For example, on the magnitude of non-CO₂ effects.

Box 1.5 continued

We have allowed for uncertainty by developing three scenarios for each of the options to reduce emissions, each of which is a more aggressive/less likely departure from the current situation in terms of policy and technology:

- **Likely scenario:** This reflects demand reductions and carbon intensity reductions likely to be achieved given current policies, investment levels and the pace of technological advance.
- **Optimistic scenario:** This would require both a significant shift from current policy (e.g. in respect to high-speed rail), an increase in the level of investment in new aircraft technologies and/or in the pace of fleet renewal as well as improvements in ATM and operations and progress on sustainable biofuels technologies.
- **Speculative scenario:** This would require both technological breakthroughs and a significant increase in the pace of aircraft fuel efficiency improvements. In addition, it would require the development of sustainable biofuels which are currently speculative (e.g. biofuels from algae), or an evolution of global population, food demand and agricultural productivity which would make possible the sustainable and large scale use of current agricultural land and water to grow biofuel feedstocks. These developments are assessed today as very unlikely.

We note that these definitions are applied to options which are not always directly comparable. For example, it is currently more likely that the possible scenario for modal shift ensues following a decision to invest in a high-speed rail line in the UK, as opposed to the possible scenario for fleet efficiency improvement, which could require a new policy approach at the European level, together with significantly increased investment in technology innovation. The scenario names should therefore be interpreted pragmatically.

Also, these should not be compared with the Committee's Current, Extended and Stretch scenarios defined in the context of UK emissions excluding aviation, where there is less uncertainty about abatement potential and more policy levers are available at the UK level.

In projecting emissions net of abatement opportunities we start with a reference emissions projection from which we net off emissions reductions under different scenarios. We adopt a prudent approach which attaches most weight to the Likely scenario, and does not currently plan for the Optimistic or Speculative scenarios in the absence of new evidence to suggest an increased likelihood that these will ensue.

Box 1.5 continued

We allow for further uncertainty over exogenous demand drivers by overlaying sensitivities across these scenarios. For example, in the Likely scenario for modal shift, videoconferencing, fleet efficiency improvement and biofuels, we consider emissions under assumptions of central, low and high fossil fuel and carbon prices. We also consider demand sensitivities for different assumptions about capacity to understand any implications of achieving the 2050 target for demand expansion in the 2020s.

Chapter 2

Reference demand and emissions projections

This chapter sets out reference demand and emissions projections across which scenarios reflecting different assumptions on modal shift, fleet fuel efficiency improvement and biofuels penetration can be overlaid (see Chapter 7).

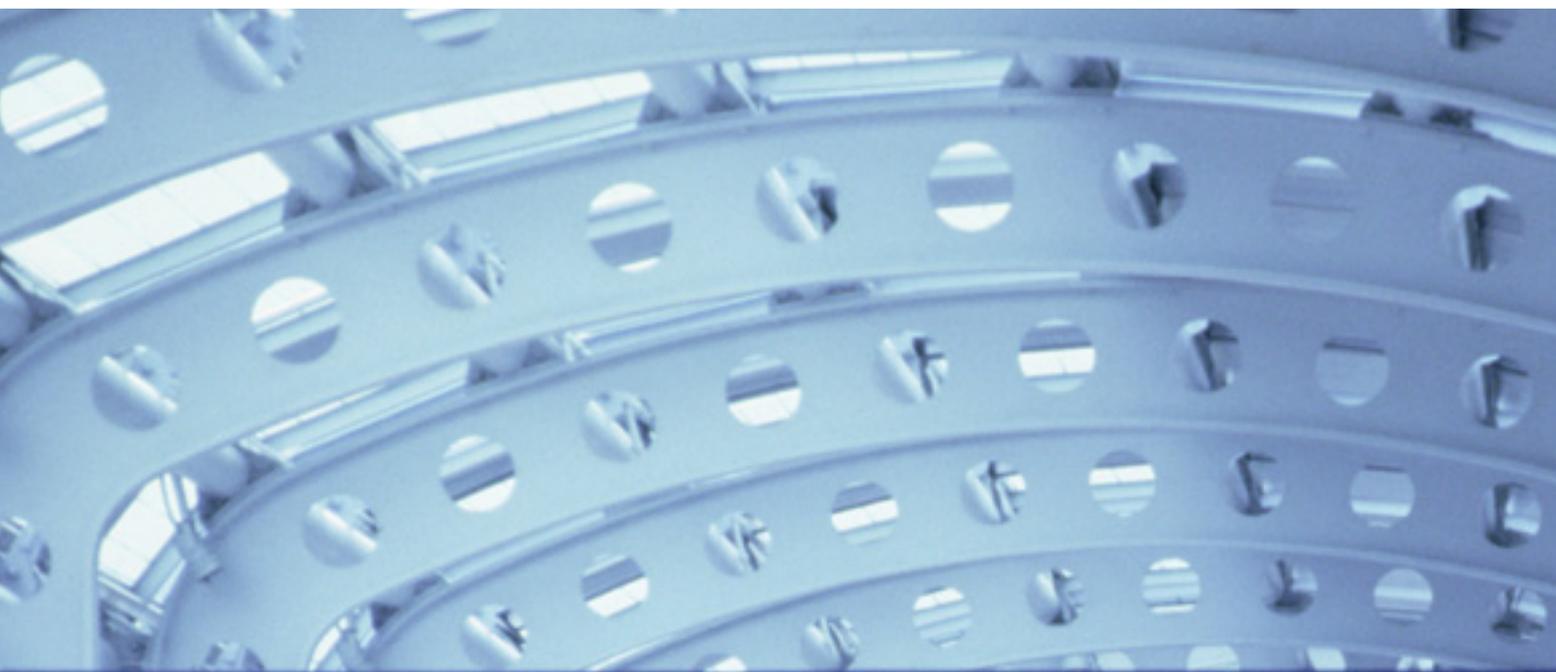
Our reference demand projections reflect alternative assumptions about fossil fuel prices, carbon prices and capacity constraints. They are constructed using a detailed model which disaggregates demand into various categories (e.g. short-haul, long-haul), combines assumptions on demand drivers with estimates of income and price elasticities, and then converts demand projections to emissions projections under assumptions about emissions factors. The model, which was independently developed, benchmarks closely to DfT's January 2009 CO₂ emissions forecasts (e.g. within 0-8% for passengers, Air Traffic Movements (ATMs) and CO₂ emissions to 2050).

Our reference emissions projections reflect, for indicative purposes, an assumption that there is no improvement in fleet fuel efficiency relative to the current situation¹; we set out our assessment of scope for improvement in fleet fuel efficiency in Chapter 4, and the impact that this would have on emissions in Chapter 7.

The key messages in the chapter are:

- In a world with unconstrained demand growth, UK aviation demand could increase by over 200% in 2050 relative to 2005 levels, from 230m passengers in 2005 to 695m annual passengers in 2050.
- In a world with currently planned infrastructure expansion (i.e. extra runway capacity at Heathrow, Stansted and Edinburgh as envisaged in the 2003 Air Transport White Paper) and a carbon constraint reflected in a 2050 carbon price of £200/tCO₂, UK aviation demand would be around 115% higher in 2050 than in 2005, increasing from 230m passengers in 2005 to 490m annual passengers in 2050.
- Emissions in 2050 would be around 100% higher than in 2005, allowing for a carbon constraint as above and planned infrastructure expansion but without any increase in fleet fuel efficiency or biofuels penetration; slightly lower emissions growth than demand growth reflects increasing load factors and changes in the destination mix over time.

¹ Specifically, the seat-km per tonne of fuel for the fleet as a whole remains constant.



↖ Gate C21 ↑ ✈ Terminals 2 3 5 🚻 Restroom
Concourses B E F 🛂 Customer Service Center
Gates C1-C20 C
🛃 Baggage Claim
🚗 Ground Transport



We set out the analysis that underpins these messages in five sections:

1. UK aviation demand since 1990
2. Demand drivers
3. Reference demand projections
4. Reference emissions projections
5. How we will use reference projections

1. UK aviation demand since 1990

Total demand, short-haul and long-haul demand

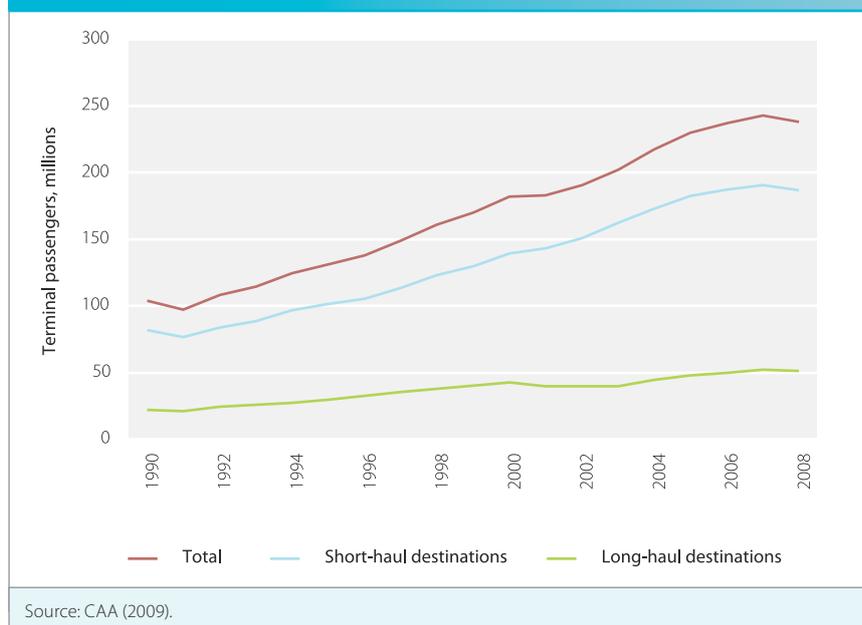
Total aviation demand in the UK² increased by around 130% (i.e. from 104m passengers to 238m passengers) between 1990 and 2008 and around 4.9% on an annualised basis, and 18% (i.e. from 202m passengers to 238m passengers) in the period 2003 to 2008 and around 3.4% on an annualised basis (i.e. the pace of increase fell in the five years to 2008). This was in a context of rising incomes and falling fares resulting in significant demand increase for both short and long-haul flying³:

- UK GDP increased by 54% between 1990 and 2008, and by 12% from 2003 to 2008.
- Air fares fell by around 50% between 1997 and 2006.
- Short-haul demand increased by 128% (i.e. from 82m passengers to 187m passengers) between 1990 and 2008, and 15% (i.e. from 162m passengers to 187m passengers) over the period 2003 to 2008 (Figure 2.1).
- Long-haul demand increased by 133% (i.e. from 22m passengers to 51m passengers) between 1990 and 2009, and 30% (i.e. from 40m passengers to 51m passengers) over the period 2003 to 2008 (Figure 2.1).

Short-haul demand currently accounts for the majority of passengers (78%) but less than 40% of passenger-kms given relative distances of short and long-haul flights; this distinction is important in understanding the relative impact of changes in demand by flight category on total aviation emissions, see Section 4 below.

² Data provided by the UK Civil Aviation Authority (CAA), and refers to all departing and arriving passengers.

³ Where underlying data is disaggregated by region we have assumed that travel to destinations in Europe is short-haul and beyond Europe is long-haul. Where actual distance is indicated, we are consistent with Defra/DECC conversion factors and assume that flights up to 3,700km are short-haul and flights greater than 3,700km are long-haul, which is broadly consistent with the Europe/Non-Europe split.

Figure 2.1 UK aviation demand since 1990

Purpose, destination and class of flying

Travel for purposes of leisure and business has changed significantly over the last twenty years (Table 2.1). Specifically:

- Survey data suggests that the number of passengers travelling for leisure purposes has increased from around 63 million in 1991 to around 180 million in 2008; leisure flights now account for around 75% of the total.
- The proportion of passengers travelling for business purposes has increased more slowly, from around 35 million in 1991 to around 60 million in 2008.

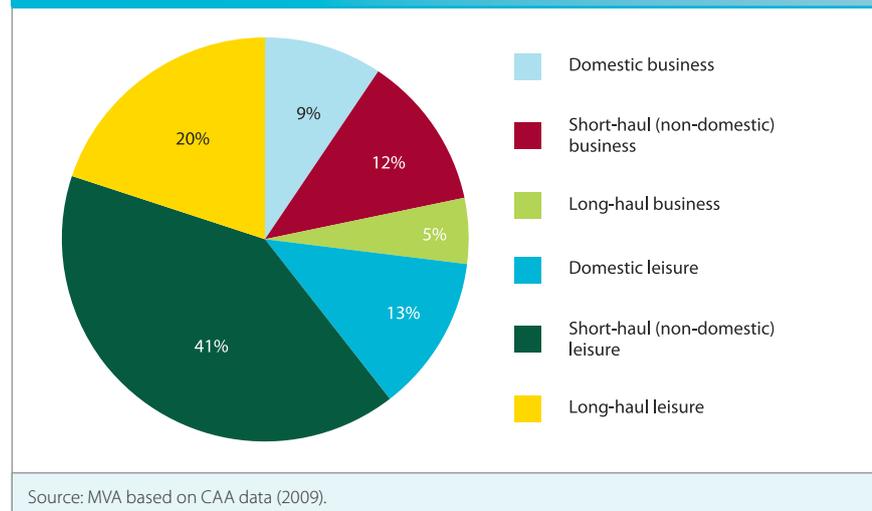
Table 2.1 Trends in UK aviation by purpose

Sector	1991		2008	
	Passengers	Proportion	Passengers	Proportion
Leisure	63m	(65%)	180m	(75%)
Business	35m	(35%)	60m	(25%)

Source: CCC calculations and CAA survey data (1991, 2008).

Figure 2.2 shows the distribution of UK aviation passengers by distance and purpose in 2005, based on CAA data.

Figure 2.2 Distribution of UK aviation passengers by distance and purpose in 2005



Demand for premium (non-economy) class travel (whether for purposes of business or leisure) has also changed significantly over time. Since 2001/02 demand for long-haul premium class travel (outside the European Economic Area [EEA]) has increased by 41% (i.e. from 2.7m departing passengers to 3.8m departing passengers) whereas demand for short-haul premium flying (within the EEA) has fallen by 68% (i.e. from 4.4m departing passengers to 1.4m departing passengers)⁴. The growth in premium class long-haul is therefore broadly in step with growth in long-haul generally, and we have assumed that this continues to be the case in projecting demand forward (Figure 2.3).

Figure 2.3 UK trends in premium class travel

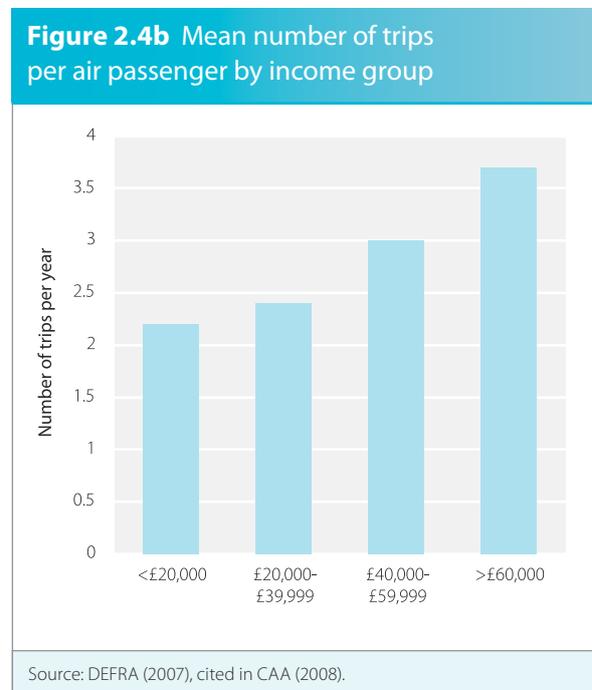
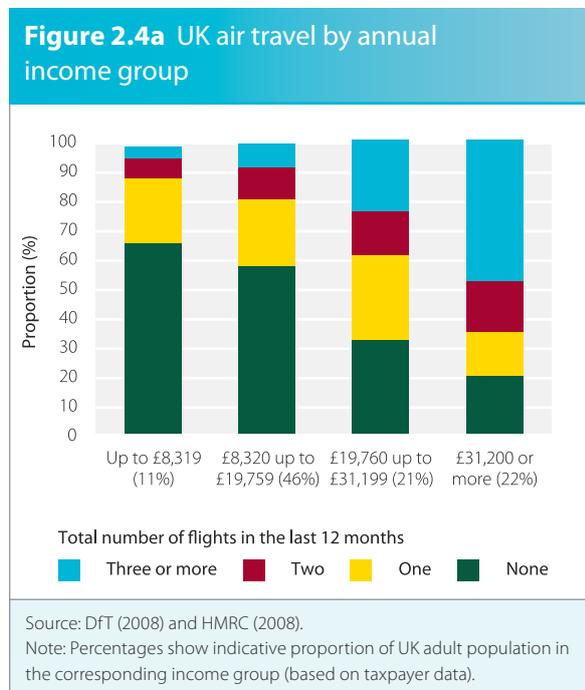


⁴ HMRC (2009), *Air Passenger Duty Bulletin*.

Number of people flying by income group

Survey evidence suggests that around 50% of the UK adult population travels by plane in any given year⁵ (a consistent proportion since 2003) and that likelihood of flying is closely related to income (Figure 2.4a).

Amongst those who fly, the average number of flights per year also varies significantly by income, with those on incomes of more than £60,000 per annum flying on average just under four times per year, and those on less than £20,000 flying two times per year (Figure 2.4b). Income elasticity of demand is thus high, both between income groups and over time. Income growth is therefore an important driver of demand growth.



Freight demand

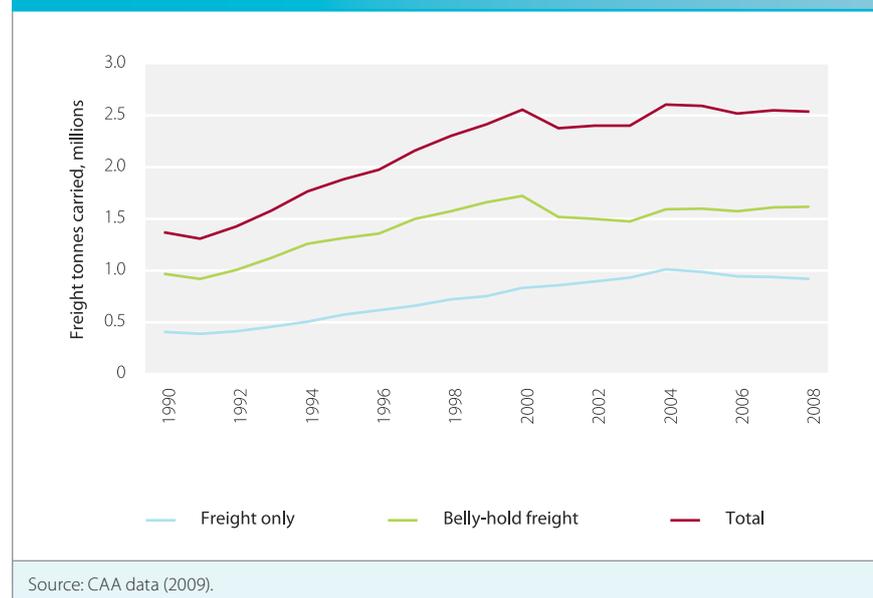
Total UK freight aviation, measured in tonnes carried, has increased by 85% over the period 1990 to 2008 (from 1.4m tonnes to 2.5m tonnes) but only 6% over the period 2003 to 2008 (from 2.4m tonnes to 2.5m tonnes).

Two-thirds of total UK freight by volume is carried in passenger aircraft ('belly-hold' freight). The volume of belly-hold freight has increased by 167% over the period 1990 to 2008 (from 1m tonnes to 2.5m tonnes), although growth has flattened out in this decade growing by 10% over the period 2003 to 2008 (Figure 2.5).

⁵ DfT (2008), *Public experiences of and attitudes to air travel*.

Freight-only flights account for only a small proportion of total UK aviation (e.g. around 3% of ATMs and 2% of emissions⁶). Volumes carried by freight-only flights increased by 127% over the period 1990 to 2008 (from 0.4m tonnes to 0.9m tonnes), although as with belly-hold freight growth has been subdued in the past decade and volumes carried fell slightly by 1% over the period 2003 to 2008 (Figure 2.5). Notwithstanding these trends, given the magnitude of freight-only aviation relative to the total, it is unlikely to have a major impact on total UK aviation emissions going forward.

Figure 2.5 Demand for UK aviation freight



The impact of the recession on demand

At the global level, the economic downturn has had a significant impact on global demand for aviation. Analysis by IATA suggests that international passenger air demand fell by up to 10% in the first half of 2009, with freight demand showing sharper falls approaching 25%.

At the UK level, aviation demand fell by 2% in 2008 and 10% in the first half of 2009 as a result of the recession.

Going forward, we would expect aviation demand growth (globally and in the UK) to resume as GDP returns to growth. Consistent with HM Treasury, we have assumed that the rate of GDP growth will ultimately return to pre-recession trends, but with a once-and-for-all reduction in the level of output; we reflect this once-and-for-all adjustment in our demand projections, to which we now turn.

⁶ DfT (2009), *UK Air Passenger Demand and CO₂ Forecasts*.

2. Demand drivers

Income and price demand elasticities

We have shown that increasing demand for aviation in the UK has occurred in a context of increasing GDP and falling fares. There is a comprehensive body of evidence which formally bears out these relationships in the UK, with income elasticities estimated to be around 1.5 (i.e. a 10% increase in income will result in a 15% increase in demand), and price elasticities of around -1 in the leisure market and close to zero in the business market; we have used DfT estimates (Table 2.2), which are consistent with the literature, as the basis for our demand projections.

Table 2.2 DfT Elasticity estimates⁷

	Price elasticities	Income elasticities
UK Business	-	1.4
UK Leisure	-1.0	1.5
Foreign Business	-	0.6
Foreign Leisure	-0.2	0.7

Source: DfT (2009).

Assumptions on growth, fossil fuel prices and carbon prices

Given our assumptions on demand elasticities, we apply these to assumptions on key demand drivers:

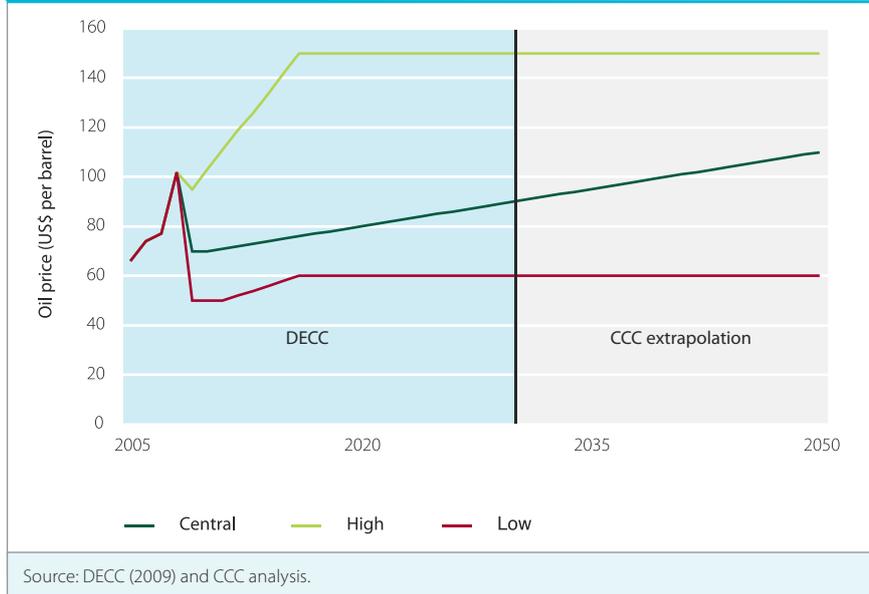
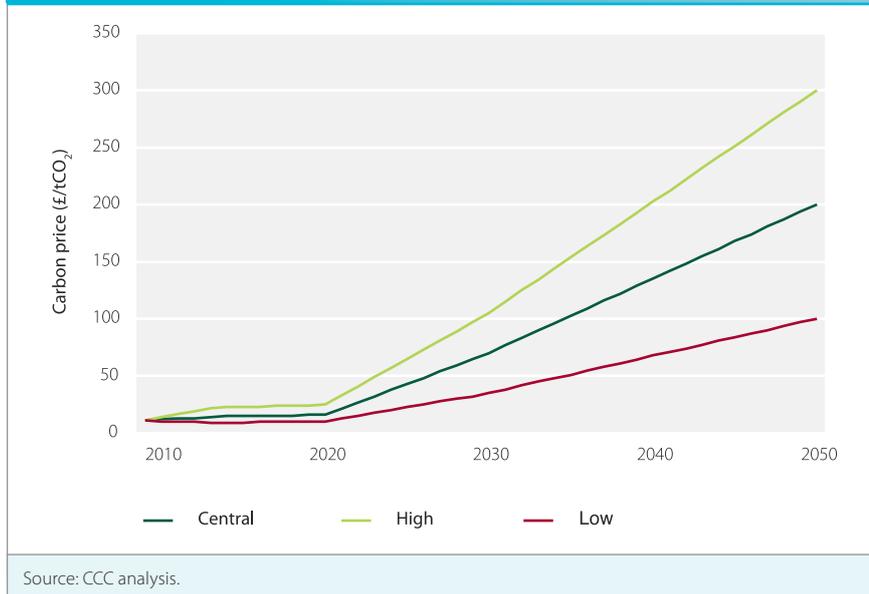
GDP growth: We use GDP growth forecasts that incorporate the effects of the economic downturn, and are based on HM Treasury forecasts for the UK and IMF forecasts for the rest of the world. For example, we have assumed average annual UK GDP growth of 2.1% over the period to 2050. The GDP growth forecasts incorporate demographic changes among other drivers.

Fossil fuel prices: We use DECC's fossil fuel price assumptions, extrapolating beyond 2030 based on the pre-2030 trend. The range of oil prices is US\$60 to US\$150/barrel in 2050 (Figure 2.6). To the extent that the oil price is above US\$150 in 2050 this would reduce the contribution required from other emissions reduction levers in meeting the 2050 target.

Carbon prices: We use our own carbon price assumptions, based on modelling using DECC's marginal abatement cost and GLOCAF models. Carbon prices range between £100 and £300/t CO₂ in 2050⁸. Our central carbon price projection rises to £200/tCO₂ in 2050 (Figure 2.7). The 2050 carbon prices are based on the assumption of a comprehensive global trading regime from 2030 onwards, and emissions reductions consistent with a long-term stabilisation goal of 475-500ppm.

⁷ DfT could not identify a statistically significant relationship between business demand and air fares in their modelling. Nevertheless, estimates from the literature reviewed for the CCC by MVA Consultancy pointed to a small but non-zero price elasticity of -0.2. We have run sensitivities on our three core scenarios with this elasticity and the impact in 2050 is less than 1 MtCO₂ in all scenarios and therefore would not materially alter our conclusions.

⁸ The impact on fares of our carbon prices is fully additional to that of Air Passenger Duty (APD). In all of our scenarios, APD is assumed to be charged according to the APD rates outlined in last year's Pre-Budget Report (HM Treasury (2008) Chapter 7, pp 138-139 available at: www.hm-treasury.gov.uk/d/pbr08_chapter7_159.pdf)

Figure 2.6 Fossil fuel price assumptions**Figure 2.7** Carbon price assumptions

These assumptions together project incomes that will be around 150% higher than today, and fares around 75% higher in a central fossil fuel price and central carbon price case. Assuming income elastic demand and less price elastic demand, suggests that we would expect to see significant demand growth to 2050.

Assumptions on infrastructure capacity

Demand growth may be constrained depending on the level of infrastructure capacity. In projecting demand, we model various scenarios reflecting different assumptions on the level of infrastructure capacity (e.g. assuming current capacity, addition of runway capacity as envisaged in the 2003 Air Transport White Paper [i.e. Heathrow, Stansted and Edinburgh], see Box 2.1).

Box 2.1 Air Transport White Paper 2003 and runway capacity assumptions

In 2003, the Government published a White Paper on the future of air transport in the UK¹. This set out a strategic framework for the development of airport capacity in the UK up to 2030.

The White Paper did not in itself authorise any new developments, but set out a framework to guide future planning applications and allow the relevant organisations to plan ahead – it was permissive not prescriptive. It recommended making best use of existing capacity where available, for example by expanding terminal capacities. It also set out where additional runway capacity may be required.

In this report we have made assumptions about airport runway capacity in line with current plans, including the 2003 White Paper and updated for recent announcements. Specifically, we assume that additional runways will be built by 2030 at Heathrow, Stansted and Edinburgh. We also assume increases in capacity resulting from more efficient use of existing runways, or changes in planning permission at: Manchester, Luton, Bristol, Birmingham, Glasgow and London City airports.

¹ DfT (2003), *The Future of Air Transport*.

Assumptions on demand saturation

Growth in demand for aviation in the UK may slow over time as the market becomes increasingly mature. This reflects, for example, decreasing opportunities for spending additional time travelling at the margin. To reflect increasing market maturity our modelling mirrors DfT's approach and adjusts income elasticities downwards over time to capture an overall slowing of growth in aviation demand.

3. Reference demand projections

We have made our demand and emission projections⁹ using a model that we commissioned from MVA Consultancy (Box 2.2).

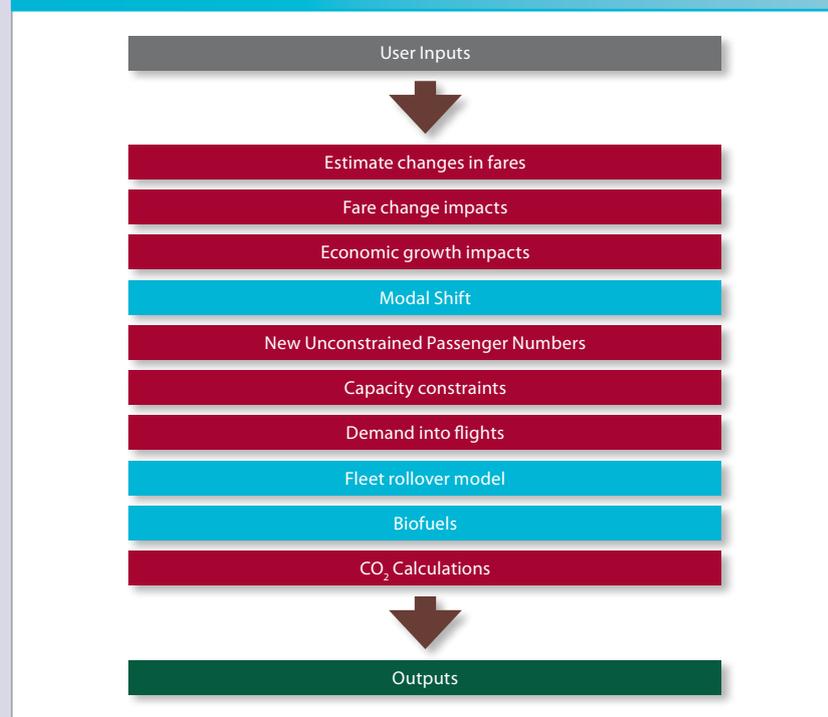
⁹ In our projections (and subsequent scenarios) the passenger demand estimates refer to all departing and arriving passengers. Emissions estimates are on an all departing basis to enable reconciliation with bunker fuel estimates.

Box 2.2 The MVA Consultancy model of UK aviation

Overview

The Committee commissioned MVA Consultancy to develop a reduced form model for projecting UK aviation demand and emissions out to 2050. The scope of the model was to forecast: aviation passenger demand within, from and to the UK; the associated air traffic movements (ATMs), both passenger and freight; and the resulting departing CO₂ emissions.

Figure B2.2 MVA model schematic



Source: MVA (2009).

The forecasts are based on data provided by the Civil Aviation Authority (CAA) for 2005 which includes detailed information on the routes flown to/from UK airports and their characteristics such as number of flights, passengers and aircraft types used.

Input assumptions are combined with the 2005 base data to estimate the effects on demand due to economic growth (covering 15 world regions) and changes in air fares (e.g. due to changes in fossil fuel and carbon prices).

Available airport capacity is a choice variable and can act as a constraint to demand growth.

The forecasts of demand can be modified to reflect the impact of modal shift to rail and videoconferencing.

Box 2.2 continued

Demand is projected first in terms of passenger numbers. These are then converted into ATMs for each of the traffic lines represented in the model, reflecting for example airlines optimising behaviour, route profitability and load factors.

The overall CO₂ emissions are calculated by combining all the above steps, and accounting for any improvements in aircraft fuel efficiency and use of biofuels.

Projecting demand and emissions

The responsiveness of aviation demand to changes in income and price are represented in the model through income and price elasticities. We have used assumptions in line with DfT forecasts which are consistent with the literature. These elasticities show that income is a strong driver of demand and that business passengers are less price sensitive than leisure passengers.

To reflect increasing market maturity, our modelling mirrors DfT's approach and adjusts income elasticities downwards over time to capture an overall slowing of growth in aviation demand.

Reconciling modelled emissions and bunker fuel estimates

In common with other detailed 'bottom-up' modelling of UK aviation emissions, there is a gap between modelled emissions and the 'top-down' estimates of CO₂ resulting from bunker fuel sales (the method used to report aviation emissions as a memo item to the UNFCCC). This discrepancy may be due to a range of factors including: deviations between actual routes and great circle distance, tankering, and the effects of aircraft ageing. Therefore, we follow the approach used by DfT and introduce a residual adjustment to reconcile the two items.

Scope

Due to the reduced form nature of the model a number of possible features are outside its scope:

- Airport capacity constraints are reflected only in terms of aircraft movements (i.e. runway capacity) and not terminal passengers.
- Thirty one airports are represented in the model. However, explicit capacity constraints are only considered for the ten largest UK airports.
- Passenger re-allocation between UK airports is not explicitly considered.
- The model is limited to improvements in the fuel efficiency of new aircraft, and therefore does not incorporate retrofitting measures.

Further detail on the modelling approach is available in a methodology technical note prepared by MVA Consultancy and available on our website at www.theccc.org.uk

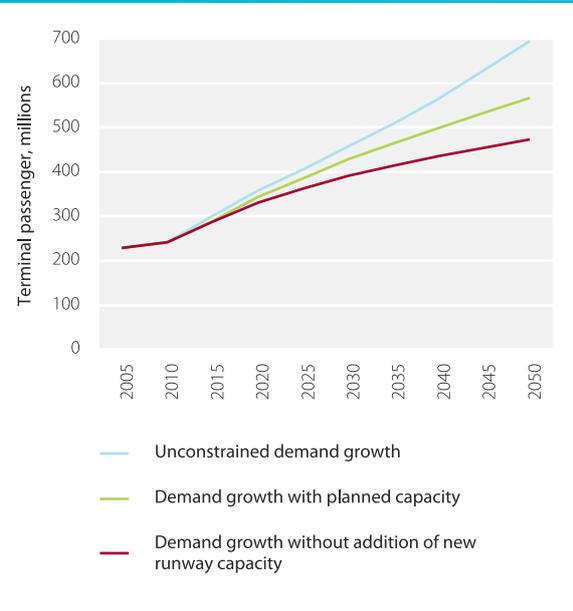
Our range of reference demand projections comprises three projections under alternative capacity assumptions and three projections with planned capacity (i.e. as in the 2003 Air Transport White Paper and recent announcements) under alternative assumptions about carbon prices and fossil fuel prices:

- **Unconstrained demand growth:** This projection assumes that airport capacity will always be available to meet any growth in demand. In 2050, demand grows by over 200% over 2005 levels (i.e. 695m annual passengers compared to 230m annual passengers in 2005).
- **Demand growth with planned capacity:** This projection constrains airport runway capacity in line with planned capacity. This scenario reflects the DfT approach to demand/emissions modelling (i.e. they assume capacity addition as envisaged in the 2003 Air Transport White Paper but no further addition). In 2050, demand grows by around 150% over 2005 levels (i.e. growing to 570m annual passengers).
- **Demand growth without addition of new runway capacity:** This projection assumes that there is no additional airport runway capacity in the UK in the period to 2050, and demand growth therefore occurs based on increased use of currently spare capacity. Demand in 2050 is around 105% above 2005 levels¹⁰ (i.e. growing to 475m annual passengers). Unless similar demand constraints were to apply across the EU, some of the demand suppressed due to capacity constraints would be displaced to hub airports in other Member States.
- **Demand growth with planned capacity and central carbon and fossil fuel price projections:** This projection assumes planned infrastructure expansion as above, and introduces a central carbon price as described in Figure 2.7. Together, this leads to demand in 2050 being around 115% higher than 2005 levels (i.e. growing to 490m annual passengers).
- **Demand growth with planned capacity and high carbon and fossil fuel prices:** Assuming high carbon and fossil fuel prices leads to demand in 2050 being around 100% higher than 2005 levels (i.e. growing to 455m annual passengers).
- **Demand growth with planned capacity and low carbon and fossil fuel prices:** Assuming low carbon and fossil fuel prices leads to demand in 2050 being around 140% higher than 2005 levels (i.e. growing to 555m annual passengers).

Our projections therefore range from demand growth of around 115% in the period 2005 to 2050 with a central carbon price and an infrastructure constraint, to over 200% without carbon prices or infrastructure constraints.

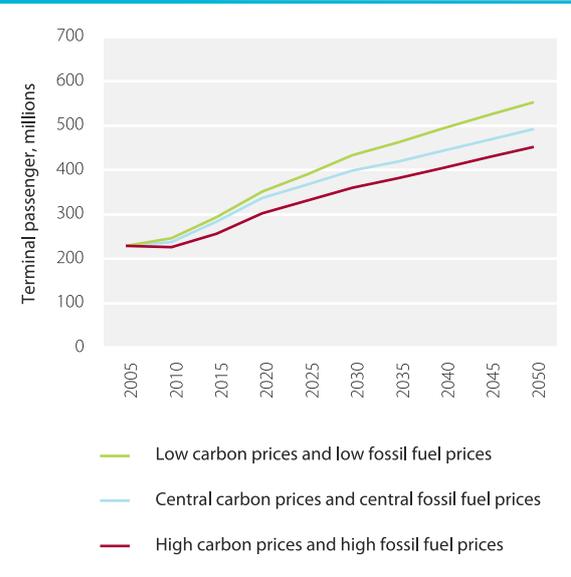
¹⁰ We have focused on runway capacity and not terminal capacity. To the extent that terminal capacity constraints exist and are not addressed demand projections could be lower.

Figure 2.8a Reference demand projections: effect of changes in runway capacity



Source: CCC modelling.

Figure 2.8b Reference demand projections: planned capacity, effect of changes in carbon and fossil fuel prices



Source: CCC modelling.

4. Reference emissions projections

We would broadly expect emissions growth to reflect: growth in overall demand; change in the composition of demand between short/long-haul; and technology improvement.

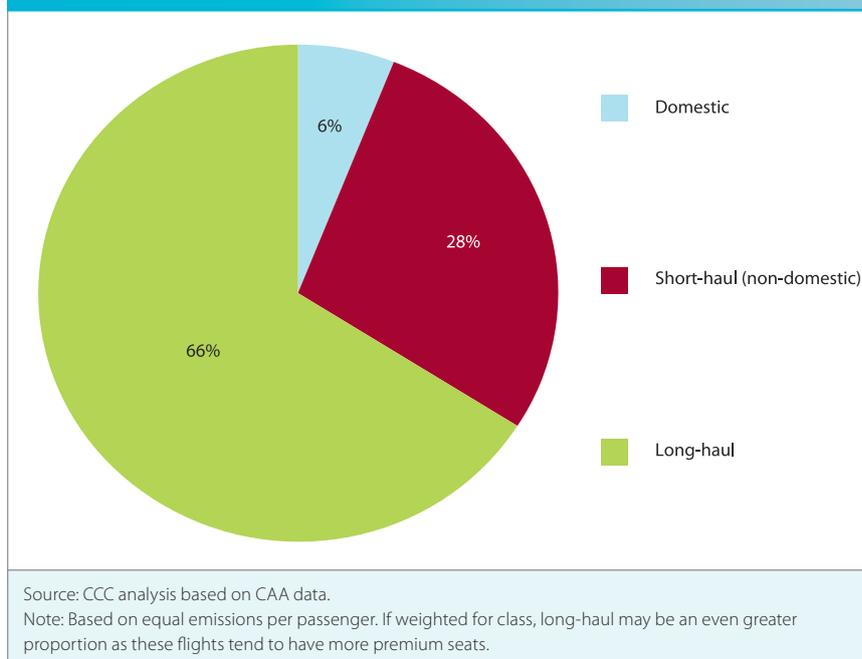
This is borne out in UK data, which shows that emissions increased by 120% over the period 1990-2007 compared to a demand increase of 130%.

That emissions have grown more slowly than demand reflects in part increasing load factors over time, but this is somewhat offset by relatively high growth in long-haul flights. These are relatively efficient in terms of emissions per passenger-km for an equivalent seat size (e.g. economy), but account for a disproportionate share of emissions given much higher mileage on long-haul compared to short-haul (Figure 2.9). Long-haul flights therefore account for the majority of UK aviation emissions, notwithstanding that short-haul flights account for higher passenger numbers (Figure 2.10).

Figure 2.9 Defra/DECC air passenger conversion factors¹¹



¹¹ We do not use per passenger conversion factors in our analysis, but use per flight conversion factors that are based on the same underlying data, i.e. the CORINAIR Emissions Inventory Guidebook.

Figure 2.10 UK aviation CO₂ emissions: indicative split by distance

Going forward, we translate our demand projections to emissions projections in two steps:

- The first step converts passenger demand¹² estimates to ATMs. This depends on airport capacity constraints, and airlines' decisions on frequency of flights and size of aircraft deployed.
- The second step converts ATMs to emissions, based on the fuel efficiency of aircraft type used and the distance flown on the route.

In our reference projections we assume that there is no improvement in fleet fuel efficiency relative to the current position. Our range of emissions projections mirrors our demand projections and therefore comprises three projections under alternative capacity assumptions and three projections with planned capacity under alternative assumptions about carbon prices and fossil fuel prices:

- **Emissions based on unconstrained demand growth:** In this projection emissions grow by around 160% in 2050 over 2005 levels (i.e. from 37.5 MtCO₂ in 2005 to just under 100 MtCO₂ in 2050).
- **Emissions based on demand growth with planned runway capacity:** In this projection emissions grow by around 130% in 2050 over 2005 levels (i.e. to around 87 MtCO₂ in 2050).
- **Emissions based on demand growth without addition of new runway capacity:** In this projection emissions grow by around 105% in 2050 over 2005 levels (i.e. to around 77 MtCO₂ in 2050).

¹² In our analysis the business/leisure split is by purpose i.e. not by class.

- **Emissions based on demand growth with planned capacity and central carbon and fossil fuel price projections:** In this projection emissions grow by around 95% in 2050 over 2005 levels (i.e. to around 74 MtCO₂ in 2050).
- **Emissions based on demand growth with planned capacity and high carbon and fossil fuel prices:** In this projection emissions grow by around 80% in 2050 over 2005 levels (i.e. to around 68 MtCO₂ in 2050).
- **Emissions based on demand growth with planned capacity and low carbon and fossil fuel prices:** In this projection emissions grow by around 130% in 2050 over 2005 levels (i.e. to around 85 MtCO₂ in 2050).

There is a broad trend evident across scenarios that emissions growth is slightly lower than demand growth, which in part reflects increasing average plane load factors in the period to 2050 from around 75% in 2005 to around 85% in 2050, and changes in the route mix. To the extent that load factors do not increase as assumed, then emissions projections would be higher and require more emissions reductions to meet the 2050 target.

Figure 2.11a Reference emissions projections: effect of changes in runway capacity

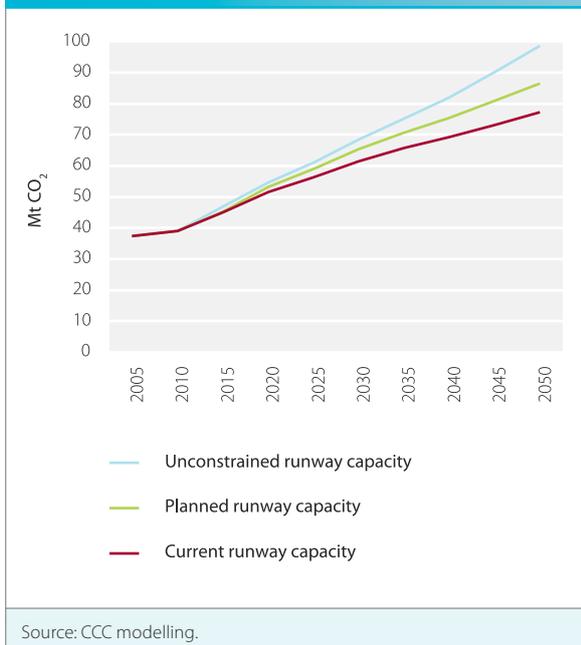
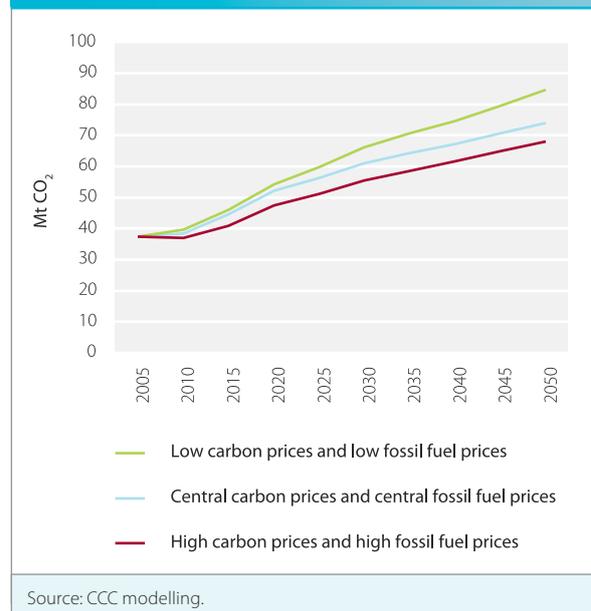


Figure 2.11b Reference emissions projections: planned capacity, effect of changes in carbon and fossil fuel prices



5. How we will use the reference projections

The reference projections provide an illustrative starting point for our analysis. In meeting the 2050 target there are a number of options for reducing emissions below the levels in the reference projections (e.g. alternatives to air travel, fuel efficiency improvement, use of biofuels).

We now consider each of these options in turn, and then bring together the different strands of analysis, overlaying emissions reductions from these options on the reference projections.

Specifically, we develop scenarios for emissions reductions from the range of options which we overlay across the central case demand/emissions projections. We also consider the impact of departure from the central case through sensitivity analysis around alternative carbon price/fossil fuel price assumptions. We illustrate alternative strategies towards aviation expansion for meeting the 2050 target.

Chapter 3

Alternatives to air travel: high-speed rail and videoconferencing

In Chapter 2 we considered various demand projections reflecting different assumptions on fossil fuel prices, carbon prices, and infrastructure investment. In this chapter, we broaden our demand analysis by considering scope for modal shift between aviation and conventional rail/high-speed rail, and for substituting air travel with videoconferencing¹.

Our approach is to develop estimates of feasible emissions reduction potential from modal shift and videoconferencing. We do not consider wider socio-economic costs and benefits (for example, travel time savings from high-speed rail for existing rail customers), impact on the local environment or scope for modal shift from cars to high-speed rail. We do not therefore attempt an economic analysis of whether investment in high-speed rail is desirable; such an analysis is beyond the remit of this report.

The main messages in the chapter are:

- Modal shift can offer a useful contribution to meeting the 2050 target, particularly if a new UK high-speed line is built and the European network becomes more fully integrated. However, the potential emissions reduction is relatively small in the context of the overall aviation target, reflecting the relatively small share of domestic and short-haul aviation emissions in total UK aviation emissions.
- It is unclear how videoconferencing will impact the demand for business travel. Based on current evidence, however, we cannot be confident that this effect will be significant. We reflect uncertainty over the potential impact of videoconferencing in a range of penetration from no net impact on business air travel demand (which models a world where there are rebound effects, and where videoconferencing is additional rather than a substitute for business travel) to a 30% reduction in business air travel demand in 2050, which is consistent with the high end estimated in the academic literature and current best practice (e.g. as achieved by BT and Vodafone).
- Taken together there is scope for demand reduction of up to 16% (i.e. 91m passengers) and emissions reduction up to 7 MtCO₂ in 2050 from modal shift and videoconferencing.

¹ Videoconferencing here encompasses a broad suite of communications technologies including the latest visual technology developments.



We now consider:

1. The potential for shifting from air to rail
2. Scope for substituting videoconferencing for air travel
3. Total emissions reductions from modal shift and videoconferencing.

1. The potential for shifting from air to rail

The choice of travel mode between air and rail is a function of relative cost, including travel time and convenience. Other things being equal (i.e. prices, service quality), passengers will choose the mode which minimises travel time.

We have reviewed the evidence on point-to-point travel times by aviation and rail. This suggests that the range beyond which rail cannot compete on travel time is around 800 km:

- On journeys of less than 400 km conventional rail will usually be faster than air for point-to-point journeys (e.g. London to Manchester is 296 km by rail, London to Brussels 373 km).
- On journeys below 800 km high-speed rail has the potential to enable significant modal shift (e.g. London to Edinburgh 632 km by rail, London to Amsterdam 605 km).
- However, above 800 km the air option is likely to be faster in terms of overall door-to-door journey time and as a result the rail option would need to have other advantages (e.g. significantly lower prices) to be competitive. For example, cities such as Berlin (1,204 km from London by rail), Milan (1,406 km) and Madrid (1,942 km) are beyond the 800 km range.

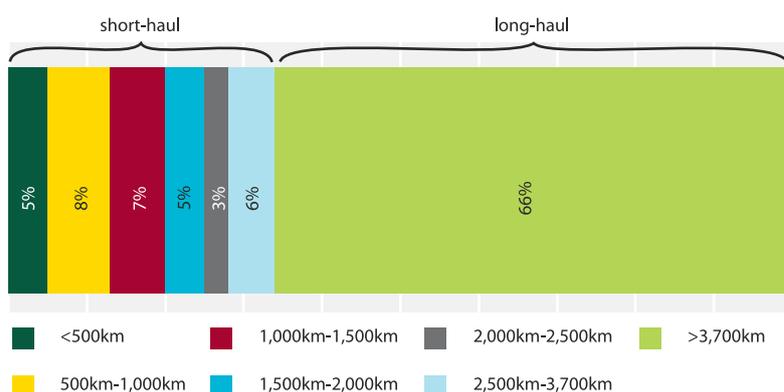
An indication of the order of magnitude for emissions reduction potential from modal shift is the share of total UK aviation emissions accounted for by journeys within the range at which rail could potentially compete. In 2005, domestic and short-haul aviation covering distances up to 1,000 km accounted for around 13% of total UK aviation emissions (i.e. up to 5 MtCO₂ – Figure 3.1).

This represents an upper bound on feasible emissions reductions from aviation given that:

- Not all flights are substitutable by rail (e.g. across the Irish Sea).
- Not all destinations will be connected by high-speed rail.
- Even for connected destinations, these will not achieve 100% market share – particularly for longer routes and where there is only partial integration of the European high-speed network.
- There are emissions associated with rail/ high-speed rail (i.e. in building new infrastructure, and in running trains to the extent that the electricity grid is not fully decarbonised).

In order to move from this high level assessment to a more detailed understanding, we commissioned analysis from consultants Steer Davies Gleave (Box 3.1).

Figure 3.1 Distribution of UK aviation emissions by distance in 2005



Source: CCC analysis based on CAA data (2009).

Box 3.1 Summary of SDG modal shift model

Overview

The SDG model estimates the potential for modal shift between UK aviation and rail. In particular, the model estimates the effect on modal share between air and rail as a result of:

- Changes in journey time and other journey time related factors: these could be either small changes such as those that are expected to result from the deployment of the Intercity Express Programme (IEP), or step changes as a result of the construction of new high-speed lines covering certain city pairs.
- Changes in the price of either mode: these could be due to possible carbon pricing or other revision to fares.

Model structure

The model covers five key elements, each of which is a separate component of the demand model:

- 1. Market share:** This estimates the extent to which air and rail market share on the routes modelled may change as a result of changes to journey time, price or other factors. It is the most important – and most complex – element of the model.
- 2. Price module:** The price module calculates the operating costs for air and rail operators and translates them into the fare charged by the rail and air operator for each modelled route.

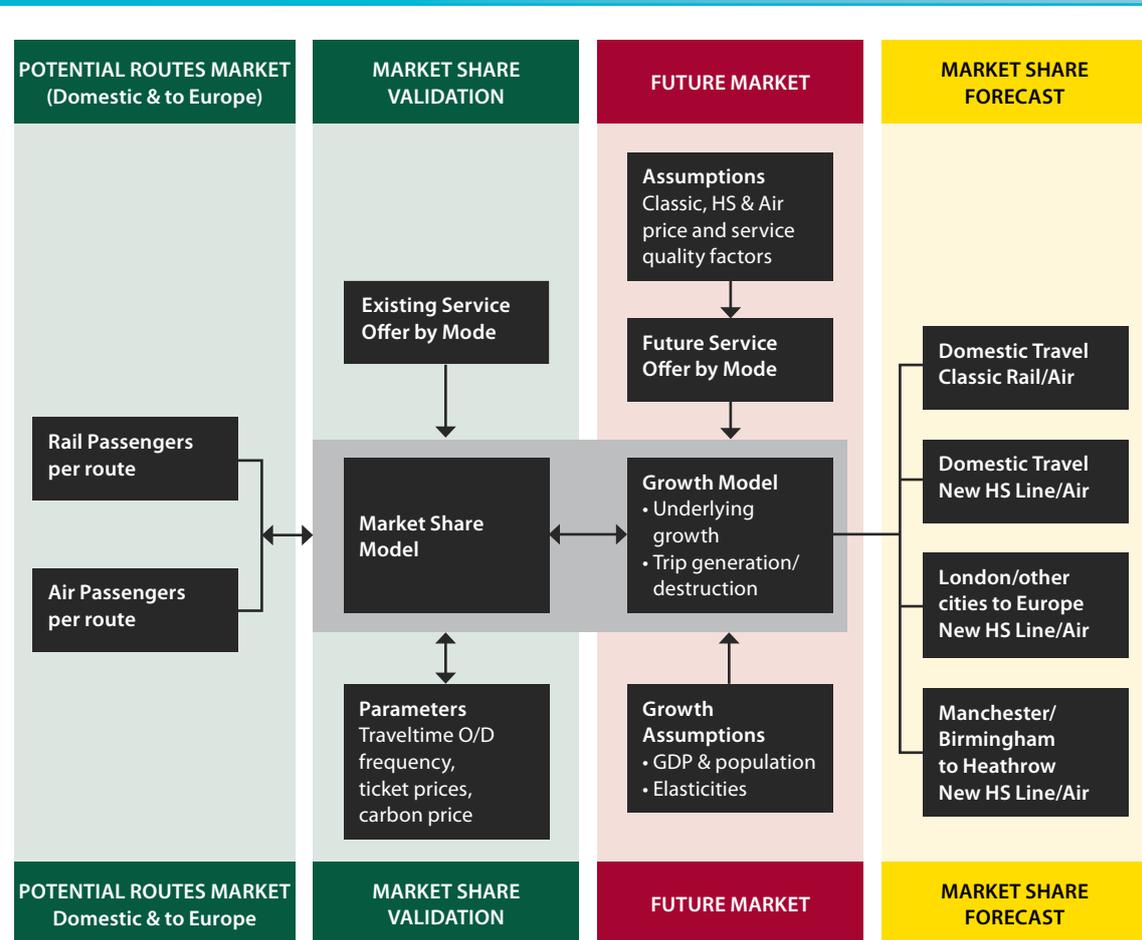
Box 3.1 continued

3. Underlying growth: Economic and population growth is reflected in projected demand growth.

4. Trip generation/reduction: Trip generation or reduction will also be a significant consequence of (for example) construction of a high-speed line or introduction of carbon pricing for air transport.

5. Route substitution: Market analysis suggests that an important effect of journey time and cost changes could be leisure passengers choosing short distance rail trips rather than longer distance air trips. The route substitution module estimates this effect.

Figure B3.1 Overview of the SDG model structure



Source: SDG (2009).

Box 3.1 continued

The model provides an assessment of the total air travel demand that may switch from air to rail. Within the scope of the study it was not possible to model every single route within the UK and between the UK and Europe. Therefore, 23 representative city pairs were modelled explicitly – 12 routes from London to mainland Europe, five routes from other UK cities to mainland Europe, six domestic routes, and three routes to Heathrow. SDG then match non-modelled routes, where there could be some modal shift, to one of the modelled routes. The model then assumes that the modal shift on the non-modelled routes will be the same as the modelled routes. The route substitution calculation was conducted on the full list of UK routes.

Market share model

The main component of the demand model is the market share module. The output from this module is the forecast modal shift between air and rail on each route as a result of changes to journey time and cost. The market share module is based around a logit model, which calculates market share on each route on the basis of the generalised cost of each mode. This cost reflects two elements, the generalised journey time and the price.

Generalised journey time is a weighted sum of all the journey time related factors (the main journey time factors are: in-vehicle time, frequency, interchanges, access and egress times and check in time). The journey time actually spent in the main mode of transport is given a weight of one and all other journey time factors are weighted in respect to this. The SDG logit model was calibrated against observed market data for the 23 selected routes.

Scenarios

SDG developed four scenarios for the CCC: low, central, high and central with full UK-Europe integration.

- The first three of these scenarios relate to different combinations of oil and carbon prices (e.g. central relates to central forecasts of oil and carbon prices – we use these assumptions, without a new UK high-speed line, in our **Likely** scenario and with a new UK high-speed line in our **Optimistic** scenario).
- The central scenario with full UK-Europe integration uses the same oil and carbon price assumptions as the central scenario, but the rail service between the UK and Europe is assumed to become fully integrated – we use these assumptions (with a new UK high-speed line) in our **Speculative** scenario. More specifically:

Box 3.1 continued

- Competing rail operators are allowed to enter the market, reducing any producer surplus over operating costs.
- Direct rail services are introduced on all modelled flows.
- The current international rail check-in time is reduced from 30 minutes to 15 minutes.
- Rail access charges are reduced on the majority of routes.

For more information on the model, scenarios and results please see the SDG report¹, which is available on our website at www.theccc.org.uk

¹ Steer Davies Gleave (2009), *Potential for modal shift from air to rail*.

We now set out our conclusions based on this analysis in three sections:

- (i) Scope for modal shift from domestic aviation to rail
- (ii) Scope for modal shift from short-haul international aviation to rail
- (iii) Emissions reduction scenarios.

(i) Scope for modal shift from domestic aviation to rail

SDG analysis suggests that incremental enhancements (e.g. Intercity Express Programme) will have limited scope to significantly change market share on routes between destinations where there is currently a high degree of air travel (e.g. Scotland to London). This is for two main reasons:

- Incremental changes are unlikely to have a large impact on travel times.
- The system is capacity constrained.

The SDG analysis also considered the impact of more radical change in the form of a new high-speed rail line (delivered by the early 2020s) connecting London to Scotland via Birmingham and Manchester, both with and without a Heathrow spur. Their analysis suggested that there may be scope for high-speed rail to gain a market share up to 90% on Anglo-Scottish routes, and 40% between Manchester and Heathrow (Box 3.2). The percentage of rail share between Manchester and Heathrow could be greater than 40% but to achieve this there would need to be integrated air and rail services (including ticketing and baggage transfer).

Box 3.2 Summary of analysis on modal shift to rail

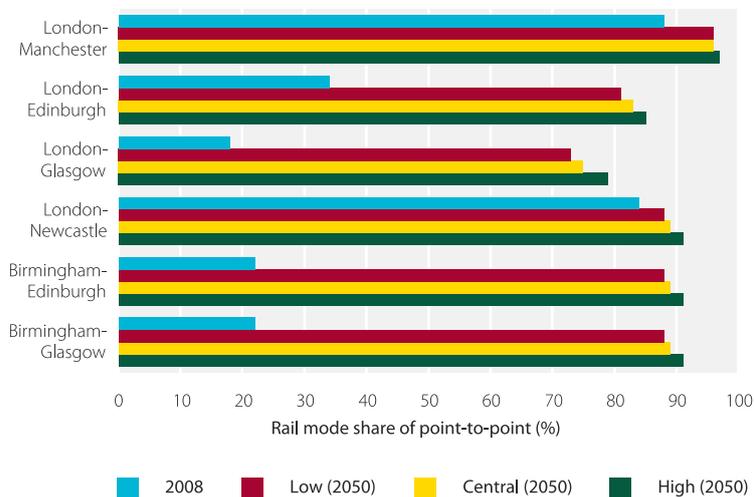
Domestic routes

Rail market share is expected to increase slightly in 2025 without a high-speed line on Anglo-Scottish routes due to committed upgrades (e.g. up to a 15 percentage point increase in rail mode share on these routes) such as completion of the West Coast Route Modernisation and the introduction of Intercity Express Programme (IEP) trains.

If a new high-speed line is introduced a much greater shift from air to rail is expected on these routes with rail mode share increasing by up to 50 percentage points in 2025.

In 2025 with a new high-speed line, rail market share is projected to increase from current levels of 20-35% to 75-90% on Anglo-Scottish routes and small increases on other key routes e.g. from 88% to 97% on London to Manchester (Figure B3.2a). The greater improvement on Anglo-Scottish routes is due to the potential for more significant reductions in travel time over these longer distances.

Figure B3.2a Projected rail mode share on selected domestic routes in 2025 (with new UK high-speed line)



Source: SDG (2009).

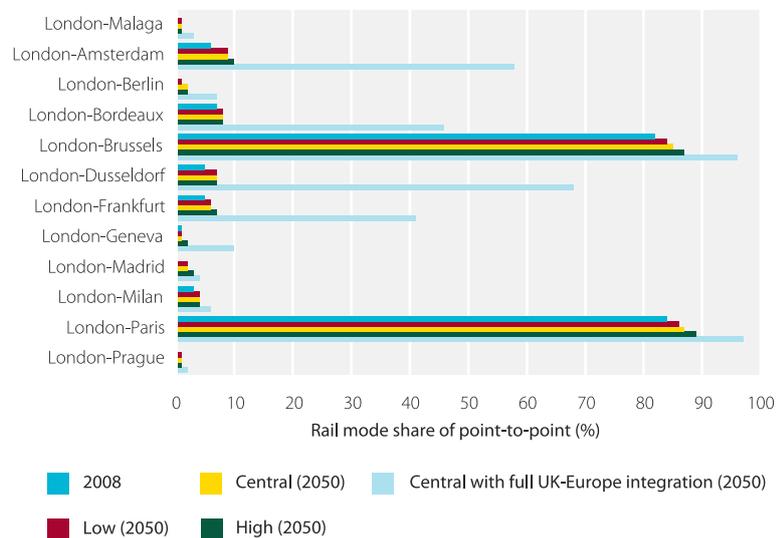
Box 3.2 continued

UK to Europe

The projected rail market share on routes from London to mainland Europe is largely dependent on integration of the European network (Box 3.1). Without integration, in the three main scenarios (low, central and high) limited modal shift is achieved in both 2025 and 2050 – up to a five percentage point increase in rail modal share.

In the central scenario with full UK-Europe integration and a significantly improved (and lower priced) rail service offer, more significant modal shift is achieved on key routes such as London-Frankfurt, London-Dusseldorf, London-Bordeaux, and London-Amsterdam, particularly in 2050 where on some of these routes rail gains a majority market share. In contrast, on much longer routes even with an integrated network very limited modal shift is expected to occur. For example, London-Malaga and London-Madrid are projected to have less than a five percent rail share in 2050 (Figure B3.2b).

Figure B3.2b Projected rail mode share on selected routes from London to mainland Europe in 2050

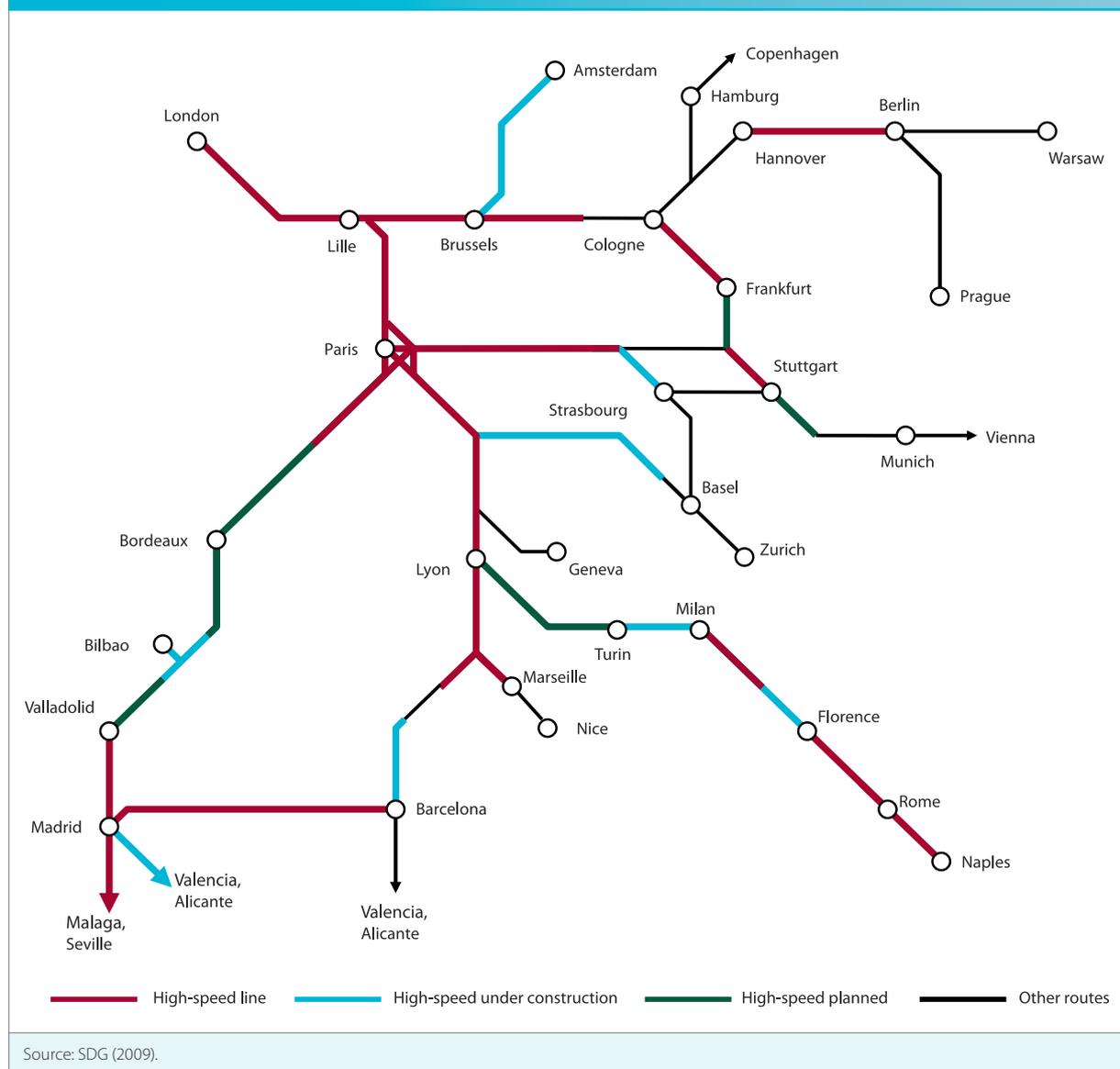


Source: SDG (2009).

(ii) Scope for modal shift from short-haul international aviation to rail

A number of European countries have or plan to have high-speed rail networks. This presents an opportunity for the UK to target modal shift from short-haul international aviation to rail using currently spare capacity through the Channel Tunnel Rail Link. UK passengers would have access to a European high-speed rail network stretching from Seville to Berlin and from Amsterdam to Naples (Figure 3.2).

Figure 3.2 Map of planned European high-speed rail network



The SDG analysis suggests that given this opportunity, high-speed rail could gain a market share of 30-60% on routes from London to Amsterdam, Dusseldorf and Frankfurt (Box 3.2), with some increase possible on routes already well served by high-speed rail (e.g. London to Paris and Brussels), particularly if the European network becomes fully integrated.

The analysis suggests, however, that there would be limited scope for significantly increased market share on longer distance routes where the vast majority of passengers currently travel by plane (e.g. London to Berlin, Milan, or Madrid).

In total, the SDG analysis suggests a range for emissions reductions from modal shift (accounting for increases in rail emissions) of 0.4 MtCO₂ to 2.2 MtCO₂ in 2050, compared to SDG projected emissions from air and rail travel domestically and to Europe of 23 MtCO₂ to 27 MtCO₂ in 2050 (Box 3.3).

Box 3.3 Total air and rail emissions reduction from modal shift

SDG's main model output was projected modal shift from air to rail. The SDG demand outputs were then input into the MVA demand and emissions model to calculate the impact on aviation demand and emissions to be consistent with the inputs and modelling of the CCC's scenarios.

Nevertheless, SDG did provide an estimate of the total CO₂ emissions from air and rail travel within the UK and between the UK and other parts of Europe. In the most optimistic scenario, air-rail mode shift reduces CO₂ emissions in 2050 by around 2.2 MtCO₂, with full integration of the European network and a new UK high-speed line. On the other hand, if the European network is not fully integrated and there are low oil and carbon prices, this emissions reduction would be closer to 0.4 MtCO₂ in 2050 (Figure B3.3).

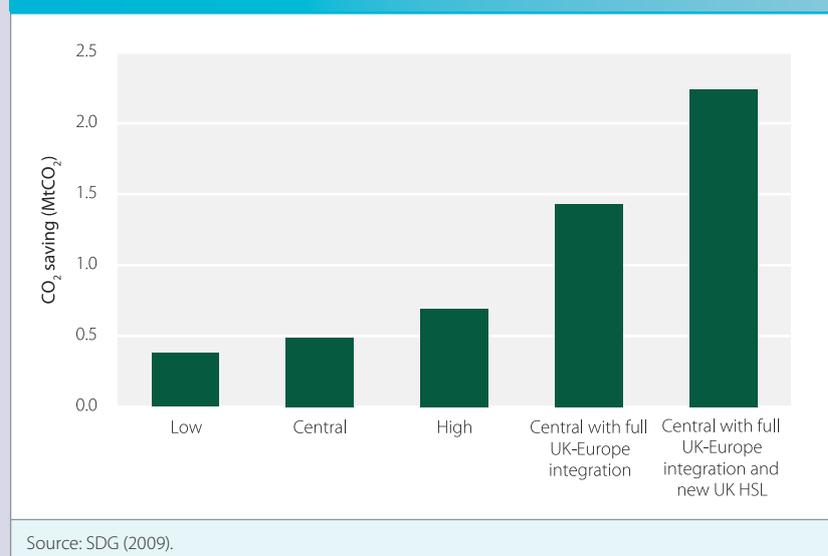
These estimates include increased emissions from rail:

- By 2050 gross savings from reduced air travel alone could be up to 10% greater than these combined air and rail emission savings estimates. In 2050 the rail emissions are small due to the assumption that the European power sector will be significantly decarbonised by this time.
- In 2025, when the power sector is likely to be less decarbonised, the total savings (gross savings from reduced air travel offset by increased emissions from rail) would be around 50% lower than gross savings from reduced air travel alone due to rail being more carbon intensive.

Therefore, power sector decarbonisation is crucial to unlock real savings from modal shift from air to rail.

Box 3.3 continued

Figure B3.3 SDG estimates of CO₂ savings from modal shift from air to rail in 2050



(iii) Emissions reduction scenarios

We have constructed three scenarios for emissions reduction² due to modal shift from domestic and short-haul international aviation to rail and high-speed rail:

- Under our **Likely** scenario we reflect current firm policy commitments. Specifically, we assume that UK investment in rail improvements to conventional rail (e.g. introduction of new Intercity Express Programme (IEP) trains) proceed as planned and so do the expected investments in the European high-speed rail network. However we assume that no new UK high-speed rail line is built and that the European network remains only partially integrated (Box 3.1). These result in a 1% demand reduction (i.e. 8m passengers) and 0.3 MtCO₂ emissions reduction in 2050.
- Under our **Optimistic** scenario we assume a policy shift in the UK, with firm commitment to investing in a new UK high-speed rail line connecting London with Scotland via Manchester and Birmingham and including a Heathrow spur. Nonetheless we assume that this augmented UK high-speed rail line still operates within a European network that remains only partially integrated. These result in a 4% demand reduction (i.e. 23m passengers) and 0.6 MtCO₂ emissions reduction in 2050.

² These estimates are based on the MVA demand and emissions model used for our scenarios and will therefore differ slightly from SDG's estimates due to slightly different modelling approaches. Nevertheless, the estimates are all within the estimated range for emissions reduction potential.

- Under our **Speculative** scenario we assume a policy shift in the UK and Europe such that there is a new high-speed rail line in the UK and a fully integrated European high-speed rail network. These result in an 8% demand reduction (i.e. 44m passengers) and 1.7 MtCO₂ emissions reduction in 2050.

The maximum emissions reduction potential from modal shift to rail in 2050 of around 2 MtCO₂ offers a useful contribution to meeting the 2050 target, notwithstanding that this is relatively small compared to our central reference projection in which total UK aviation emissions in 2050 are around 81 MtCO₂ in the unconstrained case with a carbon price, reflecting the relatively small share of domestic and short-haul aviation emissions in total UK aviation emissions.

2. Scope for substituting videoconferencing for air travel

Videoconferencing is becoming an increasingly attractive alternative to flying in the business sector. This could translate to a useful emissions reduction as videoconferencing technology improves and the cost of flying increases over time, given that business travel accounts for around a quarter of all UK aviation demand by purpose.

There is some evidence that videoconferencing could substitute for air travel:

- Academic research suggests that videoconferencing could reduce business flights by up to 35%, with low estimates centred on 10% (Box 3.4).
- A recent survey by the Institute of Travel and Meetings (ITM) indicated that travel and meeting managers of leading UK companies and Government departments expect communication technology such as videoconferencing to drive an 18% reduction in demand for business travel and travel to meetings³.
- The World Wildlife Fund (WWF) has launched the 'One in Five Challenge,' under which participating organisations aim to reduce their business flights by 20% within five years. Of the eight participants, BT and Vodafone have already achieved 20-30% reductions over recent years.

Scope for videoconferencing should not, however, be overstated:

- There is some evidence suggesting that meetings based on videoconferencing may be additional, rather than substituting for meetings which require air travel, with the possibility of rebound effects (Box 3.4).

³ ITM (Sep 2009), *Demand, Supply and Convergence*.

Box 3.4 Does videoconferencing substitute for business flights?

Academic studies

Academic studies carried out in the 1990s on the potential effects of videoconferencing on business flying predicted ambitious reductions of up to 40% in the next two decades (Arvai (1991)², Burger (1995)³).

However, recent research has shown that the relationship can actually function in the opposite direction, with greater telecommunications use accompanying increases in total travel (Wang and Law (2007)⁴, Choo and Mokhtarian (2007)⁵). This raises a question over the extent to which videoconferencing actually substitutes for business travel⁶.

A recent paper by Cairns (2009)⁷ suggests that there is significant potential for uptake of videoconferencing to substitute for business travel as:

- Technical and cost barriers have largely been addressed.
- Videoconferencing is widely perceived to reduce stress and unnecessary travelling time, particularly for routine internal meetings.

In order to assess the potential substitution effect from videoconferencing more precisely, additional information is needed relating to:

- The types of organisation and individuals that could most readily use videoconferencing. For example, are a small minority of individuals flying very frequently and would these individuals benefit from a reduction in flying? Or by contrast, is the majority of business travel constituted by individuals taking one to two trips per year, which are high value trips?
- Data on currently occurring meetings: whether they are internal or external, their frequency and whether or not they are clustered together i.e. individuals arranging several meetings for one trip.
- The types of interaction where videoconferencing could genuinely substitute for a physical event.

Box 3.4 continued

Preliminary market review

A brief market review carried out by the CCC found the following:

- Many companies are installing videoconferencing facilities.
- In the absence of strong targets for flight reductions videoconferencing uptake was generally accompanied by rising total travel volumes and in one case rising air travel per employee.
- However, those companies that had installed the facilities but had also set ambitious targets (such as those now participating in WWF's *One in Five Challenge*) were able to achieve significant reductions in air travel.

Further evidence on trip patterns and purposes is required in order to better understand the scope for substitution of videoconferencing for business travel.

2 Arvai (1991), *Telecommunications and business travel: the revolution has begun*.

3 Burger (1995), *Videoconferencing impacts on air travel demand*.

4 Wang and Law (2007), *Impacts of information and communication technologies on time use and travel behaviour: a structural equations analysis*.

5 Choo and Mokhtarian (2007), *Telecommunications and travel demand and supply: Aggregate structural equation models for the US*.

6 Bender and Stephenson (1998), *Contemporary issues affecting the demand for business air travel in the United States*.

7 Cairns (2009), *Can teleconferencing reduce business travel?*

Our view is that the impact which videoconferencing could have on air travel is very uncertain and depends on a detailed understanding of trip purpose. We therefore cover a broad range in our scenarios, from no net impact due to videoconferencing to a 30% net reduction in business travel:

- Under our **Likely** scenario we assume that videoconferencing has no net impact on aviation demand, under the assumption that it results in rebound effects and additional meetings rather than substituting for existing meetings.
- Under our **Optimistic** scenario we assume that videoconferencing results in a net demand reduction. Specifically, we assume a 10% reduction in business aviation demand in 2050 (rising on a linear trend from 2005) consistent with the low end of the range from the academic literature.
- Under our **Speculative** scenario we assume an impact consistent with the high end of the range from the academic literature and current best practice, which would probably require a combination of policies to promote videoconferencing and targets to reduce flights in companies. Specifically, we assume a reduction in business demand of 30% in 2050 (rising on a linear trend from 2005).

In order to better understand which of these scenarios may be more plausible, further analysis is required. This would focus on trip patterns, for example, the frequency with which business travellers fly, the purpose of their meeting (e.g. internal versus external), the number of meetings per trip (Box 3.4); these data are currently commercially but not publicly available.

3. Total emissions reductions from modal shift and videoconferencing

In order to allow for possible overlap between modal shift and videoconferencing (e.g. a journey which is made on high-speed rail cannot also be substituted by videoconferencing), we combine our two sets of scenarios to give overall estimates for aviation demand and emissions reduction⁴:

- Our **Likely** scenario assumptions result in modal shift equivalent to reducing air travel demand by 1% of passengers (i.e. 8m) and 2% ATMs in 2050. We assume that videoconferencing has no net impact on aviation demand. The impact on emissions is, therefore, a 0.3 MtCO₂ emissions reduction in 2050.
- Our **Optimistic** scenario modal shift and videoconferencing⁵ assumptions result in a reduction equivalent to reducing air travel demand by 7% of passengers (i.e. 40m) and 10% of ATMs in 2050, and an emissions reduction of 2.4 MtCO₂ in 2050.
- Our **Speculative** scenario modal shift and videoconferencing assumptions result in a reduction equivalent to reducing air travel demand by 16% of passengers (i.e. 91m) and 19% of ATMs in 2050, and an emissions reduction of 7 MtCO₂ in 2050.

⁴ These estimates correspond to a scenario with unconstrained demand growth; see Chapter 7 for a discussion of potential in a capacity constrained system where some of modal shift and videoconferencing translates to easing of suppressed demand rather than demand reduction.

⁵ In both the Optimistic and Speculative scenarios, emissions savings from videoconferencing could in practice be higher if passengers displaced reflect a disproportionate share of premium class travel, which have higher associated per passenger emissions.

Chapter 4

Improvement in fleet fuel efficiency through technology innovation

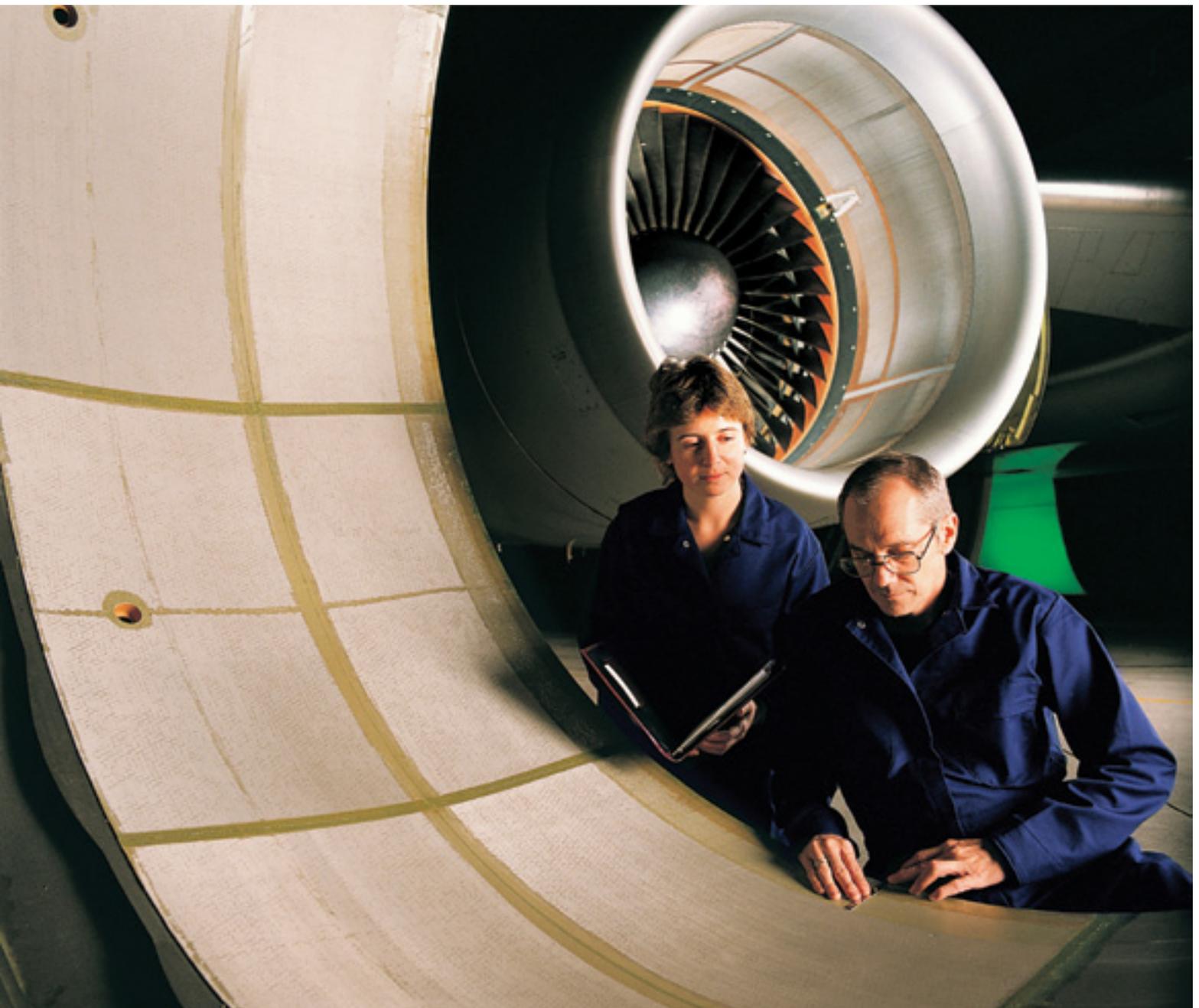
This chapter sets out our assessment of the degree to which improvements in aircraft fuel efficiency combined with improved efficiency in Air Traffic Management (ATM) and operations could contribute to reducing emissions from UK aviation. It builds on the analysis in our December 2008 report, which suggested that a new production aircraft in 2025, flying in an improved operational environment, could be up to 50% more efficient than a 2006 aircraft on a passenger-km basis, and that improvements in annual fleet fuel efficiency using upper-bound evolutionary technology of the order 1.5% may be achievable.

In developing our assessment, we have considered:

- Analysis on abatement potential from technology innovation prepared by QinetiQ for our December 2008 report;
- Analysis of the current and future aviation fleet that we have commissioned from MVA;
- A wide range of additional studies and analyses including the IATA technology roadmap report, the Sustainable Aviation roadmap, and consultancy reports commissioned by UK and foreign government agencies;
- Findings of our workshops and discussions with industry experts.

The key messages in this chapter are:

- Evolutionary technology innovation could lead to fuel efficiency improvements in new aircraft of the order 35-45% by 2025, and introduction of more speculative radical technologies could make new aircraft up to 60% more efficient by 2050, compared to 2006 levels.
- More efficient ATM and operations could contribute between an additional 6-13% per flight by 2020.
- The combination of aircraft, ATM and operational efficiency improvements could result in a range for annual improvement in fleet fuel efficiency from 0.8-1.5% per seat-km between 2005 and 2050.



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

1. Scope for improvement in aircraft fuel efficiency
2. Scope for improved efficiency in ATM and operations
3. Scenarios for improvement in annual fleet fuel efficiency.

1. Scope for improvement in aircraft fuel efficiency

Fuel burn is a key determinant of aviation economics given that fuel costs account for up to 35% of total aviation costs. The aviation industry has therefore focused on fuel efficiency improvement through engine and aircraft innovation, which has resulted in a reduction in total energy intensity of more than 60% since 1970. This section focuses on scope for further engine and airframe innovation going forward.

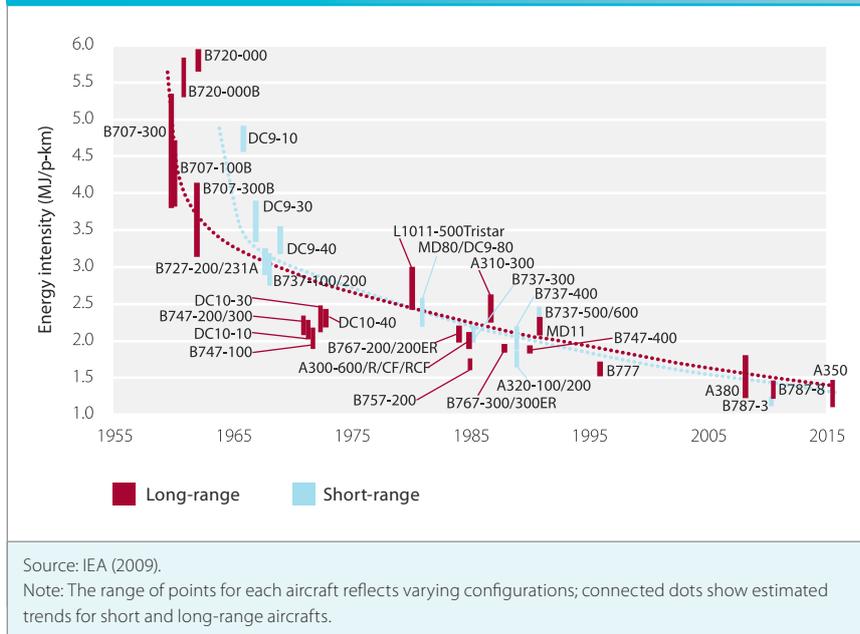
We now consider:

- (i) Historical fuel efficiency improvements
- (ii) Future improvements from evolutionary technology innovation
- (iii) Future improvements from radical technology innovation
- (iv) Scenarios for fuel efficiency improvement from engine and airframes.

(i) Historical fuel efficiency improvements

Aircraft fuel efficiency has improved substantially since the beginning of the jet era in the 1960s, and from 1970 to 2000 total energy intensity was reduced by more than 60% (Figure 4.1). This reduction was due to a combination of factors including:

- Improvement in engine efficiencies, driven for example by the introduction of high bypass ratio turbo-fan engines in the early 1970s and subsequent evolutionary improvements in engine performance;
- Airframe improvements such as reduced drag and weight (as a result of improved aerodynamics and advanced materials) and increasing size of aircraft;
- ATM and operational improvements such as more efficient routing and increasing load factors.

Figure 4.1 Historical improvements in aircraft fuel efficiency

(ii) Future improvements from evolutionary technology innovation

Technical potential for fuel efficiency improvement

There are a number of evolutionary technologies that could help achieve further fuel efficiency improvements in new aircraft over the next 20 years or so and beyond:

Evolutionary engine improvements

- **Improvements in thermodynamic efficiency of engines**, for example increasing the turbine entry temperature (TET) although this will tend to increase NO_x emissions;
- **Improvement in propulsive efficiency of engines**, including by optimisation of aerodynamic design of fan and turbine components;
- **Development of geared turbo-fan engines**, to address inefficiencies in the architecture of conventional turbo-fan engines.

Evolutionary airframe improvements

- **Airframe weight reduction**, including further replacement of metals by lighter composite materials in aircraft structures;
- **Improvements in aircraft lift/drag ratio**, for instance by improving aerodynamic design and shape of aircraft and increasing laminar flow control.

Table 4.1 Potential fuel savings from evolutionary measures by 2025

Technology/ abatement opportunity	Impact	Total Saving in 2025
Airframe	20-30%	35-45%
Engine	15-20%	

Source: QinetiQ (2008).

Analysis that we commissioned from QinetiQ in the context of our December 2008 report suggested that together these potential innovations provide scope for a 35% to 45% efficiency improvement by 2025 relative to a 2006 model (Table 4.1).

In addition, there are a number of opportunities for retrofitting of existing aircraft, including:

- **Addition of winglets and riblets**, which can improve wing aerodynamics and therefore fuel burn although this needs to be balanced against extra weight;
- **Aircraft polishing**, instead of painting can help reduce fuel burn by saving weight;
- **Airframe component replacement**, such as upgrading engines can provide improvements in fuel consumption;
- **Improved maintenance**, for example to achieve better performance retention in engines.

ACARE targets for new aircraft

The Advisory Council for Aeronautics Research in Europe (ACARE) has set targets for efficiency of a new aircraft (Box 4.1). These incorporate a reduction in CO₂ of 50% per passenger-km by 2020 measured against 2000 levels, of which it is envisaged that around 40% will ensue from engine and airframe innovation, with the remainder due to improved ATM contributions.

Meeting the ACARE target for a new aircraft by 2020 will however be very challenging given current plans for introduction of new aircraft families:

- Our expectation is that major aircraft manufacturers will start to develop new aircraft families for narrow-body aircraft to enter the market in the 2020s (e.g. B737/A320 replacements), but have no firm plans to develop new aircraft families for other market segments that would reach ACARE equivalent efficiency standards.
- The development and certification of a new aircraft family typically takes around 10 years. Where aircraft incorporate high levels of new technology introduction, the timescale is likely to be significantly longer. The earliest possible date at which a new ACARE type aircraft could be introduced is therefore around 2020. Technology innovation, integration and certification can all lead to the entry date being later than originally planned (e.g. as has been the case for the Airbus 380 and Boeing 787).

Box 4.1 ACARE process and targets

The Advisory Council for Aeronautics Research in Europe (ACARE)¹ was formed in 2001 and comprises 39 members from European Member States, the Commission and stakeholders from industry, airlines, airports and academia.

In 2002 ACARE launched a 'Vision for 2020' that set goals in five key areas: Quality and Affordability, Environment, Safety, Security, and Air Transport System Efficiency.

On the Environment, five goals were identified for 2020:

1. To reduce fuel consumption and CO₂ emissions by 50% per passenger-km:
 - Airframe contribution of 20-25%
 - Engine contribution of 15-20%
 - ATM contribution of 5-10%
2. To reduce perceived external noise by 50%
3. To reduce NO_x emissions by 80%
4. To reduce other emissions (e.g. soot, CO, UHC, SO_x, particulates etc)
5. To minimise the industry impact on the global environment, including the impact of manufacturing, maintenance and disposal.

There are likely to be trade-offs between these environmental objectives at the margin. For example, there are trade-offs in engine design and operation between CO₂, NO_x and noise. Improvements in NO_x and noise are likely to be at the expense of improvements in fuel efficiency and therefore CO₂ emissions.

To implement their Vision for 2020, ACARE developed a Strategic Research Agenda which has been reviewed and updated periodically. A full review is expected in 2010 with a new Strategic Agenda in 2012.

¹ www.acare4europe.com

At best, therefore, the ACARE target is most likely to be achieved with a narrow-body aircraft. More generally, it is very unlikely that an ACARE equivalent aircraft will be produced for turboprop, regional jet and wide-body/long-haul aircraft by 2020. At current levels of investment, and given the lead times for development of new technologies and new aircraft families, it is more likely that improvements in the ACARE range will be achieved in the late 2020s, or possibly beyond, for new aircraft introduced across a range of types.

Fleet rollover and implications for technology uptake

The pace at which engine and airframe innovation have the potential to reduce fleet emissions reflects aircraft life:

- Typical aircraft life is around twenty-five years.
- Given this, new aircraft entering the fleet annually to replace existing aircraft are unlikely to comprise a significant proportion of the overall fleet.
- New aircraft will also be required to meet incremental demand growth.

If new aircraft families were to be introduced no later than 2030, these would account for the majority of the fleet in 2050.

(iii) Future improvements from radical technology innovation

There is potential for additional fuel efficiency improvement above and beyond what is available from evolutionary innovation, although this would require technological breakthroughs and significant research, development and demonstration. Possible radical technology innovations include:

- **Open rotor engines**, where the fan blades are not surrounded by a casing. This removes some of the trade-offs between diameter, weight and drag allowing better fuel burn. There is some debate over the extent to which open rotor is an evolutionary or radical technology. The consensus among experts is that this approach will require a very high level of engine/aircraft integration and is only being considered for narrow-body aircraft. Moreover, open rotor engines may be needed for a narrow-body aircraft to be able to achieve overall ACARE type efficiency improvements in the 2020s.
- **Blended wing bodies**, offering improved airframe aerodynamics through a flattened profile and wing structures that are smoothly blended to the body.

Analysis from QinetiQ suggests that these radical measures taken together could improve efficiency by a further 15% in addition to the 35-45% increase from evolutionary innovation.

Economics of radical technologies

High levels of expenditure, in the order of tens of billions of pounds, are likely to be required to develop and demonstrate new technologies.

The result may be cost-effective technology options (i.e. resulting in net cost savings given a carbon price), although this is inherently very uncertain given the current early stage of technology development.

In order for radical technology innovation to have a significant impact in the period to 2050, this would have to be available in tandem with the introduction of new aircraft families. Given the long lead time for radical technology innovation (i.e. decades), funding would have to be made available in the short term in order to allow deployment in new aircraft families in the coming decades.

(iv) Scenarios for fuel efficiency improvement from engines and airframes

We have designed three scenarios for fuel efficiency improvement of engines and airframes. We have used a hybrid approach, combining estimates of annual improvement in the fuel efficiency of the average fleet from recent studies (i.e. top-down) with modelling of the uptake of new engine/airframe designs under different assumptions about the timing of new aircraft deployment (i.e. bottom-up).

The scenarios range from what is achievable under the current framework (Likely scenario) and likely to ensue; to what is achievable but very unlikely and would require a significant shift in policy and investment (Speculative scenario). The most ambitious scenario (Speculative), which includes technologies that are still at the concept stage, should be viewed with considerable caution unless there is new evidence to suggest a significant increase in the pace of technology innovation.

Specific assumptions in the three scenarios are:

- Under our **Likely** scenario we assume a 0.7% annual improvement in fleet fuel efficiency from engines and airframes on a seat-km basis. This is broadly consistent with: known entry into service of aircraft in the 2010s; narrow-body ACARE type aircraft starting to penetrate the fleet in the mid-late 2020s; ACARE equivalent other aircraft types starting to penetrate the fleet in the early-mid 2030s.
- Under our **Optimistic** ambition scenario we assume a 0.9% annual improvement in fleet fuel efficiency from engines and airframes on a seat-km basis. This broadly reflects a world where known entry of aircraft in the 2010s ensues; narrow-body ACARE type aircraft start to penetrate the fleet in mid-2020s; ACARE equivalent other aircraft types start to penetrate the fleet in the late 2020s to early 2030s.
- Under our **Speculative** scenario we assume a 1.2% annual improvement in fleet fuel efficiency on a seat-km basis. This is broadly consistent with a world where known entry of aircraft in the 2010s ensues; narrow-body ACARE type aircraft start to penetrate the fleet in the early 2020s; ACARE equivalent other aircraft types start to penetrate the fleet in the mid-2020s. Beyond the ACARE equivalent generation there could be a further generation that captures up to an additional 15% beyond ACARE equivalent improvements, with these aircraft starting to penetrate the fleet in the 2040s.

2. Scope for improved efficiency in ATM and operations

The fuel efficiency of flights depends not only on the aircraft but also on the efficiency of the flight plan (which in turn is affected by ATM), operational decisions including ground operations (e.g. taxiing at airport), and the optimisation of aircraft payloads.

We now consider:

- (i) Scope for ATM efficiency improvement
- (ii) Scope for operational efficiency improvement
- (iii) Scenarios for ATM and operational efficiency improvement.

(i) Scope for ATM efficiency improvement

Current inefficiencies in ATM

The Civil Air Navigation Services Organisation (CANSO) estimates that global ATM is currently 92-94% fuel efficient. Europe however (with its fragmented and congested airspace) is only between 89% and 93% fuel efficient.

Reasons for inefficiency include:

- Aircraft not flying the most direct route between airports (horizontal inefficiencies);
- Aircraft not flying at optimal height, and changing height in stages (vertical inefficiencies);
- Aircraft holding in the air at busy airports.

These inefficiencies may be explained by:

- Institutional factors:
 - Taking longer routes to fly around military airspace;
 - Handover protocols between Functional Airspace Blocks (FABs) requiring aircraft to transition between blocks at specified locations.
- Safety constraints:
 - The need to leave adequate horizontal and vertical space between flights, with implications for admissible routes and flight levels;
 - The need to avoid bad weather systems by changing route or altitude.
- Capacity constraints resulting in holding at busy airports. In the UK for example, according to NATS, aircraft circling in arrival account for roughly 2% of CO₂ emissions in their controlled airspace (around 0.5 MtCO₂). Three-quarters of these emissions are generated at Heathrow (which currently operates at 99% capacity). More generally, there is a correlation between capacity utilisation and holding (Table 4.2).

Table 4.2 Capacity utilisation and holding

Airport	Average Holding Time	Capacity utilisation
Heathrow	10 minutes	99%
Frankfurt	5 minutes	74%
Amsterdam	2 minutes	73%

Source: CCC collated data for latest available year.

- Trade-offs between fuel efficiency and noise pollution resulting in route design to avoid urban areas, and available capacity not being used early in the morning and late at night which could otherwise reduce holding.
- Cost of over-flying airspace differs between different areas and can affect whether the shortest route is chosen (e.g. London trans-atlantic flying over Ireland rather than Scotland).
- Split incentives, between Governments/Air Traffic Control agencies, who would have to drive efficiency improvement, and airlines, who would enjoy the benefit of improvement in the form of lower fuel consumption. Additionally, FABs cross national boundaries and therefore require international collaboration.

Opportunities for improving efficiency of ATM

In the UK, National Air Traffic Services (NATS) has a target to reduce emissions, in their controlled airspace, from ATM by 10% by 2020. Their plan to meet the target is described in Box 4.2.

This is a UK-based target but there are a range of other initiatives that could help, and may to some extent be necessary, for this target to be achieved.

More specifically:

- In Europe, the Single European Sky ATM Research programme (SESAR) is aiming to achieve a reduction in fuel burn for each flight within the Single European Sky airspace by 10% by 2020 relative to 2006.
- The Atlantic Interoperability Initiative to Reduce Emissions (AIRE) coordinates SESAR and NEXTGEN to increase the efficiency of flights between Europe and the US.

Box 4.2 NATS target reduction from ATM by 2020

NATS are responsible for air traffic management of UK and North Atlantic airspace, and air traffic control at 15 UK airports.

In 2009, NATS published its environmental strategy¹, which included a target to reduce CO₂ emissions by an average of 10% per flight by 2020 in their controlled airspace. They expect contributions to this target to come from all phases of flight:

- **Improving the vertical profile of flights:** Adopting smooth 'continuous climb' and 'continuous descent' approaches to the take-off and landing stage of flights could contribute to improved flight efficiency by reducing the amount of thrust and associated fuel burn. NATS estimates that fuel savings from the descent and climb phases of flight (including holding) could contribute savings per flight of 4.75% and 3.25% respectively.
- **Improving the horizontal profile of flights:** There is scope for improved flight fuel efficiency through optimisation of cruising height, speed and route. This would require better integration of air traffic control between different countries, and exploring opportunities for increased, safe access to military airspace. NATS estimates that improvements to the cruise phase could deliver potential fuel savings of 1.5% per flight in their controlled airspace in and around the UK.
- **Improving airport operations:** There is potential for fuel savings from more efficient operational procedures while aircraft are on the ground, for example from taxiing. NATS estimate fuel savings from airport operations could provide savings of 0.5% per flight (see section ii).

¹ NATS (2009), *Acting Responsibly: NATS and the Environment 2009*, [www.nats.co.uk/uploads/NATSEnvironmentPlan\(1\).pdf](http://www.nats.co.uk/uploads/NATSEnvironmentPlan(1).pdf)

(ii) Scope for operational efficiency improvement

There are a number of opportunities to improve operational efficiency beyond improving passenger load factors (i.e. seat occupancy):

- **Maximising payload:** Maximising belly-hold freight carriage in addition to seat occupancy would reduce the need for separate freight-only flights. However, this is a commercial decision for airlines, and may not be compatible with all business models such as those based on quick turnaround.
- **Reducing cabin deadweight:** QinetiQ analysis suggests that at a global level this could offer a small potential of reducing fuel burn by up to 1%.
- **Improving airport operations:** QinetiQ analysis suggests that up to a 2% reduction in global fuel consumption could be achieved by ground towing.

(iii) Scenarios for ATM and operational efficiency improvement

In designing our scenarios for increased efficiency in ATM and operations, we have taken account of the key ongoing ATM initiatives affecting the UK and potential improvement from operations identified by QinetiQ:

We have constructed three scenarios:

- Under our **Likely** scenario we assume a compounded 6% improvement from ATM and operations between 2005 to 2020, with ATM expected to contribute the majority of the improvement (i.e. 5%). This is a relatively prudent estimate which reflects the challenge of meeting and maintaining ATM improvements against a backdrop of increasing demand.
- Under our **Optimistic** scenario we assume a compounded 9% improvement from ATM and operations between 2005 to 2020, with ATM expected to contribute 7% to 8% of the improvement.
- Under our **Speculative** scenario we assume a compounded 13% improvement from ATM and operations between 2005 to 2020, with ATM expected to contribute 9% to 10% of the improvement – i.e. achieving current ambitious ATM targets by 2020 and maintaining those efficiencies against a backdrop of increasing demand to 2050. This may be near an upper bound of what is achievable through ATM and operations and could require both aircraft reconfiguration and payload maximisation.

3. Scenarios for annual improvement in fleet fuel efficiency

We have combined our scenarios for engine and airframe innovation, ATM and operations into three scenarios for overall improvement in fleet fuel efficiency:

- Our **Likely** scenario reflects improvement in average fleet fuel efficiency between 2005 and 2050 of 0.8% per year on a seat-km basis.
- Our **Optimistic** scenario reflects improvement in average fleet fuel efficiency between 2005 and 2050 of 1.0% per year on a seat-km basis.
- Our **Speculative** scenario reflects improvement in average fleet fuel efficiency of 1.5% per year on a seat-km basis.

These scenarios, which are within the envelope from recent studies (Table 4.3), are used in our analysis of options for meeting the 2050 target in Chapter 7.

Table 4.3 Comparison between CCC average annual improvements in fleet fuel efficiency and other analyses

Source	Year	Scope	Annual average improvement in efficiency to 2050 (%)
CCC	2009	UK	0.8% (Likely), 1.0% (Optimistic), 1.5% (Speculative)
DfT central	2009	UK	1.1% (to 2030), 0.75% (to 2050)
Sustainable Aviation	2008	UK	2.1%
US FAA	2009	Global	1.0% (low trend), 1.5% (optimistic trend)
IEA	2009	Global	0.9% (High Baseline), 1.1% (Baseline), 1.5% (BLUE Map scenario)
QinetiQ (for CCC)	2008	Global	up to 1.5%
IPCC	1999	Global	1.3% (to 2010), 1.0% (to 2020), 0.5% (to 2050)

Source: CCC collated data and calculations.

In addition to the percentages used in recent analysis, industry groups such as IATA and ICAO's GIACC have set aspirational fuel efficiency goals of 1.5% to 2020 and 2.0% to 2050 respectively.

Chapter 5

Use of biofuels and hydrogen in aviation

The use of biofuels in aviation has been confirmed in recent trials as being technically feasible and specifications for some types of aviation biofuels have already been included in US standards. The extent to which biofuels can be used to meet aviation emissions targets, however, will depend crucially on sustainability, and the extent to which sustainable biofuels are best used in aviation.

This chapter considers lifecycle emissions from biofuels, when emissions from growth of feedstock, fuel production and land-use change are accounted for. It sets out alternative uses for available bioenergy, including use of biofuels in road transport and shipping, renewable heat, power generation and household uses (e.g. cooking and heating). It considers broader sustainability questions relating to the use of land for biofuels in the context of a significantly increasing global population, constrained water resources, climate change impacts on agriculture and concerns about biodiversity. Based on a high-level assessment of these factors, the chapter sets out scenarios for the use of sustainable biofuels in global and UK aviation. Finally, the chapter considers possible use of hydrogen in aviation.

The key messages in the chapter are:

- There are at least three areas of uncertainty over the potential for use of biofuels in aviation:
 - It is not clear whether scarce biofuels should be used in aviation or other sectors (e.g. road transport, shipping, etc.).
 - It is also not clear that sufficient land required to grow substantial volumes of biofuels feedstock will actually be available given the need to feed a significantly increasing global population in the period to 2050, nor is it clear that risks of indirect land-use change through growth of biofuels crops can be adequately addressed.
 - Technological breakthroughs are required in order that second and third generation biofuels which do not require potential agricultural land (e.g. algae) become commercially available.



- Given this uncertainty, we set out a range of scenarios for penetration of biofuels in global aviation from 10% to 30% in 2050, with a lifecycle emissions reduction of 50% compared to oil-derived kerosene. It is prudent to plan for 10% penetration given current sustainability concerns, without ruling out the possibility of significantly higher levels of penetration.
- Evidence suggests that there are significant challenges to use of hydrogen power in aviation, and that a cautious approach is therefore justified.

We set out the analysis that underpins these messages in 2 sections:

1. Use of sustainable biofuels in aviation
2. Use of hydrogen in aviation.

1. Use of sustainable biofuels in aviation

In understanding the role for use of biofuels in aviation, we have assessed technical barriers, and high-level sustainability constraints including lifecycle emissions impacts, alternative uses for biofuels and limits on the level of sustainable biofuels given competing demands for land to produce food to feed a growing global population.

We now consider:

- (i) Technical potential for use of biofuels in aviation
- (ii) Sustainability constraints on the use of biofuels
- (iii) Scenarios for use of sustainable biofuels in aviation.

(i) Technical potential for use of biofuels in aviation

Industry focus on biofuels

There has recently been increasing interest in the use of biofuels¹ in aviation given concerns over the jet fuel prices, and carbon constraints due to the introduction of cap and trade schemes:

- Jet fuel prices: historically fuel costs have accounted for up to 35% of airlines operating costs and oil prices have been high and volatile over the past five years, reaching a maximum of almost US \$150/bbl relative to the current level of around US \$80/bbl.
- Carbon constraints: IATA estimates that inclusion of aviation in the EU ETS will result in a cost increase equivalent to a 19% increase in fuel expenses by 2020.

¹ There is a wider range of 'alternative fuels' that could in principle be used in aviation, including not only biomass derived fuels but also synthetic fuels derive from coal and natural gas. However these routes have not been included in our analysis as they are unlikely to help significantly reduce CO₂ emissions from aviation (see the recent report by RAND and MIT *Infrastructure, Safety and Environment*, 2009).

Recent trials (Box 5.1) suggest that the use of biofuels in aviation is technically feasible; additionally, some biofuels blends are already included in US jet fuel specifications with new blends expected to be included in the coming years.

Box 5.1 Aviation trials of alternative fuels

In recent years the aviation industry has been conducting a series of laboratory, ground and (since 2008) flight tests with a range of different alternative fuels in order to collect the data required by the certification process.

The main players in these tests have been the large airframe manufacturers (Boeing, Airbus), aircraft engine manufacturers (GE Aviation, Rolls-Royce, Pratt & Whitney and their respective joint ventures CFM and IAE) and the petroleum, petrochemical and gas process technology supplier, UOP.

The five flight tests conducted to date have all been of blends of fossil fuel with up to 50% of an alternative fuel. Four of the tests have used fuel derived from a range of biomass feedstocks, while one has used a Fischer-Tropsch (FT) fuel derived from natural gas. The flight tests ranged from 1.5 to 3 hours duration and included a range of 'normal' and 'non-normal' flight manoeuvres (the latter including, for example, in-flight engine shutdown and relight).

Table B5.1 Summary of civil aviation biofuels test flights

Date	Airline	Fuel supplier	Blend	Airframe manufacturer	Engine manufacturer	No. of engines	Flight duration
February 2008	Virgin Atlantic	UOP, Imperium Renewables	20% coconut and babassu methyl ester	Boeing 747-400	GE CF6-80C2	1 of 4	3 hours
February 2008	Qatar Airways	Shell International Petroleum, Qatar Fuel	40% GTL	Airbus A380	Rolls-Royce Trent 900	1 of 4	3 hours
December 2008	Air New Zealand	UOP, Terasol	50% jatropha	Boeing 747-400	Rolls-Royce RB211-524G	1 of 4	2 hours
January 2009	Continental Airlines	UOP, Terasol, Sapphire Energy	47.5% jatropha, 2.5% algae	Boeing 737-800	CFM56-7B	1 of 2	2 hours
January 2009	Japan Air Lines	UOP, Sustainable Oils	42% camelina, 7.5% jatropha, 0.5% algae	Boeing 747-300	Pratt & Whitney JT9D	1 of 4	1.5 hours
October 2009	Qatar Airways						
2010	Jet Blue	UOP		Airbus A320-200	IAE v2500		
2010	Interjet		Halophyte derived	Airbus A320	CFM56		
To be announced	British Airways						

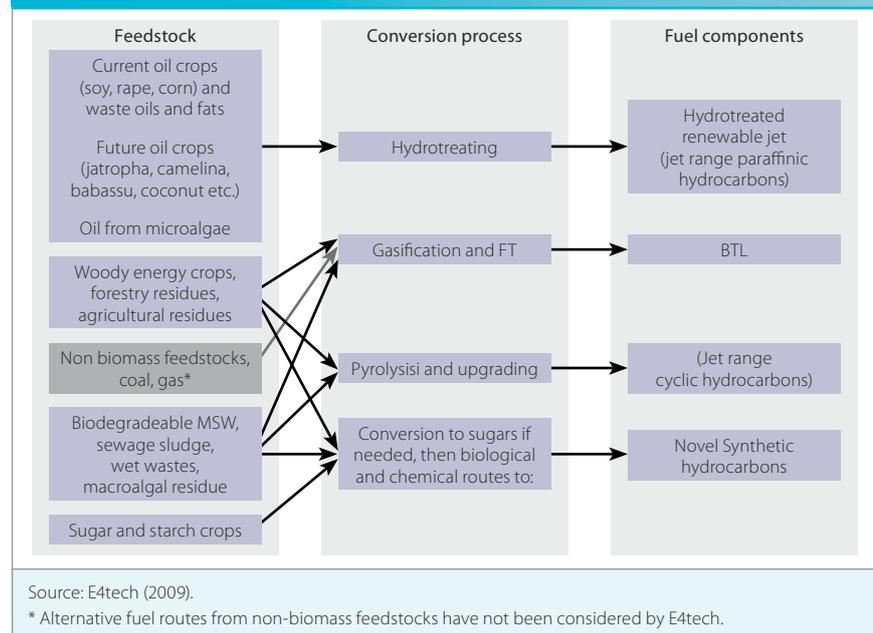
Source: E4tech (2009) based on industry press material.

Routes for production of aviation biofuels

There are several potential routes for producing aviation biofuels (Figure 5.1). In analysis commissioned by the Committee from E4tech, three main routes are identified:

- **Biomass to Liquid (BTL):** this involves gasification of biomass feedstock (e.g. woody crops or wastes), followed by Fischer-Tropsch (FT) synthesis and upgrading steps, to produce jet fuel, diesel or gasoline. A similar process is already used to produce specification-compliant jet fuels from coal (e.g. in South Africa).
- **Hydrogenated Renewable Jet (HRJ):** this involves the conversion of vegetable oils (e.g. conventional oil crops such as palm and soy, but also new oils crops such as jatropha and camelina) and algal oils to aviation fuel through a process including treatment with hydrogen.
- **'Novel synthetic hydrocarbons':** this is a generic term which covers a variety of potential novel routes relying on conversion of biomass to jet fuel via biological or chemical processes.

Figure 5.1 E4tech representation of potential biofuels routes



Current stage of development/addressing technical challenges

The three routes identified above are at different stages of development, with BTL being closest to commercial-scale production, challenges remaining in production of high yield crops for HRJ, and novel synthetic hydrocarbons at an early stage of development:

- Many of the individual technologies required for BTL are commercially available, though their integration into a coherent process is only at the demonstration scale. Commercial-scale plants for road transport BTL fuels are planned from 2012/13².
- Technologies required for HRJ are well known and very similar to those currently used for producing hydro-treated vegetable oil biodiesel for road transport. Small-scale production of jet fuel in existing biofuels plants is expected from 2010, and production in dedicated plants from 2011³. Innovation is required to produce high-yield feedstock from new oil crops such as jatropha and camelina, and to develop algal technology.
- Novel synthetic hydrocarbon technologies are at an earlier stage of development compared to the other two main routes. These technologies are being developed principally by US companies and are currently at pilot-scale testing. Demonstration may occur as early as 2013, but novel synthetic hydrocarbons are unlikely to be commercially available before 2020.

There is therefore a question over the pace at which biofuels could be introduced to aviation given current technical barriers and the required investment to achieve production at scale. These relate, however, primarily to the period to 2030. Going further out in the period to 2050, it is likely that at least some technical barriers could be addressed and that significant use of biofuels in aviation could be technically feasible.

(ii) Sustainability constraints on the use of biofuels

In assessing sustainability constraints on the use of biofuels we consider in turn:

- Emissions of greenhouse gases from growing feedstock and producing biofuels;
- Emissions associated with potential land-use change as a consequence of growing biofuels feedstock;
- Competing demands for available biofuels from other sectors;

² For example, commercial scale plants for BTL diesel are planned by CHOREN in Germany and by TRI in the US from 2012. See E4tech (2009).

³ For example, UOP plans to have a dedicated HRJ plant up and running by Q4 2011 and to commercially produce jet HVO from a diesel plant in 2010. See E4tech (2009).

- Broader sustainability considerations, such as the competing pressure on land-use from biofuels and food production (given the expected increase in population, climate change, water scarcity and therefore possible limits to improvements in agricultural productivity) and possible impacts on biodiversity.

Given that sustainability impacts work through land impacts at the global level, our approach is to consider limits on use of sustainable biofuels in aviation globally, and then to assume that UK aviation biofuels penetration is equal to the global average.

Emissions from growing feedstock and producing biofuels

The degree to which biofuels could deliver lifecycle GHG savings compared with conventional kerosene depends heavily on the type of feedstock used. Table 5.1 sets out E4tech's assessment of possible lifecycle savings for different aviation biofuels routes, based on a review of existing literature and abstracting from possible land-use change effects. This shows that production from conventional oil crops has relatively high emissions compared to production from energy crops (e.g. woody crops and grasses), residues and wastes, low input oil crops, or algae. Specifically:

- For biofuels based on conventional oils, emissions from the use of fertiliser in growth of feedstock and from the production process reduce lifecycle emissions savings by around 50-80%.
- Lifecycle GHG savings could be up to 95% for BTL, 66-89% for new oil crops, up to 98% for algae and up to 90% for novel synthetic hydrocarbons.

Other studies suggest a figure for BTL lifecycle emissions reductions of around 85% (again, abstracting from possible land-use change effects).

Table 5.1 The E4tech assessment of lifecycle savings from biofuels before land use effects

Route	Feedstock	Emissions, g CO ₂ e/MJ fuel	Savings CO ₂ e vs. jet
Fossil jet (baseline)	–	87.5	–
BTL	Energy crops	7.3	92%
	Forestry residues	4.8	95%
HRJ	Conventional oil crops (rapeseed, palm, soy etc)	40-70 (averages)	20-54%
	Jatropha	30	66%
	Camelina	13.5	85%
	Tallow	10	89%
	Algae (Open ponds)	-21 (best case) 1.5 (realistic case)	124% (best case) 98% (realistic case)
Synthetic hydrocarbons	Not specified		70-90%

Source: E4tech (2009).

Emissions from land-use change due to growth of feedstock for biofuels

Lifecycle emissions savings could be reduced if growth of biofuels feedstock were to result in direct or indirect land-use change:

- Direct land-use change occurs where growth of feedstock for biofuels results in deforestation or conversion of other carbon-rich soils.
- Indirect land-use change occurs where growth of biofuels feedstock displaces food production resulting in deforestation or conversion of other carbon-rich soils or cultivation of less productive land requiring greater use of carbon-intensive fertilisers.

Direct land-use change has occurred, for example, to support significantly increased production of palm oil in South East Asia⁴. Going forward, the risk of further direct land-use change could be mitigated through introduction of an appropriate regulatory framework.

The risk of indirect land-use change, however, is more difficult to mitigate through regulation, given complexities associated with tracking the chain of impacts from biofuels production on agricultural production.

One key factor in helping to mitigate direct and indirect land-use impacts will be whether or not carbon associated with land-use change and forestry is brought within the scope of a global climate regime.

Estimates of lifecycle emissions reduction including land-use impacts

There is therefore uncertainty about the level of lifecycle emissions reduction of biofuels when land-use change is accounted for, reflected in a wide range of estimates for lifecycle impacts:

- Sustainable Aviation assumes a 50% lifecycle saving in their roadmap.
- IATA assumes a 60-90% saving for BTL biofuels, with a negative 70% saving (i.e. GHG increase) for HRJ biofuels depending on the type of feedstock and where this is grown.

Competing demand for biofuels from other sectors

Analysis by E4tech suggests that biofuels could compete economically with conventional jet fuels in a world of increasing oil and carbon prices, particularly further out in the period to 2050. In particular, conversion of woody crops and wastes (i.e. 'Biomass to Liquid') and use of woody crops such as jatropha and camelina (i.e. 'Hydrogenated Renewable Jet') could become viable from the 2020s.

⁴ See for instance Augustyn (2007). 'A burning issue'. *World Watch Magazine*.

However, even if biofuels could in theory compete in the future with conventional jet fuels there is additional uncertainty about whether supply-constrained biomass should be used in aviation or other sectors:

- Biofuels are currently used in road transport. While, as we set out in our December 2008 report, electrification is likely to be the key technology for decarbonising the surface transport sector, this technology is not applicable to HGVs. In addition, liquid fuels would still be used in hybrid and plug-in hybrid electric vehicles. Biofuels are therefore likely to play a role in road transport in a carbon-constrained world.
- Biomass will continue to be used for cooking and heating in developing countries; currently around two-thirds of global biomass use is for this purpose.
- Biomass could be increasingly used in combined heat and power (CHP) applications or co-firing with coal using CCS technology such that operation results in zero or even negative emissions.
- Biofuels could in principle be used to contribute to emissions reduction from the shipping sector (e.g. first generation biofuels such as biodiesel and vegetable oils can readily be used for ships' diesel). Analysis for our December 2008 report suggested that fuel consumption from the shipping sector in 2050 may exceed fuel consumption from aviation, so potentially this sector could impose a significant extra demand on biomass resource.

The IEA BLUE scenarios⁵ assume that total bioenergy demand will amount to 3.6 billion tonnes of oil equivalent in 2050, with total demand for transport biofuels accounting for around 700 million tonnes (or 19%) of this total and demand from aviation alone accounting for around 165 million tonnes under an assumption of 30% penetration (Box 5.2).

Box 5.2 Land-use requirements from transport biofuels in the IEA BLUE Map scenario

In their Energy Technology Perspectives 2008, the IEA set out global scenarios for penetration of BTL-derived biofuels in aviation, reaching 15% by 2050 in the BLUE Conservative scenario and 30% in the BLUE Map scenario (Figure B5.2a), while noting that rates of penetration could be much higher if sufficient land for growing feedstock became available.

In their recent World Energy Outlook 2009, the IEA presented a more ambitious scenario consistent with stabilisation of atmospheric concentrations of GHG at 450ppm where aviation biofuels achieve a global penetration of 15% by 2030.

⁵ IEA (2008). *Energy Technology Perspectives*.

Box 5.2 continued

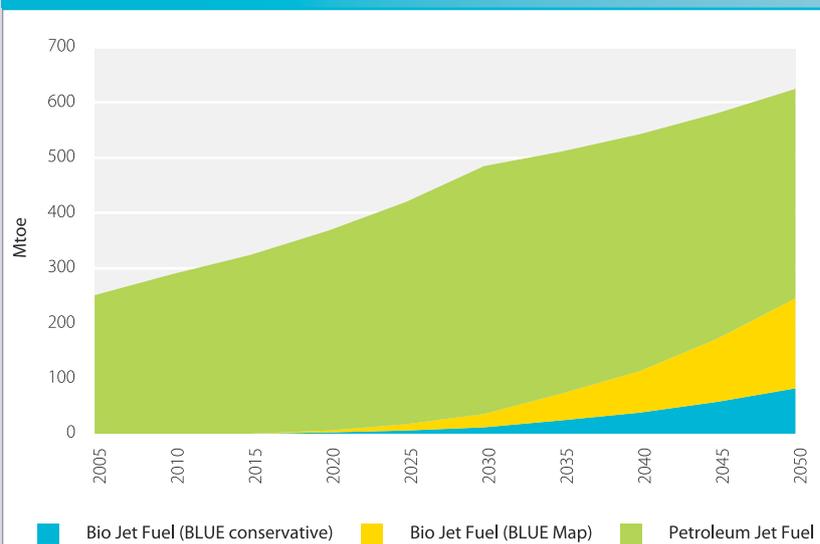
The IEA aviation biofuels scenarios were set in the context of biofuels penetration in the transport sector (including surface transport and shipping in addition to aviation) growing over time to provide energy equivalent to 700 Mtoe by 2050 in the BLUE Map scenario (Figure B5.2b), and of total bioenergy demand (including demand from transport biofuels and from other sectors) increasing to 3.6 billion tonnes of oil equivalent in 2050.

Land requirements for transport biofuels were projected to increase to around 1.6 million km² by 2050 under the BLUE Map scenario (Figure B5.2c).

Land requirements for other biomass uses (e.g. in the power sector and in industry) were projected to increase to between 2.15 and 5.9 million km² by 2050.

Overall land requirements for biomass production in 2050 in the BLUE Map scenarios were estimated to be between 3.75 and 7.5 million km².

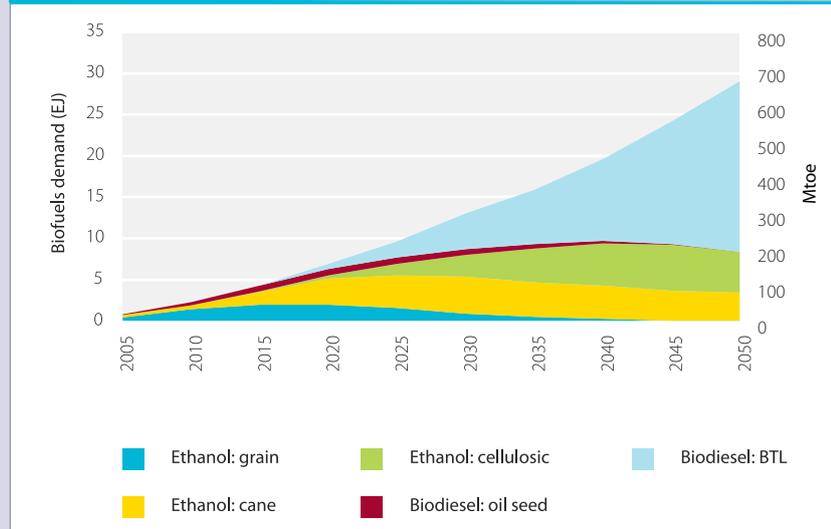
Figure B5.2a The IEA scenarios for biofuel penetration to 2050



Source: IEA (2009).

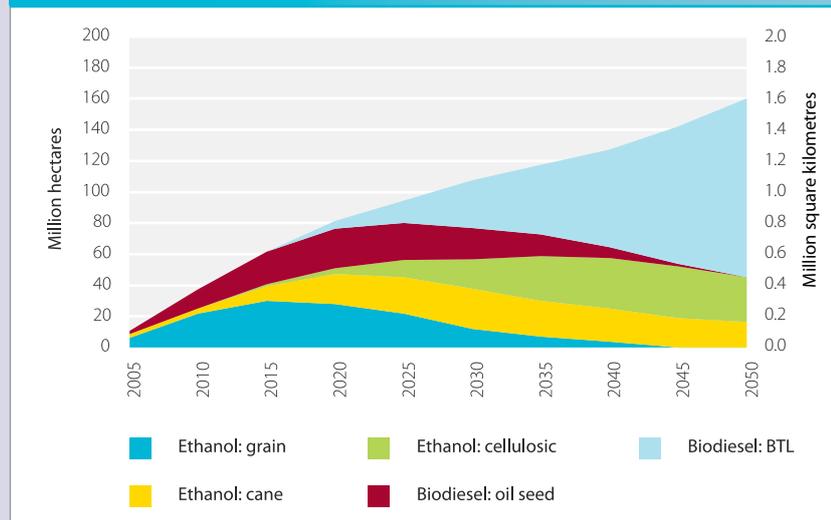
Box 5.2 continued

Figure B5.2b Demand for transport biofuels in the IEA BLUE Map scenario



Source: IEA (2008).

Figure B5.2c Land requirements for biofuel production in the IEA BLUE Map scenario

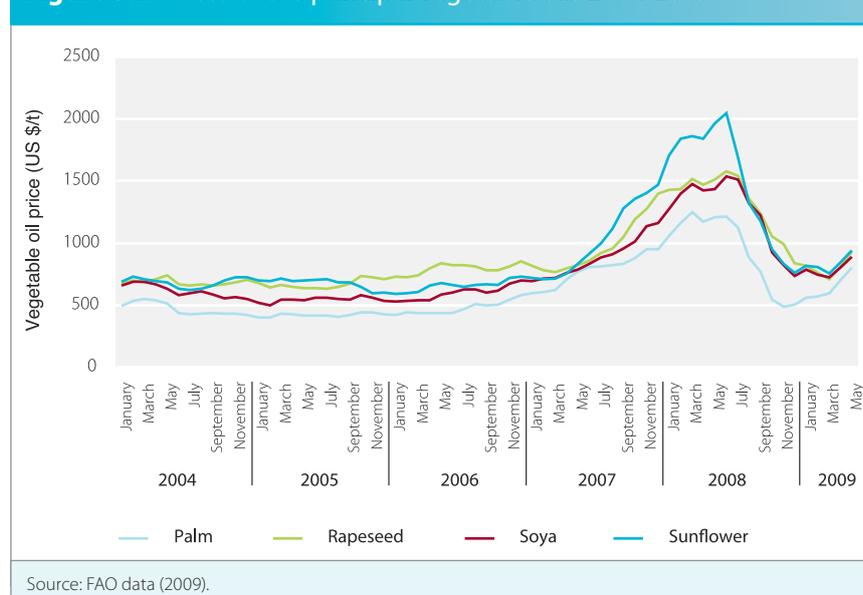


Source: IEA (2008).

Broader sustainability considerations: tensions between production of biofuels and food, and possible impacts on biodiversity

Increasing use of land for the growth of crops for first generation road transport biofuels (e.g. corn-based ethanol), and the ensuing displacement of food production, was a key driver of the food price shock in 2008⁶. Prices of major staples, such as grains and oilseeds, doubled in just two years between mid-2006 and mid-2008 (Figure 5.2), which in turn led to significant social consequences, particularly for the poor in developing countries. Going forward (and notwithstanding a shift to less land-intensive second and third generation biofuels), there could be further tension between deeper penetration of biofuels and biomass in aviation and other sectors, and increasing agricultural production required to feed a growing global population.

Figure 5.2 Prices of the principal vegetable oils 2004-2009



If 100% of projected aviation fuel use in 2050 were to come from BTL biofuels, E4tech analysis suggests that this would imply a land requirement for growth of feedstock of around 2.5 million km². Together with use of biofuels in other sectors as set out in the IEA's BLUE Map scenario (as described above), the implied land requirement for biofuels feedstock would be around 3.4 million km². In addition, the IEA estimate that there could be an additional demand for other biomass uses of up to 5.9 million km².

This may be compared to the 0.36 million km² that are currently used for biofuel feedstock production, out of the overall 14 million km² currently dedicated to crop production. Going forward, estimates of unused agricultural land vary from very low to nearly 14 million km² depending on assumptions about agricultural productivity improvement, while marginal land that could be converted to biofuel feedstock production may amount to a few million km².

⁶ See Mitchell (2008). *A note on rising food prices*. World Bank Policy Research Working Paper 4682.

Figure 5.3 compares estimates of land requirements for 100% BTL biofuels penetration in aviation by 2050 and other biomass uses with estimates of available idle and marginal land under optimistic assumptions about agricultural productivity improvement⁷, while Figure 5.4 provides more detail on the amount and type of land that may be available in a very optimistic scenario.

Figure 5.3 Potential land requirements in 2050 from aviation biofuels and other biomass uses

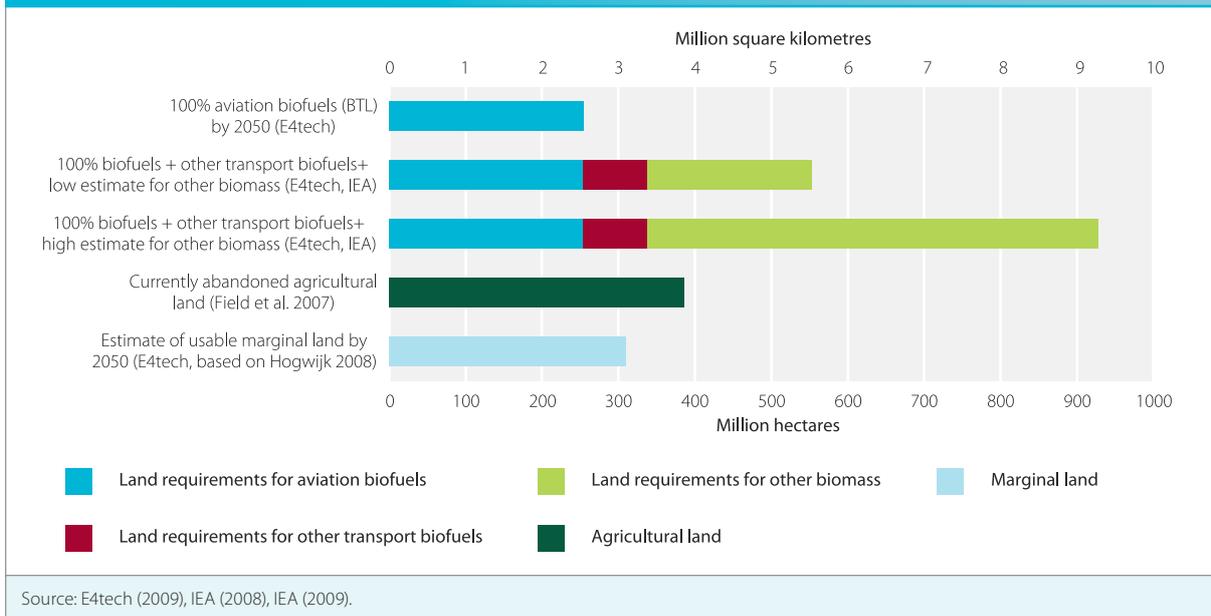
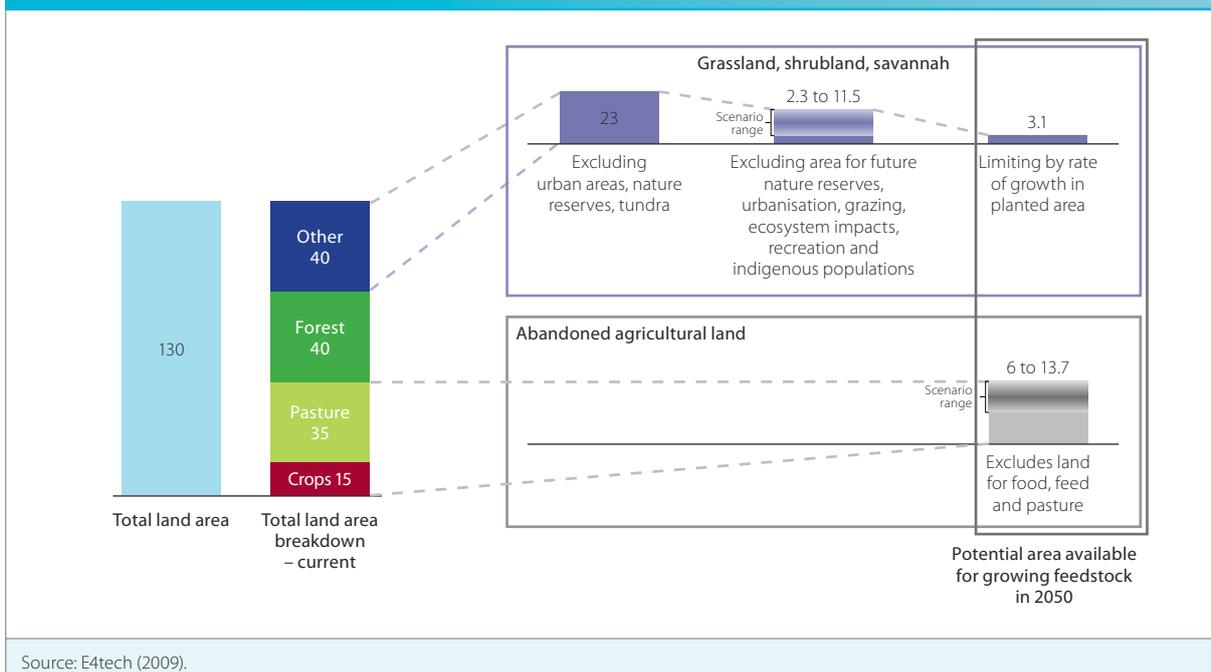


Figure 5.4 E4tech assessment of potential land availability for biomass feedstock (million km²)



⁷ As noted by Field et al. (Field et al (2007). 'Biomass Energy: the scale of the potential resource'. *Trends in Ecology and Evolution*.) the available lands for biomass feedstock are likely to be at the lower end of the spectrum for fertility and climate, with implications for yields.

However, the extent to which unused agricultural land or marginal land will be available depends crucially on global population growth and agriculture productivity improvement:

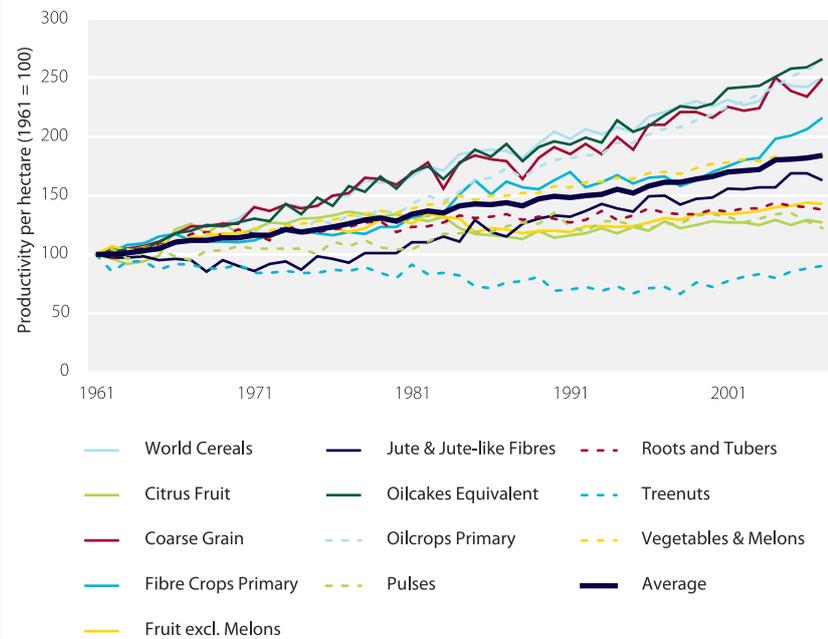
- In the period to 2050, it is expected that the global population will increase from the current level of around 6.7 billion to over 9.1 billion. The FAO estimates that meeting the associated increasing demand for food (and the predicted shift toward western-style diets in developing countries) will require a 70% increase in global food production by 2050⁸.
- Over the last 50 years, agricultural production has increased at rates that have outpaced population growth. FAO statistics show an increase of 138% in gross world food production since 1961, and an increase of more than 200% in overall agricultural production, largely driven by productivity and crop yield improvements (Figure 5.4) and with only a modest increase in cultivated land. Over the same period, population increased by 123%. As a result, the Royal Society estimates that for each person alive today there is, in theory, an additional 29% more food compared with 1960.
- If historical rates of growth in agricultural productivity could be maintained in the period to 2050, then the challenge of feeding a growing population could be met without converting marginal and idle land into agricultural production, which would leave more scope for energy crops. However the 'green revolution' of the early 1960s relied heavily on the use of fertilisers, pesticides and water, and it is uncertain that these rates of growth in productivity can be sustained in the future given greenhouse gas targets, particularly as the impact of unavoidable climate change beyond a point will be to reduce agricultural productivity (Box 5.3).
- In addition to land constraints, there are constraints on available water resource as the global population increases. These have been highlighted for instance by John Beddington, the UK government's Chief Scientific Adviser. He argues that demand for water in 2050 will be 30% above current levels, and that this will limit availability of water for use in agriculture⁹.

Recognising the tension between land-use for growth of biofuels, and possible uses of biofuels in other sectors, the IEA in their Energy Technology Perspectives 2008 set out a range of scenarios for biofuels penetration from 15% to 30% in 2050, while acknowledging the possibility that biofuels may reach much higher penetration levels (and ultimately completely replace conventional aviation kerosene) if sufficient land for growing feedstock were to become available.

⁸ The increase in demand for food will reflect not only increased population but also changes in diet, with a wide range of assumptions possible as to how far developing world diets will converge towards developed world resource intensive patterns (e.g. with higher proportion of meat and dairy). Estimates of total additional agricultural production required range from 50 to 100%.

⁹ Beddington (2009). *Food, Energy, Water and the Climate: A Perfect Storm of Global Events*.

See http://www.dius.gov.uk/news_and_speeches/speeches/john_beddington/--/media/publications/P/Perfect-Storm-Paper

Figure 5.5 Agricultural productivity per hectare since 1961

Source: FAO data (2009).

Box 5.3 Potential for future productivity improvements in agriculture

A number of major recent studies have looked at the challenges facing the global agricultural sector in meeting the growing demand for food in the period to 2050. A key underlying factor is the extent to which crop yields can keep improving at the same rate as over the past 40 to 50 years in the period to 2050, under a series of additional constraints such as climate change, water scarcity and the need to limit the use of pesticides and nitrogen-based fertilisers.

The **OECD/FAO Outlook¹** offers some medium-term perspectives on these issues. It identifies three critical supply factors that could affect the rate of growth in agricultural productivity:

- Land availability (including the speed with which new land can be brought into production)
- Water availability
- Agricultural productivity, including crop yields and livestock productivity.

Box 5.3 continued

Overall, the OECD/FAO report concludes that agricultural production could be increased considerably. However the report highlights the need for investments (e.g. in water efficiency) and risk management, as well as the potential role that concerns about broader environmental impact, GM technology and food quality may have in shaping the future of the agricultural sector.

A recent **Royal Society** report² looks at these issues over the longer term (to 2050) and focuses more clearly on the need for the agricultural sector to increase food production within clear sustainability boundaries. The report acknowledges the remarkable success of the 'green revolution' in feeding an expanding world population, but also points to its environmental shortcomings (including increasing emissions of nitrates and pesticides and depletion of aquifers) and uneven distribution of the benefits in different regions of the world and among different social groups. It then sets out a blueprint for 'sustainable intensification' of the global agricultural sector.

The constraints on future crop production that need to be addressed according to the Royal Society report are the following:

- Climate change, as a cross-cutting threat which will aggravate the effects on crops of heat, drought, salinity and submergence
- Unsustainable water abstraction
- Temperature extremes
- Increased tropospheric concentrations of ozone, which can damage crops
- Soil quality depletion through erosion, pollution and urbanisation
- The need to maintain adequate levels of crop nutrition while reducing the amount of synthetic nitrogen fertilisers
- The need for effective control of pests, diseases and weed competition
- The need to manage energy and CO₂ implications of agriculture
- The need to maintain genetic diversity in crops.

The report suggests that in order to achieve a sustainable intensification in global agriculture a combination of many different agricultural practices and technologies will be needed, including:

Box 5.3 continued

- Advanced biotechnology and crop genetics (both through GM crops and conventional breeding techniques)
- Improved crop and soil management practices (e.g. integrated pest and nutrient management, soil and water conservation, water harvesting, integration of agroforestry into crop systems).

A recent report by **UNEP**³ (which by contrast with the previous two reports focuses on biofuels) also acknowledges these challenges and points to the importance of fostering sustainable land-use for biomass production, including increasing agricultural yields in an environmentally benign manner (focusing in particular on regions where productivity increases have lagged), directing new fields to degraded land and making more efficient use of biomass, including enhancing the use of waste and residues.

1 OECD/FAO (2009). *Agricultural Outlook 2009-2018*.

2 Royal Society (2009). *Reaping the benefits: science and the sustainable intensification of global agriculture*.

3 UNEP (2009). *Towards sustainable production and use of resources: assessing biofuels*.

An alternative view is set out in scenarios commissioned by the Committee from E4tech (Box 5.4). These assume that agricultural productivity improvement is sufficiently large to offset population increases and/ or that there are technological breakthroughs relating to biofuels with lower land requirements:

- The E4tech analysis is based on primary studies which assume that the growth in agricultural productivity will not slow down in the foreseeable future, so that currently unused agricultural land and marginal land will be available to grow crops for biofuels.
- E4tech envisage that a significant contribution to the aviation biofuel mix could come from the BTL route, which in principle could rely on forest residues and waste and would therefore have a lower land-use impact than woody crops.

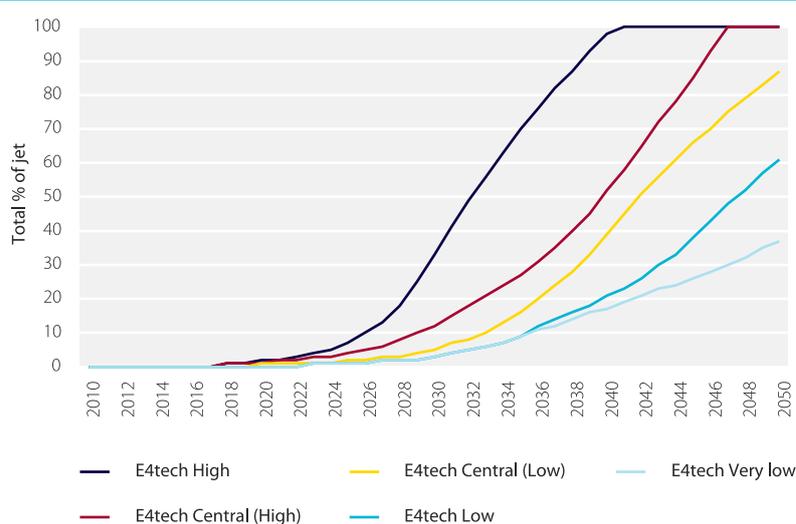
Given these assumptions E4tech set out a range for penetration of sustainable biofuels in aviation from 37% to 100% in 2050 (see Box 5.4).

Box 5.4 E4tech scenarios for aviation biofuels penetration

E4tech considered the technological and economic aspects of use of biofuels in aviation. They then developed scenarios for different combinations of oil prices and carbon prices and different assumptions on the use of conventional vegetable oils and the speed and success of technology development in new oil crops, algae, and novel synthetic hydrocarbons. In all scenarios, uptake was limited by the speed at which new conversion plants could be built, and new crops and algae plants established. Uptake is given as a percentage of the highest global aviation fuel demand scenario used in the IPCC 4th Assessment report (Consave ULS).

The full set of 18 scenarios was then narrowed down to five summary scenarios illustrated in Figure B5.4. None of the summary scenarios included use of conventional oil crops for HRJ, as a result of potential sustainability impacts, and the likelihood that prices will remain above the level needed to make production competitive with conventional jet fuel. In the Central (Low), Low and Very Low scenarios, commercial introduction of new crops and algae is delayed by five years, and the development of synthetic hydrocarbons is not successful for jet fuels.

Figure B5.4 Proportion of biofuel penetration in aviation in the E4tech scenarios



Source: E4tech (2009).

(iii) Scenarios for use of sustainable biofuels in aviation

Our scenarios for aviation biofuels penetration cover the period to 2050. For the initial part of this period, the binding constraints on biofuels penetration relate to technical barriers (e.g. the need for a technology breakthrough), limits on planting rates for biofuels feedstock, limits on the pace of investment in new plant for biofuels production, and commercial viability of biofuels given relatively high initial costs and relatively low oil and carbon prices.

Further out to 2050, sustainability constraints and use of biofuels in other sectors become increasingly important.

We set out three scenarios covering a range of uncertainty over possible penetration of biofuels in aviation. The scenarios are defined by the penetration of biofuels over time and the lifecycle biofuels emissions reduction.

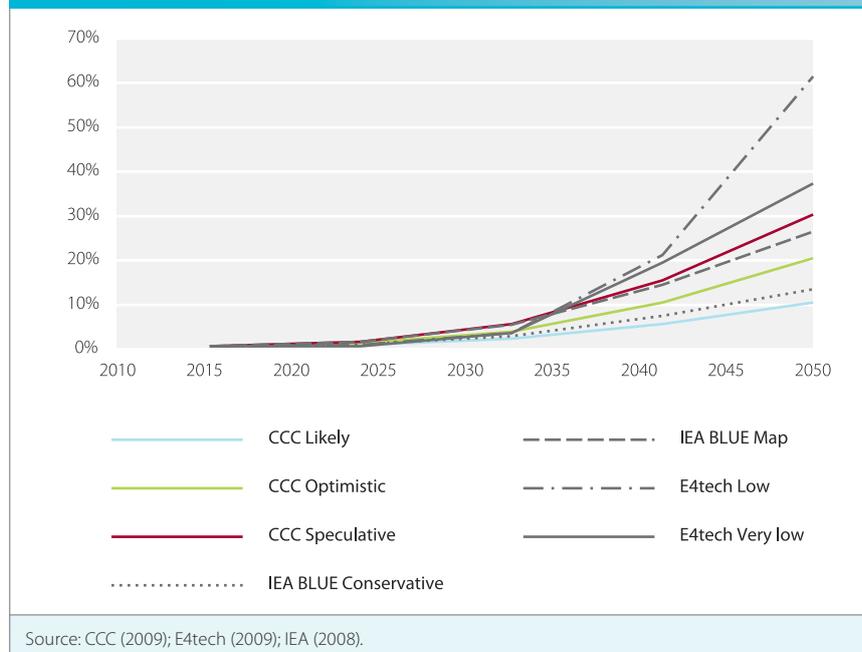
We assume penetration in 2050 from 10% to 30% and lifecycle GHG savings of 50%, which we have chosen to reflect current significant sustainability risks. It is currently prudent to plan for 10% penetration although significantly higher levels of penetration should not be ruled out (e.g. subject to new evidence that there will be abundant supplies of waste or residues, or technological breakthroughs to facilitate mass production of sustainable algae or to allow production of biofuels feedstocks in deserts using solar power and water desalination):

- Under our **Likely** scenario we assume that penetration of aviation biofuels is below 2% in 2030 and reaches 10% by 2050, reflecting a world where there is very limited resource available for use of biofuels in the aviation sector (either due to land constraints, limited progress developing biofuels from routes requiring less land input, or demand for biofuels from other sectors). This is slightly more prudent than the IEA's 'BLUE conservative' scenario, which assumes a 15% penetration of aviation biofuels by 2050. We follow Sustainable Aviation and assume greenhouse gas lifecycle savings of 50% to reflect emissions in production of biofuels and possible land-use change impacts. Under these assumptions, an aviation emissions reduction of 5% is achieved in 2050 compared to a counterfactual where no biofuels are being used.
- Under our **Optimistic** scenario we assume that penetration of aviation biofuels is around 3% by 2030 and 20% by 2050; this scenario reflects constraints on the availability of sustainable biofuels and use of sustainable biofuels in aviation, and is slightly higher than the IEA's 'Blue conservative' scenario. Assuming greenhouse gas lifecycle savings of 50%, these assumptions translate into a reduction of emissions from aviation of 10% by 2050 compared to a counterfactual where no biofuels are used.

- Under our **Speculative** scenario we assume that penetration of aviation biofuels reaches 5% by 2030 and 30% by 2050; this scenario is consistent with the high end of the range from the IEA Blue scenarios, and the low end of the range from the E4tech analysis. Assuming greenhouse gas lifecycle savings of 50%, this would translate into reductions in emissions from aviation of around 15% by 2050 compared to a counterfactual where no biofuels are being used.

Figure 5.6 illustrates our scenarios and compares them to the most relevant scenarios from E4tech and IEA. We use these scenarios in our wider analysis of options for meeting the 2050 UK aviation emissions target in Chapter 7.

Figure 5.6 Proportion of biofuel penetration in aviation: CCC scenarios and comparable scenarios from E4tech and IEA



2. Use of hydrogen in aviation

In the next section we outline the technical status and barriers of using hydrogen-fuelled aircraft. Given challenges and uncertainties for using hydrogen in aviation, we do not reflect any possible emissions reduction in our scenarios.

In our December 2008 report we stated that in addition to biofuels, hydrogen was another potential alternative fuel source to kerosene in the longer term. However, we also highlighted significant infrastructure issues, the need for a sustainable source of hydrogen and that the climate effect of water vapour at altitude would need to be investigated more fully. Taking each in turn:

Technical feasibility

Hydrogen-fuelled engines first ran in the 1930s. Since then research has shown the feasibility of civil aircraft powered by liquid hydrogen and manufacturers suggest that one could be developed in the medium term. Last year, the Committee asked QinetiQ to review the potential for hydrogen use in aviation and their key technical findings were as follows:

- Due to the need for civil aircraft to travel at high speed, liquid hydrogen, as opposed to the gaseous form used in airships, at low temperatures and/or under pressure offers the most potential.
- For the aircraft itself, the key issues surrounding liquid hydrogen are storage and reduction of drag; liquid hydrogen needs four times the size of fuel tank to carry the same energy – this requires a bulkier or longer aerodynamic shape.
- The propulsion can be driven by a gas turbine and the modifications required are relatively straightforward.
- One issue for the aircraft is that of safety, especially as the Hindenburg and R101 airship fires remain in the public memory. However from a technical perspective, in the open atmosphere, hydrogen rises quickly and burns below the detonation limit without explosion. It does not form a burning pool and Airbus suggests, in their CRYOPLANE project, that a hydrogen aircraft could be at least as safe as a conventional aircraft. Public perception, however, may remain an issue.

Availability of sustainably produced hydrogen

Notwithstanding the technical issues described above, there are barriers to hydrogen as a sustainably-sourced energy carrier. Currently, commercial production of hydrogen is dominated by the use of fossil fuels without carbon capture and storage (CCS), primarily natural gas, although the use of low-carbon energy sources for hydrogen production is technically proven. However, in most locations these low-carbon resources can be used in other ways to reduce emissions, often by a greater amount, in more mature applications and at lower cost.

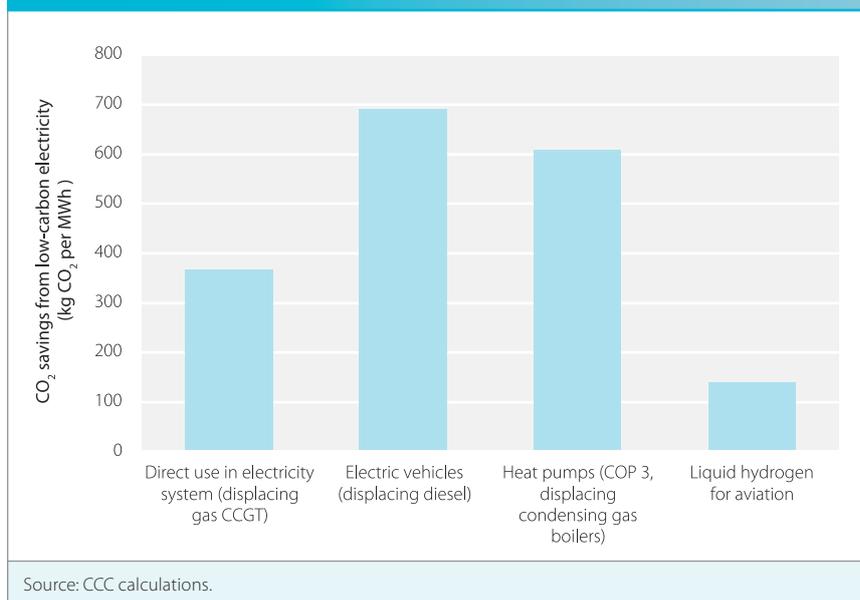
Hydrogen production using low-carbon electricity, via the electrolytic splitting of water, would, in almost all countries in the short to medium-term, reduce emissions by considerably less than the use of the same electricity simply to reduce fossil fuel power generation (see Figure 5.7). There are three main reasons for this:

- i) The extra step of using electricity for hydrogen production involves energy losses of at least 20% that could be avoided by its direct use in the electricity system

ii) Fossil fuel-derived electricity is almost always more carbon-intensive than transport fuels, per unit of energy

iii) The further energy requirement for the liquefaction of the hydrogen for use in aviation would take electricity equivalent to at least a further 30% of the energy content of the hydrogen.

Figure 5.7 CO₂ savings from use of hydrogen produced with low-carbon electricity



Until electricity generation is almost entirely decarbonised, it is difficult to see how electrolytic hydrogen production could be considered genuinely low-carbon. Such levels of electricity decarbonisation are unlikely to occur until 2030 at the earliest in most countries, although there are parts of the world in which 'stranded' renewable electricity resources (i.e. those with limited or no access to an electricity grid) could sensibly be used before then.

The use of biomass for hydrogen production again competes with a variety of other uses, as outlined [in (iii) of section 1], including the production of liquid biofuels.

The most promising medium-term source of low-carbon hydrogen may be the use of fossil fuels with CCS, via processes such as coal gasification and steam methane reforming. Although these processes are mainly being considered as 'pre-combustion' CCS electricity generation options, the production of hydrogen is one of the steps in the generation of electricity within such plants. Indeed, avoiding the subsequent hydrogen combustion step for electricity generation promises significant efficiency advantages in using the hydrogen for transport.

The high energy consumption of the hydrogen liquefaction process will, however, counteract this advantage unless a process with substantially lower energy consumption can be used¹⁰. Furthermore, as CCS has not yet been demonstrated at large scale it is not reasonable to expect significant quantities of low-carbon hydrogen production via this route before 2025 at the earliest.

In addition to the challenge of producing hydrogen sustainably, the introduction of hydrogen-fuelled aircraft poses a significant logistical problem, as either two fuel systems are maintained worldwide, which would be expensive, or a fleet switchover would be required over say five to ten years, which would 'write off' the residual value of any kerosene-powered aircraft.

Climate effects of hydrogen

Hydrogen-fuelled aircraft would not emit any CO₂, the main emission from hydrogen combustion being water. Therefore, sustainably produced hydrogen would for the most part resolve the CO₂ issue, but the water vapour would have significant non-CO₂ climate effects that could well be greater than those from kerosene-powered aircraft:

- The burning of hydrogen generates about 2.6 times as much water as the same energy content in kerosene. Accounting for the additional energy required to lift and propel the bulkier aircraft, this rises to a factor of around 3.
- The greater water content of the exhaust from a hydrogen engine will cause contrails and induced cirrus to form under a wider range of atmospheric conditions. The CRYOPLANE project suggests that cloud cover due to contrails may be up to 50% higher for hydrogen compared to kerosene (see Chapter 6 for a discussion of the relative importance of induced cloudiness and CO₂ on warming).
- It is also possible that a bulkier hydrogen-fuelled aircraft would cruise at higher altitude in order to reduce drag. Water vapour emissions would therefore be delivered into the lower stratosphere, which is very dry. The resulting climate warming effect is estimated to be some 13 times larger than that of CO₂ emissions from a lower flying, kerosene-powered aircraft¹¹.

In conclusion, hydrogen-fuelled aircraft could be and indeed have been built. There are, however, significant technical and logistical barriers including, but not limited to: public perception, sustainably sourcing hydrogen and logistical issues at airports. Even then, the concept should not be pursued until the total climate impacts are more clearly understood.

¹⁰ For example, the pre-cooling of hydrogen via heat exchange with liquefied natural gas (LNG) as outlined in Allam & James (US patent no. 2005/0210914 A1), which is claimed to have the potential to reduce the energy consumption for hydrogen liquefaction by around 70%.

¹¹ See the Royal Commission on Environmental Pollution (2002). *Short Report: The Environmental Effects of Civil Aircraft in Flight*.

Chapter 6

Non-CO₂ climate effects of aviation

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Chapter 6 | Non-CO₂ climate effects of aviation

The report so far has only considered aviation CO₂ emissions. There are, however, potentially significant non-CO₂ effects from aviation which lead to both additional warming and cooling effects on the climate. Overall the consensus is that considered together, these effects have an overall additional warming effect. A comprehensive framework for reducing the climate effects of aviation should account for these non-CO₂ effects. In this chapter we:

- Summarise scientific understanding of aviation non-CO₂ effects;
- Consider at a high level policy options to mitigate these effects;
- Consider possible implications of aviation non-CO₂ effects for UK economy-wide and aviation emissions targets.

The key messages in the chapter are:

- There is high scientific confidence that the total climate warming effect of aviation is more than that from CO₂ emissions alone.
- As scientific understanding develops, aviation non-CO₂ effects are likely to be accounted for in any international framework to address global emissions.
- This could have implications for UK economy-wide and aviation emissions targets, and could require additional emissions reduction effort within aviation.

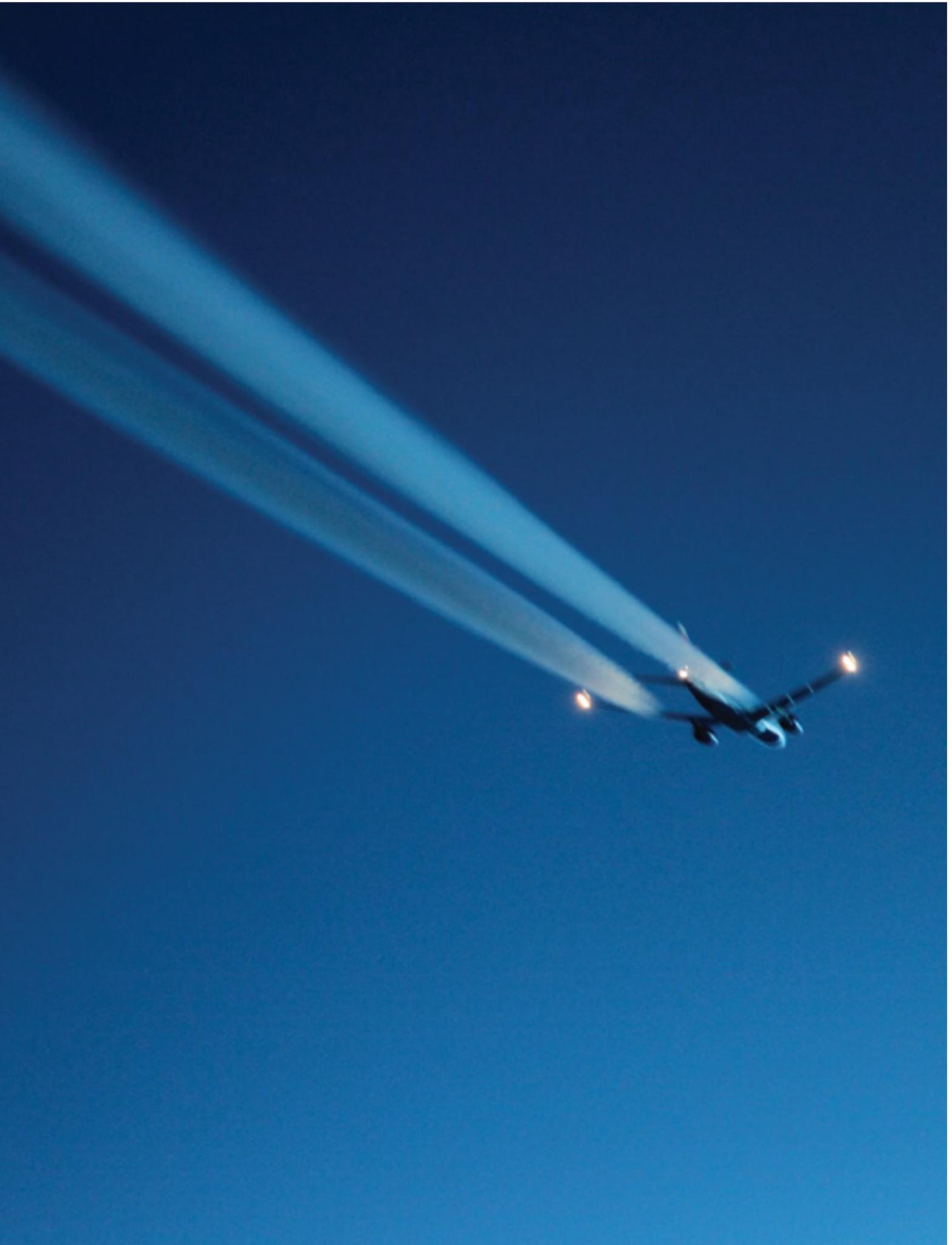
We set out the chapter in three sections:

1. The non-CO₂ effects of aviation
2. Policy options for reducing the non-CO₂ effects of aviation
3. Possible implications of non-CO₂ effects for UK aviation

1. The non-CO₂ effects of aviation

Types of effects

Non-CO₂ climate effects of aviation arise from emissions of gases and particles, and also from induced cloudiness (see Box 6.1):



- **Emission of gases and particles:** Aside from CO₂, combustion of aviation fuel results in emission of water vapour, nitrogen oxides (NO_x) and aerosols. NO_x are indirect Greenhouse Gases (GHGs), in that they do not give rise to a radiative effect themselves, but influence the concentration of other direct GHGs by enhancing ozone (leading to warming) and suppressing methane (leading to cooling). With the exception of sulphate aerosols, all other emissions cause warming.
- **Induced cloudiness:** Depending on meteorological conditions, the flight of aircraft can also cause formation of linear ice clouds (contrails) and can lead to further subsequent aviation-induced cloudiness. These cloud effects cause additional warming.

Box 6.1 Radiative forcing effects of aviation

The overall effect of aviation on climate is currently the subject of active scientific research. Radiative Forcing (RF) is a standard metric used to compare the contribution of changes in individual atmospheric constituents (forcing agents) to the energy imbalance of the earth-atmosphere system since pre-industrial times. Figure B6.1 shows global average RF from global aviation in the year 2005, with positive RF values indicating warming and negative values indicating cooling.

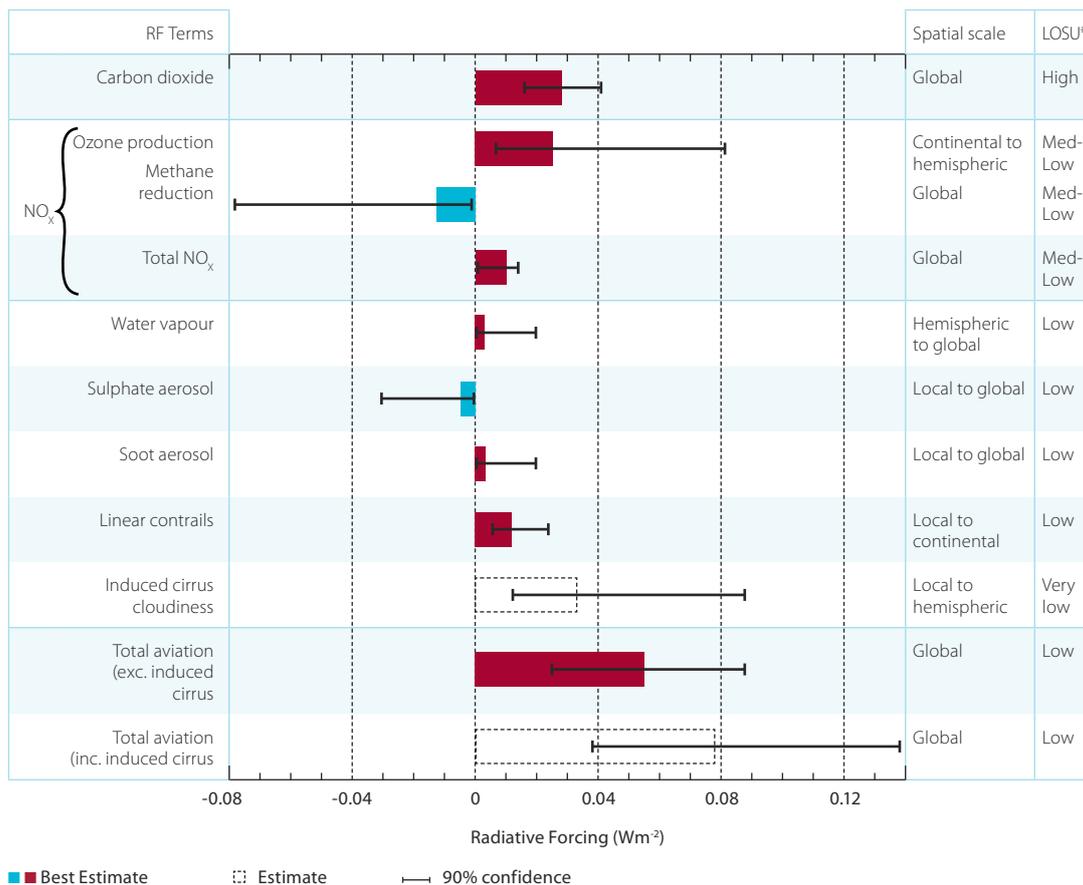
It is important to understand that RF measures the energy imbalance at a given point in time. It is determined in part by the current stock of each forcing agent in the atmosphere, and so depends on the emissions history of that agent and its lifetime. For instance, CO₂ remains in the atmosphere for many centuries, so the CO₂ RF results from the accumulation of emissions since the start of aviation activity. In contrast, contrails only remain for up to several hours, and so the contrail RF is due only to contrails formed by activity in 2005.

RF indicates the current imbalance arising from past activity up until now; it does not give an indication of how current activity will contribute to future climate change. This is because a long-lived forcing agent emitted now will continue to exert RF for much longer than a short-lived agent.



Box 6.1 continued

Figure B6.1 Aviation radiative forcing components in 2005



Source: Reproduced from Lee et al. (2009)¹. Global average radiative forcing (in Watts per square metre, Wm) in the year 2005 from global aviation. Bars are shown for each of the identified aviation effects, with total bars (with and without induced cloudiness) at the bottom. The right hand columns indicate the spatial scales over which these forcing effects operate and the level of scientific understanding (LOSU) regarding each forcing.
Note: *Level of Scientific Understanding

As can be seen from Figure B6.1, aviation to date has given rise to radiative forcing in the following ways:

- Emissions of CO₂ resulting in a positive RF (warming);
- Emissions of NO_x resulting in the formation of tropospheric ozone (O₃) via atmospheric chemistry, with a positive RF (warming);
- Emissions of NO_x resulting in the destruction of ambient methane (CH₄), also via atmospheric chemistry, with a negative RF (cooling). This destruction of CH₄ leads to further, longer-term loss of tropospheric O₃;
- Emissions of water vapour resulting in a positive RF (warming);
- Emissions of sulphate particles arising from sulphur in the fuel resulting in a negative RF (cooling);
- Emissions of soot particles resulting in a positive RF (warming);
- The formation (depending upon atmospheric conditions) of persistent linear contrails, and further induced cloudiness effects, resulting in an overall positive RF effect (warming).

¹ Lee et al. (2009) 'Aviation and global climate in the 21st century'. *Atmospheric Environment*

Issues in quantifying effects

The UNFCCC already has an agreed framework for comparing the relative effects of specific non-CO₂ GHG emissions covered by the Kyoto Protocol (such as methane and nitrous oxide). This makes use of the 100-year Global Warming Potential (GWP) metric to quantify emissions equivalence¹.

For emissions of gases not covered by the Kyoto Protocol (e.g. NO_x) and for other induced changes (i.e. contrails and cirrus), there are additional complications in quantifying emissions equivalence:

- **Scientific uncertainty:** Their radiative effects have poorer levels of scientific understanding than that for CO₂ (Box 6.1), ranging from 'medium-low' for NO_x effects to 'very low' for aircraft-induced cloudiness. Their assessment requires detailed modelling of atmospheric chemistry and of highly uncertain physical processes that affect aerosol abundance and cloud formation.
- **Spatial and temporal variation:** Kyoto GHGs have long lifetimes (on the order of several years or more) allowing them to become well-mixed in the atmosphere and provide a homogeneous global forcing. In contrast, aviation non-CO₂ effects occur on a range of scales from very short-lived and local (e.g. contrails), to long-lived and global (e.g. effect of NO_x on methane).

Metrics

The importance of additional aviation effects on climate has been widely recognised in policy circles². However, there is ongoing discussion about how these effects can best be quantified (Box 6.2).

Box 6.2 Metrics for aviation climate effects

Metrics

Three common metrics are discussed here. They can be grouped into one that measures current effects as a result of past emissions (Radiative Forcing Index) and those that measure future effects arising from present emissions (Global Warming Potential and Global Temperature Potential):

- **Radiative Forcing Index (RFI):** The Radiative Forcing Index (RFI), introduced by the IPCC in their 1999 report¹, describes the relative contribution to radiative forcing (RF, see Box 6.1) of all forcing agents from aviation, compared with that of carbon dioxide alone. RFI is the ratio of the total RF from aviation to the RF from CO₂. Because RF measures the effect of activity to date, rather than the future effect of current activity, the RFI is not an appropriate measure of emissions equivalence.

¹ See Chapter 9, Box 9.1, from our 2008 report *Building a low-carbon economy* for more details on Kyoto GHGs.
² See for instance DFT (2004) *Aviation and Global Warming*.



Box 6.2 continued

- **Global Warming Potential (GWP):** Global Warming Potential (GWP) is designed as an emissions equivalence metric. It measures the total RF accumulated over a given time horizon arising from a unit emission of forcing agent, relative to that of CO₂. A time horizon of 100 years is used for the international reporting of Kyoto GHG emissions. There are certain theoretical difficulties in producing measures of the GWP of the non-CO₂ effects of aviation, particularly in taking into account short-lived effects, and effects that do not relate to emissions in a straightforward way (e.g. the formation of contrails and cirrus cloud coverage only occurs under certain atmospheric conditions). Nevertheless, the GWP is finding some favour as the only current way of formulating a CO₂ emissions-equivalence for aviation's non-CO₂ effects² that is consistent with the current policy framework. It is also important to note that GWP varies with time horizon, even for long-lived greenhouse gases, and that the choice of 100 years is a policy selection rather than a scientific one. The overall GWPs for aviation effects have been assigned a 'very low' level of scientific understanding (Box 6.3) simply because of the uncertainties in the input data to these metrics (i.e. not an uncertainty in the concept of the metric itself) – this is illustrated by an overall aviation NO_x GWP which ranged from -2.1 to +71.
- **Global Temperature Potential (GTP):** The GTP may be considered analogous to the GWP in that it considers the equivalence of a unit release of emissions to that of CO₂. Rather than calculating the ratio of RFs accumulated over a period of time for that agent and CO₂, however, it calculates the ratio of global mean surface temperature responses at some specific future point in time.

Comparing metrics

The RFI is not intended to measure the equivalence of future non-CO₂ effects. The GWP and GTP are both suitable metrics for this purpose, and recent research has produced estimates of aviation effects using both these metrics (Box 6.3). However, the convention remains under the United Nations Framework Convention on Climate Change (UNFCCC) to express non-CO₂ emissions in terms of CO₂-equivalent using the 100-year GWP metric. A recent workshop of the IPCC³ concluded that it would be inappropriate at the current time to propose replacing the GWP with the GTP as more research was required on the GTP's performance and potential applications.

Finally, none of the global measures fully address the likely importance of localised forcing of the climate system. For example, because of its relatively short timescale, the ozone impact of NO_x is limited mainly to the Northern Hemisphere, whereas the longer timescale of its methane effect means that it is global. Even if a global metric were to imply that these two effects offset each other, they may still in fact lead to climate change if one or the other effect dominated in each hemisphere.

1 IPCC (2009), *Aviation and the global atmosphere*. Intergovernmental Panel on Climate Change, Cambridge University Press, UK.

2 See for instance Forster et al. (2007) Corrigendum to 'it is premature to include non-CO₂ effects of aviation in emission trading schemes'. *Atmospheric Environment*; Fuglestedt et al. (2009) Transport Impacts on Atmosphere and Climate: Metrics. *Atmospheric Environment*

3 IPCC (2009), *Summary report of the IPCC expert meeting on the science of alternative metrics* (<http://www.ipcc.ch/meetings/session30/doc13.pdf>).

One approach to quantification has been to use estimates of current radiative forcing of the individual effects relative to that of CO₂ (the Radiative Forcing Index, RFI) as a 'multiplier' of CO₂ emissions to determine future effects. This is now regarded as inappropriate, however (Box 6.2), and more recent estimates based on suitable metrics such as Global Warming Potential and Global Temperature Potential have been proposed (Box 6.3).

Box 6.3 GWP and GTP estimates of aviation climate effects

The recent European Assessment of Transport Impacts on Climate Change and Ozone Depletion (ATTICA, <http://ssa-attica.eu>) was a series of integrated studies investigating atmospheric effects and applicable climate metrics for aviation, shipping and land traffic. Results have been published which provide metrics to compare the different effects across these sectors in an objective way, including estimates of Global Warming Potentials (GWPs) and Global Temperature Potentials (GTPs) over different time horizons (20, 50 and 100 years). Table B6.3 shows the 20-year and 100-year GWPs, plus 100-year GTPs, for each forcing agent from aviation. Based on estimates of fuel usage and emission indices for 2005, the emission equivalent of each agent for these metrics is given on the right, and on the bottom right is the overall ratio of total CO₂-equivalent emissions to CO₂ emissions for aviation in 2005.



Box 6.3 continued

Table B6.3 Findings of ATTICA project

	Metric values			CO ₂ e emissions (MTCO ₂ e/yr) for 2005			LOSU
	GWP ₂₀	GWP ₁₀₀	GTP ₁₀₀	GWP ₂₀	GWP ₁₀₀	GTP ₁₀₀	
CO ₂	1	1	1	641	641	641	High
Low NO _x	120	-2.1	-9.5	106	-1.9	-8.4	Very low
High NO _x	470	71	7.6	415	63	6.7	Very low
Water vapour	0.49	0.14	0.02	123	35	5.0	–
Sulphate	-140	-40	-5.7	-25	-7	-1.0	–
Black carbon	1600	460	64	10	2.8	0.38	–
Contrail	0.74	0.21	0.03	474	135	19	Low
AIC	2.2	0.63	0.089	1410	404	57	Very low
CO ₂ e emissions/CO ₂ emissions for 2005							
Low NO _x , inc. AIC				4.3	1.9	1.1	Very low
High NO _x , inc. AIC				4.8	2.0	1.1	Very low
Low NO _x , exc. AIC				2.1	1.3	1.0	Very low
High NO _x , exc. AIC				2.6	1.4	1.0	Very low

Source: Adapted from Lee et al. (2009)¹. The level of scientific understanding (LOSU) is given for each process in the right column. Values are presented for both high and low GWP values for NO_x reflecting the wide uncertainties in current estimates. The ratios on the bottom right are presented both including and excluding aviation induced cloudiness (AIC) because of uncertainties both in estimates of the magnitude of this effect and in the future incidence of AIC due to air traffic. The different time horizons illustrate how a unit emission of CO₂ increases in importance relative to shorter-lived effects as longer timescales are considered.

¹ Lee et al (2009) Transport impacts on atmosphere and climate; Aviation, *Atmospheric Environment*

The results in Box 6.3 show that the non-CO₂ radiative effects arising from current aviation activity are significant, even when looking over relatively long time horizons. Following the UNFCCC by using 100-year GWPs, the total effect could be up to two times greater than that from CO₂ emission alone; we use these GWPs to illustrate possible implications of aviation non-CO₂ effects for UK emissions targets in section 3 below. We first consider options for reducing the non-CO₂ effects of aviation.

2. Policy options for reducing the non-CO₂ effects of aviation

Demand reduction (e.g. through response to a carbon price, modal shift or increased use of videoconferencing) or controlling fuel burn via Air Traffic Management and operations efficiency improvements could help limit non-CO₂ effects of aviation, as well as CO₂ emissions.

However, other efficiency measures and use of biofuels would not reduce and, in some specific cases, could increase non-CO₂ effects:

- There is an eventual trade-off in engine design and operation between reducing CO₂ and NO_x emissions, i.e. decreasing CO₂ emissions may lead to increased NO_x emissions and vice versa.
- Increased fuel efficiency of planes – through more efficient engines or better aerodynamic design – reduces CO₂ emissions but is unlikely to fully address effects from contrails and induced cloudiness.
- It is likely that the use of biofuels in aviation will have broadly comparable non-CO₂ tailpipe effects to those from conventional kerosene, although there is some uncertainty over this and research is required to provide definitive answers as to whether these are greater, lesser or equivalent.

There are options that could possibly mitigate aviation non-CO₂ effects:

- Engine design to further reduce NO_x emissions (notwithstanding the trade-off highlighted above).
- Airframe design to reduce contrails and induced cloudiness.
- Air Traffic Management options to avoid areas in which contrails and cloudiness may occur. Greater scientific understanding of cloud radiative effects will indicate whether these route changes would be a worthwhile trade-off against the increased CO₂ emission that could arise.

Given possible trade-offs between CO₂ emissions and non-CO₂ effects, it would **not** be appropriate to adopt a policy based around reducing CO₂ emissions only (e.g. cap and trade with non-CO₂ effects included on the basis of a CO₂ multiplier); this could result, for example, in reduced CO₂ emissions and increased non-CO₂ effects, rather than finding an appropriate balance between CO₂ emissions and non-CO₂ effects.

In order to address non-CO₂ effects therefore, flanking instruments could in principle be introduced to complement capping of aviation CO₂ emissions. For example:

- The European Commission has scoped a scheme of NO_x landing and en-route charges as well as NO_x cruise certification that would provide incentives for reduction of NO_x emissions beyond existing regulations.



- As systems for atmospheric monitoring improve, it is plausible that aircraft could be rerouted under or around areas of potential cloud formation.

Further consideration is required, however, before introduction of these options would become practical, particularly as regards contrails and cirrus, where more research is required to understand these effects properly and develop operational methods to reduce them.

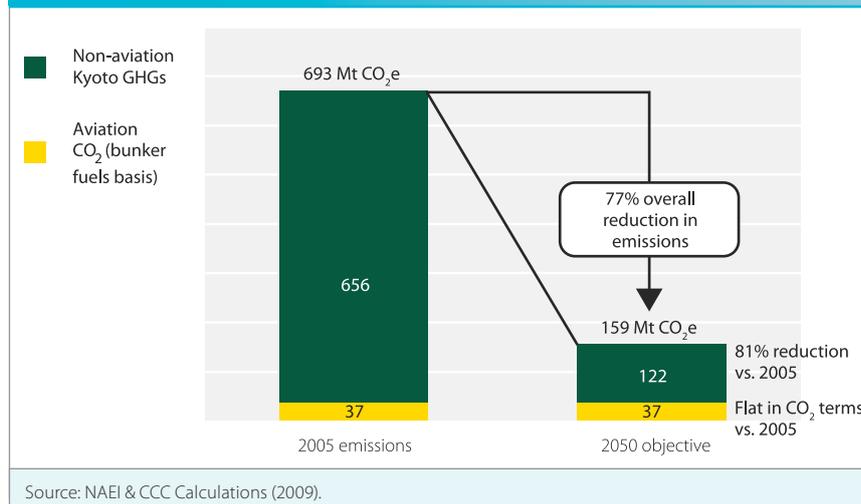
3. Possible implications of non-CO₂ effects for UK aviation

The Kyoto Protocol covers the major long-lived GHGs: carbon dioxide (CO₂), nitrous oxide (N₂O), methane (CH₄), sulphur hexafluoride (SF₆) and other fluorinated gases (HFCs and PFCs). Under the Climate Change Act, the UK's framework is consistent with the Kyoto Protocol and therefore does not include aviation non-CO₂ effects as they do not derive directly from emissions of the Kyoto gases.

Accordingly, the Committee's December 2008 advice to Government on the economy-wide 2050 target did not reflect or include aviation non-CO₂ effects, although it did highlight them as an issue. The current long-term target requires that Kyoto GHG emissions should fall from 693 MtCO₂e in 2005 to 159 MtCO₂e in 2050 (80% below 1990 levels), with the possibility of further reductions depending on new scientific evidence; this advice was accepted by Government.

The Committee presented a scenario in its 2008 report that would achieve this 2050 target, with aviation CO₂ emissions not exceeding approximately 2005 levels and cuts of 90% relative to 1990 across all other CO₂ emitting sectors (Figure 6.1). This scenario is broadly consistent with the Government's January 2009 target to reduce UK aviation CO₂ emissions back to 2005 levels in 2050 (i.e. 37.5 MtCO₂).

Figure 6.1 UK emissions in 2005 and target for 2050 as recommended in the CCC's 2008 report, showing contribution from aviation CO₂



In our letter to the Government on international aviation in September 2009, we argued that:

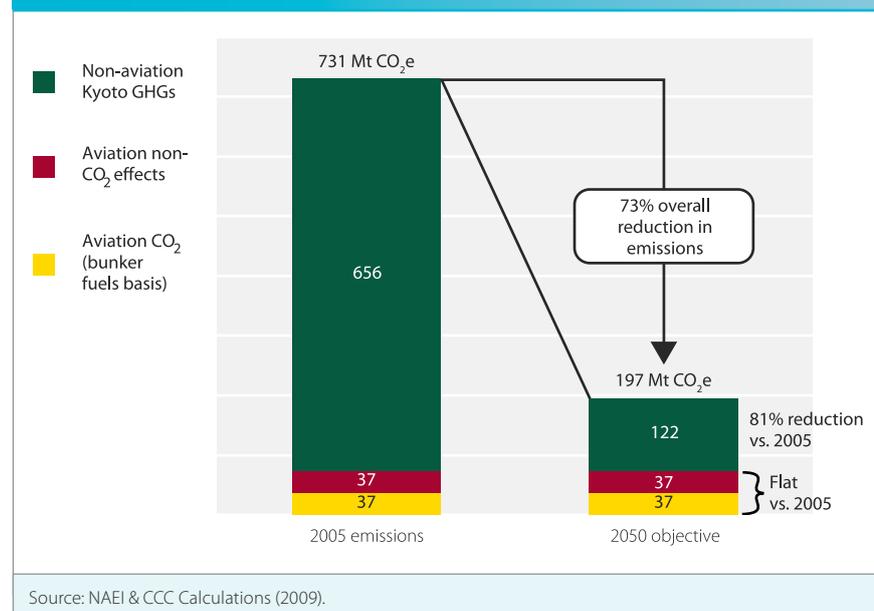
Non-CO₂ effects of aviation must be addressed as part of any international framework through commitment to a schedule for introduction of appropriate policy instruments (e.g. covering NO_x, cirrus and contrails).

More generally, as scientific understanding develops, and to the extent that this confirms the significant additional warming from aviation non-CO₂ effects, it is very likely that these will become fully accounted for in the international framework for limiting climate impacts. We now illustrate the consequences of reflecting the non-CO₂ effects of aviation directly in the UK's targets, based on the GWP estimates in Box 6.3.

Assuming that the total emissions equivalence of aviation in 2005 was two times greater than that from CO₂ emissions alone, and that there is no mitigation of aviation non-CO₂ effects going forward, including this at the UK level would change both historic and projected emissions (Figure 6.2):

- 2005 total UK emissions would become 731 MtCO₂e and aviation emissions 75 MtCO₂e.
- In 2050, achieving the 159 MtCO₂e target as defined under the Climate Change Act would actually result in emissions equivalent to 197 MtCO₂e including aviation non-CO₂ effects.

Figure 6.2 Illustrative addition of aviation non-CO₂ effects onto 2005 emissions and the 2050 target for the UK





Assuming instead that the level of allowable UK CO₂-equivalent emissions in 2050 holds (i.e. remains 159 MtCO₂e even if aviation non-CO₂ effects are included), there would be three options for addressing the impact of aviation non-CO₂ effects:

- Reducing allowed emissions in aviation from 75 MtCO₂e including non-CO₂ effects (i.e. below 2005 levels), see Figure 6.3a.
- Reducing allowed emissions in other sectors from 122 MtCO₂e (i.e. below what we had previously envisaged would be appropriate), see Figure 6.3b.
- A combination of the two above.

Figure 6.3a Illustrative inclusion of aviation non-CO₂ effects with all of the additional reduction effort made in aviation CO₂-equivalent emissions

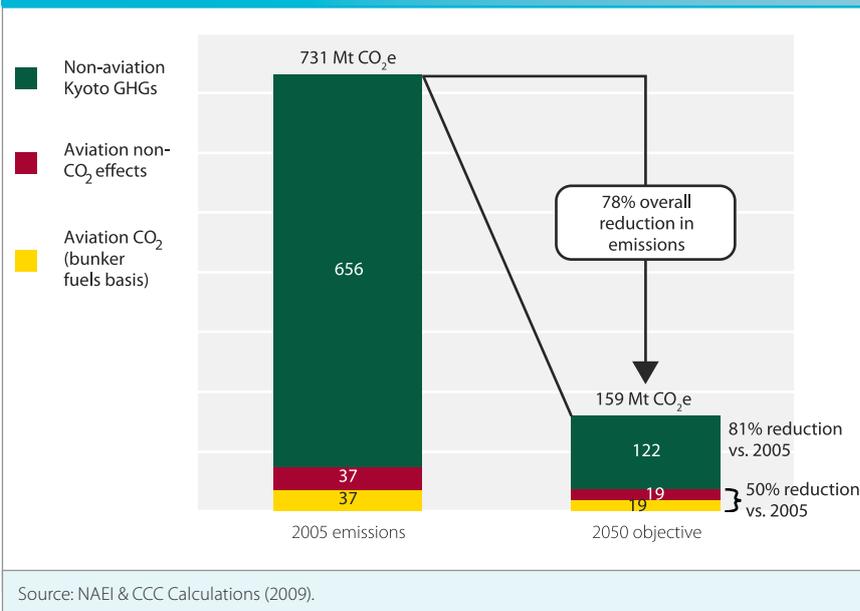
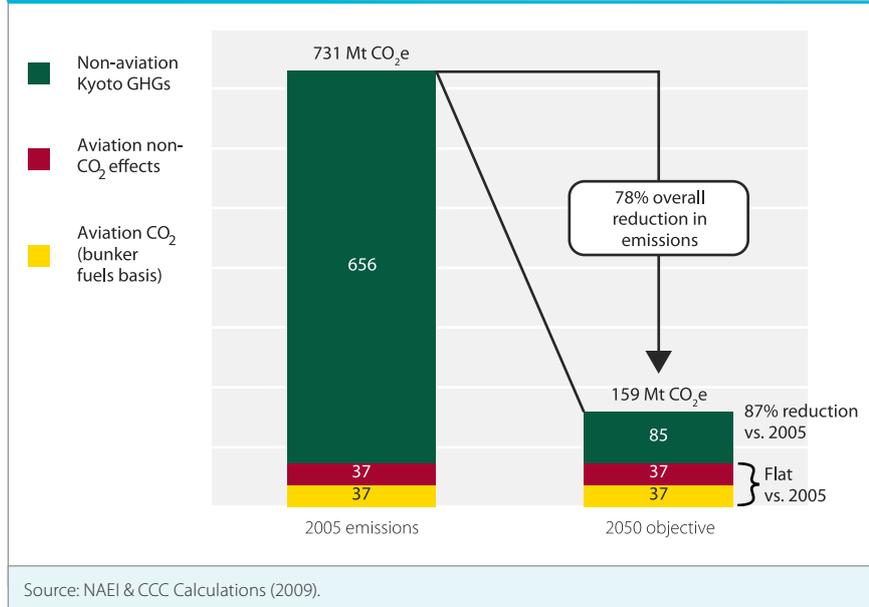


Figure 6.3b Illustrative inclusion of aviation non-CO₂ effects with all of the additional reduction effort made in emissions from other UK sectors



The balance between these options would require detailed analysis of the scope for, and cost of, further emissions reductions in aviation versus other sectors. It is reasonable to assume, however, that some additional emissions reduction effort would be required in aviation.

The Committee is not recommending that the UK aviation target should currently be redefined to include non-CO₂ effects. However, recognising that aviation non-CO₂ effects are likely to become accounted for in any international framework in decades to come, Chapter 7 considers at a high level possible implications for UK aviation expansion in the 2020s.

Chapter 7

Meeting the 2050 aviation target

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This chapter brings together the analysis in Chapters 1 to 5 and sets out emissions scenarios under alternative assumptions about demand-side factors, improvement in fleet fuel efficiency, and use of sustainable biofuels.

The scenarios are built in the following way:

- **Demand assumptions:** We start with emissions projections reflecting different assumptions on the extent of demand response to carbon prices, modal shift from domestic/short-haul aviation to rail/high-speed rail and reduction in the need for travel through videoconferencing.
- **Fleet efficiency assumptions:** We then overlay alternative assumptions about improvement in fleet fuel efficiency from engine/airframe and Air Traffic Management (ATM) and operations; scenario assumptions on aircraft efficiency differ as regards the pace of innovation.
- **Biofuels assumptions:** We next consider emissions projections which overlay different levels of biofuels penetration onto scenarios for demand-side measures and improvement in fleet fuel efficiency. We model a range of scenarios from 10% to 30% penetration in 2050, on an assumption that lifecycle emissions reductions would be 50%.

We develop three sets of scenarios:

- **Likely scenario:** This reflects demand reductions and carbon intensity reductions likely to be achieved given current policies, investment levels and the pace of technological advance.
- **Optimistic scenario:** This would require both:
 - A significant shift from current policy (e.g. in respect to high-speed rail), and an increase in the level of investment in new aircraft technologies and/or in the pace of fleet renewal as well as improvements in ATM and operations so as to make a 1.0% per annum improvement in carbon efficiency attainable.
 - Progress of biofuel technologies which would make it reasonable to assume that a 20% penetration was compatible with sustainability.
- **Speculative scenario:** This would require both technological breakthroughs and a significant increase in the pace of aircraft fuel efficiency



improvements. In addition, it would require the development of sustainable biofuels which are currently speculative (e.g. biofuels from algae), or an evolution of global population, food demand and agricultural productivity which would make possible the sustainable and large scale use of current agricultural land and water to grow biofuel feedstocks. These developments are assessed today as very unlikely.

We reflect the full range of uncertainty by considering various combinations from these sets of scenarios. In particular, we overlay alternative assumptions about biofuels penetration across each of the scenarios for improvement in fleet fuel efficiency. We then define three core scenarios which combine Likely, Optimistic and Speculative assumptions across each of the options. We consider any gap between projected emissions under these scenarios and the 2050 target, and options for addressing this.

The key messages in this chapter are:

- In our Likely scenario, we assume fleet efficiency improvement of 0.8% annually and biofuels penetration of 10% in 2050. Together these would allow meeting the target with demand growth of around 60% in the period to 2050 (e.g. compared to unconstrained demand growth of over 200%). Demand growth based on planned capacity expansion, with demand response to the carbon price and opportunities for modal shift could be around 115%. Explicit constraints on demand growth in addition to the carbon price would therefore be required to meet the 2050 target.
- There are scenarios with a faster pace of fleet efficiency improvement and higher levels of biofuels penetration where the target is achieved without the need for explicit constraints on demand growth. However, unless and until new evidence is available that the pace of fleet fuel efficiency and the level of sustainable biofuels may be higher than currently envisaged, it is prudent to plan for a world where explicit constraints on demand growth are required to meet the target.
- There are no clear implications of our analysis for specific airports (e.g. Heathrow). The key implication for aviation expansion is that whatever the pattern of capacity development, this should be consistent with constraining demand growth in 2050 to around 60% on 2005 levels if the target is to be achieved.

We set out the analysis that underpins these messages in four sections:

1. Emissions projections including demand response to the carbon price, modal shift, and videoconferencing
2. The impact of improvement in fleet fuel efficiency on emissions
3. Emissions projections including biofuels
4. Options for meeting the 2050 target: planning for demand growth constraint



1. Emissions projections including demand response to the carbon price, modal shift, and videoconferencing

Unconstrained demand growth

We first consider demand response in a context where demand growth is not constrained by runway capacity and where therefore there are further additions to runway capacity beyond what is envisaged in the 2003 Air Transport White Paper (i.e. Heathrow, Stansted, Edinburgh) as required to meet a growing demand.

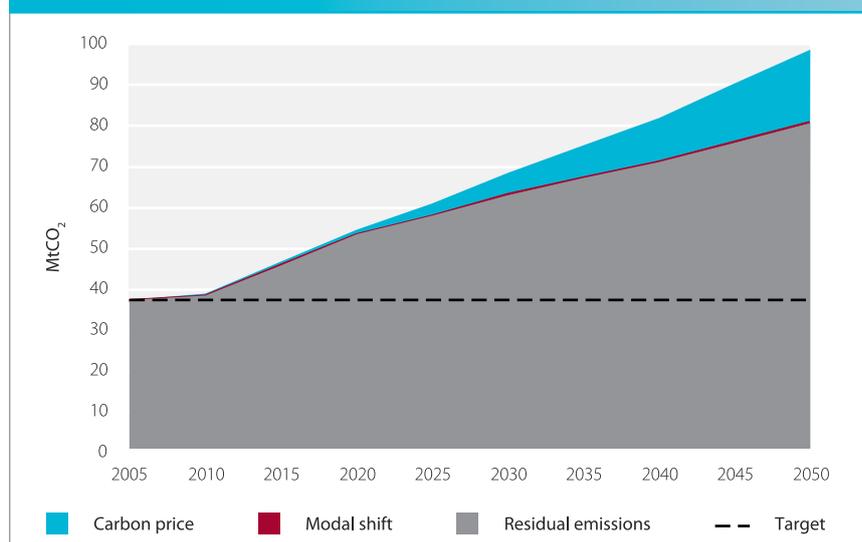
In Chapters 2 and 3 we set out three scenarios for demand response to the carbon price, modal shift and videoconferencing:

- Our **Likely** scenario assumptions result in modal shift equivalent to reducing air demand by 1% of passengers and 2% ATMs in 2050. We assume that videoconferencing has no net impact on aviation demand.
- Our **Optimistic** scenario modal shift and videoconferencing assumptions result in a reduction equivalent to reducing air demand by 7% of passengers and 10% of ATMs in 2050.
- Our **Speculative** scenario modal shift and videoconferencing assumptions result in a reduction equivalent to reducing air demand by 16% of passengers and 19% of ATMs in 2050.

We now overlay these scenarios for demand response to the reference emissions projection for unconstrained demand growth. Emissions projections net of demand response range from 74 MtCO₂ to 81 MtCO₂ in 2050:

- In the Likely scenario, the demand response due to the carbon price results in an emissions reduction of just under 18 MtCO₂ in 2050 from the reference case, with a small additional reduction due to modal shift (Figure 7.1).

Figure 7.1 Likely scenario: demand response with unconstrained runway capacity



Source: CCC modelling.

- In the Optimistic scenario, modal shift and videoconferencing result in a further reduction of just over 2 MtCO₂ beyond the carbon price impact (Figure 7.2).
- In the Speculative scenario, modal shift and videoconferencing result in a further reduction of 7 MtCO₂ beyond the carbon price impact (Figure 7.3).

In none of the scenarios, therefore, does demand response alone result in achieving the 2050 target.

Figure 7.2 Optimistic scenario: demand response with unconstrained runway capacity

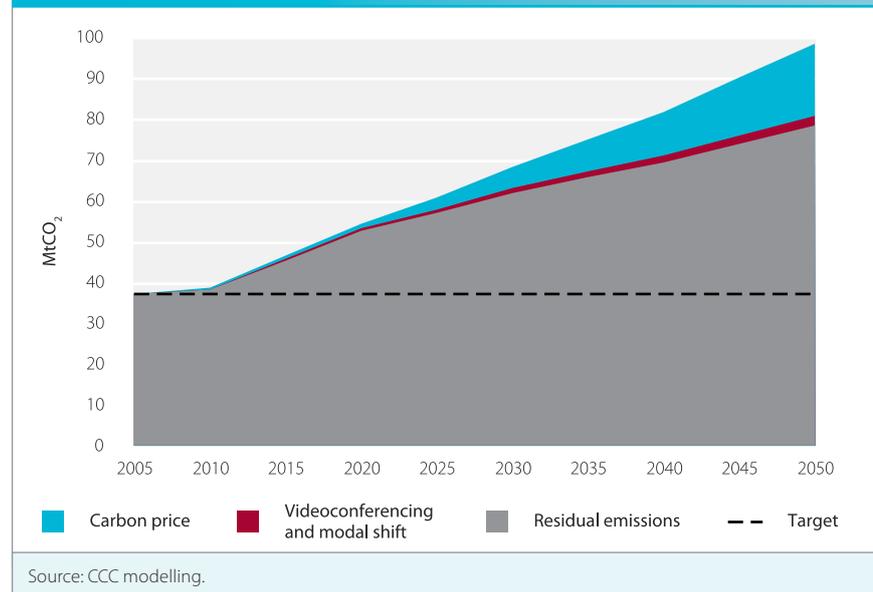
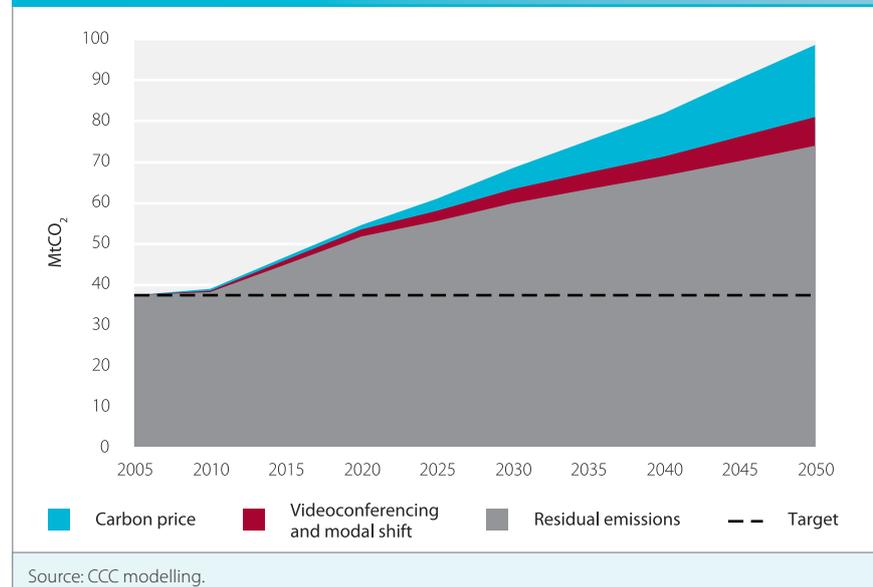


Figure 7.3 Speculative scenario: demand response with unconstrained runway capacity





Demand growth with planned capacity expansion

The DfT modelling approach assumes that no capacity is added beyond that envisaged in the 2003 Air Transport White Paper. There are two implications of this assumption for emissions projections:

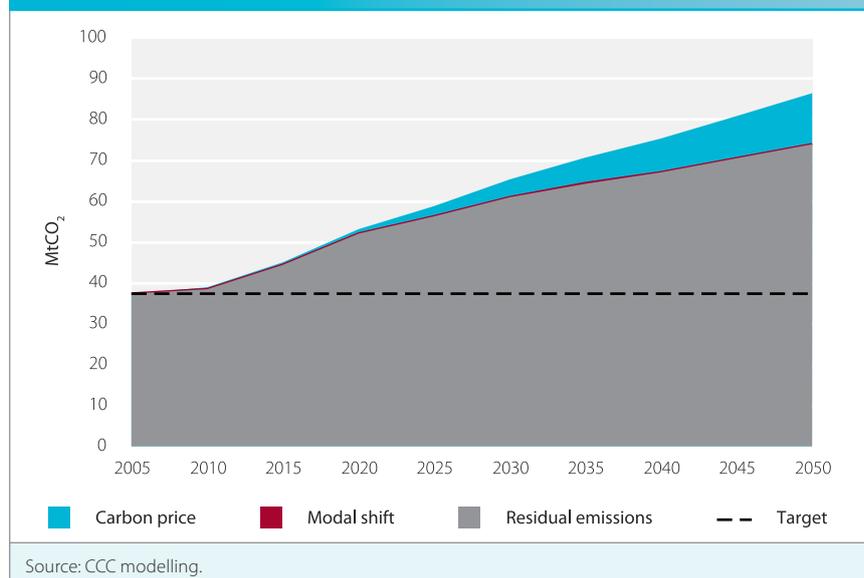
- The reference emissions projection is lower than in the case of unconstrained demand growth (e.g. by around 12 MtCO₂ in 2050).
- The emissions reductions due to modal shift and videoconferencing fall. The reason for this is that where the system operates at capacity, modal shift and videoconferencing free up slots which can therefore be used to meet suppressed demand.

When overlaying scenarios for demand responses to the carbon price, modal shift and videoconferencing, emissions projections in a scenario with only planned capacity additions range from 70 MtCO₂ to 74 MtCO₂ in 2050:

- In the Likely scenario, the demand response due to the carbon price results in an emissions reduction of 13 MtCO₂ in 2050 from the reference case, with a negligible further reduction due to modal shift (Figure 7.4).
- In the Optimistic scenario, modal shift and videoconferencing together result in a further reduction of 1 MtCO₂ beyond the carbon price impact.
- In the Speculative scenario, modal shift and videoconferencing together result in a further reduction of 4 MtCO₂ beyond the carbon price impact.

Demand response alone is therefore still not sufficient to achieve the 2050 target even in a system with capacity constraints; we follow DfT and model a system with planned capacity constraints as envisaged in the 2003 Air Transport White Paper in the remainder of this chapter.

Figure 7.4 Likely scenario: demand response with planned runway capacity



2. The impact of improvement in fleet fuel efficiency on emissions

In Chapter 4 we set out three scenarios for improved fleet efficiency through engine and airframe innovation, air traffic management and operations:

- Our **Likely** scenario reflects annual improvement in fleet average fuel efficiency between 2005 and 2050 of 0.8% per year on a seat-km basis.
- Our **Optimistic** scenario reflects annual improvement in fleet average fuel efficiency between 2005 and 2050 of 1.0% per year on a seat-km basis.
- Our **Speculative** scenario reflects annual improvement in fleet average fuel efficiency of 1.5% per year on a seat-km basis.

We now overlay emissions reductions corresponding to these scenarios onto the emissions projections including demand response to carbon prices/ modal shift/videoconferencing in Section 1 above:

- With Likely efficiency improvements and Likely demand response, emissions are above allowed aviation emissions in the period to 2050, and around 13 MtCO₂ above the 2050 target (Figure 7.5).
- With Optimistic efficiency improvement and Optimistic demand response, emissions are around 8 MtCO₂ above the 2050 target (Figure 7.6).
- With Speculative efficiency improvement and Speculative demand response, emissions are around 1 MtCO₂ below the 2050 target (Figure 7.7).

The 2050 target is therefore only achieved in the Speculative efficiency improvement scenario, and not in the Likely or Optimistic scenarios.

Figure 7.5 Likely scenario: impact of fuel efficiency improvements

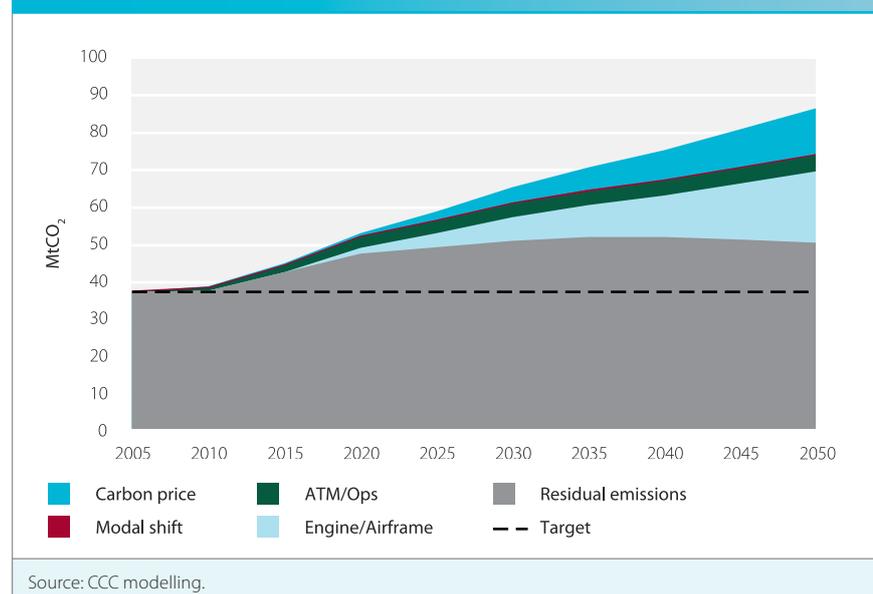




Figure 7.6 Optimistic scenario: impact of fuel efficiency improvements

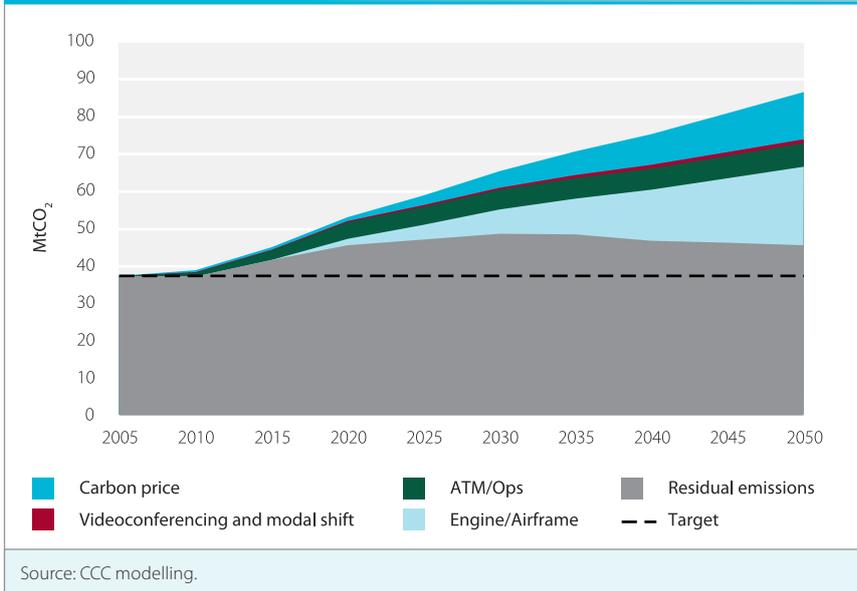
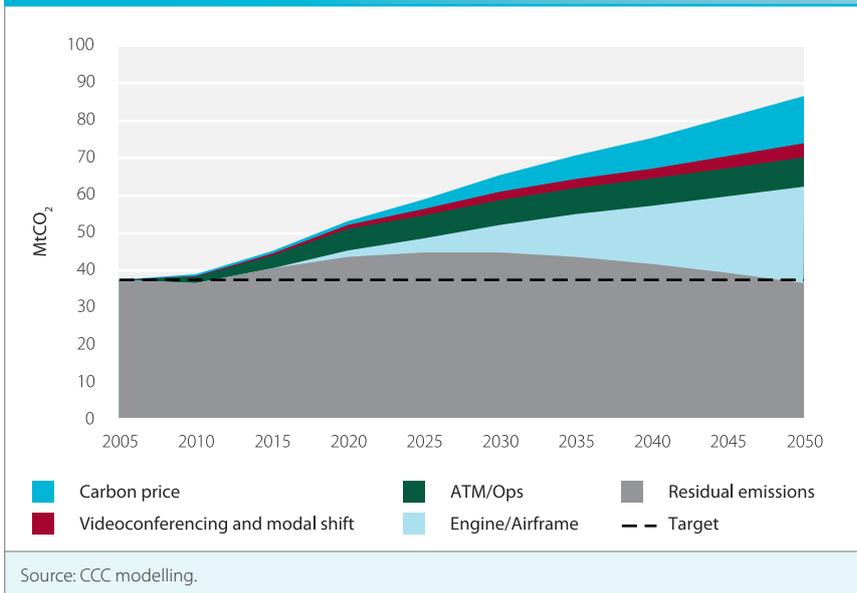


Figure 7.7 Speculative scenario: impact of fuel efficiency improvements



3. Emissions projections including biofuels

Scenario assumptions

The next step is to overlay scenarios for biofuels penetration across the scenarios in section 2 above. In Chapter 5, we set out three scenarios for increased biofuels penetration, in each of which we assume a 50% lifecycle emissions reduction:

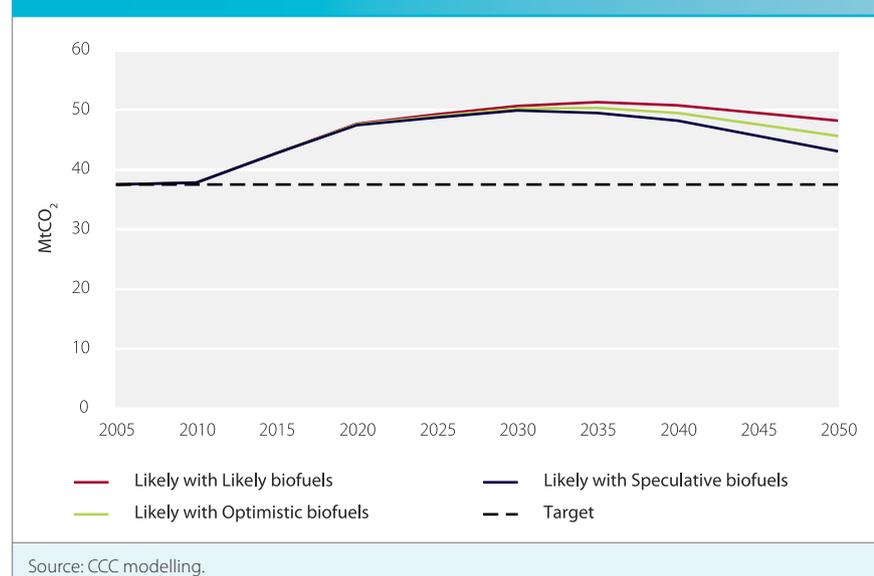
- Under our **Likely** scenario we assume that penetration of biofuels is below 2% in 2030 and reaches 10% by 2050.
- Under our **Optimistic** scenario we assume that penetration of biofuels reaches around 3% by 2030 and 20% by 2050.
- Under our **Speculative** scenario we assume that penetration of biofuels reaches 5% in 2030 and 30% by 2050.

Emissions projections including the impact of biofuels

Combining scenarios for biofuel penetration with the demand responses and fleet efficiency improvement scenarios presented above in Sections 1 and 2 gives the following results for the core set of scenarios:

- The Likely scenario (including Likely demand response, efficiency improvement and biofuels penetration) gives emissions that are 11 MtCO₂ above the 2050 target (Figure 7.8). Triggering the Optimistic and the Speculative scenarios for biofuels on top of Likely scenarios for the other wedges would leave a gap of 8 MtCO₂ and 6 MtCO₂ respectively.
- The Optimistic scenario (including Optimistic demand response, efficiency improvement and biofuels penetration) gives emissions that are around 4 MtCO₂ above the 2050 target (Figure 7.9). Triggering the Speculative scenarios for biofuels on top of Optimistic scenarios for the other wedges would still leave a small gap of 1 MtCO₂.

Figure 7.8 Likely scenario: impact of alternative biofuels assumptions





- The Speculative scenario (including Speculative demand response, efficiency improvement and biofuels penetration) gives emissions reductions that are around 6 MtCO₂ below the 2050 target (Figure 7.10). The target would still be exceeded by around 3 MtCO₂ when overlaying the Likely biofuels scenario on top of the Speculative wedges.

Figure 7.9 Optimistic scenario: impact of alternative biofuels assumptions

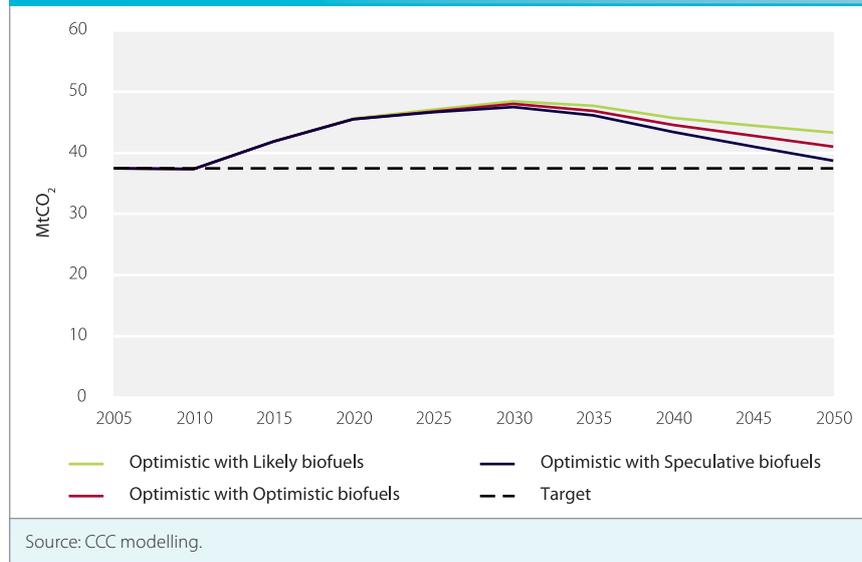
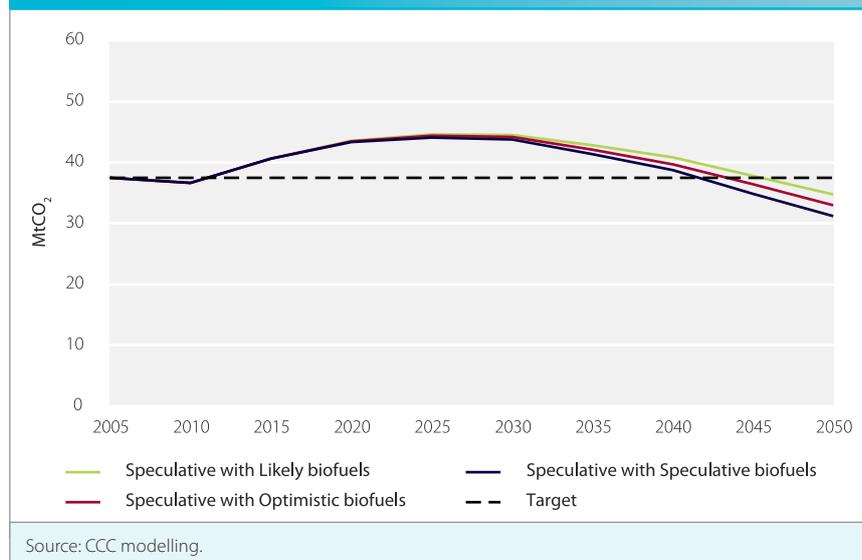


Figure 7.10 Speculative scenario: impact of alternative biofuels assumptions



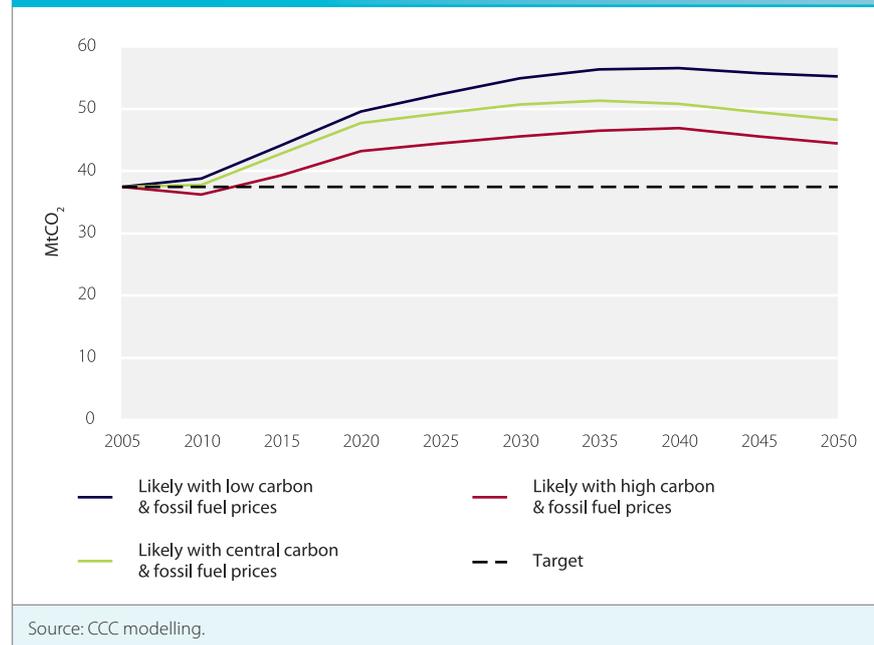
Demand sensitivities: alternative assumptions on fossil fuel and carbon prices

Having looked at sensitivity incorporating a range of biofuels assumptions across different scenarios we now look at the sensitivity of the full Likely scenario (i.e. with Likely biofuels assumptions) to carbon and fossil fuel prices. The Likely scenario with demand sensitivities for low fossil fuel prices and low carbon prices gives emissions that are 18 MtCO₂ above the target, and 7 MtCO₂ above the target with high fossil fuel prices and high carbon prices (Figure 7.11); demand reduction due to high fossil fuel and carbon prices is therefore not sufficiently high to achieve the target.

Summary of biofuels scenarios and sensitivities

The 2050 target is only achieved in those scenarios which combine significant demand-side responses and ambitious efficiency improvements with a significant level of biofuels penetration.

Figure 7.11 Likely scenario: sensitivity to low and high carbon and fossil fuel prices





4. Options for meeting the 2050 target: planning for demand growth constraint

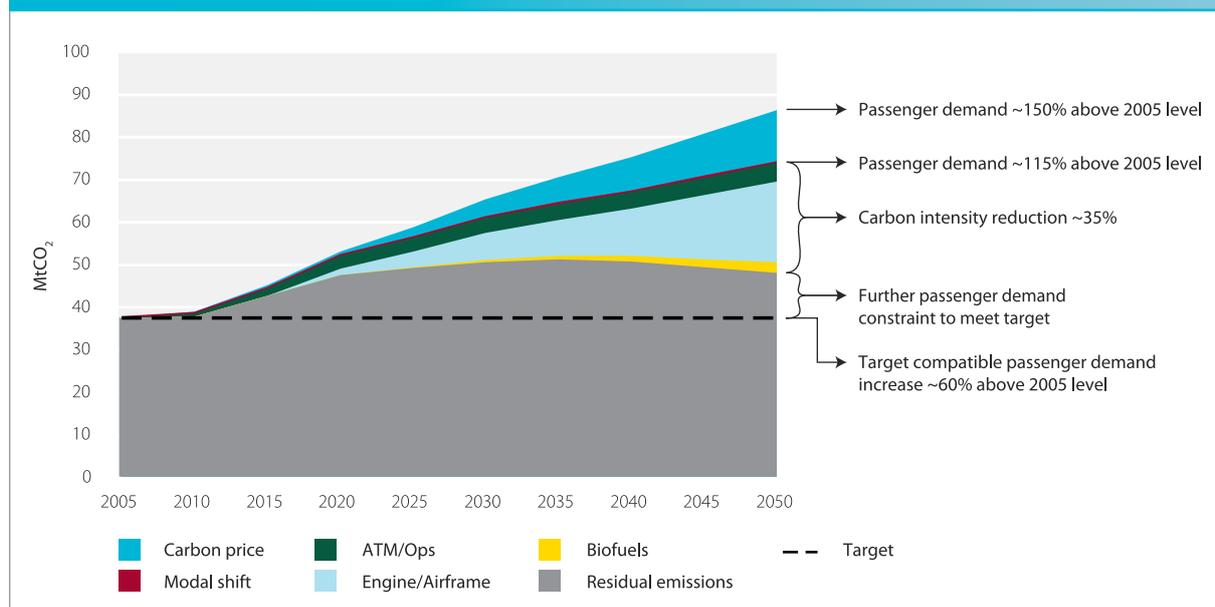
Meeting the target in the Likely scenario

In our Likely scenario we assume annual improvements in fleet fuel efficiency of 0.8% together with 10% biofuels penetration in 2050. This combination of improvement in fleet fuel efficiency and biofuels penetration implies a carbon intensity reduction of around 35% in 2050 relative to the reference projection (Figure ES.6). As a result, an increase in ATMs of around 55% relative to 2005 levels would be compatible with the target of ensuring that 2050 CO₂ emissions did not exceed the 2005 level of 37.5 MtCO₂. Given increasing load factors over time, an increase in passengers of around 60% on 2005 levels by 2050 would be possible, taking total annual passenger numbers from 230 million to around 370 million. This would be equivalent to taking total passenger trips (one departure plus one arrival) from 115 million in 2005 to around 185 million in 2050.

This target-compatible demand growth of around 60% compares with the growth of over 200% which might result in a world where there were no capacity constraints and no carbon price.

On the demand side, however, the Likely scenario incorporates the future capacity limits assumed by the 2003 Air Transport White Paper. It also allows for the impact of carbon price in line with our central projections (rising gradually to around £200/tCO₂ by 2050), and for some modal shift to conventional rail. These assumptions generate a demand growth of 115% relative to current levels by 2050.

Figure 7.12 Likely scenario (planned capacity)



Source: CCC modelling.

Meeting the 2050 target that CO₂ emissions are no higher than 37.5 MtCO₂ is therefore likely to require policy measures to restrain demand which go beyond our central projected carbon price. The policy instruments which could achieve this restraint include a carbon tax on top of the forecast carbon price, limits to further airport expansion, and restrictions on the allocation of take-off and landing slots even where airports have the theoretical capacity available.

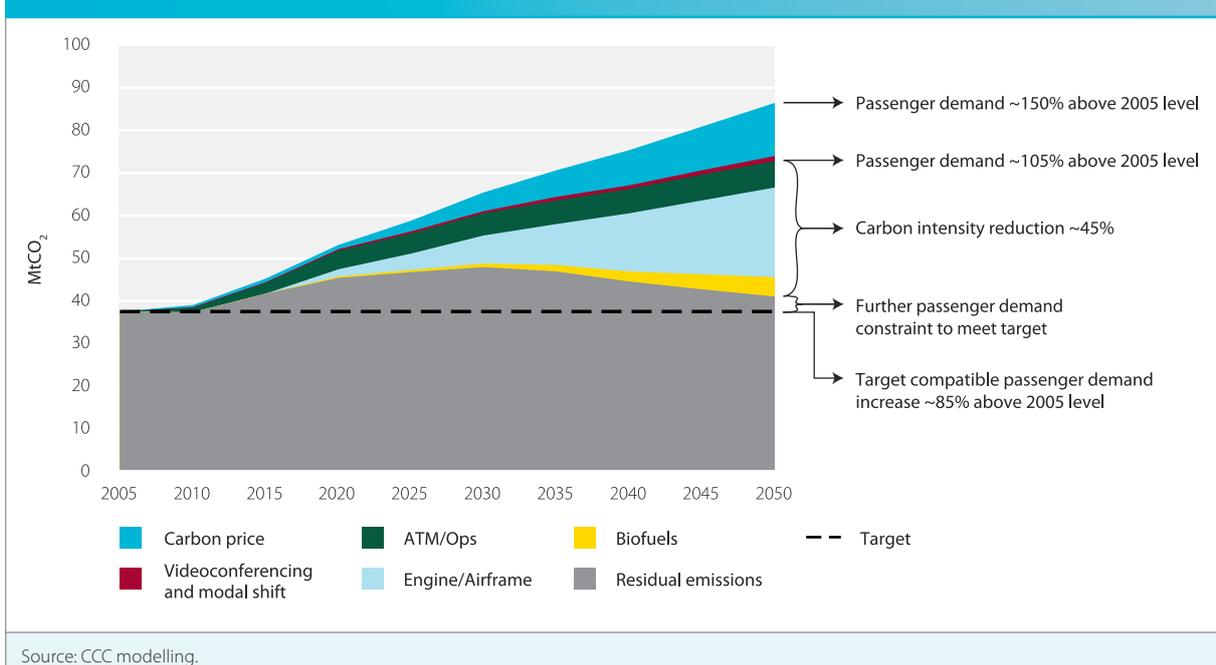
Meeting the target in other scenarios

In the *Optimistic* scenario, we assume 1.0% annual improvement in fleet fuel efficiency and 20% biofuels penetration in 2050. This combination of improvement in fleet fuel efficiency and biofuels penetration implies a carbon intensity reduction of around 45% in 2050. As a result, it would be possible to increase ATMs by around 80% and passenger numbers by around 85% and still meet the target that CO₂ emissions should not exceed 37.5 MtCO₂ in 2050 (Figure 7.13). Passenger trips (one departure plus one arrival) could increase from 115 million in 2005 to around 215 million in 2050.

Given demand growth under this scenario of 115%, meeting the target would still require additional policy measures to constrain demand beyond those implied by the 2003 Air Transport White Paper and the central carbon price projection. But these additional measures would not need to be as restrictive as in the Likely scenario.

In the *Speculative* scenario, we assume annual improvement in fleet fuel efficiency 1.5% and biofuels penetration of 30% in 2050. The implied carbon intensity reduction is around 55% by 2050. This would make an increase in ATMs of around 125% and of passengers of around 135% compatible with

Figure 7.13 Optimistic scenario (planned capacity)





meeting the target. The combination of already planned capacity limits, the demand response to the projected carbon price and opportunities for modal shift and videoconferencing, would produce a demand increase below this 135%. No additional policy measures would therefore be required to meet the target (Figure 7.14).

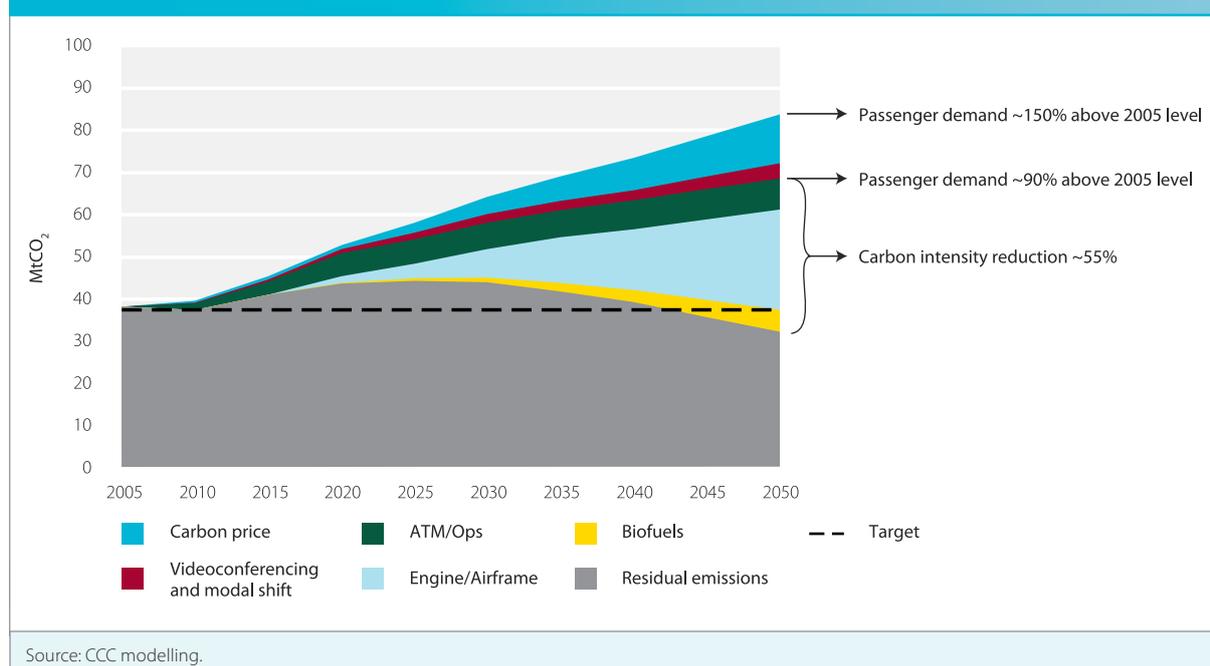
It should be noted however that even in this scenario the maximum demand increase compatible with the target (135% increase in passengers) is much lower than the increase which our projections suggest would occur in a world of no constraints (i.e. with no carbon price and unlimited airport expansion).

The high growth in aviation demand which would occur in an unconstrained environment illustrates the high value which people place on the opportunity to fly, in particular for leisure purposes. If the Optimistic or Speculative scenarios can be achieved, the number of flights compatible with meeting the 37.5 MtCO₂ target increases.

In considering the difference between scenarios, three aspects should be distinguished:

- Achieving greater modal shift to rail and greater use of videoconferencing does not increase the total target-compatible level of demand, but it makes it possible for more of that total to be devoted to other uses (e.g. long-haul leisure) where there are no alternatives to air travel. Investing in a new high-speed rail line and promoting full integration of UK and European high-speed networks can increase the potential for modal shift. Promotion of videoconferencing technologies could ensure higher levels of business travel substitution.

Figure 7.14 Speculative scenario (planned capacity)



- Achieving more rapid fuel efficiency improvements directly increases target-compatible demand growth. It could be fostered through increasing investment in R&D, introducing regulatory limits on new aircraft CO₂ performance, exploring possible benefits from early scrappage of older aircrafts, and full implementation of SESAR and NATS initiatives on ATM efficiency improvement.
- The higher the percentage of biofuels use which can be considered sustainable the greater the target-compatible demand increase. Here however it is not clear that higher investment will necessarily drive more rapid improvement, since there is inherent uncertainty about what progress can be achieved, and about the implications of population growth and food demand for land use. We therefore need to observe through time the development of speculative technologies, and trends in agricultural productivity and land availability. Governments could however encourage investment in those technologies most likely to be sustainable. And expanded use of biofuels will need to be underpinned by a global policy framework to mitigate the risks of harmful land-use changes resulting from the growth of biofuel feedstocks.

Several of these developments which might make possible more rapid demand increases than in the Likely scenario are ones over which the UK acting alone has only small influence. EU or broader international action would be required to accelerate the pace of improvement of fleet fuel efficiency and international action would be required to develop a framework to mitigate against risks of indirect land use impacts from biofuels.

The prudent assumption on which to base policy today is therefore that reductions in the carbon intensity of air travel will be limited to the reduction of around 35% achieved in the Likely scenario, implying a maximum allowable increase in ATMs of around 55% and a maximum demand increase of around 60%. If faster technology progress is in fact achieved this can be reflected in adjustments in policy over time.

Implications for airport expansion and slot allocation

The 2003 Air Transport White Paper proposed that there could be airport runway capacity expansions at Edinburgh, Heathrow and Stansted, but at no other airports. In January 2009, the Government decided in favour of a third runway at Heathrow and in favour of increasing slot capacity there from 480,000 to 605,000. It decided however that any decisions on the allocation of further slot capacity (to the maximum theoretical potential of 702,000 with a third runway in place) should be subject to recommendations from the Committee on Climate Change in 2020 on whether further expansion then appears compatible with the target of restricting CO₂ emissions to a maximum 37.5 MtCO₂ in 2050. The Terms of Reference for this report in addition asked the Committee to consider “the implications [for meeting the 2050 target] of further aviation expansion in the 2020s”.



The key implication from our analysis is that future airport policy should be designed to be in line with the assumption that total ATMs should not increase by more than about 55% between 2005 and 2050, i.e. from today's level of 2.2 million to no more than around 3.4 million in 2050. This constraint could be consistent with a range of policies as regards capacity expansion at specific airports.

Total current theoretical capacity at all airports in the UK is about 5.6 million ATMs which is already in excess both of today's actual ATMs and of maximum ATMs compatible with the 2050 target (Table 7.1a and b). But demand cannot be easily switched between different geographical locations, and there is a tendency for demand to concentrate at major hubs, given the advantages of inter-connection between different routes. As a result, capacity utilisation differs hugely between for instance 97% at Heathrow and well below 50% at some smaller airports outside the top ten.

If demand was allowed to grow in line with the demand assumptions of the Likely scenario, with passenger numbers growing 115% ATMs would reach about 4 million by 2050. Our modelling suggests that an allocation of demand at this level would entail Heathrow operating at its maximum 702,000 capacity (with a third runway) with several other airports highly utilised (Table 7.1b). Our analysis suggests however total ATMs need to be restricted to a maximum of about 3.4 million in 2050, about 0.6 million below the level modelled in the Likely scenario.

Table 7.1a: Actual runway capacity and utilisation in 2005

Airport	Maximum runway capacity (ATMs, '000s)	Actual use (ATMs, '000s)	Capacity utilisation	Spare capacity (ATMs, '000s)
Heathrow	480	466	97%	14
Gatwick	260	248	95%	12
Stansted	241	166	69%	75
London City	73	60	82%	13
Luton	100	72	72%	28
Bristol	188	58	31%	130
Birmingham	186	111	60%	75
Manchester	276	213	77%	63
Glasgow	188	93	50%	95
Edinburgh	186	106	57%	79
<i>Other UK Airports</i>	<i>3,400</i>	<i>568</i>	<i>17%</i>	<i>2,832</i>
Total	5,577	2,160	39%	3,417

Source: CCC modelling.

Table 7.1b: Projected runway capacity, utilisation and target compatible ATMs in 2050 (Likely scenario assumptions)^{1,2}

Airport	Maximum runway capacity (ATMs, '000s)	Planned capacity, ATM distribution ('000s)	Capacity utilisation	Spare capacity (ATMs, '000s)
Heathrow	702	702	100%	0
Gatwick	260	260	100%	0
Stansted	480	317	66%	163
London City	120	120	100%	0
Luton	135	135	100%	0
Bristol	226	127	56%	98
Birmingham	206	206	100%	0
Manchester	500	449	90%	51
Glasgow	226	198	88%	27
Edinburgh	450	224	50%	226
<i>Other UK Airports</i>	<i>4,000</i>	<i>1,227</i>	<i>31%</i>	<i>2,773</i>
Total	7,304	3,965	54%	3,339
Target compatible ATMs		3,418		
Difference between the Likely scenario and target compatible ATMs		547		

Source: CCC modelling.

This restriction could be achieved through a range of different policies relating to taxes, capacity expansion or slot allocation at specific airports. Optimal decisions on specific airport capacity do not therefore mechanically follow from national aggregate demand, but need to reflect a wide range of other factors such as customer preference, alternatives to air travel, local environmental impact, competition between UK airports and continental hubs, and economic impacts both local and national. It is not the Committee's role to assess these factors.

The Committee's clear conclusion is, however, that the combination of future aviation policies (combining tax, capacity expansion and slot allocation decisions) should be designed to be compatible with a maximum increase in ATMs of about 55% between now and 2050, and that this should continue to be the policy approach until and unless technological developments suggest that any higher figure would be compatible with the emission target.

1 The ATM distribution is an indicative model output rather than a definitive view on the distribution in the Likely scenario.

2 Stansted utilisation and total demand may be higher in practice when suppressed demand is reallocated from other London airports.

Future work of the Committee on aviation

Further work on aviation emissions by the Committee over the next year will include:

- Assessing whether international aviation emissions should be included in carbon budgets given the final mechanisms agreed by the EU for allocating EU ETS allowances across Member States.
- Assessing the relative costs of emission reductions in different sectors of the economy (including aviation) within the context of the Committee's development of recommendations for the fourth budget period (2023-2027) which will be delivered in December 2010. This will entail consideration of the feasibility of reductions in other sectors sufficient to offset the fact that aviation emissions are likely to grow before falling back to the 37.5 MtCO₂ level.

Over the longer term the Committee will:

- Review any new evidence on improvement in fleet fuel efficiency, sustainable biofuels and aviation non-CO₂ effects and their implications for the maximum demand increase compatible with meeting the emissions target.
- In 2020 advise Government on whether release of the second tranche of slots from Heathrow capacity expansion (from 605,000 to 702,000) is then compatible with meeting the 2050 target.

The Committee's next annual report to Parliament in June 2010 will include an assessment of latest data on UK aviation emissions and will reflect any developments on international aviation policy resulting from the Copenhagen climate change summit.

Glossary

Abatement

Avoiding or reducing pollution or emissions through external intervention.

Advisory Council for Aeronautics Research in Europe (ACARE)

A joint European initiative with the purpose to improve the competitiveness of the European aviation industry through research.

Air Traffic Management (ATM)

A service provided by ground-based controllers who direct aircraft on the ground and in the air.

Air Traffic Movements (ATMs)

Unit of travel referring to a flight.

European Assessment of Transport Impacts on Climate Change and Ozone Depletion (ATTICA)

A series of integrated studies investigating the atmospheric effects of aviation, shipping, land traffic and applicable climate metrics. See Box 6.3 for details.

Biofuel

A fuel derived from biomass and used to power vehicles (can be liquid or gas). Biofuels are commonly derived from cereal crops but can also be derived from other plant material, trees and even algae.

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.

Biomass to liquid (BTL)

Production of jet fuel, diesel or gasoline through gasification of biomass feedstock (e.g. woody crops or wastes), followed by Fischer-Tropsch (FT) synthesis and upgrading steps.

Blended wing body

Radical aircraft design in which airframe dynamics are improved through a flattened profile and wing structures that are smoothly blended to the body.

Bunker Fuel

Fuel consumed for international marine and air transportation.

Bypass ratio

The ratio between the mass flow rate of air drawn in by the fan but bypassing the engine core to the mass flow rate passing through the engine core.

**Carbon Budget**

Allowed emissions under the UK Climate Change Act, defining the maximum level of CO₂ and other Kyoto GHGs which the UK can emit over five year periods.

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 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

Displacement of carbon emissions from one country to another due to the existence of (stringent) environmental policy in one country which makes it more attractive or viable for high carbon businesses to operate in a country with less stringent regulations.

Carbon Price

Price at which carbon is traded under an emissions trading scheme (see below).

Climate Change Act

UK law of 26 November 2008. It makes it the duty of the Secretary of State for Energy and Climate Change to ensure that the net UK carbon account for all six Kyoto greenhouse gases for the year 2050 is at least 80% lower than the 1990 baseline.

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.

CONSAVE

Consave 2050 was an EC Accompanying Measure Project that developed scenarios on aviation and emissions, with a particular focus on 2050.

Contrail

Condensation trail (i.e. white line cloud often visible behind aircraft).

Elasticity of demand

The proportion by which demand changes in response to changes in Price (Price Elasticity) or Income (Income Elasticity).

Emissions factor

Constant measure of carbon intensity used for calculation of emissions from some activity, e.g. to calculate emissions from aviation in the knowledge of the number of flights realised the appropriate emissions factor would be the average CO₂ emissions per flight realised.

Emissions trading

Approach to pollution control which leverages economic incentives to deliver emissions cuts in an efficient manner by allowing polluters with the ability to cut their emissions more cheaply to 'sell' emissions credits to other polluters with less flexibility.

European Economic Area (EEA)

Trading group comprising members of the European Free Trade Association (EFTA) and the European Union (EU).

European Union Emissions Trading Scheme (EU ETS)

Cap based emissions trading system covering the power sector and energy intensive industry in the EU.

Exogenous

A variable in an economic model which is determined outside of the model and is not a result calculated by the model, e.g. consumer tastes in a supply and demand model.

Fischer-Tropsch (FT) process

Catalytic production process for the production of synthetic fuels. Natural gas, coal and biomass feedstocks can be used.

Fleet rollover model

Technology model which represents the evolution and characteristics of a vehicle fleet taking into account the age and scrappage cycle of the vehicles.

Functional Airspace Block (FAB)

An area of airspace established based on operational requirements and not national boundaries, e.g. Central Europe, Danube, Baltic.

Fossil fuel

A hydrocarbon deposit, such as petroleum, coal, or natural gas, derived from the accumulated remains of ancient plants and animals and used as fuel.

Fuel Efficiency

The efficiency by which a vehicle converts energy contained in a carrier fuel into motion. In the context of aviation this can be expressed in terms of fuel burn per seat-km or per passenger-km.

G8 Countries

A forum for governments of the eight richest countries in the world to discuss key issues. These are the UK, USA, France, Italy, Germany, Russia, Japan and Canada.

**Global Temperature Potential (GTP)**

A means for measuring the radiative effect of emissions based on the effect on the global mean surface temperature at some future point in time. See Box 6.2 for details.

Global Warming Potential (GWP)

A metric for comparing the climate effect of different greenhouse gases, all of which have differing lifetimes in the atmosphere and differing abilities to absorb radiation. The GWP is calculated as the integrated radiative forcing of a given gas over a given time period, relative to that of carbon dioxide. Standard international reporting processes use a time period of 100 years.

GLOCAF

The Global Carbon Finance model was developed by the Office of Climate Change to look at the costs to different countries of moving to a low carbon global economy, and the kind of international financial flows this might generate.

Great Circle Distance (GCD)

A definition of the shortest flight distance between two points, taking the curve of the earth's surface into account.

Greenhouse Gas (GHG)

Any atmospheric gas (either natural or anthropogenic in origin) which absorbs thermal radiation emitted by the Earth's surface. This traps heat in the atmosphere and keeps the surface at a warmer temperature than would otherwise be possible, hence it is commonly called the Greenhouse Effect.

Gross Domestic Product (GDP)

A measure of the total economic activity occurring within a country.

Heavy Good Vehicle (HGV)

A truck over 3.5 tonnes (articulated or rigid).

Hydrogenated Renewable Jet (HRJ)

Conversion of vegetable oils (e.g. conventional oil crops such as palm and soy, but also new oils crops such as jatropha and camelina) and algal oils to aviation fuel through a process including treatment with hydrogen.

International Air Transport Association (IATA)

A trade association comprising 230 airlines with the mission to represent, lead and serve the airline industry.

International Energy Agency (IEA)

Intergovernmental organisation which acts as energy policy advisor to 28 countries.

Intergovernmental Panel on Climate Change (IPCC)

The IPCC was formed in 1988 by the World Meteorological Organisation (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.

Kyoto gas

A greenhouse gas covered by the Kyoto Protocol.

Kyoto Protocol/Agreement

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).

Level of Scientific Understanding (LOSU)

This is an index on a 4-step scale (High, Medium, Low and Very Low) designed to characterise the degree of scientific understanding of the radiative forcing agents that affect climate change.

Lifecycle

Lifecycle assessment tracks emissions generated and materials consumed for a product system over its entire lifecycle, from cradle to grave, including material production, product manufacture, product use, product maintenance and disposal at end of life. This includes biomass, where the CO₂ released on combustion was absorbed by the plant matter during its growing lifetime.

Load Factor

Number expressing the degree of occupancy of an aircraft – the higher the number the fuller the aircraft, such that a full aircraft has a load factor of 100%.

Long-haul flight

A flight of distance greater than 3,700km. In practice in this report flights between the UK and destinations outside Europe have been considered long-haul.

MARKAL

Optimisation model that can provide insights into the least-cost path to meeting national emissions targets over the long-term.

Mha

One Million Hectares = 10,000 km².

Mitigation

Action to reduce the sources (or enhance the sinks) of factors causing climate change, such as greenhouse gases.

Modal shift

A change from one means of transport to another e.g. car to cycling, air to rail.

MtCO₂

Million tonnes of Carbon Dioxide (CO₂).

Narrow-body aircraft

An airliner with a fuselage aircraft cabin diameter typically of 3 to 4 metres (10 to 13 ft), and airline seat arranged 2 to 6 abreast along a single aisle.

National Air Traffic Services (NATS)

ATM service provider for aircraft flying in UK airspace, and over the eastern part of the North Atlantic.

National Atmospheric Emissions Inventory (NAEI)

Data source compiling estimates of the UK's emissions to the atmosphere of various (particularly greenhouse) gases.

NO_x

A generic term for mono-nitrogen oxides (NO and NO₂). These oxides are produced during combustion, especially combustion at high temperatures.

Novel synthetic hydrocarbons

Generic term which covers a variety of new methods for the production of biofuels relying on conversion of biomass to jet fuel via biological or chemical processes.

Offset credits

Credits corresponding to units of abatement from projects, such as those generated under the Kyoto treaty's project based flexibility mechanisms, Joint Implementation (JI) and Clean Development Mechanism (CDM).

Passenger-kilometre (Pax-km)

Unit of travel referring to one passenger moved through a distance of one kilometre.

Open rotor engine

Radical engine design in which the rotating fan blades are not surrounded by a casing.

Point-to-point

Modelling term for a journey between two cities. Modelling in this way allows emissions to be calculated on the basis of real trips as opposed to basing them on hypothetical geographical ranges.

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.

Reference case

Hypothetical projection of a given variable (e.g demand or emissions) which is used as a basis for developing scenarios or for comparison with alternative scenarios.

Radiative Forcing (RF)

A standard metric for measuring the contribution of changes in individual atmospheric constituents to the energy imbalance of the earth-atmosphere system, relative to pre-industrial times (usually dated at 1750).

Radiative Forcing Index (RFI)

An index designed by the IPCC for their 1999 report to measure the total radiative effect of aviation compared to that from CO₂. See Box 6.2 in main body of report for details.

Renewable Energy

Energy resources, where energy is derived from natural processes that are replenished constantly. They include geothermal, solar, wind, tide, wave, hydropower, biomass and biofuels.

Riblet

One of a series of microscopic grooves inscribed on the surface of an adhesive backed tape and used on aeroplanes and boat hulls to reduce drag.

Seat-kilometre (Seat-km)

Unit of travel referring to one vehicle seat (occupied or otherwise) moved through a distance of one kilometre.

Sensitivity Analysis

The study of how the variation (uncertainty) in the output of a mathematical model can be apportioned to variation in different input assumptions.

Short-haul flight

A flight of distance less than 3,700km. In practice in this report flights between the UK and Europe have been considered short-haul.

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.

Turbine Engine Temperature (TET)

Temperature at which air enters a jet engine.

United Nations Framework Convention on Climate Change (UNFCCC)

Signed at the Earth Summit in Rio de Janeiro in 1992 by over 150 countries and the European Community, the UNFCCC has an ultimate aim of 'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.'

**Videoconferencing**

A means of digital communication by which user(s) are able to interact visually and auditorially with people in geographically distant locations.

Wide-body aircraft

A large airliner with a fuselage diameter of 5 to 6 metres and twin aisles.

Winglet

A short vertical fin on the tip of an aircraft wing for reducing drag.



Committee on Climate Change

4th Floor
Manning House
22 Carlisle Place
London SW1P 1JA

www.theccc.org.uk

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