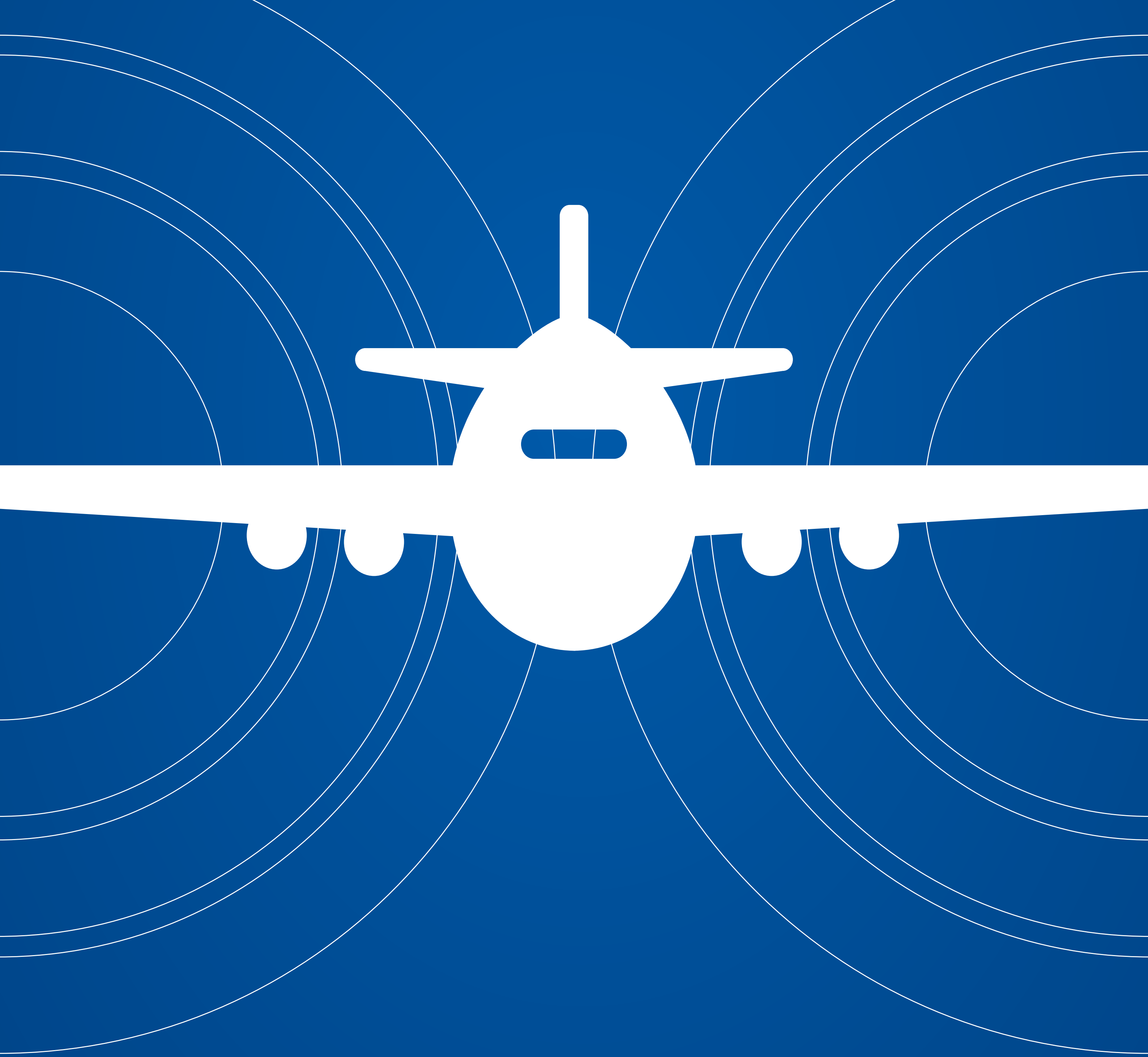
Meeting the UK aviation target – options for reducing emissions to 2050

Committee on Climate Change
December 2009

Executive Summary



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THE QUEEN'S AWARDS FOR ENTERPRISE: SUSTAINABLE DEVELOPMENT 2007

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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 CO_2 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.

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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.

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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.

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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.

Acknowledgements

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The core team that prepared the analysis for the report. This was led by David Kennedy and included: Owen Bellamy, Ben Combes, Elgon Corner, Michele Pittini, Stephen Smith and Jonathan Stern. It also included Professor David Lee as an expert adviser.

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 number of organisations for their support, including the Aviation Environment Federation, the Civil Aviation Authority, the Department for Transport, the Department for Business Innovation and Skills, the Department for Energy and Climate Change, the International Air Transport Association, the International Energy Agency, National Air Traffic Services, Rolls-Royce, Shell, Sustainable Aviation and the World Wildlife Fund.

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 CO_2 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 CO_2 emissions in 2005 were estimated to be 37.5 $MtCO_2$ on a bunker fuels basis. This report therefore sets out the Committee's assessment of the actions required to ensure that UK aviation CO_2 emissions in 2050 do not exceed 37.5 $MtCO_2$, 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-CO_2 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 CO_2 emissions to no more than 37.5 $MtCO_2$.

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/tCO_2 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 MtCO_2 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 CO_2 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-CO_2 effects

- **Aviation non-CO_2 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-CO_2 effects, consistent with international convention and the UK Climate Change Act, as they do not derive directly from emissions of Kyoto gases.

  – Aviation non-CO_2 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-CO_2 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 CO_2 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-CO_2 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 CO_2 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 CO_2 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 CO_2 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-CO_2 effects of aviation

- Non-CO_2 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):

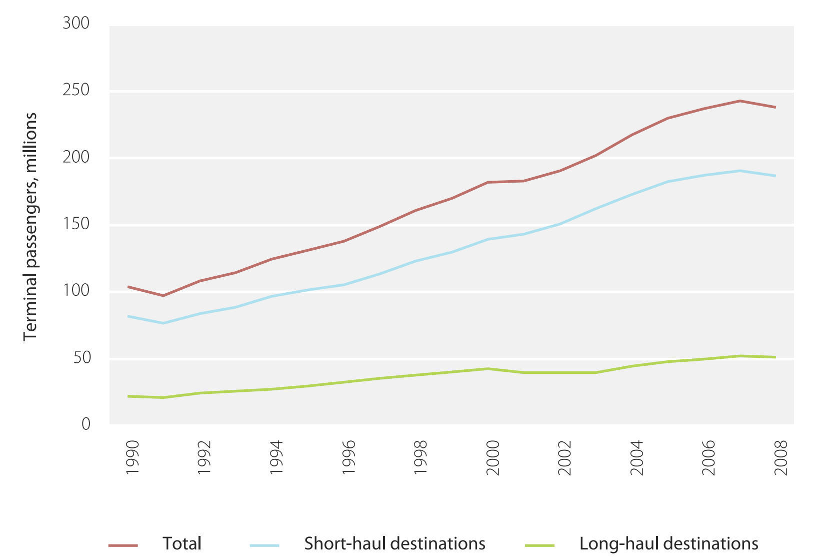
- Short-haul demand has increased by 128% from 82 million to 187 million passengers per year.
- Long-haul demand has increased by 133% from 22 million to 51 million passengers per year.

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



Source: CAA (2009).

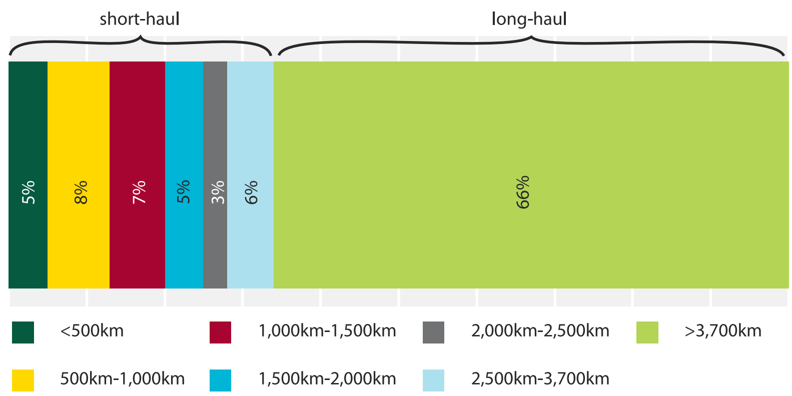
Emissions growth has been slightly less than demand growth (e.g. 120% compared to 130%) over the period 1990 to 2007. Three main factors account for this difference:

- 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



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

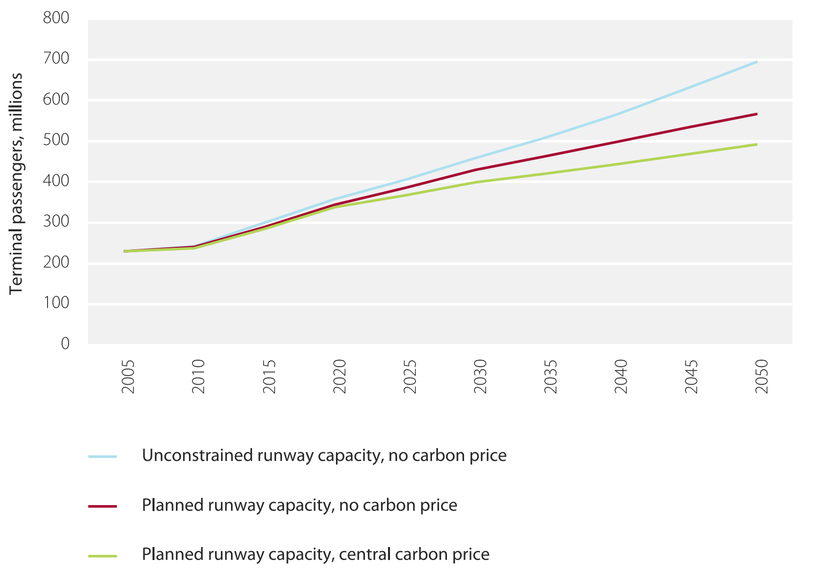
Table ES.1 DfT Elasticity estimates[1]

	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 $MtCO_2$ in all scenarios and therefore would not materially alter our conclusions.

Figure ES.3 Reference demand projections



Source: CCC modelling.

- 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/tCO_2 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 MtCO_2 in 2050. With planned capacity constraints and a central case carbon price, and with no technological progress, emissions would rise to around 74 MtCO_2 in 2050.

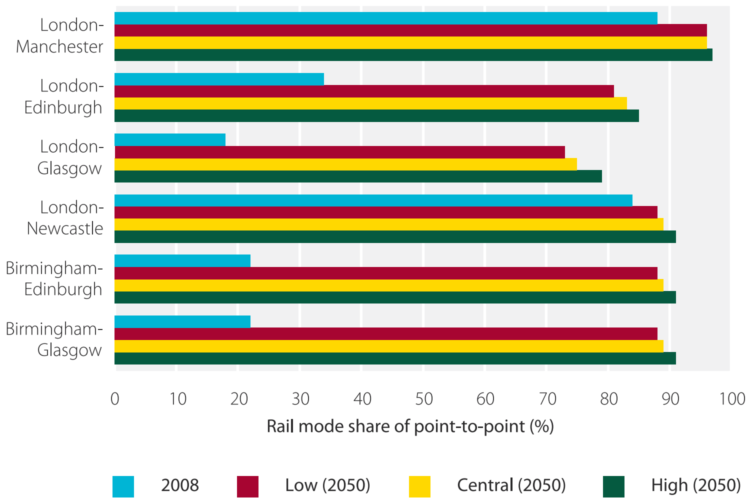
2. Reducing emissions through modal shift and videoconferencing

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.

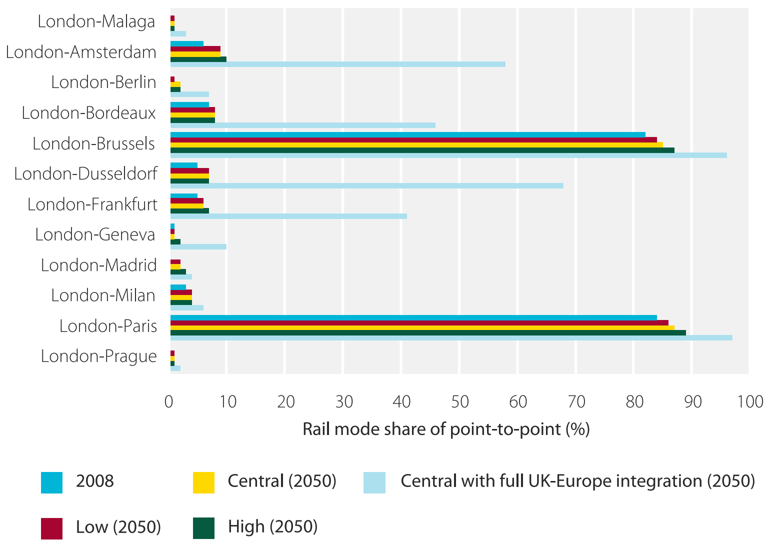
Overall our scenarios for modal shift and videoconferencing suggest a potential to reduce emissions by up to 7 $MtCO_2$ in 2050. Under a policy regime which involved constraints on capacity but which allowed demand to increase to fill the allowed capacity, some of this reduction would be offset by increases 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 km^2 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 richer[2]. 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-CO_2 climate effects of aviation

The Kyoto framework, the UK's Climate Change Act and the UK's 2050 aviation target all exclude aviation non-CO_2 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-CO_2 effects – particularly contrails and other induced cloud formation – is to increase the global warming impact of aviation beyond that suggested by CO_2 emission alone (Figure ES.5).

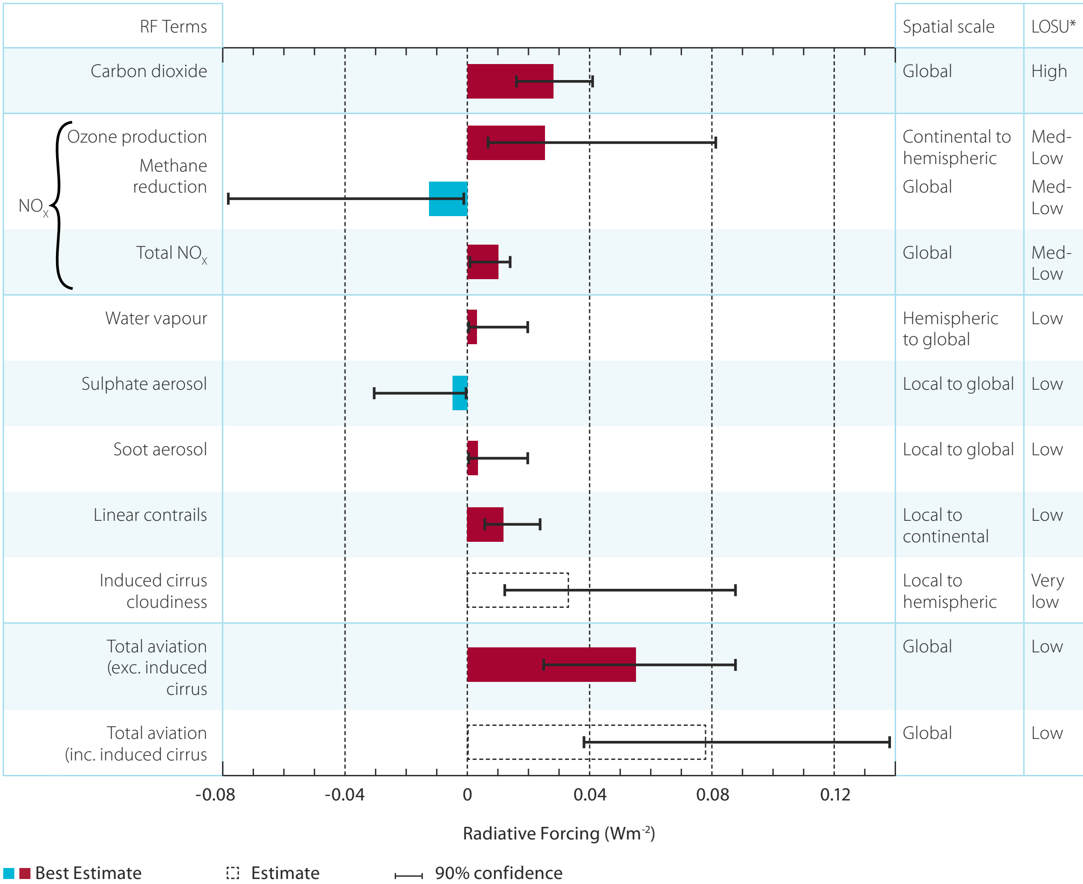
The precise scale of the additional impact is unclear and there are considerable scientific uncertainties still to be resolved, but it is highly likely that these non-CO_2 effects are significant. It will therefore be important that they are accounted for in future international policy frameworks and 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 CO_2 alone, we therefore comment also on the possible implications of considering non-CO_2 effects. The inclusion of non-CO_2 aviation effects into the UK policy framework could be reflected in three different ways (or a mix of these ways):

- The total level of CO_2 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 (CO_2 and non-CO_2 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-CO_2 effects with total CO_2 equivalent emissions (combining CO_2 and non-CO_2 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, 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

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 biofuels[4]:

- ***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.

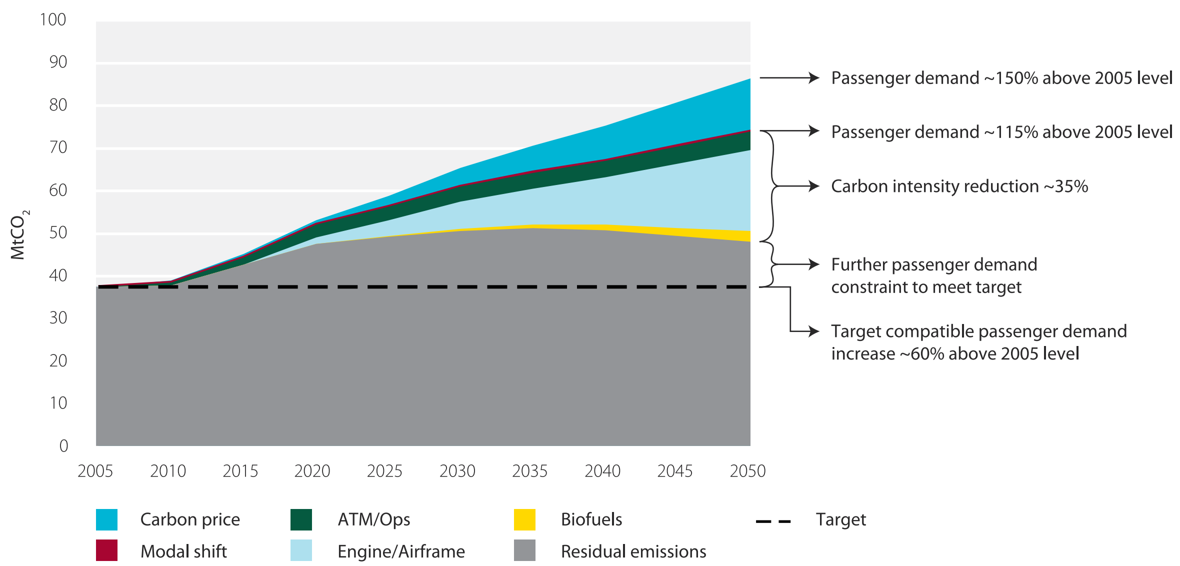
Meeting the target in the Likely scenario

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 CO_2 emissions did not exceed the 2005 level of 37.5 $MtCO_2$. 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)



Source: CCC modelling.

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/tCO_2 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 CO_2 emissions are no higher than 37.5 MtCO_2 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 CO_2 emissions should not exceed 37.5 MtCO_2 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).

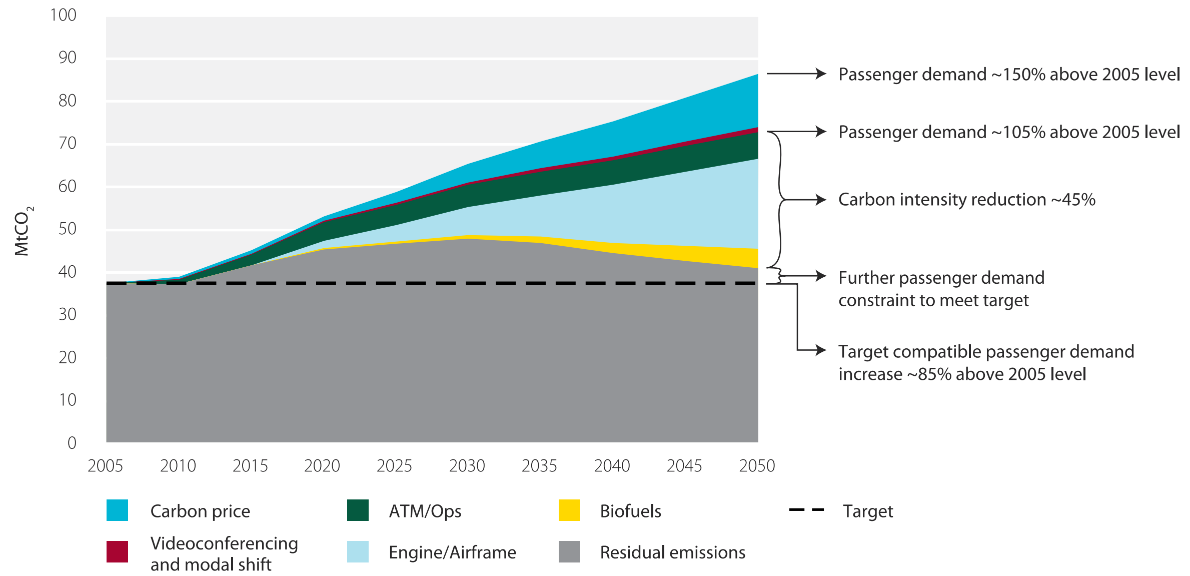
The high growth in aviation demand which would occur in an unconstrained environment illustrates the high value which people place on the opportunity to fly, in particular for leisure purposes. If the Optimistic or Speculative scenarios can be achieved, the number of flights compatible with meeting the 37.5 $MtCO_2$ 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.

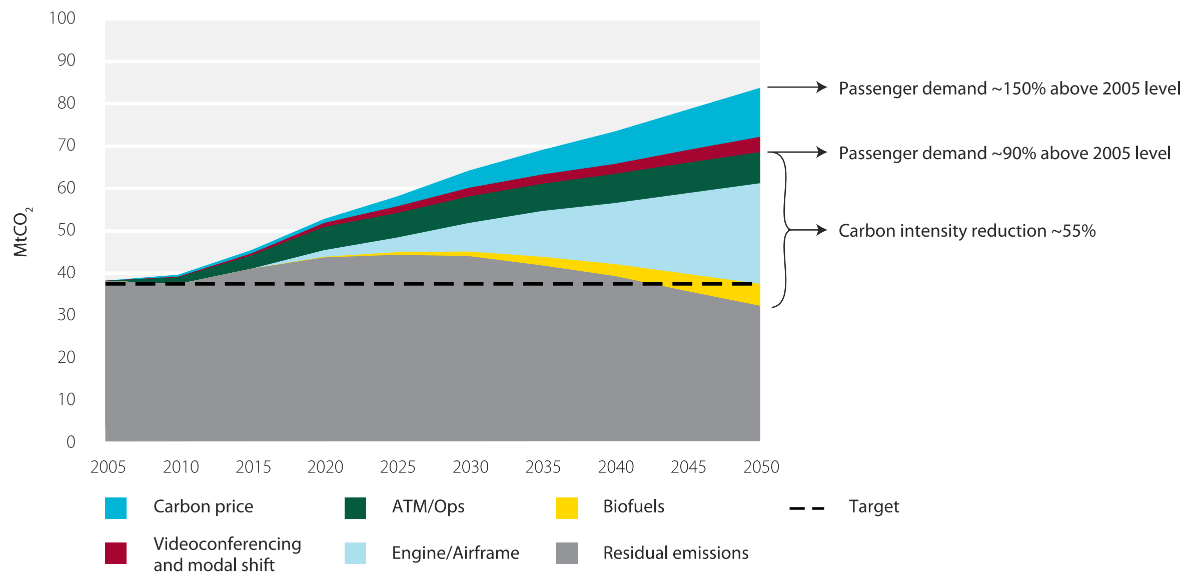
- Achieving more rapid fuel efficiency improvements directly increases target-compatible demand growth. It could be fostered through increasing investment in R&D, introducing regulatory limits on new aircraft CO_2 performance, exploring possible benefits from early scrappage of older aircrafts, and full 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 CO_2 emissions to a maximum 37.5 $MtCO_2$ 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
Other UK Airports	*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
Other UK Airports	*4,000*	*1,227*	*31%*	*2,773*
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 $MtCO_2$ level.

Over the longer term the Committee will:

- Review any new evidence on improvement in fleet fuel efficiency, sustainable biofuels and aviation non-CO_2 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.

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