Airports Commission

Discussion Paper 03:
Aviation and Climate Change

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An independent commission appointed by Government

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1. Introduction

1.1 Aviation has a significant impact on the Earth's atmosphere, most visibly the familiar contrails (condensation trails) that we are all used to seeing when planes pass overhead. Less visible, but probably more important, are the other emissions from aircraft, such as carbon dioxide (CO_2), nitrogen oxides (NO_X) and soot, all of which contribute in various ways to climate change.

1.2 Globally, aviation accounts for around 1–2% of greenhouse gas (GHG) emissions. At a UK level, domestic and international aviation is responsible for around 6% of national GHG emissions.[1] Whilst this is currently smaller than for road transport, it is likely to make up an increasing proportion of total emissions over time. Aviation is one of the most challenging sectors to decarbonise, because aircraft are longer lived than, for example, road vehicles, and so far there are few realistic alternatives to kerosene.

1.3 Since the Intergovernmental Panel on Climate Change's (IPCC) landmark 1999 report *Aviation and the Global Atmosphere*, the science around aviation and climate change has continued to develop.[2] So too has the policy landscape. At a European level there is now the EU Emissions Trading System (ETS) which, notwithstanding the current measure to 'stop the clock',[3] is intended to cover aviation emissions. And at a national level the UK has enacted the Climate Change Act 2008 which includes a legally binding target to reduce the UK's emissions.

1.4 In making its assessment of the UK's future aviation capacity and connectivity needs, the Airports Commission will need to take account of the evolving climate science and policy. It is clear that, in respect of climate change, the world has moved on significantly since the UK Government last considered airport capacity in its 2003 aviation White Paper.[4] Analysis undertaken as part of that process would not necessarily support a robust decision today.

1.5 This paper, one of a series of discussion papers on the costs and benefits of

1 Department for Transport (2013) *Aviation Policy Framework*, p. 40, available at https://www.gov.uk/government/publications/aviation-policy-framework. There is currently no internationally agreed method for allocating international emissions to individual countries. The percentage shares are based on the percentage of bunker fuel sales to the aviation sector from the UK.

2 IPCC (1999) *Special Report: Aviation and the Global Atmosphere: summary for policymakers*, available at http://www.ipcc.ch/pdf/special-reports/spm/av-en.pdf.

3 See Chapter 3 of this document.

4 Department for Transport (2003) *The Future of Air Transport*, available at http://webarchive.nationalarchives.gov.uk/+/http://www.dft.gov.uk/about/strategy/whitepapers/air/utureofairtransportwhite5694.pdf.

aviation for the UK,[5] is intended to begin a dialogue with stakeholders around climate change issues. It provides an overview of climate science and policy as it relates to aviation, and discusses some approaches to forecasting aviation emissions. It also considers the implications of airport capacity constraints for emissions, and concludes with a discussion of the climate change adaptation challenges facing the aviation sector.

1.6 The aim of this paper is to open up discussion around these issues, rather than to reach firm conclusions. To support this debate, the paper presents some new analysis of the potential emissions implications of airport capacity constraints. This is something that has not previously been a focus for analysis, so we are keen to hear views on the methodology and assumptions used, as well as suggestions of other approaches and evidence that the Commission could consider.

1.7 Evidence submitted by stakeholders will inform the Commission's assessment of the nature, scale and timing of the UK's aviation capacity and connectivity needs, as part of its interim report at the end of 2013.

1.8 The paper is structured as follows: **Chapter 2** provides a high-level overview of the latest science around aviation and climate change. It surveys some of the potential technological and operational developments that might affect the carbon intensity of future air travel, and considers some of the limitations and tradeoffs around their use. It also discusses potential alternatives to air travel, such as high-speed rail and videoconferencing, and their scope for reducing aviation emissions.

1.9 **Chapter 3** sets out the national and multinational policy frameworks that will have a bearing on the Commission's work, and highlights some examples of voluntary action already being undertaken by the aviation industry.

1.10 **Chapter 4** discusses approaches to forecasting aviation emissions, drawing in particular on forecasts by the Department for Transport (DfT) and the UK Committee on Climate Change (CCC). It examines some of the complexities and uncertainties around emissions forecasts, including the treatment of non-CO_2 emissions and sensitivity to future changes in the carbon price.

1.11 **Chapter 5** builds on the discussion of modelling approaches, and sets out some new analysis of the emissions implications of airport capacity constraints, drawn from the DfT aviation model. It seeks to quantify the potential for emissions 'leakage' from capacity-constrained UK airports to overseas airports, and considers the impact of constraints on airport capacity relative to other levers for curbing emissions.

1.12 Finally, **Chapter 6** discusses the climate change adaptation challenges for the aviation sector, and how the Commission might take account of these in carrying out its work.

5 Previous papers in this series are *Aviation Demand Forecasting* and *Aviation Connectivity and the Economy*. Forthcoming papers will cover subjects including the economics of airport operating models. For the full series see https://www.gov.uk/government/organisations/department-for-transport/series/airports-commission-discussion-papers.

2. Aviation and the global climate

2.1 Aviation impacts the global climate through emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), water vapour, sulphates and soot, and through the formation of linear contrails and aircraft induced cirrus (AIC).[6] Each of these emissions components affects the atmosphere in different ways, and the level of scientific understanding is also different in each case. This has complicated efforts to decarbonise air travel, and creates some tradeoffs around potential emissions reduction measures.

2.2 This chapter provides a high-level overview of the latest science around aviation and climate change. It also discusses some of the potential technological and operational developments that might affect the carbon intensity of future air travel, and some of the limitations and tradeoffs around their use, as well as potential alternatives to air travel.

Measuring the climate effects of aviation emissions

2.3 'Radiative forcing' (RF) is the most common metric used to compare the climate effects of different types and sources of emissions. It expresses the current energy imbalance in the Earth's climate system (usually relative to its pre-industrial state) in Watts per square metre (Wm^{-2}). A positive figure indicates a warming effect, whilst a negative figure indicates a cooling effect.

2.4 Figure 2.1 shows the estimated forcings for each component of aviation emissions, and the spatial scale of their climate impact. The error bars indicate uncertainties around these estimates (at 90% confidence intervals), and the rightmost column shows the current level of scientific understanding for each component.

CO_2 effects

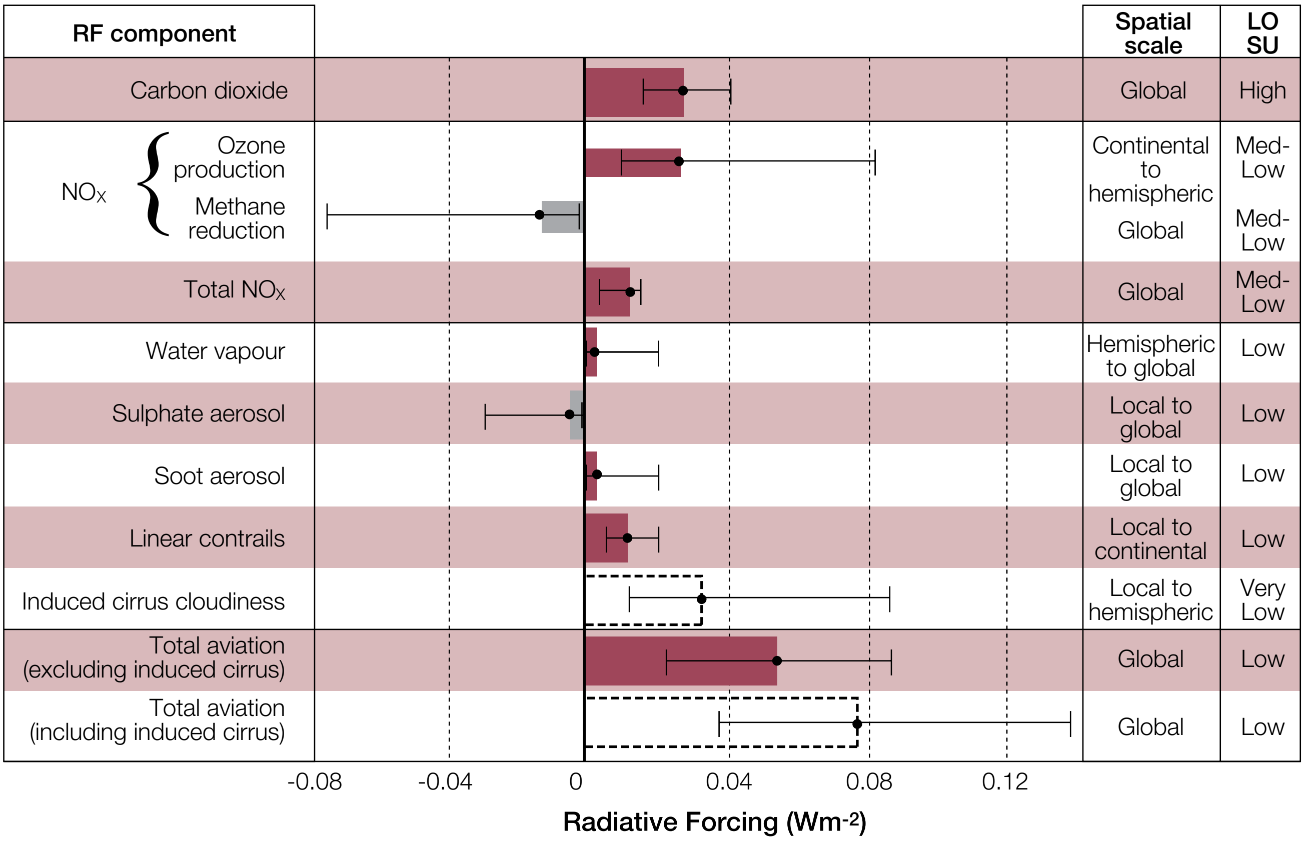
2.5 Of the various emissions shown in Figure 2.1, those of CO_2 are the best understood. Carbon dioxide has a significant warming effect, and CO_2 emissions from aviation are relatively straightforward to estimate, as they are effectively a direct function of aircraft fuel burn.

2.6 Aviation is estimated to account for 2–2.5% of total *annual* anthropogenic (human-induced) CO_2 emissions at the global level, based on International Energy Agency (IEA) statistics of fuel sales.[7] At present, it only accounts for an estimated 0.9% of *cumulative* anthropogenic CO_2 emissions since the pre-industrial period, because affordable

6 Changes in cirrus cloud coverage that are attributable to aircraft.

7 See Lee (2009) 'Aviation and Climate Change: the science', in Earthscan (2009) *Climate Change and Aviation: issues, challenges and solutions*, pp. 27–67, available at http://www.gci.org.uk/Documents/Aviation-and-Climate-Change_.pdf.

Figure 2.1: Climate effects of aviation emissions components



Source: Lee et al (2010), 'Transport impacts on atmosphere and climate: aviation', *Atmospheric Environment*, vol. 44, pp. 4678–4734.

Notes: Error bars denote 90% confidence intervals, and LOSU indicates the Level of Scientific Understanding regarding each effect. Induced cloudiness (AIC) is shown as a dotted line because of high uncertainty.

mass air travel is a relatively recent phenomenon.

2.7 In the UK, aviation emissions account for about 6% of greenhouse gas (GHG) emissions or about 22% of the transport sector's GHG. 40% of transport emissions are attributable to cars, 14% to heavy goods vehicles and 8% to shipping.[8] The historical trend for CO_2 emissions from UK aviation is shown in Figure 2.2.

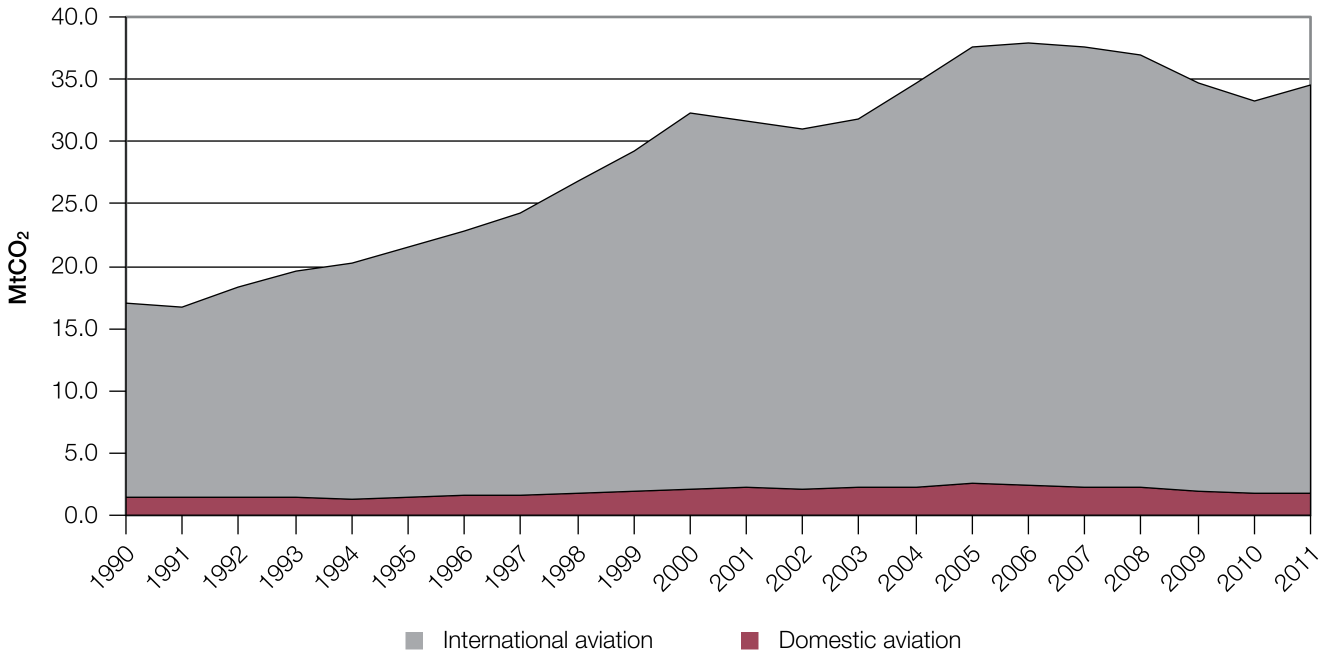
2.8 However, if demand for air travel grows in line with current projections, and other sectors begin to decarbonise relatively more quickly, aviation emissions are likely to make up a growing proportion of global and UK totals. One reason that aviation is expected to take longer to decarbonise than other sectors is the lack of an obvious low-carbon alternative to aviation fuel (kerosene). In addition, the long service life of aircraft compared to most other vehicles means that it takes longer for new technologies to penetrate the aircraft fleet than, for example, the car fleet. These issues are discussed in more detail below.

Non-CO_2 effects

2.9 Aside from the well-understood effects of CO_2 emissions, there is also good evidence that aircraft NO_X emissions affect the climate by producing ozone (O_3), with a warming effect, and destroying methane (CH_4), with a cooling effect. However, the overall magnitude of their effect is less certain. Importantly,

8 Domestic and international aviation emissions on the basis of bunker fuel sales in the UK to the aviation sector. Department of Energy and Climate Change (2013) *2011 UK Greenhouse Gas Emissions, Final Figures*, available through https://www.gov.uk/government/publications/final-uk-emissions-estimates.

Figure 2.2: Historical UK CO_2 emissions from aviation



Source: DECC (2013), *2011 UK Greenhouse Gas Emissions, Final Figures*, available at https://www.gov.uk/government/publications/final-uk-emissions-estimates.

NO_X emissions are not a direct function of fuel burn, as is the case for CO_2, but are engine and technology specific.

2.10 Less well understood are the climate effects of water vapour, sulphates, soot, linear contrails and AIC. In these cases, as can be seen from Figure 2.1, the direction of the effect (warming or cooling) tends to be known, but in some cases there are significant uncertainties around its magnitude. The effects of AIC have proved particularly difficult to quantify, although it is thought that they may have a potentially significant warming effect.

2.11 As Figure 2.1 indicates, the effects of the various emissions components also differ in their spatial scale. For example, CO_2 has a warming effect at the global level, whilst the effects of linear contrails and induced cirrus are more localised. Furthermore, CO_2 is a long-lived GHG, whereas some other emissions components have shorter lifetimes (on the order of just hours for contrails, for example).

2.12 Overall, aviation emissions have been estimated to account for around 3.5% to 4.9% of total present-day (2005) global anthropogenic warming, depending on whether AIC is included.[9]

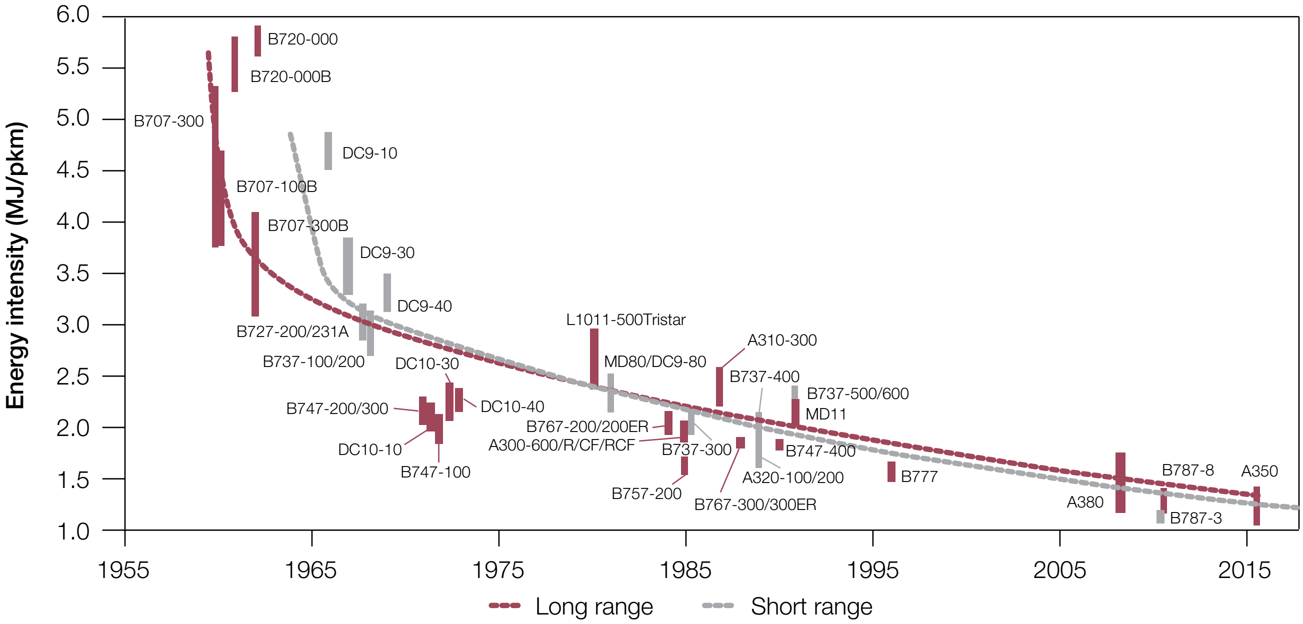
Technological and operational scope to reduce aviation emissions

2.13 Prospective technological and operational innovations could reduce the carbon intensity of air travel, and thereby the quantity of emissions relative to any given level of future demand. However, there are a number of limitations and tradeoffs around their use.

2.14 Forecasts for future aviation emissions depend to a significant extent on what is assumed in terms of future technological

9 Lee et al (2010), 'Transport impacts on atmosphere and climate: aviation', *Atmospheric Environment*, 44, pp. 4678–4734.

Figure 2.3: Historical improvements in aircraft fuel efficiency



Source: International Energy Agency (2009), *Transport, Energy and CO_2*, Figure 7.2, p. 317, available at http://www.iea.org/publications/freepublications/publication/transport2009.pdf.

Note: The range of points for each aircraft reflects varying configurations; connected dots show estimated trends for short- and long-range aircraft.

progress and operational efficiencies. This section provides a high-level overview of prospective developments, whilst Chapter 4 sets out more detail on the numerical assumptions that underpin current forecasts.

Fuel efficiency

2.15 Aircraft have become steadily more fuel-efficient over the past fifty years as a result of developments in engine and airframe technologies, for example the development of high bypass-ratio turbofan engines during the 1970s.[10] Historical improvements in aircraft fuel efficiency are shown in Figure 2.3.

2.16 Potential future developments include further evolutionary innovations in engine and airframe design, such as improvements in engine thermodynamic efficiency and reductions in airframe weight, as well as more speculative technologies such as blended wing aircraft bodies (although these may not be realistic in the 2050 timeframe).[11]

Operational efficiencies

2.17 There is also scope for emissions reductions from operational changes by airlines, airports and air traffic management (ATM) organisations. These could include more efficient flight routing and altitudes, reduced holding in the air, optimisation of passenger load factors,[12] and reduced taxiing on the ground.

2.18 For example, the UK National Air Traffic Services (NATS) has adopted a target to reduce air traffic movement (ATM) CO_2 emissions in their airspace by an

10 Bypass ratio is 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.

11 Blended wing bodies improve airframe dynamics through a flattened profile and wing structures that are smoothly blended to the body.

12 Load factors express the degree of occupancy of an aircraft. The higher number, the fuller the aircraft (e.g. a full aircraft would have a load factor of 100%).

average of 10% per flight by 2020, by modernising airspace around London and other major English cities. Similarly, the Single European Skies (SES) initiative is improving the management of European airspace by replacing national airspace boundaries with 'functional airspace blocks' (FABs).

Biofuels

2.19 The prospect of rising oil prices, combined with carbon constraints arising from cap and trade schemes, has resulted in growing interest in the potential use of biofuels as an alternative to kerosene in jet engines. Recent tests by engine and airframe manufacturers have shown biofuels use in aircraft to be technically feasible – indeed, biofuels are now officially certified for use up to 50% blend with conventional jet fuel. However, there are important questions around their sustainability (see under 'limitations and tradeoffs' below), which will need to be taken into account as policy develops.

Potential limitations and tradeoffs

2.20 The limitations of these technological and operational innovations explain why aviation is expected to take relatively longer to decarbonise than other sectors.

2.21 In the first place, the potential for technological innovations to reduce emissions is constrained by the relatively slow turnover of the aircraft fleet compared to other vehicle types, with aircraft having a typical service life of up to around twenty-five years. This means there can be significant lead-in times before new technologies achieve significant fleet penetration and deliver sizeable emissions reductions. Potentially fleet turnover could be accelerated, for example by mandating an early retirement date for aircraft, but this is likely to be costly (see Chapter 5).

2.22 Operational changes can often be introduced more quickly, but are also subject to some important limitations. For example, once airspace has been optimised, it does not provide a source of further ongoing emissions reductions.

2.23 There are also significant questions around the potential for biofuels to act as a sustainable alternative to kerosene. Whilst biofuels use in aviation has been shown to be technically feasible, the pace and timing of biofuels penetration in the aviation sector remains uncertain, owing to the technical barriers that need to be overcome and the investment needed to achieve commercial-scale production.

2.24 In the longer term, there are important sustainability concerns around large-scale biofuels use. The CCC and others have highlighted in particular:[13]

- **Emissions from producing biofuels.** These are heavily dependent on the type of feedstock used, meaning that the potential lifecycle GHG savings from biofuels vary significantly depending on the production route.
- **Effects of land-use change.** Where growth of biofuels feedstock results in land-use change directly (e.g. deforestation) or indirectly (e.g. displacement of food production), this can reduce lifecycle GHG savings significantly.

13 Committee on Climate Change (2009) *Meeting the UK Aviation Target: options for reducing emissions to 2050*, available at http://downloads.theccc.org.uk/Aviation%20Report%2009/21667B%20CCC%20Aviation%20AW%20COMP%20v8.pdf.

- **Competition for available biofuels.** Aviation will have to compete for scarce biofuels with other sectors such as road transport, shipping, household cooking and heating, and energy generation.
- **Tensions between biofuels and food production.** Projected population growth and rising living standards in developing countries are likely to lead to increasing requirements for global food production. It is unclear whether sufficient land and water will be available for growing biofuels feedstock on a large scale.

2.25 Finally, there are some tradeoffs between reducing different components of aviation emissions, and between emissions reductions and other environmental objectives. For example, the development of high bypass-ratio turbofan engines has led to reduced fuel consumption and CO_2 emissions, and also contributed to noise reductions, but these engines tend to increase NO_X formation unless extra measures are taken to address this. Similarly, curbing noise pollution by designing routes that avoid flying over heavily populated urban areas ('noise preferential' routes) can lead to increased fuel burn and higher CO_2 emissions where those routes require aircraft to fly further.[14]

Alternatives to air travel

2.26 Aside from technological and operational changes, emissions could also be reduced through use of alternative less-carbon intensive transport modes, such as high-speed rail, or new technologies such as videoconferencing. In the case of high-speed rail, the greatest potential for substitution is likely to be on domestic routes and international short-haul routes to destinations in northern and central Europe, which account for a relatively small proportion of aviation emissions. In the longer term, however, and with significant investment, substitution could become more viable on longer routes.

2.27 The scope for videoconferencing to reduce aviation demand is less well understood. In particular, the extent to which such technologies act as substitutes or complements for air travel is currently unclear. The DfT is conducting further research in this area.[15]

2.28 The World Wildlife Fund's (WWF) 'One in Five Challenge' encourages participating organisations to reduce their business flights by 20% over five years. Seven organisations have so far achieved the target, in some cases in significantly less than five years, through a mix of measures such as modal switching and videoconferencing.[16]

14 Lee (2009) 'Aviation and Climate Change: the science'.

15 See Department for Transport (2013) *Aviation Policy Framework*, p. 49.

16 http://www.wwf.org.uk/how_you_can_help/get_your_business_involved/one_in_five_challenge/

3. Climate change policy frameworks

3.1 The climate effects of aviation are a global problem and would, ideally, be addressed through a global framework. Establishing such a framework has, however, proved challenging, for example ensuring an equitable balance between developed countries (which are responsible for the majority of aviation emissions to date) and developing countries (which will be responsible for an increasing share of future emissions). As a consequence there are currently a number of overlapping national and multinational frameworks in operation.

3.2 This chapter sets out the current and prospective policy frameworks that will have a bearing on the Commission's work. It also discusses voluntary action being undertaken by the aviation industry.

Progress towards a global policy framework

3.3 The International Civil Aviation Organization (ICAO) has been debating options for a global market-based measure to tackle aviation emissions. Market-based measures could include emissions trading schemes or emissions offsetting. ICAO believes that such a measure would contribute to achieving a specific emissions reduction in the most cost-effective and flexible manner.[17]

3.4 However, progress towards a global market-based measure has been relatively slow, and the ICAO Council on 9 December 2012 agreed to set up a high-level group to try to resolve the issues that had been preventing more rapid progress. The high-level group has since met three times, most recently in March 2013. It will make recommendations that will be debated at the ICAO General Assembly in September 2013. The Airports Commission will continue to monitor the ICAO discussions as our work progresses.

3.5 Alongside steps towards a global market-based measure, ICAO's Committee on Aviation Environmental Protection (CAEP) has been debating a new CO_2 standard for aircraft. Agreement has now been reached on a system for measuring emissions and on certification procedures. Work is continuing around the stringency and scope of the standard.[18]

3.6 However, international rules and regulations also place some constraints around potential policies to tackle aviation emissions. For example, the 1944 Convention on International Civil Aviation (the 'Chicago Convention'), which established the ICAO, prohibits signatory states from imposing taxes on

17 http://www.icao.int/environmental-protection/Pages/market-based-measures.aspx

18 http://www.icao.int/environmental-protection/Pages/technology-standards.aspx

fuels purchased for use in international aviation.[19]

European policy framework

3.7 In lieu of a global deal, aviation emissions have been included in the EU Emissions Trading System (EU ETS) since January 2012. The EU ETS is a cap and trade system, covering flights arriving at or departing from airports in the European Economic Area (EEA), irrespective of the nationality of the carrier. Tradable emissions allowances are issued up to the level of the cap, and allocated to market participants through a mixture of free allocations and auctions. The initial annual cap for aviation emissions has been set at 97% of average emissions between 2004 and 2006. From 2013 to 2020, it will be reduced to 95% of 2004–2006 emissions.

3.8 The aim of the EU ETS, in common with the market-based measures being contemplated by ICAO, is to deliver a specific reduction in emissions in the most cost-effective way. It is also designed to incentivise investment in emissions abatement measures, since any sector that emits less than the relevant cap can sell its surplus allowances to participants in other sectors.

3.9 However, as a result of the economic downturn, there is currently a significant surplus of emissions allowances in the market. The European Commission (EC) is trying to tackle this by rescheduling the release of further allowances into the market, and by reducing the amounts auctioned in the early part of Phase III, which runs from 2013 to 2020.

19 http://www.icao.int/publications/pages/doc7300.aspx

3.10 A further issue is the opposition the ETS has provoked from third party states, including the United States, Russia, China and India. These countries argue that the ETS infringes their sovereignty (by covering non-EU airlines) and is extra-territorial (by including emissions outside EU airspace). Twenty-six nations have signed a declaration formally opposing the inclusion of aviation in the ETS, and several have directed their airlines not to comply with the ETS, or are contemplating doing so.

3.11 As a result of the formation of the high-level group at ICAO, and the potential for progress towards a global measure, the EC announced in November 2012 that it would 'stop the clock' on the enforcement of ETS obligations on flights between European airports[20] and the rest of the world. This was intended as a goodwill gesture, and to enable the current negotiations in ICAO to make further progress. However, the EC has stated that if 'clear and sufficient progress' is not evident by the ICAO General Assembly in September 2013, then it intends to reinstate ETS obligations on these flights.[21]

UK national policy framework

3.12 The Climate Change Act 2008 established the UK's legislative framework for reducing greenhouse gas emissions. It set out a legally binding target to reduce overall UK emissions by at least 80% below 1990 levels by 2050 and a system of five-year carbon

20 Airports located in the European Economic Area (EEA), including for this purpose Croatia, Switzerland and the dependent territories of EEA States.

21 Department of Energy and Climate Change, and Department for Transport (2013) *Implementing the Aviation Emissions Trading System 'stop the clock' Decision in UK Regulations*, available at https://www.gov.uk/government/consultations/implementing-the-aviation-emissions-trading-system-stop-the-clock-decision-in-uk-regulations.

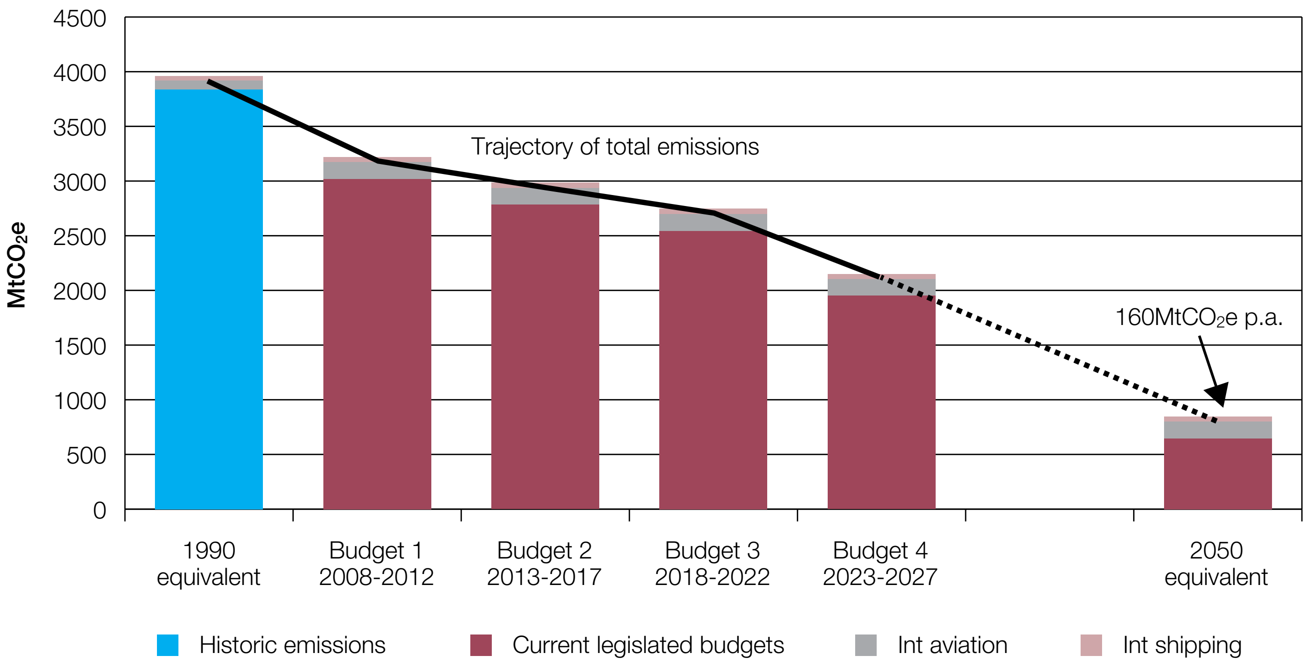
budgets to support this. It also established the Committee on Climate Change (CCC), an independent statutory body, to advise the Government on emissions targets and report to Parliament on progress towards meeting them.

3.13 In its initial advice to Government, the CCC recommended against including emissions from international aviation in legislated carbon budgets, citing difficulties in estimating these emissions at the UK level. In particular, at that time the methodology for allocating the EU ETS cap to individual Member States had not yet been settled, and the CCC expressed concern that some of the proposed methodologies did not fairly represent emissions from UK aviation. For similar reasons it also recommended that emissions from international shipping should be excluded.

3.14 However, to ensure that the UK remains on an overall emissions trajectory consistent with the 80% target, both the CCC and the Government have taken the approach of assuming emissions pathways that include international aviation and shipping emissions. Effectively, currently legislated carbon budgets two to four (covering 2013 to 2027) have been set by calculating the total emissions compatible with the 80% economy-wide target, then deducting notional emissions from international aviation and shipping to derive the legislated carbon budget. This approach is illustrated in Figure 3.1.

3.15 The Climate Change Act required the Government to make proposals on formally including international aviation and shipping emissions in legislated carbon budgets by the end of 2012, or to lay before Parliament a report

Figure 3.1: Existing carbon budgets assume an emissions pathway that allows for emissions from international aviation and shipping



Source: CCC (2012) *Scope of Carbon Budgets: statutory advice on inclusion of international aviation and shipping*, available at http://www.theccc.org.uk/publication/international-aviation-shipping-review/. See also DECC (2012) *International Aviation and Shipping Emissions and the UK's Carbon Budgets and 2050 Target*, available at https://www.gov.uk/government/publications/uk-carbon-budgets-and-the-2050-target-international-aviation-and-shipping-emissions.

Notes: International aviation and shipping are shown for Budget 1 for illustrative purposes only. Emissions from 1990 and 2050 have been scaled up five times to be equivalent in scale to the five-year carbon budgets.

explaining why it had not done so. The CCC published updated advice in April 2012,[22] in which it concluded that the earlier methodological difficulties in estimating aviation emissions at the UK level had largely been resolved, and that there was no longer any reason to treat these emissions differently. It recommended that emissions from both international aviation and shipping should be formally included in carbon budgets and the 2050 target.

3.16 The Government, responding in December 2012 following the EU's decision to 'stop the clock', has deferred a decision on including these emissions in carbon budgets, citing the need to allow international negotiations relating to the aviation EU ETS to be resolved, since these could impact on the methodology for allocating emissions to individual Member States.[23]

3.17 Separate from the UK statutory framework, in the context of its 2009 decision to allow an expansion of Heathrow airport, the then-Government adopted a target that gross CO_2 emissions from UK aviation in 2050 should not exceed 2005 levels. Analysis undertaken by the CCC at that time suggested that demand growth of around 60% between 2005 and 2050 was compatible with that target, given prudent assumptions around aircraft fuel efficiency and future technological developments.

3.18 The current Government is awaiting greater certainty over the future scope of the EU ETS, and the outcome of the ICAO negotiations towards a global deal on aviation emissions, before making a decision on whether the UK should retain a national emissions target for aviation.[24]

3.19 The CCC has recognised the importance of planning assumptions for longer-term emissions from individual sectors, although it argues that, for international sectors such as aviation and shipping, the key driver of emissions reductions should be global or EU policies, rather than UK unilateral approaches.[25]

3.20 Whilst the aim of constraining aviation emissions to 2005 levels in 2050 is not itself legally binding, legislated carbon budgets have been set on the assumption that aviation emissions out to 2050 are constant at the level of the EU ETS cap in 2020. Given that the EU ETS cap has been set with reference to average emissions between 2004 and 2006 (i.e. very close to 2005 emissions levels), a significant overshoot of 2005 aviation emissions levels in 2050 would suggest more challenging reductions in other sectors.

22 CCC (2012) *Scope of Carbon Budgets: statutory advice on inclusion of international aviation and shipping*, available at http://www.theccc.org.uk/publication/international-aviation-shipping-review/.

23 Department for Energy and Climate Change (2012) *International Aviation and Shipping Emissions and the UK's Carbon Budgets and 2050 Target*.

24 DfT (2013) *Aviation Policy Framework*, p. 47.

25 CCC (2012) *Scope of Carbon Budgets*, box 1, p. 11.

Action by industry

3.21 Outside these formal national and multinational frameworks the aviation industry is also undertaking voluntary action to reduce its emissions. For example, Sustainable Aviation, an alliance of UK airlines, airports, aircraft manufacturers and air navigation service providers, has set out a CO_2 Road-Map based on improvements in air traffic management, greater fuel efficiency, use of sustainable fuels, and carbon trading.[26]

3.22 The International Air Transport Association (IATA), which represents about 240 airlines around the world, has adopted a set of targets to reduce net aviation emissions. These include a cap on aviation CO_2 emissions from 2020, an average improvement in fuel efficiency of 1.5% per year from 2009 to 2020, and a reduction in CO_2 emissions of 50% by 2050, relative to 2005 levels.[27]

3.23 Individual airlines, airports and manufacturers are also working to reduce their emissions. For example, British Airways is undertaking a joint project with US renewable energy company Solena to develop a sustainable biojet fuel from municipal waste, and is aiming to build the first commercial scale biojet fuel plant in Europe in south-east England. The airline has also joined up with Rolls-Royce on a project supported by the US Federal Aviation Association (FAA) to enable wider use of sustainable fuel in the aviation sector.

3.24 At Heathrow airport, Singapore Airlines, Airbus, NATS and the airport's then owner BAA worked to develop a new take-off procedure for A380s. The procedure, which has been in use since 2010, saves around 300 kg of fuel per flight, which equates to about 1 tonne of CO_2 emissions.

26 Sustainable Aviation (2012), *Sustainable Aviation CO_2 Road-Map 2012*, available at http://www.sustainableaviation.co.uk/wp-content/uploads/SA-CO2-Road-Map-full-report-280212.pdf

27 http://www.iata.org/policy/environment/climate/Pages/index.aspx

4. Forecasting aviation emissions

4.1 In order to assess the UK's future aviation capacity and connectivity needs, and the climate change implications of meeting those needs, the Commission will require credible forecasts of future aviation emissions. This chapter discusses two sets of forecasts for CO_2 emissions from UK aviation: those produced by the DfT alongside its demand forecasts, most recently in January 2013; and those produced by the CCC as part of its 2009 analysis of the UK aviation sector-specific emissions target. It compares the methodology used in each case and the key results.

4.2 The chapter also discusses some potential uncertainties around aviation emissions forecasts, including the treatment of non-CO_2 emissions and sensitivity to future changes in the carbon price.

Department for Transport forecasts

4.3 The DfT produces forecasts of CO_2 emissions from UK aviation on a regular basis alongside its demand forecasts. The most recent set of forecasts for passenger numbers and emissions were published in January 2013.[28] As set out in our recent discussion paper *Aviation Demand Forecasting*,[29] the Commission currently expects to use DfT's forecasting approach as the starting point for our own assessment of future aviation demand. However, we are seeking evidence and views as to how the DfT approach might be enhanced or supplemented to make it as effective as possible in supporting our work.

Methodology

4.4 There are three basic stages to the DfT's aviation emissions forecasting approach, which are also shown in Figure 4.1:

i. **Forecasting numbers of flights from UK airports to different destinations:** The National Air Passenger Allocation Model (NAPAM) divides traffic to 48 international zones into different classes of plane size, depending on the type of airline flying the route (e.g. low-cost carrier vs. full-service airlines), the historical characteristics of planes used on similar routes and the level of demand for each route. In effect this means that routes to short-haul destinations tend to use smaller aircraft whilst 'thicker' routes with more passengers will tend to use larger aircraft.

ii. **Matching flights to types of aircraft:** The Fleet Mix Model maps the six aircraft size categories and

28 Department for Transport (2013) *UK Aviation Forecasts*, available at https://www.gov.uk/government/publications/uk-aviation-forecasts-2013.

29 Airports Commission (2013) *Discussion Paper 01: Aviation Demand Forecasting*, available at https://www.gov.uk/government/publications/discussion-paper-on-aviation-demand-forecasting.

three airline types output from NAPAM to specific types of aircraft. The mix of aircraft within the fleet is projected forwards from the existing position by assuming retirement ages by aircraft type (the current average is 22 years). Although in the near future retired aircraft are replaced with known types of aircraft, assumptions are required about the nature of new aircraft types that enter the fleet post-2020.

iii. **Calculating implied CO_2 emissions:** The CO_2 Emissions Model combines the distance of flights to the different destination zones with information about fuel efficiency for existing aircraft types and assumptions about fuel efficiency for future aircraft types to predict the resulting amount of carbon emitted. The primary source of aircraft fuel efficiency information is the European Environment Agency's CORINAIR Emissions Inventory Guidebook, updated and supplemented by an independent study made by QinetiQ.[30] Further adjustments are made to reflect realistic flight routings, operational improvements by airlines and air traffic controllers, the volume of sustainable biofuel usage[31] and to bring estimates into line with latest outturn emissions data. A range of assumptions are considered, reflecting the inherent uncertainty in predicting future technological developments – these are combined with the high and low demand scenarios used as inputs to NAPAM to produce an overall range of CO_2 projections.[32]

4.5 An important feature of these forecasts is that they assume there will be no radical step-change in aircraft technology over the forecast period. Fuel efficiency of new aircraft types improves steadily, reaching a total improvement of around 30–32% by 2040 in the central case, against a 2000 baseline. These assumptions were developed by AEA Technology as part of the DfT Aviation Marginal Abatement Cost (MAC) Curve project.[33]

Results

4.6 Table 4.1 shows DfT's central forecast and overall forecast range for CO_2 emissions from UK aviation to 2050. As can be seen, under the central forecast aviation emissions rise from 33.3 $MtCO_2$ in 2010 to 43.5 $MtCO_2$ in 2030, within the range 39.7 $MtCO_2$ to 48.2 $MtCO_2$. After 2030, the growth in aviation CO_2 emissions is forecast to slow as the effects of market maturity and airport capacity constraints cause the growth of activity at UK airports to slow.

4.7 At the same time fuel efficiency gains continue, with aircraft design improvement and the carbon intensity of emissions reducing with the introduction of biofuels. By 2040, the balance of these effects causes emissions to stabilise, before starting to fall by 2050. The forecasts suggest that in 2050 UK aviation CO_2 emissions will reach 47.0 $MtCO_2$, within the range 34.7 $MtCO_2$ to 52.1 $MtCO_2$. Overall, this results in over

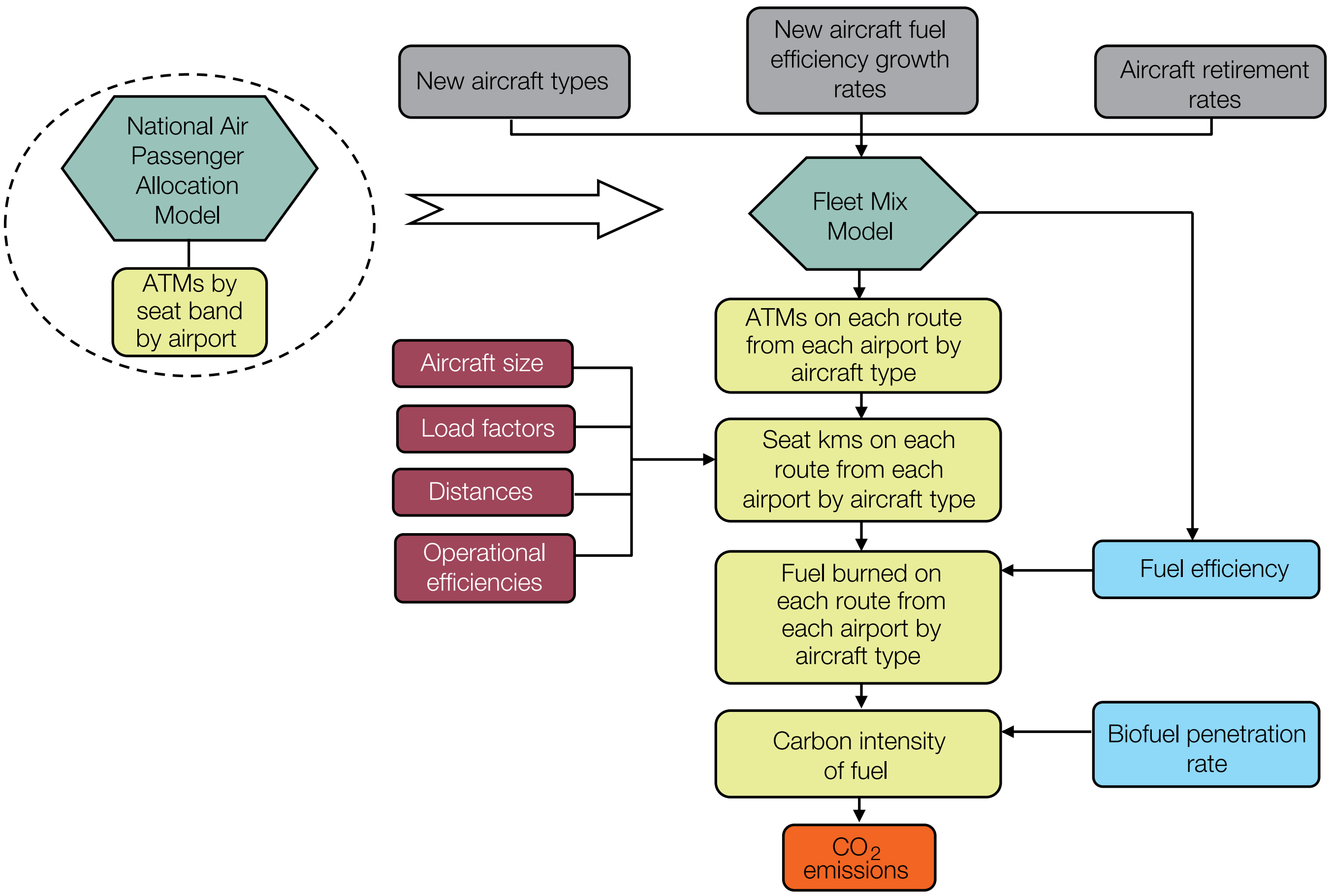
30 QinetiQ (2009) *Future Aircraft Fuel Efficiencies*, available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/4515/future-aircraft-fuel-efficiency.pdf.

31 It is assumed that sustainable biofuel use reaches 2.5% of total aviation fuel use by 2050 in the central case, but this varies from 0% to 5% across the range of assumptions presented.

32 More details are available on pp. 64–65 of *UK Aviation Forecasts*.

33 EMRC & AEA (2011) *A Marginal Abatement Cost Curve Model for the UK Aviation Sector, Technical Report: Final*, available at http://assets.dft.gov.uk/publications/response-ccc-report/mac-report.pdf.

Figure 4.1: DfT aviation model flow chart



Source: Department for Transport (2013) *UK Aviation Forecasts*, available at https://www.gov.uk/government/publications/uk-aviation-forecasts-2013.

a 40% increase in carbon emissions between 2010 and 2050 resulting from an increase in forecast flights of around 90% for the same period.

4.8 Figure 4.2 shows the range of CO_2 forecasts alongside historic aviation CO_2 emissions.

Committee on Climate Change forecasts

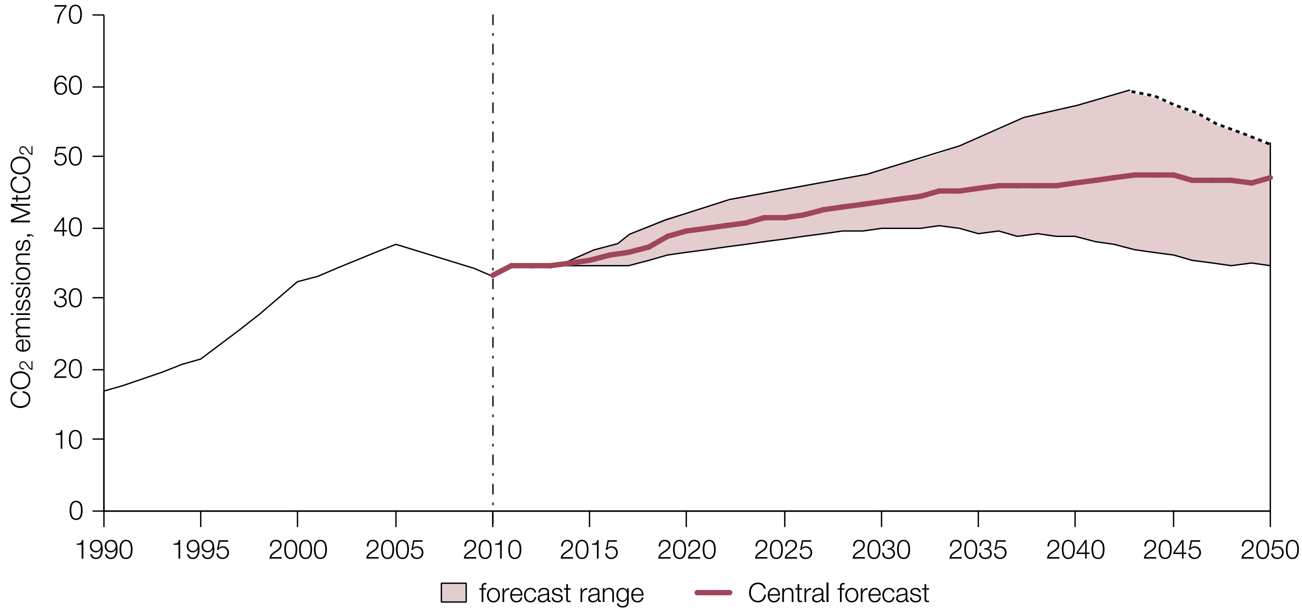
4.9 The CCC commissioned MVA consultancy to produce a reduced form UK aviation demand and emissions model to support its 2009 analysis of options for meeting the aviation sector-specific emissions target. The model has not been updated since and as a

Table 4.1: DfT forecasts for UK aviation CO_2 to 2050 ($MtCO_2$)

	Low	Central	High
2010	**33.3**	**33.3**	**33.3**
2020	**36.3**	**39.4**	**42.5**
2030	**39.7**	**43.5**	**48.2**
2040	**38.7**	**46.4**	**56.9**
2050	**34.7**	**47.0**	**52.1**

Source: DfT (2013) *UK Aviation Forecasts*, available at https://www.gov.uk/government/publications/uk-aviation-forecasts-2013.

Figure 4.2: DfT forecast ranges for UK aviation CO_2 emissions, 2010-2050



Source: DfT (2013) *UK Aviation Forecasts*, available at https://www.gov.uk/government/publications/uk-aviation-forecasts-2013.

consequence the assumptions used (for example around economic growth and oil prices) are now out of date. This means that the results are not directly comparable to the latest DfT forecasts, but the methodology is discussed here as a useful comparator to the DfT approach.

Methodology

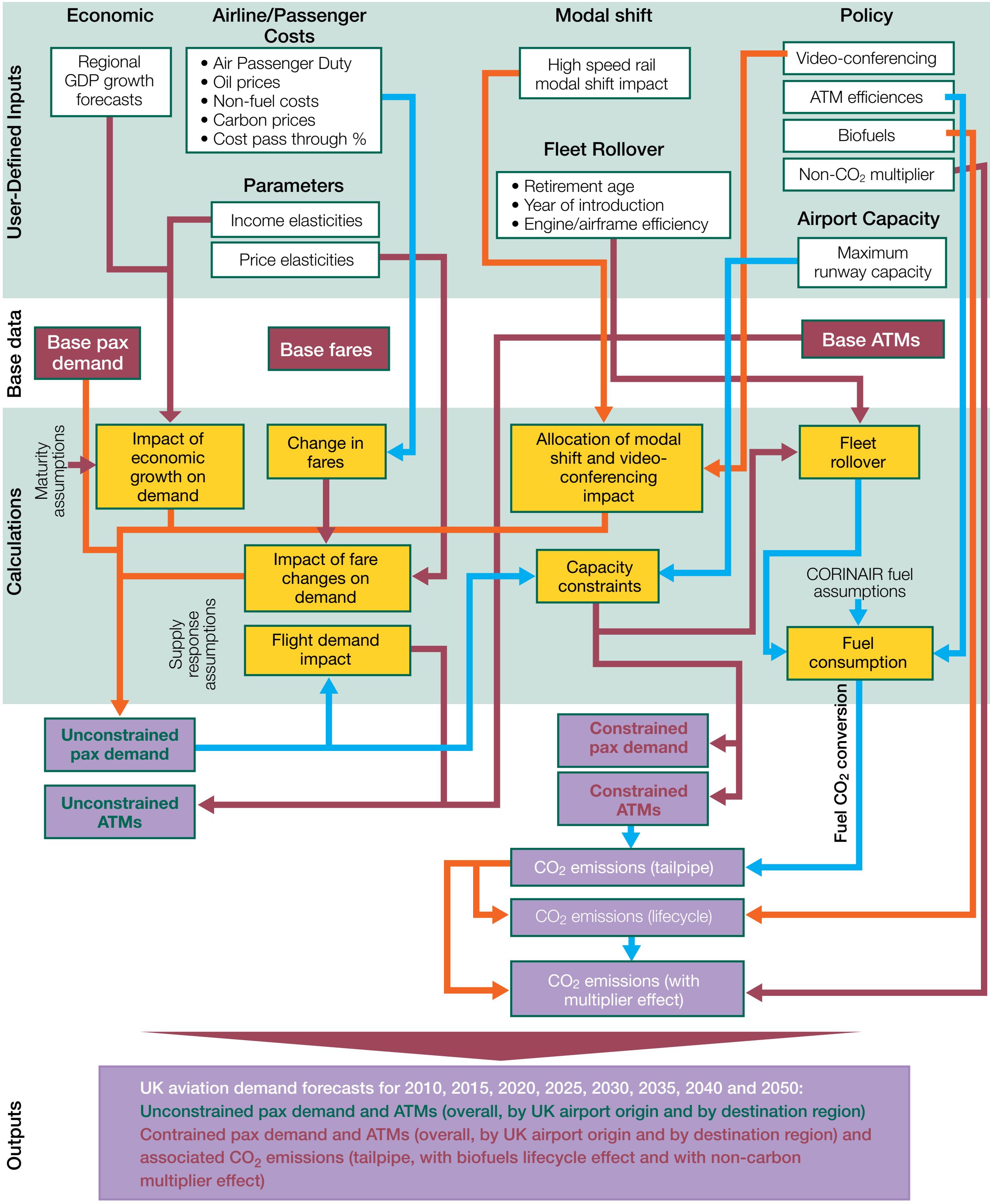
4.10 The CCC/MVA model forecasts air passenger demand within, from and to the UK; the associated air traffic movements (ATMs), both passenger and freight; and the resulting CO_2 emissions. It forecasts future unconstrained demand relative to a base year of 2005, using projected economic growth and ticket prices, and assumptions around the sensitivity of demand to these factors (price elasticities). These forecasts are then constrained using assumptions around future airport capacities. This forecasting approach is illustrated in Figure 4.3.

4.11 The CCC developed three scenarios, 'likely', 'optimistic', and 'speculative', which combined progressively more optimistic assumptions about demand response (from modal shift and videoconferencing), fuel efficiency, and biofuels penetration. Each of these scenarios was modelled with and without carbon emissions constrained to 2005 levels, to test how the aviation sector emissions target could be met under each of the scenarios.

Results

4.12 The CCC found that, without a carbon price and with unconstrained airport capacity growth, UK aviation demand could grow by more than 200% between 2005 and 2050, resulting in a significant overshoot of the 2050 aviation emissions target. The 'likely' scenario, which includes a carbon price and prudent assumptions around fuel efficiency and biofuels, would result in an increase in emissions that are 11 $MtCO_2$ above the 2050 target, falling to around 3 $MtCO_2$ under the 'speculative' scenario.

Figure 4.3: CCC/MVA model flowchart



Source: MVA Consultancy (2009) *UK Aviation Demand and Emissions: model methodology*, 2009, available at http://downloads.theccc.org.uk/Aviation%20Report%2009/MVA%20(2009),%20UK%20aviation%20demand%20and%20emissions%20-%20model%20methodology%20note.pdf.

4.13 Under the 'likely' scenario, a 60% increase in passengers by 2050, relative to the 2005 baseline, would be compatible with the aviation sector emissions target. Effectively, this is the level of growth that is exactly offset by fuel efficiency improvement and biofuels. The demand growth that could be accommodated within the target rises to around 135% in the 'speculative' scenario with its more optimistic assumptions.

Comparing assumptions on technical and operational efficiencies

4.14 Table 4.2 compares the key assumptions from the 2013 DfT 'central' forecast and the CCC's 'likely' scenario (with and without the carbon constraint). As can be seen, the DfT 'central' scenario is slightly more pessimistic than the CCC 'likely' scenario without carbon constraint, in relation to savings from fuel efficiency and biofuels penetration. Acting in the opposite direction are DfT's more optimistic assumptions driving average passenger numbers per flight. However, a far greater difference in fuel efficiency improvements and average numbers of passengers per flight is evident between the DfT 'central' scenario and the CCC 'likely' scenario when a carbon constraint is included.

4.15 This highlights the need for the Commission to build an understanding of how a 'carbon constrained' DfT forecast would compare to the DfT's 'central' forecast, both in terms of the overall level of demand growth and how this is allocated to individual airports and routes, and ultimately how this would differ from the CCC's 2009 analysis.

Uncertainties and sensitivities

4.16 In an earlier discussion paper, *Aviation Demand Forecasting*, we set out some of the uncertainties around forecasting aviation demand long periods into the future. Both DfT's and CCC's CO_2 forecasts are based on their respective demand forecasts, so these uncertainties and sensitivities feed through to the CO_2 forecast results. In addition, there are some further uncertainties in relation to climate change more specifically that the Commission will need to take into account in its analysis.

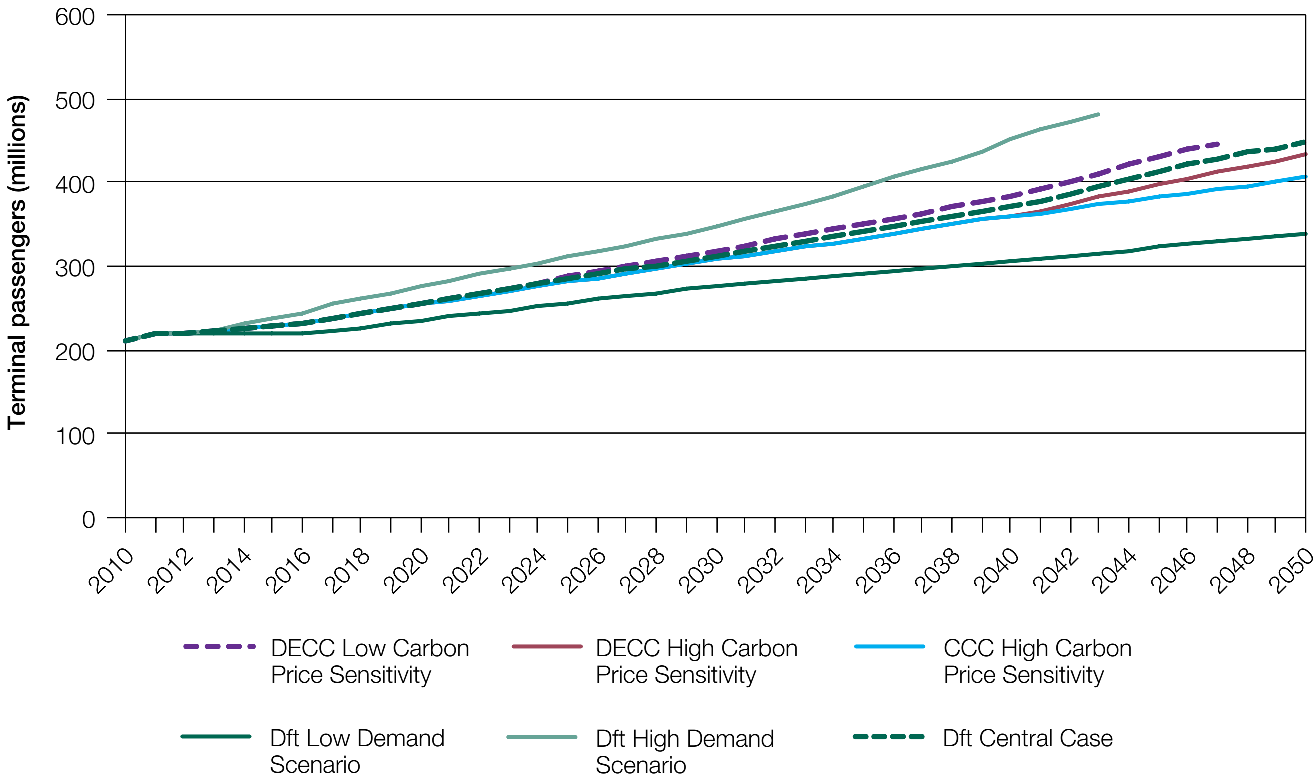
4.17 As discussed in Chapter 2, one key area of uncertainty for emissions forecasts is around potential future technological progress and operational efficiencies, which could reduce the carbon intensity of air travel, and thereby the quantity of emissions relative to any given level of future demand.

Table 4.2: DfT and CCC assumptions on technical and operational efficiencies

	DfT (2013) 'central' scenario	CCC (2009) 'likely' scenario no carbon constraint	CCC (2009) 'likely' scenario with carbon constraint
Savings from fuel efficiency improvement per flight, 2005-2050	22%	27%	32%
Savings from biofuels, of which:	2.5%	5%	5%
Biofuel penetration by 2050	*2.5%*	*10%*	*10%*
Lifecycle GHG savings relative to kerosene	*100%*	*50%*	*50%*
Savings from higher passenger numbers per flight, 2005-2050	20%	16%	3%

Source: CCC and DfT. Assumptions about fuel consumption and aircraft and passengers per flight are made at detailed aircraft and route level in the DfT forecasts. The numbers shown in this table are aggregated averages estimated on the basis of the constrained forecasts.

Figure 4.4: Sensitivity of demand forecasts to carbon prices



Source: Airports Commission analysis, based on DfT aviation model. Indicative carbon prices from DECC and CCC.

4.18 A further complication around forecasting aviation emissions is how to account for non-CO_2 emissions. As discussed in Chapter 2, unlike carbon dioxide, many of the non-CO_2 emissions are not a simple function of aircraft fuel burn. For example, NO_X emissions are engine and technology specific. In addition, whereas CO_2 is long-lived and affects the global climate, many of the non-CO_2 emissions are short-lived and/or more local in their effects.

4.19 The DfT has developed an approach to estimating non-CO_2 emissions from aviation. More recently, this methodology has not been used on the grounds of the scientific uncertainty around the effect of these emissions. Similarly, in its recent advice on the inclusion of aviation and shipping in carbon budgets, the CCC recommended that non-CO_2 emissions not covered by the Kyoto Protocol[34] (including NO_X, contrails and AIC) should not be included in carbon budgets at present, but that options to reduce them will need to be developed over the coming years.

4.20 A final sensitivity is around the future carbon price which, by affecting the cost of air travel, feeds through to both the demand and emissions forecasts. The Commission will need to test its key conclusions around the UK's future aviation capacity and connectivity needs against a range of future carbon prices. The DfT central forecast adopts DECC's central projection of carbon prices, reaching £200/MtCO$_2$[35] in 2050. For indicative purposes, Figure 4.4 shows the effect of adopting DECC's high and

34 Emissions targets under the Kyoto Protocol cover the six main greenhouse gases, namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_20), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6).

35 In real, 2009 prices.

low carbon price scenarios as well as an alternative high carbon price from the CCC[36] where carbon prices reach £500/ $MtCO_2$ in 2050. It suggests that, even with substantially higher carbon prices, the forecast remains well within the range of DfT high and low scenarios unless other input assumptions are varied.

36 http://www.theccc.org.uk/wp-content/uploads/2012/12/1672_CCC_Energy-Bills_bookmarked.pdf.

5. Aviation emissions and airport capacity constraints

5.1 The climate change impacts of aviation have featured prominently in recent debates around airport capacity in the UK. Arguments against airport expansion on climate change grounds presuppose that physical constraints on capacity effectively curb global aviation emissions, in much the same way as traditional policy levers such as carbon pricing or regulation. Conversely, it has been suggested that capacity constraints might either have no effect on global emissions, assuming aviation is included in overall national or multinational emissions caps, or could even be counterproductive, if constraints at UK airports cause flights and their associated emissions to be displaced to overseas airports (so-called emissions ‘leakage’). In addition, airports operating at maximum capacity might find it more difficult to implement operational improvements that could contribute to reduced fuel usage.

5.2 The Commission will need to develop a better understanding of the potential implications of UK airport capacity constraints for global aviation emissions. To begin this process, this chapter sets out some provisional analysis drawn from the DfT aviation model. It seeks to quantify the extent to which capacity constraints at UK airports might act to reduce emissions, and the extent to which they might act to displace them to overseas airports. It also considers the impact of physical constraints on airport capacity relative to some other potential carbon abatement measures for the aviation sector.

5.3 Some of the analysis presented in this chapter represents a new use of the DfT aviation model, so the Commission is keen to hear views from stakeholders on the methodology and the results. We would also welcome any real-world evidence against which the model could be tested.

Carbon savings and the scope for ‘leakage’

5.4 Emissions savings from UK aviation, whether due to capacity constraints or other factors, would contribute towards a UK-specific aviation emissions reduction target. Where this results from the displacement of flights to overseas airports, it could potentially be at the expense of emissions ‘leakage’ to other countries.

5.5 It is important to note that, assuming the EU ETS (or an equivalent scheme) continues out to 2050, aviation continues to be included and that the scheme functions as intended, this would not result in any change in CO_2 emissions at an EU level. In such a scenario, CO_2 savings or displacement to other European countries by the UK aviation sector would all fall within the overall ETS cap, so there would in theory be no scope for emissions ‘leakage’ from UK to European airports.

5.6 However, the Commission recognises that there is inevitable uncertainty around the international policy framework for climate change out to 2050, so we will need to understand the potential implications of UK airport capacity for global aviation emissions under a range of scenarios. We have therefore undertaken some provisional modelling of potential CO_2 emissions savings and 'leakage' attributable to projected capacity constraints at UK airports, based on the latest (January 2013) set of DfT forecasts.

5.7 To do this, we have used DfT's existing estimates of the number of trips foregone or displaced as a result of capacity constraints at UK airports (i.e. the difference between DfT's unconstrained[37] and constrained forecasts). These estimates have then been disaggregated by journey type, using detailed figures provided by DfT. By 2050, the breakdown is as follows:

a) Around 9 million fewer direct point-to-point trips to or from UK airports;

b) Around 0.5 million fewer domestic end-to-end trips;[38]

c) Around 2 million trips to or from the UK that now connect via an overseas hub rather than via a UK hub; and

d) Around 1 million trips by international transfer passengers who now connect via an overseas hub rather than via a UK hub.

5.8 Disaggregating the foregone and displaced trips in this way enables us to estimate what proportion of the apparent reduction in CO_2 emissions resulting from UK airport capacity constraints is likely to represent a genuine carbon saving, and what proportion is likely to be attributable to 'leakage'.

5.9 The fall in the numbers of point-to-point trips within the UK or between UK airports and overseas airports (i.e. categories (a) and (b) above) should result in a direct reduction in UK emissions. Furthermore, as these trips cannot by definition be displaced elsewhere, there is no offsetting increase in other countries' emissions. There cannot therefore be any emissions 'leakage' associated with point-to-point trips, so a reduction in their number owing to capacity constraints should result in a proportionate reduction in global aviation emissions.

5.10 Where transfer passengers from outside the UK opt, in the capacity-constrained world, to transfer via overseas hubs instead of UK hubs (category (d) above) there will be a reduction in UK emissions, but in this case there will also be an offsetting increase in other countries' emissions. The loss of these trips from capacity-constrained UK airports is therefore unlikely to result in a net reduction in global aviation emissions, and in the capacity-constrained world the emissions associated with these trips can be said to have 'leaked'.

5.11 The more complex case is that of transfer passengers from the UK who, in the capacity-constrained world, switch to using an overseas hub (category (c) above). Here, the initial leg of these trips (i.e. between a UK airport and an overseas hub) will continue to count towards UK emissions and is likely to result in a small increase, since it is

37 Unconstrained carbon projections provided by DfT.

38 Note that we are using 'trips' rather than 'terminal passengers' to provide more consistency between different types of passengers. The differences between the two measures are explained on page 13 of DFT (2013) *UK Aviation Forecasts*.

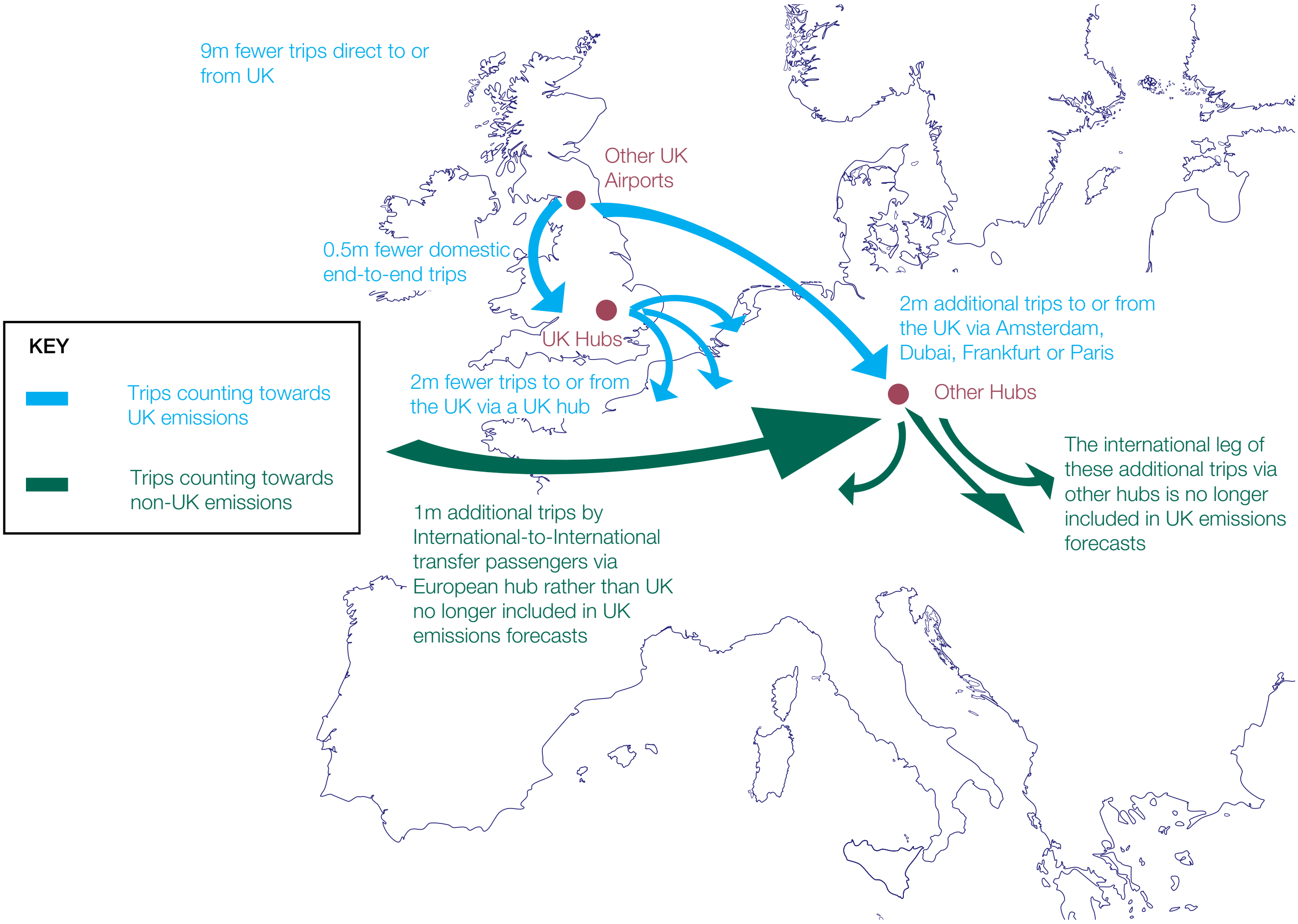
further to fly to an overseas hub than to a domestic one. However, whilst the international leg of these trips (i.e. between the overseas hub and a foreign origin or destination point) will no longer count towards UK emissions, it will count towards other countries' emissions, and can therefore be said to have 'leaked'.

5.12 The balance of these factors by 2050 is shown in Figure 5.1. Trips that will continue to count towards UK emissions are highlighted in blue. Trips that will now count towards other countries' emissions, and where the associated emissions can therefore be said to have 'leaked', are highlighted in green.

5.13 The CO_2 that would have been emitted from these flights from overseas hubs that are no longer counted within the UK's emissions can be approximated using the results of the DfT model. Using this approach, Table 5.1 shows our estimates of potential CO_2 emissions 'leakage' to overseas airports from 2010 to 2050. The rightmost column indicates the proportion of the apparent carbon saving in the capacity-constrained world that, according to our modelling, can be attributed to 'leakage'.

5.14 Note that, in 2030, total 'leakage' exceeds the apparent carbon saving, implying that at this point capacity constraints are actually acting to increase global emissions. This is due to the differential impact of capacity constraints across UK airports. Because

Figure 5.1: Trip displacement effects of capacity constraints at UK airports, 2050



Source: Airports Commission analysis, based on DfT (2013) *UK Aviation Forecasts*.

Table 5.1: Estimated CO_2 'leakage' resulting from capacity constraints at UK airports

	Difference between constrained and unconstrained carbon ($MtCO_2$)	Total Leaked Carbon ($MtCO_2$)	Leakage as proportion of difference*
2010	**–**	**–**	**0%**
2020	**0.2**	**0.2**	**80%**
2030	**0.5**	**0.7**	**120%**
2040	**1.8**	**1.4**	**80%**
2050	**2.1**	**1.2**	**60%**

Source: Airports Commission analysis, based on DfT (2013) *UK Aviation Forecasts.*

*Notes: Figures may not sum because of rounding.

airports with large volumes of transfer traffic are expected to fill up sooner than UK regional airports, the primary effect of capacity constraints in the early years is to displace transfer trips from the UK to overseas hubs. However, as there is still capacity at other relatively large UK airports, point-to-point trips can switch to alternative airports within the UK. Therefore, for a period around 2030, the carbon emissions from increased transfer trips through overseas hubs (which in some cases will result in less efficient routing) exceed the domestic carbon saving from point-to-point trips.

5.15 In the longer term, however, as more UK regional airports start to reach capacity, there are progressively fewer point-to-point trips relative to an unconstrained world and all of these reductions represent direct carbon savings. By 2050, as Table 5.1 shows, the balance of these effects has shifted and only around 60% of apparent carbon savings in the constrained world would have been lost through 'leakage'.

5.16 The story these figures tell is perhaps the intuitive one that the scope for emissions 'leakage' is greatest when a few airports are highly capacity-constrained, but significant room for growth remains at other locations.[39] As more and more airports fill up, there is progressively less scope for flights to be displaced elsewhere, and capacity constraints act increasingly to reduce total emissions. The DfT forecasts do not extend beyond 2050, but with capacity remaining unchanged it is likely that at some point the proportion of apparent carbon savings attributable to 'leakage' would fall below 50%, so that the primary effect of further capacity constraints would be to reduce global aviation emissions.

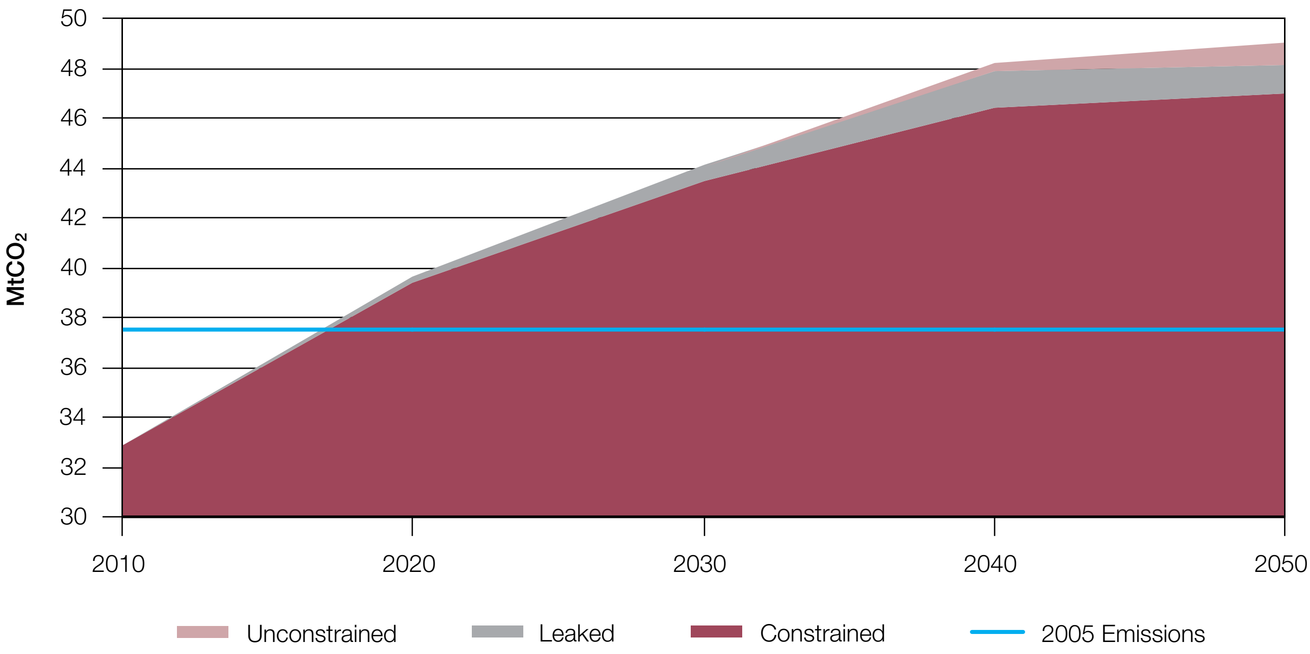
5.17 Figure 5.2 shows the trajectory of estimated CO_2 emissions 'leakage' from UK airports to overseas airports between 2010 and 2050.

Other potential carbon implications of capacity constraints

5.18 Aside from reducing point-to-point flights and displacing transfer traffic to overseas airports, the other main carbon effect of capacity constraints is to

39 Note that the model assumes that there are no capacity constraints at overseas hubs – see Box 5.1.

Figure 5.2: Estimated CO_2 'leakage' resulting from capacity constraints at UK airports



Source: Airports Commission analysis, based on DfT (2013) *UK Aviation Forecasts*.

Box 5.1: Approach to analysis of emissions 'leakage'

To estimate trip displacement, we have used detailed information provided by the DfT about the number of trips displaced as a result of capacity constraints in their 2013 forecasts. This is the difference between DfT's central projections for unconstrained and constrained demand for the 'international-to-international interliner' and 'international-interliner' passenger categories.

Emissions 'leakage' is estimated by scaling up the DfT's constrained UK emissions forecasts by the number of 'leaked' passengers for each of the 48 international zones captured within the model. This takes into account the higher proportion of long-haul trips amongst this group but assumes that the mix of aircraft and load factors remains constant at the levels seen in the DfT constrained forecast.

The Commission's *Aviation Demand Forecasting* discussion paper highlighted that there could be some limitations to the way the DfT captures the degree of competition between major international hubs that would affect the projections used in this analysis. For example, the model may not fully capture the impact that capacity constraints could have on the UK's share of this market, but it also assumes that there are no capacity constraints at foreign hubs. The overall effect of this is unclear, and the Commission is continuing to explore how such issues can be addressed in future modelling and would seek to update this analysis accordingly.

Furthermore, the Commission recognises that the analysis presented here is new, and that there are important forecasting and policy uncertainties when looking ahead as far as 2050. We would therefore welcome views from stakeholders on our analysis, including alternative ways of looking at these issues, and any evidence that could be used to confirm or challenge our initial findings.

increase emissions from aircraft holding in arrivals 'stacks' before they can land. Compared to the issues discussed above, however, the effect is likely to be relatively small.

5.19 NATS estimate that aircraft circling in arrival holds before they land accounted for around 2% of all the CO_2 in NATS' controlled airspace in 2006.[40] Three-quarters of these emissions were generated by Heathrow. Whilst some of this will be due to capacity constraints at that airport, other factors will also have an effect – for instance, some inbound flights will inevitably arrive earlier or later than scheduled and have to hold before they can land. In addition, these figures are not directly comparable to the DfT's forecasts for UK aviation emissions, because 'stacking' results from arriving flights, whereas the DfT forecasts are based on departing flights.

Abatement potential of capacity constraints and other levers

5.20 The relative effectiveness of various measures to curb emissions can be compared using Marginal Abatement Cost (MAC) curves. MAC curves are analytical tools that compare estimates of the emissions savings from different policy measures ('abatement potential') and the net cost of the measure (costs minus benefits) per tonne of emissions saved (the 'cost effectiveness').

5.21 The DfT commissioned an aviation MAC as part of the Government's response to the CCC's 2009 report.[41] This analysis included airport capacity constraints, alongside a number of technological, operational and behavioural measures:

Aviation technology

- A potential CO_2 standard introduced under the International Civil Aviation Organization's Committee on Environmental Protection (ICAO-CAEP) [regulatory CO_2 standard];
- Regulation/incentive to accelerate fleet turnover [early fleet retirement];
- Support for the achievement of ICAO-CAEP fuel-burn goals [Achieve CAEP goals]; and
- Support for retrofitting more fuel-efficient technologies to the existing fleet covering engine-related and other options [retrofitting].

Aviation operations

- Capacity constraints with respect to airport slots [airport capacity];
- Action to reduce inefficiencies in Air Traffic Movements and Air Navigation Service Provider (ATM and ANSP) related operations [ATM efficiency]; and
- Incentives to reduce inefficiencies in air carrier operations [operational incentives].

Biofuels

- Supporting biofuels demonstration plant covering fuel production, refining and demonstration [biofuel demonstration plant]; and
- Regulation to mandate biofuels uptake in aviation (subsidised or unsubsidised) [mandatory biofuels].

40 NATS (2009) *Acting Responsibly: NATS and the environment 2009*, available at http://www.nats.co.uk/wp-content/uploads/2012/07/NATSCorporateResponsibilityReport2009.pdf.

41 EMRC & AEA (2011) *A Marginal Abatement Cost Curve Model for the UK Aviation Sector*, available at http://assets.dft.gov.uk/publications/response-ccc-report/mac-report.pdf.

Behavioural change

- Promotion of behavioural change aimed primarily at the leisure market [behavioural change]; and
- Promotion/incentivisation of remote meetings including Webinar and videoconferencing, aimed primarily at the business market [videoconferencing].

5.22 The high-level results of this analysis are shown in Table 5.2. As can be seen, capacity constraints came out third overall in terms of abatement potential, and sixth overall in terms of cost-effectiveness. The DfT report notes that the main costs associated with capacity constraints that are included in the model are welfare losses for those no longer able to fly, higher fares for the remaining passengers, and reduced airline and airport profitability. The main modelled benefits, aside from the reduced emissions, are infrastructure cost savings.

5.23 However, the DfT MAC curve analysis does not attempt to quantify emissions 'leakage' resulting from capacity constraints, although the report acknowledges it is possible that the displacement of air traffic could lead to less efficient routing of passengers and cargo, with consequential increase in global demand for aviation and hence CO_2 emissions.

5.24 Conversely, the model is also unable to account for a number of indirect benefits of capacity constraints, aside from the reduced emissions. For example, it does not include environmental benefits such as reduced noise and better air quality around constrained airports.

5.25 The MAC curve analysis was based on DfT's 2011 aviation demand and emissions forecasts, and is therefore not directly comparable with the results of the Commission's analysis. In addition, DfT used a different definition of capacity constraints to the Commission. Whereas

Table 5.2: Overview of the estimated emission savings and cost-effectiveness of each policy measure

Policy measure	Total emissions savings, $MtCO_2$, 2010 to 2050	Cost-effectiveness, £/t CO_2
Operational incentives	112 (1st)	40
Mandatory biofuels	72 (2nd)	24
Airport capacity	51 (3rd)	61
Achieve CAEP goals	37	331
Biofuels demonstration plant	29	5 (3rd)
Early fleet retirement	29	>1000
ATM efficiency	26	-77 (1st)
Behavioural change	25	-5 (2nd)
Regulatory CO_2 standard	9	>1000
Videoconferencing	6	159
Retrofitting	3	892

Source: EMRC & AEA (2011) *A Marginal Abatement Cost Curve Model for the UK Aviation Sector*, Table iv, p. 8.

Notes: The MAC curve analysis incorporated a number of scenarios and the estimates here represent averages across the various scenarios.

we have modelled the difference between the unconstrained and constrained forecasts, DfT modelled further reductions in airport capacity below those assumed in the constrained forecasts.

Implications

5.26 Despite the different approaches, the various pieces of analysis presented in this chapter are alike in telling a more nuanced story around the emissions implications of capacity constraints. Significantly, it appears that the effects of capacity constraints on emissions are not uniform, and will vary depending on the type of airport being constrained and the amount of spare capacity at other airports in the route network.

5.27 Whilst the analysis suggests that constraints on UK airport capacity do not necessarily translate directly into global emissions reductions, they will still affect UK emissions and, as a consequence, any UK-specific aviation emissions reduction target. The Commission will work to assess the implications of any proposals for new airport capacity in relation to all relevant climate targets.

6. Adapting to climate change in the aviation sector

6.1 However successful the UK and other countries may be in reducing emissions over the next few decades, historic emissions mean that some future climate change is now extremely likely. In the UK, the most recent set of projections (UK Climate Projections 2009) suggest that we could experience hotter and drier summers, warmer and wetter winters, higher sea levels, and a greater risk of extreme weather events such as floods and heat waves.[42] Aviation, like any other sector, will need to plan ahead and adapt to these potential changes.

6.2 This chapter sets out the UK statutory framework for climate change adaptation. It also summarises some of the main climate risks that have been identified for aviation and considers how adaptation issues might be taken into account in planning future airport capacity.

Statutory framework for climate change adaptation

6.3 The Climate Change Act 2008 provides a statutory framework to ensure the UK is prepared for the risks of future climate change. It requires the Government to undertake a five-yearly assessment of the major risks and opportunities from climate change in the UK. The Adaptation Sub-Committee (ASC) of the CCC provides advice to Government on the preparation of these risk assessments. The first assessment was completed in 2012, and in 2013 Government will publish its first statutory National Adaptation Programme setting out its plans to address the risks identified in the assessment.

6.4 The Act also established an adaptation reporting power. This enables the Secretary of State to require key public service organisations and infrastructure providers ('reporting authorities') to produce reports (every five years) setting out the risks they face from climate change and the steps they are taking to adapt to these. Around 100 organisations, 31 of which were transport organisations, including the CAA, NATS and ten major airports, produced adaptation reports under the first round in 2012. The second reporting round will be published in 2017 and will seek progress reports from the first reporting authorities.

Adaptation challenges for aviation

6.5 The Climate Change Act reporting power process identified a number of potential changes in the climate that create adaptation challenges for the aviation industry. At a global level these might include, for example, changes in the jet stream, which could impact preferred transatlantic routes, and changes in travel patterns and tourism.

42 http://ukclimateprojections.defra.gov.uk/

6.6 Within the UK, some of the challenges identified were:[43]

- **Increased frequency of extreme weather events**, such as the 2010 snow disruption, with potential for flight diversions, delays and airport closures;
- **Increased temperatures/heat waves**, which could result in damage to runways and aprons,[44] or increased fire risk;
- **Increased rainfall and flood risk**, which could cause surface water flooding with implications for airport capacity and accident risk; and
- **Changes in wind patterns**, which could affect air traffic movements.

6.7 Crucially, the reporting process highlighted that aviation has a number of interdependencies with other sectors facing climate risks, notably surface transport, water, energy and telecoms.

6.8 Further to the risks identified by existing reporting authorities during the first round, additional factors may be important for potential airport developments at new sites. For example, proposals for new airports at coastal or estuarial sites will need to take account of risks from sea-level rise and coastal erosion.

Adaptation and airport capacity planning

6.9 It seems likely that adaptation issues will differ significantly between individual airport sites, and that they will therefore be most relevant to the second phase of the Commission's work, when we will be considering the specific locations that might offer the best prospects of meeting any future capacity and connectivity needs that we might identify.

6.10 However, the Commission would also welcome views from stakeholders on any potential adaptation issues that might affect our prior assessment of the UK's overall capacity and connectivity needs, which we will set out in our interim report by the end of 2013.

6.11 The Commission is also interested in stakeholders' views of potential opportunities arising from future changes in the climate that should be taken into account when planning future airport capacity. For example, are there potential changes in passenger flows and travel destinations that we should be taking into account?

43 Defra (2012) *Adapting to Climate Change: helping key sectors to adapt to climate change: Government report for the adaptation reporting power*, available at http://www.defra.gov.uk/publications/files/pb13740gov-summary-adapt-reports.pdf.

44 Loading and refuelling areas.

7. Conclusions

7.1 This paper has discussed a number of issues around aviation and climate change that the Commission will need to consider when making its assessment of the nature, scale and timing of the UK's aviation capacity and connectivity needs. It has presented an overview of climate science and policy as it relates to aviation, and discussed some approaches to forecasting aviation emissions. It has also considered the implications of airport capacity constraints for emissions, and discussed adaptation challenges facing the aviation sector.

Questions

7.2 We have set out in the document a number of particular areas in which we would welcome views and evidence. To guide those preparing submissions on climate change, we have set out below a number of more specific questions of interest. This should not be considered an exhaustive list, however, and we would welcome submissions covering any other relevant topics or issues.

- Do you consider that the DfT CO_2 forecasts present a credible picture of future UK aviation emissions? If not, why not?
- To what extent do you consider that the analysis presented in this paper supports or challenges the argument that additional airport capacity should be provided?
- How could the analysis be strengthened, for example to allow for the effects of non-CO_2 emissions?
- How can we best deal with uncertainty around demand and emissions, including in relation to future carbon prices?
- What conclusions should be drawn from the analysis of effectiveness, and relative cost, of airport capacity and other abatement measures in Chapter 5? Are there alternative analytical approaches that could be used to understand these issues?
- Are there examples of how other countries have considered carbon issues in relation to airport capacity planning that we should be looking at? (Please specify and briefly explain why.)
- What do you consider to be the main climate risks and adaptation challenges that the Commission will need to consider (a) in making its assessment of the UK's overall aviation capacity and connectivity needs, and (b) in considering site-specific options to meet those needs?
- Are there any opportunities arising from anticipated changes in the global climate that should be taken into account when planning future airport capacity?

7.3 Submitted evidence will inform the Commission's assessment of the nature, scale and timing of the UK's aviation capacity and connectivity needs, as part of its interim report at the end of 2013.

How to respond

7.4 Submissions of evidence should be no longer than 15 pages and should be emailed to climatechange.paper@airports.gsi.gov.uk, clearly marked as a response to the 'Aviation and Climate Change discussion paper'. Evidence will be reviewed thereafter by the Commission. If further information or clarification is required, the Airports Commission Secretariat will be in touch.

7.5 We are therefore inviting submissions and evidence by 17 May 2013 to inform our consideration of the climate change implications of future airport capacity.

7.6 In exceptional circumstances we will accept submissions in hard copy. If you need to submit a hard copy, please provide two copies to the Commission Secretariat at the following address:

Airports Commission
6th Floor
Sanctuary Buildings
20 Great Smith Street
London SW1P 3BT

7.7 We regret that we are not able to receive faxed documents.

7.8 We are also expecting to hold public evidence sessions later this year to help us form our assessment of the UK's future capacity and connectivity needs. These sessions are expected to be based on this paper and the other thematic papers the Commission will be publishing, including on the economics of airport operating models, and on demand forecasting. More information on the structure and scope of these sessions will be published on our website:
https://www.gov.uk/government/organisations/airports-commission.

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