

Government Response to the
Committee on Climate Change Report
on Reducing CO₂ Emissions from UK
Aviation to 2050

The information or guidance in this document (including third party information, products and services), is provided by DfT on an 'as is' basis, without any representation or endorsement made and without warranty of any kind whether express or implied.

The Department for Transport has actively considered the needs of blind and partially sighted people in accessing this document. The text will be made available in full on the Department's website in accordance with the W3C's Web Content Accessibility Guidelines. The text may be freely downloaded and translated by individuals or organisations for conversion into other accessible formats. If you have other needs in this regard please contact the Department.

Department for Transport
Great Minster House
76 Marsham Street
London SW1P 4DR
Telephone 0300 330 3000
Website www.dft.gov.uk

© Crown copyright 2011

Copyright in the typographical arrangement rests with the Crown.

You may re-use this information (not including logos or third-party material) free of charge in any format or medium, under the terms of the Open Government Licence. To view this licence, visit www.nationalarchives.gov.uk/doc/open-government-licence/ or write to the Information Policy Team, The National Archives, Kew, London TW9 4DU, or e-mail: psi@nationalarchives.gsi.gov.uk.

Where we have identified any third-party copyright information you will need to obtain permission from the copyright holders concerned.

Contents

Foreword	1
1. INTRODUCTION.....	3
The policy context.....	4
Responding to the CCC	5
2. UK AVIATION FORECASTS.....	8
UK Aviation CO ₂ Forecasts to 2050.....	9
Interpreting the forecasts	11
3. AVIATION MARGINAL ABATEMENT COST CURVE ANALYSIS	12
Baseline	12
The policy measures.....	13
Limitations of the MAC curve approach	14
Overall results and interpretation of the MAC curve analysis.....	15
Abatement potential	16
Cost-effectiveness	16
Results for specific policy levers on the central MAC curve.....	19
Results for levers not on the central 2050 MAC curve	23
Other impacts	24
Sensitivity cases	28
Conclusions	30
ANNEX A: MARGINAL ABATEMENT COST CURVE MODELLING.....	31
Baseline assumptions.....	31
Modelling approach	34

Foreword

The Coalition Government believes that supporting sustainable economic growth is essential to delivering our goal of tackling the deficit while protecting the environment. I have made promoting this approach for aviation one of my Department's five priorities, with a specific objective to adopt a Sustainable Framework for UK Aviation by March 2013.

Aviation makes a positive contribution to our lives. It gives us the freedom to travel and enables UK businesses to compete in the global economy, but a responsible Government cannot ignore its climate change impacts. I believe that to present the challenge we face as one of deciding between economic growth and reducing carbon emissions is a false choice. This Government is anti-carbon, not anti-aviation, and our goal is to find ways to meet our carbon reduction targets while supporting economic recovery.

Aviation is a global business and so is best governed by international action. We fully support the inclusion of aviation in the EU Emissions Trading System from next year and we will continue to work to secure global solutions. This approach provides an important way to ensure that the aviation sector takes strong, cost-effective action to address its climate change impacts while avoiding competitive disadvantage to the UK. However, it is right that we also consider the potential for action at home where that makes sense.

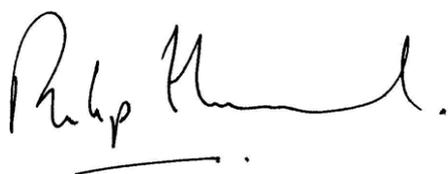
Tackling climate change should be seen in the context of the economic opportunities for the UK in developing new low-carbon technologies. These opportunities can help boost the economy while maintaining the UK's leadership role in tackling carbon emissions. We also need to consider the potential long term economic costs of failing to tackle climate change.

In December 2009, the Committee on Climate Change (CCC) published its report on options for reducing CO₂ emissions from UK aviation to 2050. This is an important report which is why, although it was commissioned by the previous administration, this Government made a commitment to respond to it. I thank the Committee for its work which has taken us a step further towards understanding the issues. This response builds on the CCC's work by setting out the additional analysis we have undertaken and widens the evidence base we will be considering in developing our broader aviation policy.

In March, the Government published *Developing a Sustainable Framework for UK Aviation: Scoping Document*, starting a dialogue with stakeholders towards delivering a lasting strategy that will allow the UK to enjoy the benefits of aviation without paying an unacceptable environmental price. The Scoping Document sets out the issues and asks a series of questions to which we are seeking evidenced contributions. Responses will inform the delivery of a draft Sustainable Framework for UK Aviation which we will publish for consultation next March. This process will allow us to consider a range of approaches to carbon reduction including deciding whether or not to adopt a unilateral UK target specifically for aviation CO₂ emissions, in the widest context, taking account of the latest evidence. Before taking a final decision on this issue, we want to expose this additional work to wider scrutiny. It makes sense to set this question in the broader context of aviation's membership of the EU Emissions Trading System from 2012, and the decision on whether to include international aviation emissions in the UK's wider 2050 climate change target.

This response to the Committee on Climate Change is founded on two new, important pieces of evidence. Firstly, we are publishing revised UK aviation forecasts to provide an assessment of how emissions in the air transport sector could grow in the absence of further action. Secondly, we are presenting an analysis of the cost-effectiveness of a number of potential aviation policy interventions to deliver carbon emission reductions. This work will contribute not only towards developing the new Sustainable Framework for UK Aviation but will also inform decisions on how best to reduce carbon emissions across the wider economy including, for example, where to allocate limited bio-energy supply to achieve the most cost-effective carbon reductions.

I am publishing this material now so that those responding to the Scoping Document have time to comment upon it and to take it into account as they frame their responses. We want this to be an inclusive process which uses public engagement as a way to test the analysis that we have carried out and shape our approach to the future of aviation.



The Rt Hon Philip Hammond MP

Secretary of State for Transport

1. INTRODUCTION

- 1.1** The overriding priority for the Coalition Government is returning the UK economy to sustainable growth. Aviation has a crucial role to play in this and promoting sustainable aviation is one of the Department for Transport's five Business Plan priorities. Aviation improves people's lives and contributes to the economy, allowing visits to friends and relatives while giving businesses the connectivity they need to thrive. It is the Government's intention to ensure that the aviation sector remains strong and that the UK can continue to take a lead in both reducing CO₂ emissions and providing green jobs to support a strengthening economy.
- 1.2** Globally, the aviation sector is responsible for about one to two percent of greenhouse gas (GHG) emissions¹. Domestic and international² aviation emissions amount to about six percent of the UK's GHG emissions. This represents 21 per cent of the UK transport sector's GHG emissions and compares to 43 percent of transport GHG emissions emitted by cars³. However, as other economic sectors decarbonise over the coming decades, aviation is likely to make up an increasingly large proportion of the UK's total GHG emissions. The Government is therefore determined to address the sector's carbon footprint and make aviation a core part of its vision for a greener transport system.
- 1.3** In January 2009 the previous administration asked the Committee on Climate Change (CCC) to provide advice on options for reducing CO₂ emissions from UK aviation⁴ down to, or below, 2005 levels by 2050 (the 2050 aviation CO₂ target). The CCC published its report in December 2009⁵ (the CCC report), and we welcome the very useful contribution it made to understanding the issues. The report set out three scenarios, based on different assumptions about future

¹ Reducing Transport Greenhouse Gas Emissions: Trends and Data, International Transport Forum, 2010 <http://www.internationaltransportforum.org/Pub/pdf/10GHGTrends.pdf>

² There is currently no internationally agreed way of allocating international emissions to individual countries. "UK international aviation emissions" are defined here as those associated with the sale of bunker fuel to the aviation sector from the UK. This is roughly equivalent to emissions from domestic flights, and international flights departing from the UK.

³ UK Greenhouse Gas Emissions, Department for Energy & Climate Change, 2009 www.decc.gov.uk/en/content/cms/statistics/climate_change/gg_emissions/uk_emissions/2009_final/2009_final.aspx

⁴ UK emissions are taken to be the sum of all domestic flights and the emissions from international flights departing the UK.

⁵ Meeting the UK aviation target – options for reducing emissions to 2050, Committee on Climate Change, December 2009 <http://www.theccc.org.uk/reports/aviation-report>

technology and policy developments, and described a range of options for reducing emissions.

- 1.4** In May 2010 the Coalition set out its *Programme for Government*⁶ and in doing so ruled out additional runways at Heathrow, Gatwick and Stansted. This Government believes that any growth in aviation has to be sustainable, and that in order to grow the industry needs to create headroom by reducing its environmental impact. We expect that the necessary headroom can be achieved through a combination of technology, better systems, operating procedures and behaviours. By taking a leading role in promoting the necessary changes, we believe that UK businesses can gain an edge in a competitive world market and are supporting the industry's existing efforts to invest in new technologies through the work of the *National Aerospace Technology Strategy*⁷.
- 1.5** This response to the CCC report provides evidence and analysis to further the debate on reducing aviation's climate change impact, in the broader context of developing a new Sustainable Framework for UK Aviation.

The policy context

- 1.6** The Government believes that an effective way to tackle emissions in an international sector like aviation is through international agreement. Consequently we are pressing ahead with the introduction of aviation in the largest multilateral trading system, the EU Emissions Trading System (ETS), from 1 January 2012. Airlines already have a considerable cost incentive to reduce fuel consumption which directly reduces emissions. Inclusion in the EU ETS will further incentivise airlines to reduce emissions to stay within the cap, or to invest in other sectors where options for reducing carbon are easier and cheaper to deliver. We will also continue to push for an ambitious global agreement to reduce CO₂ emissions from aviation. While the goals⁸ agreed at the 2010 International Civil Aviation Organization (ICAO) Assembly are a step in the right direction towards such an agreement, they are not ambitious enough if aviation is to make a fair contribution to global efforts to reduce climate change emissions.
- 1.7** In addition to the action we are taking internationally to agree limits to aviation CO₂ emissions, a number of other developments are contributing towards carbon reduction. We will be publishing later this year analysis of the best use of available biofuel in the transport sector. The Government is committed to a national high speed rail network and

⁶ http://www.cabinetoffice.gov.uk/sites/default/files/resources/coalition_programme_for_government.pdf

⁷ <http://www.bis.gov.uk/policies/economic-development/leps/lep-toolbox/helping-smes/individual-sectors/aerospace>

⁸ http://www.icao.int/icaonet/dcs/9958/9958_en.pdf

expect that, in the longer term, demand for domestic aviation and much of that for near-European short-haul aviation could be met by high speed rail. We are working to improve the design and use of airspace, for example working with the aviation regulator the Civil Aviation Authority (CAA) on their *Future Airspace Strategy*⁹ and with the EU on the Single European Sky initiative. Both of these initiatives have the potential to reduce fuel burn and emissions and deliver operational efficiencies. The UK is also actively contributing to technical work on setting international noise standards for new aircraft types within ICAO's Committee on Aviation Environmental Protection (CAEP).

- 1.8** In the UK, there are important decisions to be taken before the end of next year on targets for aviation carbon reduction. *The Climate Change Act 2008*¹⁰ requires the Government, by the end of 2012, either to include international aviation and shipping emissions in the UK's wider 2050 climate change target and associated carbon budgets or to submit a report to Parliament explaining why it will not do so. The Government's decision will be informed by advice from the CCC by March next year. We also need to decide whether to adopt the 2050 aviation CO₂ target, announced by the previous administration in the context of its decision to support a third runway at Heathrow, now that decision has been reversed.
- 1.9** The CCC report concluded that passenger growth of 60% by 2050 could be compatible with emissions returning to 2005 levels, under certain assumptions about fuel efficiency, the use of sustainable fuels and behavioural change. However, the CCC did not assess the cost-effectiveness of the different measures identified for reducing aviation's CO₂ emissions nor the policies that might achieve them. We have therefore undertaken work to assess a range of possible policy levers to ensure that our decision on whether to adopt a domestic target for UK aviation CO₂ emissions is based on a robust understanding of the potential costs and benefits of doing so. Before taking a final decision on this issue, we want to expose this additional work to wider scrutiny. We also consider that it makes sense to set this question in the broader context of the decision on whether to include international aviation emissions in the UK's wider 2050 climate change target and of the Sustainable Framework for UK Aviation, which we will publish for public consultation next March.

Responding to the CCC

- 1.10** The aim of this response is therefore to complement and build on the evidence provided in the CCC report. It is the second stage in a three

⁹ <http://www.caa.co.uk/docs/2065/20110630FAS.pdf>

¹⁰ Climate Change Act 2008, <http://www.legislation.gov.uk/ukpga/2008/27/contents>. The Scottish Parliament has also passed legislation setting ambitious CO₂ targets: Climate Change (Scotland) Act 2009 <http://www.scotland.gov.uk/Topics/Environment/climatechange/scotlands-action/climatechangeact>

stage process that will move us from options and scenarios to evidence-based policy decisions which take into account contributions from a wide range of stakeholders. The CCC Report provided advice on the technical abatement potential for reducing emissions from aviation. This response to the CCC assesses the policy options that could deliver this technical abatement. The Sustainable Framework for UK Aviation will use evidence and analysis from a wide range of sources, including this material to inform the Government's developing policy for reducing aviation emissions.

- 1.11** The next two chapters introduce the two technical reports we are publishing as part of this response.
- 1.12** Chapter 2 explains the background to the revised aviation forecasts, including setting out the important developments that have been taken into account since the previous forecasts were published in January 2009 and how these new forecasts have been used in the context of the work described in the following chapter.
- 1.13** Chapter 3 explains the background to the Aviation Marginal Abatement Cost (MAC) curve analysis. This sets out a number of possible policy options – excluding fiscal measures which are a matter for HM Treasury – setting out their potential for reducing CO₂ emissions from aviation, along with an estimate of their costs, out to 2050. This work will inform discussions around appropriate policy measures to ensure that any growth in aviation is sustainable. Further work will be necessary, however, to turn proposals into workable policies.
- 1.14** The analysis makes use of the best available evidence, but the results of any assessment that extends so far out into the future will be inherently uncertain. So we are keen for stakeholders to help us to improve and refine our estimates of the cost and abatement potential of these measures and welcome evidence on this being included in responses to the *Developing a Sustainable Framework for UK Aviation: Scoping Document*¹¹ (“the Scoping Document”).
- 1.15** The analysis concentrates on reducing emissions of CO₂ as these represent the bulk of aviation's contribution to climate change¹². Research to reduce uncertainties about the non-CO₂ impacts of aviation such as NO_x¹³ and water vapour is ongoing. As our understanding of the non-CO₂ effects of aviation increases we will be in a position to address their impact. As part of the MAC curve analysis we also provide a discussion of the other potential impacts of the measures, such as on noise levels and air quality, which are so

¹¹ Developing a sustainable framework for UK aviation: Scoping document, <http://www.dft.gov.uk/consultations/open/2011-09/consultationdocument.pdf>. Responses should be sent to aviation.policyframework@dft.gov.uk by 20 October.

¹² CO₂ makes up 99% of the Kyoto basket of 6 greenhouse gas emissions from aviation. Source: National Atmospheric Emissions Inventory.

¹³ NO_x is a generic term for the mono-nitrogen oxides NO and NO₂ (nitric oxide and nitrogen dioxide).

important to those living near airports. While not quantified as part of the MAC curve analysis, any policies that focus on reducing CO₂ emissions will need to take into account such impacts. Table 2 on page 25 sets out some of these noise and air quality impacts, while the Scoping Document seeks views and evidence on how they can be addressed.

- 1.16** All the analysis presented in this response is for the UK as a whole, and while aviation policy is largely a reserved matter, certain issues such as the environment are the responsibility of the Devolved Administrations (DAs). We hope that this analysis will aid the DAs in their own work to reduce the environmental impact of aviation.

2. UK AVIATION FORECASTS

- 2.1** The Department for Transport (DfT) produces forecasts of air passengers using UK airports and of CO₂ emissions from UK aviation to inform and monitor long term strategic aviation policy and wider Government policy on tackling climate change. We are publishing updated air passenger and aviation CO₂ forecasts as part of this response to inform the development of the Sustainable Framework for UK Aviation. The forecasts are being published as a technical report - *UK Aviation Forecasts, 2011* - which also includes details of the methods and assumptions used to produce them.
- 2.2** The updated forecasts represent our assessment of how activity at UK airports and the associated CO₂ emissions are likely to change into the future, given existing policy commitments. The forecasts have been central to the MAC curve analysis presented in the following chapter, forming the baseline against which a range of policy options for reducing CO₂ emissions from UK aviation have been assessed.
- 2.3** The updated forecasts reflect several important developments since the Department last published forecasts in *UK Air Passenger Demand and CO₂ forecasts*¹⁴ in January 2009. These include:
- the Government's decision to rule out new runways at Heathrow, Gatwick or Stansted airports
 - the decision to include aviation in the EU Emissions Trading System (ETS) from 2012
 - the Government's policy to support the development of a high speed rail route running from London to Birmingham, Manchester and Leeds
 - changes to Air Passenger Duty
 - changes to projections of economic growth and oil prices
 - changes to our forecasting methodology resulting from a process of continual development¹⁵

¹⁴

<http://webarchive.nationalarchives.gov.uk/+/http://www.dft.gov.uk/pgr/aviation/atf/co2forecasts09/co2forecasts09.pdf>

¹⁵ These developments are explained in more detail in the technical report UK Aviation Forecasts 2011 that is being published alongside this response.

- 2.4** All aspects of the forecasting methods used to produce the updated forecasts have been subject to independent peer review. A series of peer review reports written by the independent peer reviewer, and a covering letter summarising the conclusions of the review, are being published alongside the updated forecasts on the DfT website.
- 2.5** To reflect the inherent uncertainty involved in forecasting to 2050, we have developed a range of forecasts against which to assess possible policies for reducing aviation CO₂ emissions. Low and high forecasts define the outer bounds of the range, and a central case has been defined to lie broadly in the middle of the range. The assumptions underpinning these forecasts are presented in Annex A. The main factors driving the range in passenger forecasts are different assumptions about future economic growth, growth in oil and EU ETS carbon allowance prices, the effects of market maturity on air travel demand and the extent to which there will be a ‘bounce-back’ of demand following the significant reductions observed as a result of the recession in 2008/09. We have also varied assumptions on improvements in aircraft fuel efficiency and biofuel penetration of the aircraft fleet, and these are significant in driving the range of aviation CO₂ emissions forecasts.

UK Aviation CO₂ Forecasts to 2050

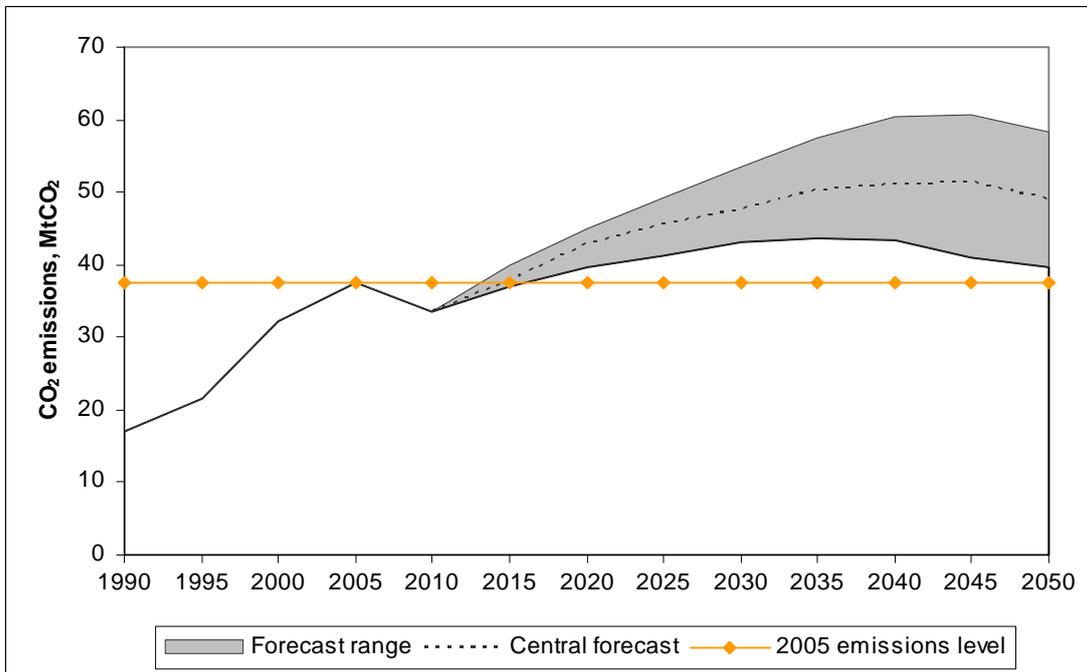
- 2.6** There is currently no internationally agreed way of allocating international emissions to individual countries. We forecast CO₂ emissions produced by all flights departing UK airports to 2050, adjusted to match the DECC published estimate of outturn aviation CO₂ emissions (using the UNFCCC¹⁶ reporting method) in the base year¹⁷. The forecasts therefore include CO₂ emitted from all domestic and international flights departing UK airports, irrespective of the nationality of passengers or carriers and include all freighter traffic.
- 2.7** Figure 1 below presents the updated UK aviation CO₂ forecasts. Following the drop in emissions associated with the impact of the recent economic downturn on aviation activity, we forecast UK aviation CO₂ emissions to grow steadily without further government intervention over the next 20 years, growing from 34 MtCO₂ in 2010 to 48 MtCO₂ in 2030 in the central case. Post 2030, the effects of market maturity and airport capacity constraints cause the growth of activity at UK airports to slow. Improvements in aircraft fuel efficiency are expected to continue beyond 2030 and, in the central and high forecasts, biofuels are expected to penetrate the aircraft fleet as kerosene and EU ETS

¹⁶ <http://unfccc.int/2860.php>

¹⁷ This covers the 31 largest airports in the UK. Emissions from the other minor airports are unlikely to be significant as they offer only short range services. DECC's estimates of outturn CO₂ emissions from aviation are based on the amount of aviation fuel uplifted from bunkers at all UK airports. Our 'forecast' for 2008 is about 0.5 MtCO₂ (1%) below the latest revised DECC estimate for that year.

allowance prices increase. By 2040, the balance of these two effects causes emissions to stabilise, before starting to fall by 2050.

Figure 1: UK Aviation CO₂ forecasts to 2050



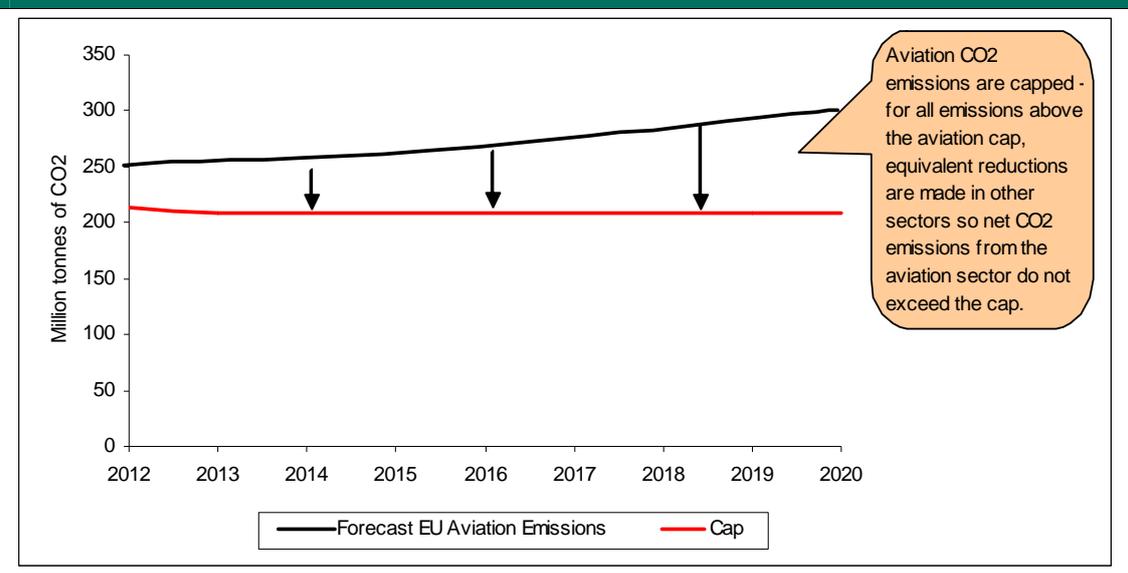
2.8 For comparison, Figure 1 shows the level of CO₂ emissions in 2005 – 37.5 MtCO₂. By 2050, our updated forecasts suggest that UK aviation CO₂ emissions will lie somewhere in the range 40 – 59 MtCO₂ with a central forecast of 49 MtCO₂. This suggests that without further action emissions will exceed their level in 2005.

2.9 The technical report – *UK Aviation Forecasts, 2011* – presents the results of a series of tests, which illustrate the sensitivity of the forecasts to changes in key drivers. The range of CO₂ forecasts presented in Figure 1 does not represent the most extreme combination of the sensitivity tests possible. An extreme range, in which the sensitivity tests for each driving variable are combined to minimise or maximise the aviation CO₂ forecasts are reported in the technical report. The more extreme range is regarded as less useful as the basis for aviation policy development as it is based on combinations of input assumptions that are unlikely to be realised. For example, combining low GDP growth projections with high oil price and EU ETS allowance price projections produces lower CO₂ forecasts than the lower bound of the range presented in Figure 1, but the positive relationship between GDP and oil and EU ETS allowance prices means that this scenario is significantly less likely to occur.

Interpreting the forecasts

- 2.10** Aviation's entry into the EU ETS from 1 January 2012 will mean that CO₂ emissions in the aviation sector will be limited (or capped) at the EU level. Aircraft operators flying into, within and out of the EU will be required to surrender allowances and credits to cover their annual CO₂ emissions. In 2012, the emissions limit (or cap) for the aviation sector will be set at 97% of the average level of emissions over the period 2004-2006 (equivalent to 212.9 million tonnes of CO₂) and will tighten to 95% of average 2004-2006 emissions from 2013 onwards (208.5 million tonnes of CO₂). If aircraft operators across the EU want to exceed the aviation cap, they will be required to buy allowances from other sectors included in the ETS where emissions reductions have taken place.
- 2.11** Therefore, although CO₂ emissions from aviation are forecast to continue to grow in the UK and other EU countries, this growth will not result in any overall increase in the total CO₂ emissions from sectors included in the ETS, because the aviation sector will have to pay for reductions to be made elsewhere. The overall result will be that the net contribution of the aviation sector to CO₂ emissions will not exceed the level of the cap. Figure 2 shows the ETS in operation.

Figure 2: Aviation in the EU ETS



3. AVIATION MARGINAL ABATEMENT COST CURVE ANALYSIS

- 3.1** Governments have a range of policy tools at their disposal to reduce emissions from any individual sector. Each tool will have different levels of CO₂ abatement potential and different costs. Government needs to understand these impacts and costs to deliver robust policies that achieve emissions reductions in the most effective way. Marginal Abatement Cost (MAC) curves are an analytical tool to present and 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”). Whilst a MAC curve is a key piece of evidence that needs to be considered when taking decisions about the most appropriate policy measures to adopt to reduce emissions, it does not capture other important factors that also need to be considered, such as the impact on local air quality or deliverability of the policy.

Baseline

- 3.2** The central forecast of aviation CO₂ emissions presented in chapter 2 forms the central baseline for our MAC curve analysis, against which the potential additional policy options are assessed. The baseline reflects improvements in fuel efficiency of new aircraft over time, driven by the market, as well as existing Government policy, so that the impact on aviation emissions of building a high speed rail line from London to Birmingham, Manchester and Leeds, and of aviation joining the EU ETS from 2012, is included.
- 3.3** Given the combination of a number of assumptions out to 2050, and therefore the significant uncertainty inherent in the baseline, we have also used the “low” and “high” forecasts presented in chapter 2. The impact of the measures has been estimated using all three baselines in order to assess their abatement potential and cost-effectiveness in different future states of the world. The estimates of cost and abatement potential of the policy measures against the high and low

baseline cases are summarised on page 28, and presented in the accompanying technical report on the MAC curve analysis¹⁸.

- 3.4** A fuller description of the assumptions used in the baselines is provided in Annex A.

The policy measures

- 3.5** The policies that have been assessed are intended to reflect potential options that Government might be able to pursue in order to deliver the technical abatement potential identified by the CCC. These policies may be pursued or implemented to different degrees, and we have therefore analysed three cases for each policy measure – “low”, “mid” and “high”. The policies that we have assessed and a brief description of these measures in our “mid” policy case, are set out in table 1 below. The levers fall within the broad categories of incentivising technology, operational measures, promoting the use of sustainable biofuels in aviation, and encouraging behavioural change.

Table 1: Definition of policy measures in the “mid” policy case.

Policies		Description (in the mid policy case)
Incentivising technology	Regulatory CO ₂ Standard	Standard to regulate the CO ₂ emissions level of new aircraft types entering service.
	Early fleet retirement	Regulation or incentive to accelerate fleet turnover by preventing all aircraft over the age of 21 from using UK airports.
	Support for the achievement of the ICAO-CAEP fuel burn goals	Achievement of the ICAO/CAEP fuel burn goals' technologies through international collaboration and progressing technology towards entry into service.
	Support for retrofitting	Support for a range of retrofitting technologies such as winglets, riblets or engine upgrades.
Operational measures	Capacity constraints	Constraining airport and terminal capacity to only existing capacity out to 2050.
	Range of Levers to reduce inefficiencies in Air Traffic Management (ATM) &	Building on existing measures to improve ATM performance, such as the Single European Sky (SES) II performance framework, the Single European Sky ATM Research (SESAR)

¹⁸ EMRC and AEA (August 2011), A Marginal Abatement Cost Curve Model for the UK Aviation Sector.

	Air Navigation Service Provider related operations (“ATM efficiency improvements”)	technology programme and the CAA’s Future Airspace Strategy.
	Range of levers to reduce inefficiencies in air carrier operations (“operational incentives”)	Provision of information and guidance and measures to encourage airlines to adopt practices set out in the guidance material, including an escalating penalty on aircraft departing below Maximum Take-Off Weight.
Biofuels	Support for biofuels demonstration plants	Financial support to set up biofuel demonstration plants that leads to an additional take-up of biofuel, reaching 2% above the baseline from 2025 onwards.
	Regulation to mandate biofuels uptake in aviation (unsubsidised).	Mandating a given percentage of aviation fuel to come from sustainable biofuels every year, rising over time to 20% by 2050.
	Regulation to mandate biofuels uptake in aviation (subsidised).	Mandating a given percentage of aviation fuel to come from sustainable biofuels every year, rising over time to 20% by 2050. Government subsidises take-up.
Behavioural change	Promotion of behavioural change (reduction in leisure travel)	Information provision to support more informed choices. Assumed to result in a 2% reduction in leisure travel and a 5% switch in leisure travel from long haul to short haul destinations.
	Promotion of videoconferencing (reduction in business travel)	Range of measures to encourage videoconferencing, such as voluntary agreements. Assumed to result in a 2% reduction in business travel by 2050.

3.6 The results estimated in the “low” and “high” policy cases are summarised on page 29, and presented in the accompanying technical report on the MAC curve analysis¹⁹.

Limitations of the MAC curve approach

3.7 The abatement potential and the relative cost of alternative policies, presented in the MAC curves, are key pieces of evidence to consider when choosing between policy options to reduce emissions. The relative cost, or cost-effectiveness, is calculated as the net cost of each

¹⁹ EMRC and AEA (August 2011), A Marginal Abatement Cost Curve Model for the UK Aviation Sector.

measure (monetised costs minus the monetised benefits), divided by the estimate of CO₂ savings from the measure, over the assumed lifetime of the policy. Our estimates of the costs and benefits of the policy measures include, for example, the change in cost compared to the baseline of technology, infrastructure, fuel, and impact on consumers of air services.

- 3.8** However, there are certain impacts which may be associated with, and vary between, the different policy options which we have not been able to monetise, and are therefore not reflected in the relative cost of the measures. These include impacts on the UK's growth agenda, air quality, noise, non-CO₂ emissions and consumer choice. Any decisions around appropriate measures to implement in order to reduce CO₂ emissions may also need to take these impacts into account. We have therefore made a qualitative assessment of the key unquantified impacts for each policy measure, set out in table 2 on page 25.
- 3.9** Further, the MAC curve is not able to illustrate the feasibility or deliverability of the alternative policy options, which will vary between the measures. So, for example, some of the measures would require an international agreement (with international funding) to be reached before the emissions savings could be realised in practice. These may be harder (or take longer) to implement than domestic measures.
- 3.10** The MAC curves simply present the estimated cost and abatement potential of a range of policy options. They do not provide an answer to the question of how to deliver these measures; nor do they assess the practical issues this would involve. Thus before a decision is taken on whether any of the options assessed in the MAC curve work should be taken forward, the feasibility and deliverability of each one would need to be considered.

Overall results and interpretation of the MAC curve analysis

- 3.11** The MAC curve that we have generated, given the assumptions used in the central baseline and for each of the policy levers under the “mid” policy case, is presented below. Each policy option is represented by a block, with the width of the block representing the estimate of emissions savings from that measure in 2050, and the height of the block representing the total net cost (cost minus benefits) of the measure per tonne of CO₂ emissions that it saves over the assumed lifetime of the policy. The first MAC curve presents the results for all measures assessed; the second provides the same estimates but with a different scale on the x-axis to make the results of the measures easier to read.

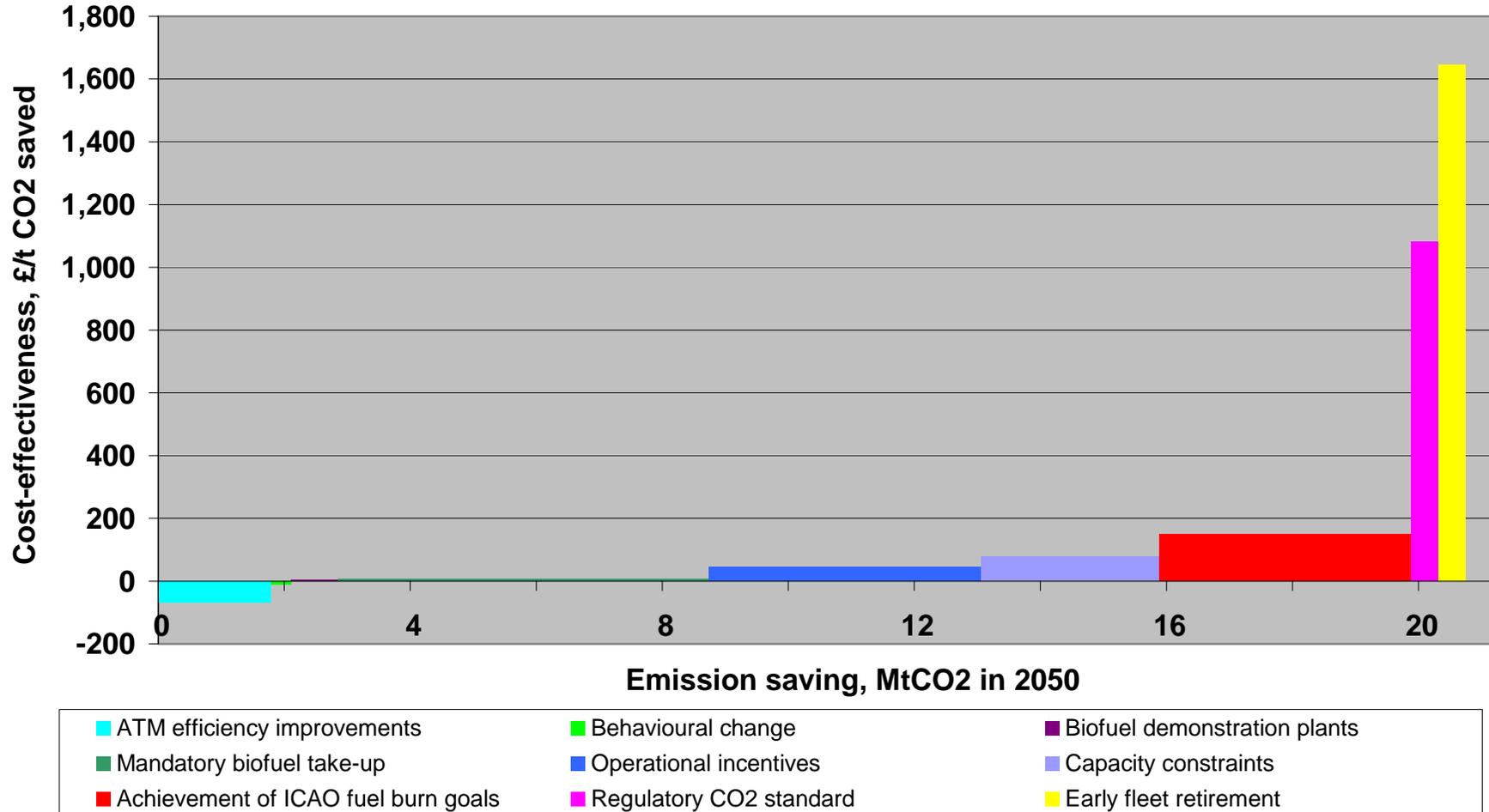
Abatement potential

- 3.12** The results suggest that if all policies assessed were successfully implemented, and each of them achieved the central estimate of emissions savings, UK aviation emissions could be reduced by about 20 million tonnes of CO₂ (MtCO₂) in 2050. This would reduce the estimate of total UK aviation emissions in 2050 (in the absence of further government intervention) under our central baseline forecast to about 30 MtCO₂ in 2050.
- 3.13** The estimated emissions savings would contribute towards a UK-specific aviation emissions reduction target. However, it should be noted that, assuming the EU ETS continues out to 2050, this would not result in a reduction in aviation emissions at an EU level, due to the aviation sector's membership of the EU ETS from 2012. This is because an ETS cap on aviation emissions is set at the EU level. Any reductions from within the aviation sector would reduce their demand for ETS allowances from other sectors, therefore displacing emission reductions from elsewhere within the system (rather than being additional).

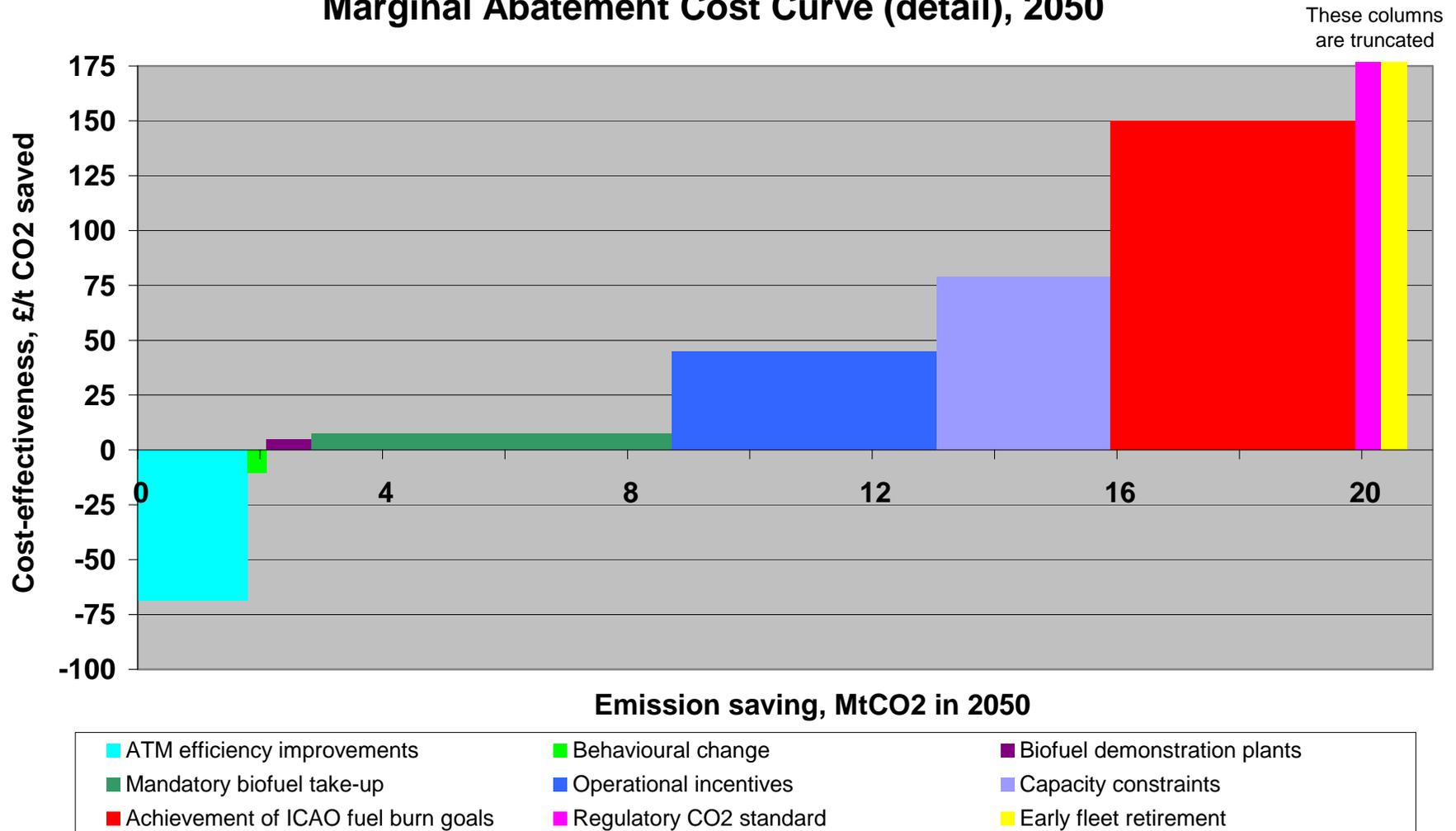
Cost-effectiveness

- 3.14** The estimated net cost of the policy measures varies from a saving of about £69 per tonne of CO₂ saved (ATM efficiency improvements), to a cost of over £1,600 per tonne of CO₂ saved (early fleet retirement). This represents the estimated cost-effectiveness of measures given that the EU ETS is included in the baseline; that is, the estimate of cost-effectiveness includes the reduction in cost associated with having to purchase fewer EU ETS allowances as a consequence of producing fewer emissions. The MAC curves can therefore be interpreted as the estimated benefits exceeding the estimated costs for any measures with a negative cost-effectiveness (below the x-axis); whereas the estimated costs outweigh the estimated benefits for policies with a positive cost-effectiveness (above the x-axis).
- 3.15** It should be noted that these estimates of cost-effectiveness are based on the estimated level of emissions savings achieved from domestic flights and flights departing from the UK only; that is, the emission reductions that would count against a UK-specific aviation target. They do not take account of changes in the level of emissions from non-UK aviation that might also result. For example, the regulatory CO₂ standard is assumed to be implemented at an international level in order to be effective. However, the estimate of cost-effectiveness only takes account of the emission reductions in the UK as a result of implementing the international lever.

Marginal Abatement Cost Curve, 2050



Marginal Abatement Cost Curve (detail), 2050



Results for specific policy levers on the central MAC curve

Range of levers to reduce inefficiencies in ATM & Air Navigation Service Provider related operations (“ATM efficiency improvements”)

- 3.16** These levers are assumed to be targeted at improving the performance of the ATM system to generate fuel savings associated with, for example, taxi delays, continuous climb, direct routes, speed control and optimal descents. This would require additional capital investment.
- 3.17** The lever appears to be relatively cost-effective as the financial savings to airlines from lower fuel costs outweigh the assumed costs of the capital investment. Given the assumptions used, emissions savings are estimated to begin in 2021 after the successful introduction of the lever, and gradually increase in each year out to 2050.
- 3.18** However, it should be noted that it is difficult to attribute ATM efficiency improvements to the level of capital investment assumed – if the level of capital investment required to generate the assumed emissions savings was higher, this would reduce the cost-effectiveness of the lever.

Promotion of behavioural change (reductions in leisure travel)

- 3.19** This measure considers the impact of a voluntary change in people’s leisure travel choices that might result as a consequence of receiving improved information on the environmental consequences of air travel. However, it is acknowledged that there is significant uncertainty around the impact that improved information would actually have on people’s behaviour. This uncertainty has been reflected in the modelling approach used²⁰.
- 3.20** Based on the illustrative assumptions that we have used to model this lever, the results suggest that it is relatively cost-effective compared to other potential levers. The results reflect the assumption that if people voluntarily change their behaviour in response to information provided by the Government, this behavioural change is essentially costless. The benefit to remaining passengers in terms of less congested airports outweighs the cost of the provision of information, resulting in a net benefit overall for the policy.
- 3.21** Significant caution should be attached to the results for this policy option because we do not have any evidence to suggest that a given level of expenditure by the Government on an information campaign

²⁰ See explanation given in Annex A.

would result in the voluntary change in leisure travel modelled. No assessment has been made in this study of what the wider impact might be of imposing disincentives on leisure travel, with our focus being solely on voluntary choices that might be made by travellers.

Support for biofuel demonstration plants

- 3.22** Different biofuel feedstocks have different levels of life-cycle emissions. The use of sustainably sourced biofuels in aviation would be expected to result in lower levels of emissions than the use of kerosene, but would not reduce emissions to zero. IPCC guidance is that the use of biofuels as a fuel by the transport sector should be allocated zero emissions for accounting purposes. Any emissions from biofuel production and transportation would count against the emissions of the relevant sectors. This is consistent with the accounting of biofuel use in the UK's carbon budgets and for aviation in the EU ETS. Within this analysis, the use of biofuels by the aviation sector has therefore been allocated zero emissions for accounting purposes.
- 3.23** This policy involves part funding of demonstration plants and represents a pump priming measure to encourage the production of biofuels and their use by the aviation sector. It is assumed that this funding would accelerate the take-up of biofuels by the aviation sector so that penetration rates are 5% higher than those in the baseline from 2025. There is considerable uncertainty, however, in estimating the extent to which such plant would stimulate biofuels take-up and whether take-up would necessarily be in the aviation sector.
- 3.24** There are also issues surrounding the interaction between this policy and the mandatory targets for the use of biofuel in aviation associated with the following policy. The demonstration plant projects could lead to a more rapid and widespread take-up of biofuels under the following lever, and funding for demonstration plants might therefore be considered a precursor to mandating a given level of take-up.

Mandated levels of biofuel take-up

- 3.25** Two mutually exclusive policy measures were considered – a mandatory level of biofuel take-up by the aviation sector which is (a) unsubsidised; and (b) subsidised by the government. Whilst the level of biofuel take-up (as a proportion of fuel use) would be the same under either option, the abatement potential and cost-effectiveness may be different. Under option (a), if the projected price of biofuel is higher than the projected price of kerosene plus the EU ETS allowance price²¹, it would be expected that as the airline industry is broadly competitive, this higher cost would be passed on to passengers in the

²¹ This is because aircraft operators do not need to surrender EU ETS allowances or credits to cover their use of biofuel. Therefore the cost of biofuel should be compared with the combined cost of kerosene and the EU ETS allowances that would need to be purchased to cover its use.

form of higher fares. The higher fares would have the effect of reducing passenger demand, which could reduce emissions further. However, pricing some passengers off who would otherwise have wanted to travel would have a negative impact on consumer and producer welfare. Thus the overall impact on cost-effectiveness is unclear. Under option (b), the difference in the price between biofuel and kerosene plus the EU ETS allowance price is assumed to be subsidised by the government. Thus there would not be an impact on fares or by extension, on demand.

3.26 The policy option included in the MAC curve reflects policy option (b). The cost of this policy is based on the differential between projected biofuel prices and the cost of kerosene plus carbon allowance prices in the EU ETS. The estimated cost-effectiveness of mandating a particular level of biofuel take-up is therefore very dependent on the assumed biofuel price out to 2050. We do not currently have robust forecasts for the price of biofuel consistent with achievement of this policy (the regulated levels of take-up by the aviation sector might be expected to increase the price of a limited supply of the relevant biofuel). Assuming a higher price projection of biofuel out to 2050 would reduce the cost-effectiveness of this lever, whilst a lower assumed price would increase its cost-effectiveness.

3.27 Further, it is assumed that the amount of biofuel required to be available to the aviation sector in order to achieve the assumed mandated levels of take-up could be supplied sustainably. Limits to the amount of sustainable biofuel that could be supplied would result in either higher biofuel prices (thus reducing the cost-effectiveness of the policy) or would render the policy unachievable.

Range of levers to reduce inefficiencies in air carrier operations

3.28 The ICAO Independent Expert group identified that there is significant abatement potential associated with improvements in air carrier operations²². The assumptions used result in the estimated emissions savings gradually increasing from 2015 up to 2040, and then declining slightly out to 2050. This is consistent with an assumption of increasing the level of efficiency improvement annually to reach a 10% efficiency improvement in 2040, and then maintaining a constant 10% out to 2050.

3.29 Again, the results from this lever should be treated with caution, given that the impact of the lever on air carrier operations (and therefore on emissions) is highly uncertain.

²² Report of the Independent Experts on the Medium and Long Term Goals for Aviation Fuel Burn Reduction From Technology, 2010 (Doc 9963). Available through <http://store1.icao.int/documentItemView.ch2?ID=10260>.

Capacity constraints

- 3.30** The assumed baseline for this lever out to 2050 is existing runway capacity, and an associated increase in terminal capacity (and other infrastructure improvements) to make maximum use of the existing runway capacity. The policy lever modelled reduces airport capacity below that assumed in the baseline. Reducing airport capacity would impose welfare costs on those no longer able to fly and higher fares faced by the remaining passengers. There would also be losses of profitability to airlines and airports from reduced traffic. Against this there would be some saving in infrastructure costs.
- 3.31** In terms of the abatement potential, there would be emissions savings from aviation compared to the baseline at the UK level. Given the assumptions used, emissions savings from this lever are estimated to begin in about 2026, and show a generally upward trend out to 2050. However, some of this displaced traffic (such as connecting passengers) would switch to continental hubs and others would switch to other transport modes (road or rail) that are not accounted for in our modelling. It is possible that the displacement of air traffic could lead to less efficient routing of passengers and cargo, with a consequential increase in global demand for aviation and hence CO₂ emissions. Further to this, there could be a loss to the UK economy if tourists and business people are discouraged from travelling to the UK.
- 3.32** Conversely, the UK economy could benefit if UK residents spend more of their incomes in the UK rather than overseas. There could also be environmental benefits, including lower noise levels and better air quality, around airports that are constrained. No account is taken of these potential wider impacts in the results presented.

Achievement of ICAO fuel burn goals

- 3.33** Given the assumptions used, emissions savings start in about 2025 and gradually increase out to 2050. The estimated cost of this policy is the proportion of total EU funding on research to improve the fuel efficiency of new aircraft that is assumed to come from the UK.
- 3.34** To generate the estimated level of emissions savings, this policy would require both (a) significant additional funding to be forthcoming from other industry and/or EU sources; and (b) the research funded to result in fuel efficiency improvements consistent with achieving the ICAO fuel burn goal technologies. The estimate of cost-effectiveness is only appropriate if these two assumptions hold. Otherwise, both the abatement potential and the cost-effectiveness of the lever could be (significantly) lower than presented.

Regulatory CO₂ standard

- 3.35** A regulatory CO₂ standard could only be implemented through an international agreement. Given the assumptions used, emissions savings from UK aviation specifically are estimated to be realised from about 2024, and increase gradually out to about 2040, when they stay roughly constant out to 2050.
- 3.36** The lever looks relatively cost-ineffective at reducing UK aviation emissions. This is mainly because of the assumed constraints on aircraft production lives as a result of the CO₂ standard, leading to increased aircraft list prices. This is combined with the assumption that the baseline fleet operating in the UK is relatively young compared to the global fleet, and, hence, already relatively fuel efficient. As a result, the emissions savings in the UK arising from the implementation of the CO₂ standard are not very large. However, implementing an international regulatory CO₂ standard through an international agreement would lead to a much greater total level of emissions savings world-wide. We have not taken account of these potential savings in global emissions since our modelling is focused only on UK aviation emissions.

Early fleet retirement

- 3.37** Early fleet retirement appears to be the least cost-effective option for reducing UK aviation emissions, as it requires bringing forward the purchase date for new aircraft over the 40 years of the appraisal period, and therefore more aircraft are purchased than in the baseline. The emissions savings from the policy are lower than might be expected, given the assumption that the fleet using UK airports in the baseline is already relatively fuel efficient.

Results for levers not on the central 2050 MAC curve

- 3.38** Two of the policy levers assessed do not appear on the central MAC curve for 2050 – these are the promotion of videoconferencing (to reduce the need for business travel) and retrofitting more fuel efficient technologies to the fleet.

Promotion of videoconferencing (reductions in business travel)

- 3.39** Given the lack of directly applicable evidence which links the promotion of videoconferencing to reductions in business travel, for the purpose of this analysis we have assumed an illustrative 2% reduction in business travel for our mid policy case as a result of the incentivisation of the use of videoconferencing by 2050.

- 3.40** This lever does not appear on the MAC curve because the modelling suggests that this policy would not reduce emissions. The reason for this is that as airports fill up, reductions in (generally shorter) business trips frees up capacity for (generally longer) leisure trips. Our modelling suggests that the reduction in emissions associated with fewer business trips is more than offset by an increase in emissions from an increase in the number of leisure trips. There is also the possibility that in addition to substituting demand for air travel, increased use of videoconferencing could have the effect of stimulating additional travel. This latter effect is not captured in our modelling.
- 3.41** In their 2009 report, the CCC concluded that there is some evidence that videoconferencing could substitute for air travel. However, they also cautioned that the scope for videoconferencing should not be overstated, as there is some evidence to suggest that meetings based on videoconferencing may be additional, rather than substituting for meetings which require air travel, with the possibility of rebound effects.

Support for retrofitting fuel efficient technologies to existing fleet

- 3.42** This policy lever does not appear in the MAC curve for 2050 as it has no impact on emissions in 2050. This is because the technologies that could be supported are assumed to already be incorporated in new aircraft designs, and the old designs of aircraft for which this lever is applicable will have retired from the fleet by 2050.
- 3.43** This lever would, however, deliver emissions savings (and therefore appear on the MAC curves) in earlier years – in our mid policy case, emissions savings are estimated to peak in the 2020's, and then slowly reduce down to zero from the 2030's onwards.

Other impacts

- 3.44** Where we have been able, we have included an estimate of all the costs and benefits associated with a policy measure in the cost-effectiveness calculation. However, there are some impacts that we have not been able to monetise. A qualitative assessment of the broad impacts that we consider might be most significant is provided in table 2 below.
- 3.45** There may be additional impacts, positive or negative, as a result of implementing a lever, such as on biodiversity, landscape, or the UK's Growth Agenda. The precise impacts of each policy would depend on its detailed design, and would need to be considered alongside the impacts that we have been able to monetise.

Table 2: Potential impacts of the policies in addition to those on CO₂ emissions

Policy Lever	Non-CO ₂	Local air quality	Noise
Regulatory CO ₂ standard	<p>The action of the standard as modelled is to remove older aircraft types from production. In general, more modern types have lower pollutant emissions than older ones, so an overall benefit.</p> <p>Greater propulsive efficiencies of engines would potentially increase contrails/cirrus by a small amount due to lower exhaust plume temperatures.</p>	Newer types will have to have met tighter regulatory standards (assuming ongoing stringencies, particularly for NO _x , and potentially particulates) (co-benefit).	Newer types will have to have met tighter regulatory standards (assuming ongoing stringencies) (co-benefit).
Early fleet retirement	Possible small reduction in NO _x emissions due to a greater proportion of more modern aircraft/engines in the fleet. More modern engines have greater propulsive efficiencies; will potentially increase contrails/cirrus by a small amount	Better, more modern engines should improve air quality (co-benefit)	Better, more modern engines should improve noise (co-benefit)
Support for the achievement of the ICAO fuel burn goals' technologies	If engine overall pressure ratios are driven up, EINO _x (NO _x Emissions Index) may increase without additional efforts to limit NO _x emissions; total NO _x countered by relative reductions in fuel usage. Additional costs may be incurred in combustion development to meet NO _x regulations at	If overall pressure ratios are driven up, EINO _x may increase without additional efforts to limit NO _x emissions; but total NO _x countered by relative reductions in fuel usage. May be a larger effect than on climate as take-off thrust	Greater overall pressure ratios tend to go hand in hand with lower noise (co-benefit). Open rotors will introduce a step-change and will incur additional costs to meet the noise regulations.

	the higher pressure ratios. Greater propulsive efficiencies of engines will potentially increase contrails/cirrus by a small amount.	tends to be dependent on aircraft weight, while cruise thrust can also benefit from improvements in aircraft aerodynamics. No anticipated effects on carbon monoxide (CO), hydrocarbons, smoke	There may be a limit to future noise reduction for narrow-body/short-range types. En-route noise (well beyond airports) may be a growing issue.
Support for retrofiting	No significant effects anticipated. Improved NOx performance of newer engines in most cases	Better, more modern engines should improve air quality (co-benefit)	Better, more modern engines should improve noise (co-benefit)
Capacity constraints	Reduced emissions, reduced impacts (co-benefit)	Reduced emissions, reduced impacts (co-benefit)	Reduced movements, reduced impacts (co-benefit)
Reducing ATM inefficiency	Reduced emissions, reduced impacts (co-benefit)	Reduced emissions, reduced impacts (co-benefit)	Reduced movements, reduced impacts (co-benefit)
Reducing operational inefficiency	Reduced emissions, reduced impacts (co-benefit)	Reduced emissions, reduced impacts (co-benefit)	Reduced movements, reduced impacts (co-benefit)
Support for biofuel demonstration plant	Non-CO ₂ effects remain unchanged according to current understanding (even with reduction in particle emissions, since contrails will form on background particles taken into engine)	Particle emissions potentially reduced	No change

Regulation to mandate biofuels uptake in aviation	Non-CO ₂ effects remain unchanged according to current understanding (even with reduction in particle emissions, since contrails will form on background particles taken into engine)	Particle emissions potentially reduced	No change
Promotion of behavioural change (reduction in leisure travel)	Reduced emissions, reduced impacts (co-benefit)	Reduced emissions, reduced impacts (co-benefit)	Reduced movements, reduced impacts (co-benefit)
Promotion of videoconferencing (reduction in business travel)	Reduced emissions, reduced impacts (co-benefit)	Reduced emissions, reduced impacts (co-benefit)	Reduced movements, reduced impacts (co-benefit)

Sensitivity cases

3.46 Given the uncertainty inherent in forecasting aviation CO₂ emissions and the impact of policy measures out to 2050, we have also produced MAC curves using the high and low baselines presented in chapter 2, and varying the strength that each policy lever is implemented. The technical report sets out the results in more detail, but we provide a summary below.

High baseline case

3.47 The results for the central baseline case (mid policy) suggest that if all policy measures were implemented successfully and delivered the estimate of emissions savings, the total amount of CO₂ that could be reduced from UK aviation in 2050 amounts to about 20 MtCO₂. Using the high baseline (mid policy) case, this increases to just over 28 MtCO₂ in 2050. This is because baseline emissions are higher under the high baseline, and the policy measures, which are often expressed as a percentage improvement, are therefore impacting on a greater total amount of emissions.

3.48 In the high baseline case, UK aviation emissions in 2050 could therefore potentially be reduced to just over 30 MtCO₂ if all measures assessed were implemented successfully and delivered the estimated emissions savings in the mid policy case. Estimated emissions savings for the individual policy options are either about the same as the central baseline case or slightly higher in 2050.

3.49 As well as the potential level of emissions savings that might be achieved from each policy option, the estimate of cost-effectiveness will also differ depending on the baseline used. In the high baseline case, all measures become more cost-effective than in the central baseline case (as the estimated increase in emissions savings is proportionately higher than the increase in the net cost of the measure). The only exception is restricting airport capacity which becomes more cost-ineffective in the high baseline case. This is because the higher emissions baseline reflects higher passenger demand, and therefore capacity constraints prevent a greater number of people from using airport capacity who would otherwise wish to.

Low baseline case

3.50 The results for the low baseline case (mid policy) suggest that if all policy measures were implemented successfully and delivered the estimate of emissions savings, the total amount of CO₂ that could be reduced from UK aviation in 2050 would amount to about 15 MtCO₂ (compared to about 20 MtCO₂ in the central baseline (mid policy) case). This is because baseline emissions are lower under the low

baseline, and the policy measures, which are often expressed as a percentage improvement, are therefore impacting on a smaller total amount of emissions. Emissions could therefore potentially be reduced to about 25 MtCO₂ in 2050 if all measures assessed were implemented successfully and delivered the estimated emissions savings in the mid policy case.

- 3.51** Estimated emissions savings for the individual policy options are either about the same as the central baseline case or lower in 2050. The one exception is behavioural change (reductions in leisure travel) which has higher estimated emissions savings in 2050 than in the central case. This is probably because the lower level of demand in the baseline reduces the amount of ‘rebound’ traffic i.e. any space freed up as a result of the lever is not taken up (or to a lesser degree) by previously suppressed passenger demand.
- 3.52** In terms of cost-effectiveness, generally the policy options have a worse cost-effectiveness in the low baseline case than in the central case. The only exception is the capacity constraint lever, which improves under the low policy case, as there is a lower level of demand which is being suppressed by the restrictions on capacity.

Results using alternative strength policy levers

- 3.53** We have estimated the impact of the policy levers if they are “pulled” both harder and less hard than in the mid policy case. The definition of the levers under these cases is set out in the accompanying technical report. Again, the same caveats around the results and their heavy reliance on the specific assumptions used to generate them apply equally to the results in the alternative policy cases.

High policy case

- 3.54** Using the central baseline, the high policy case would increase estimated emissions savings in 2050 from 20 MtCO₂ to just under 31 MtCO₂.
- 3.55** The impact on the estimated cost-effectiveness of each option depends on whether the increase in emissions savings is proportionately greater than (improvement in cost-effectiveness) or less than (a worsening of cost-effectiveness) the increase in cost as a result of pulling the lever harder. The estimate of cost-effectiveness for three of the eleven levers assessed (early fleet retirement; biofuel demonstration plants and behavioural change) improves under the high policy case, whereas the estimate of cost-effectiveness worsens for the remaining eight measures assessed.

Low policy case

- 3.56** Using the central baseline, the low policy case would reduce estimated emissions savings in 2050 from 20 MtCO₂ to about 11 MtCO₂. Given the assumptions used, four of the measures (regulatory CO₂ standard; retrofitting; behavioural change and promotion of videoconferencing) do not reduce emissions in 2050. Of the remaining measures, the estimate of cost-effectiveness is worse for two options (support for achievement of ICAO fuel burn goals technologies and early fleet retirement) and improves for the other five policy options.
- 3.57** The results for the remaining combinations of the different baselines and policy cases are presented in the accompanying technical report.

Conclusions

- 3.58** Attempting to forecast aviation emissions and the impact of policy levers out to 2050 is inherently uncertain, and very dependent on the specific assumptions used in the analysis. We have attempted to capture some of this uncertainty by varying the input assumptions and strength of the policy levers. The results presented here are not intended to be definitive, and are subject to revision as the evidence base improves.
- 3.59** We would welcome any further evidence that would help refine and improve the estimates of abatement potential and cost-effectiveness.

ANNEX A: MARGINAL ABATEMENT COST CURVE MODELLING

A.1 This annex provides a brief explanation of the methodology used to produce the results set out above. The technical report²³ published alongside this response to the CCC provides a more detailed explanation of the modelling approach used, and presents the results for each of the baseline and policy cases assessed.

Baseline assumptions

A.2 The key assumptions used to develop the baseline forecasts of emissions against which the impact of the policy levers are assessed, is provided in table 3 below. The baseline forecasts incorporate market-driven fuel efficiency improvements; the impact of the aviation sector joining the EU Emissions Trading System from 2012; and the development of a high speed rail route running from London to Birmingham, Manchester and Leeds.

²³ EMRC and AEA (August 2011), A Marginal Abatement Cost Curve Model for the UK Aviation Sector.

Table 3: Central baseline forecast assumptions²⁴

Input assumption	Low baseline	Central baseline	High baseline
Economic growth	Low GDP growth	Central GDP growth	High GDP growth
Oil prices	DECC oil price scenario 1 (“low global energy demand”)	DECC oil price scenario 2 (“timely investment, moderate demand”)	DECC oil price scenario 4 (“high demand and significant supply constraints”)
Air Passenger Duty	Same as central	Rates announced in 2011 Budget	Same as central
EU ETS carbon price	DECC low traded carbon price projection	DECC central traded carbon price projection	DECC high traded carbon price projection
High speed rail	Same as central	New routes from London to Birmingham, Leeds and Manchester	Same as central
Capacity	Same as central	Max use of existing runways and associated increase in terminal capacity. No new runways to 2050.	Same as central
Fuel efficiency improvements	The 2020 generation aircraft are assumed to have a 23.5% improvement in fuel burn (narrow-body) and 19.5% (wide-body) relative to 2000 types; 2030 generation aircraft 28.5% and 31.5%, and 2040 generation aircraft approx 37.0% and 35.0% improvement respectively. Aircraft mix in	The 2020 generation aircraft are assumed to have a 21.5% improvement in fuel burn (narrow-body) and 17.5% (wide-body) relative to 2000 types; 2030 generation aircraft 24.5% and 27.5%, and 2040 generation aircraft approx 31.5% and 29.5% improvement respectively. Aircraft	The 2020 generation aircraft are assumed to have a 19.5% improvement in fuel burn (narrow-body) and 15.5% (wide-body) relative to 2000 types; 2030 generation aircraft 20.5% and 23.5%, and 2040 generation aircraft approx 26.0% and 24.0% improvement respectively. Aircraft mix in supply pool as per

²⁴ Further information on the assumptions used in the baselines is available in UK Aviation Forecasts (DfT, August 2011).

	supply pool as per the current DfT baseline.	mix in supply pool as per the current DfT baseline, though the actual technology implemented in the future aircraft types, and their entry into service years, have been chosen to reflect the rate at which the manufacturers are able to develop new aircraft types.	the current DfT baseline.
Efficiency improvements related to Air Traffic Management (ATM)	1% improvement in ATM efficiency by 2050 to reflect implications of low traffic growth in easing delays and congestion	Zero trend in ATM efficiency assumed as ATM improvements are offset by the effects of increased congestion.	4% degradation in ATM efficiency by 2050 to reflect the implications of high traffic growth on delays and congestion, and taking ATM efficiency back to the 1999 level, identified by CANSO (i.e. removing the 4% improvement from 1999 to 2005).
Biofuel use	Biofuels make up 0% of aviation fuel use out to 2050.	Biofuels make up 0.5% of aviation fuel use in 2030 and 2.5% of aviation fuel use out to 2050.	Biofuels make up 1% of aviation fuel use in 2030 and 5% of aviation fuel use by 2050.
Videoconferencing	10% reduction in business air travel relative to central baseline by 2050, corresponding to the CCC's "optimistic" scenario	As implied by model baseline (i.e. little or no impact on traffic) and consistent with CCC's "likely" scenario	5% increase in business air travel by 2050, reflecting evidence cited by CCC of rebound effect on travel outweighing any substitution effects

Modelling approach

A.3 The MAC curve modelling considered a range of abatement options and for each of these, assessed the emissions reduction potential and the cost per tonne of CO₂ saved. The analysis we have undertaken implicitly recognises the interlinkages between policies and considers the cumulative impact of individual measures, in order to avoid any double counting of the emissions savings. For example, as the lever regulating a given level of biofuel take-up is expressed as a percentage of aviation fuel, the actual CO₂ savings from the use of biofuel will depend on the estimate of the total quantity of aviation fuel used, which in turn will depend on the assumed efficiency (and therefore fuel efficiency measures assumed to be in place) of the aircraft using the fuel.

“What if?” modelling

A.4 Where possible, our modelling approach has been to consider the abatement potential of measures based on what we expect different policies to be able to deliver. This differs from the approach taken by the CCC, who identified the technical abatement potential from given levels of fuel efficiency improvements, the use of biofuels and behavioural change.

A.5 However, for certain measures, we do not currently have sufficient evidence to inform the assumption to use about the impact of the lever. For these measures, we have undertaken the analysis on a “what if?” basis, applying the best assumptions that we have available. The measures that rely on this type of modelling are:

- a. behavioural change i.e. information provision leading to a reduction in leisure demand accompanied by a small switch from long haul to short haul travel; and
- b. encouraging the use of videoconferencing equipment to reduce the demand for business travel.

A.6 This type of analysis inherently contains greater uncertainty than analysing a measure that has supporting legislation which requires a specific level of emission reduction, for example.

Ordering of the policies

A.7 Given that we have estimated the cumulative emissions savings for each policy (that is, taking account of the estimated emissions savings from the preceding policy measures), the ordering of the modelling of the measures will impact on the estimated emissions savings for each individual policy. For example, a mandatory percentage take-up of biofuel will result in a lower absolute amount of emissions savings if it

follows a measure which is assumed to improve the fuel efficiency of aircraft.

A.8 The policies were modelled in the following order:

- Regulatory CO₂ standard;
- Support for achievement of ICAO fuel burn goals;
- Range of levers to reduce inefficiencies in air carrier operations;
- Early fleet retirement (incentive to accelerate fleet turnover);
- Support for retrofitting;
- Range of levers to reduce inefficiencies in ATM and ANSP related operations;
- Support for biofuel demonstration plant;
- Mandating a given level of biofuel take-up (subsidised);
- Promotion of behavioural change;
- Promotion of videoconferencing; and
- Capacity constraints.

Cost-effectiveness

A.9 For each of the measures modelled, we have assessed the emissions reduction potential and the cost-effectiveness; that is, the net cost of the measures per tonne of emissions saved. This is calculated as:

$$\text{cost-effectiveness} = \frac{\text{PVC} - \text{PVB (excl carbon emissions savings)}}{\text{Tonnes of CO}_2 \text{ saved}}$$

where PVC is the present value of costs, and PVB is the present value of benefits, and the present value is the value of the future stream of costs or benefits discounted to 2010 values, using a discount rate of 3.5%, in line with HM Treasury guidance.