Airports Commission

Economy: Carbon Policy Sensitivity Test

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An independent commission appointed by Government

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Glossary

ATM (1)	Air Transport Movement. Landings or take offs of aircraft engaged in the transport of passengers or freight on commercial terms
ATM (2)	Air Traffic Management
ANSP	Air Navigation Service Provider
Base/'do minimum'	Specifically the option of adding no new runway capacity as assessed in the Interim Report
Baseline	The generic term for base set of demand and carbon modelling assumptions and model runs used in the report *Strategic Fit: Updated Forecasts*
Capacity constrained	Modelling case where passenger and ATM demand must fit available future capacity where no significant additional runway or terminal capacity is added
Carbon emissions	Generic term for carbon dioxide emissions from aviation
Carbon-capped forecast	Modelling scenario where CO_2 emissions are limited to 2005 levels through both an ETS and higher carbon prices
Carbon-traded forecast	Modelling scenario where CO_2 emissions are part of an ETS
CCC	UK Committee on Climate Change
CO_2	Carbon dioxide
DECC	Department of Energy and Climate Change
DfT	Department for Transport
DOC	Direct Operating Costs
EC	European Commission
EU ETS	European Union Emissions Trading System
GAL	Gatwick Airport Limited, promoter of Gatwick Airport Second Runway option.
GF	Demand Scenario *global fragmentation*
Great Circle Distance	The shortest distance between two points around the earth's curvature as distinct from the shortest linear distance between two points
HAL	Heathrow Airport Limited, the promoter of the Heathrow Airport North West Runway option.
HH	Heathrow Hub Limited, the promoter of the Heathrow Airport Extended Northern Runway option.

ICAO	International Civil Aviation Organisation. An agency of the United Nations establishing safe principles and fostering the planning and development of airports of member states
ICAO-CAEP	International Civil Aviation Organisation, Committee on Aviation Environmental Protection
I-I	International-to-international interliners i.e. passengers who are transferring via a UK airport with their origin and destination outside the UK
IPCC	Inter-governmental Panel on Climate Change
LCC	Low-cost carrier
LGW 2R	Gatwick Airport Second Runway, the option promoted by Gatwick Airport Limited
LHR NWR	Heathrow Airport North West Runway, the option promoted by Heathrow Airport Limited
LHR ENR	Heathrow Airport Extended Northern Runway, the option promoted by Heathrow Hub Limited
MAC	Marginal abatement cost: a set of measures or investments to reduce emissions
MACC	Marginal abatement cost curve: as above with the measures arranged in order of cost efficiency per unit of abatement
mppa	Million passengers per annum
Mt	Million tonnes
$MtCO_2e$	Million tonnes of carbon dioxide equivalent
NAPAM	The DfT's National Air Passenger Allocation Model
NAPDM	The DfT's National Air Passenger Demand Model
pa	Per annum
Passenger-kilometres, passenger-km	The number of kilometres travelled by an aircraft multiplied by the number of passengers on board, sometimes referred to as RPK (revenue passenger kilometer).
Seat-kilometres, seat-km	The number of kilometres travelled by an aircraft multiplied by the number of seats
TRL	Technical readiness level – NASA index of technology development ranging from 1-9 with 9 being the most mature.
UCL	University College London. The Energy Institute are host to AIM (the Aviation Integrated Model) and authorities in research in reducing the environmental impact of air transportation.
WebTAG	Department for Transport Appraisal Guidance

1. Introduction

Report overview

1.1 As part of the Economy module, the Commission has carried out a carbon policy sensitivity test. This test has allowed the Commission to demonstrate the compatibility of each shortlisted scheme with the Committee on Climate Change's (CCC) current assessment of how the UK climate change targets can most effectively be met.

1.2 The Commission has identified an indicative set of policies that could enable aviation emissions for each short-listed scheme to be restricted to a level consistent with the CCC's planning assumption of 37.5MtCO_2 from aviation by 2050, and carried out a sensitivity test to calculate the potential costs and transport economic efficiency and wider-economic benefits on this basis. This test responds to comments made by stakeholders in consultation that it is important to demonstrate how this might be achieved.

1.3 The test has been produced using the Airports Commission's version of the Department for Transport's (DfT) aviation forecasting model. Technical advice and support, including undertaking model runs, has been provided by DfT modellers. This report sets out the forecasting and appraisal methodology of the test, as well as the associated forecasts of passenger numbers, aviation carbon dioxide emissions, carbon policy costs, transport economic efficiency and wider economic impact benefits for the three capacity development options together with a do minimum of no new runway capacity.

Carbon Dioxide emission targets

1.4 An important aspect of the Commission's appraisals is they are not based on only one potential view of the future. As part of the Strategic Fit module, the Commission has prepared two sets of forecasts based on different approaches to handling carbon dioxide emissions from aviation[1].

1.5 'Carbon-traded' – These forecasts assume that carbon emissions from flights departing UK airports are traded at the European level until 2030 and then as part of a liberal global carbon market. As such the carbon-traded forecasts assume that

1 Emissions of carbon dioxide are referred to in this report as emissions of carbon, carbon dioxide and CO_2. Carbon pricing is used to denote a method of placing a price on each tonne of carbon dioxide.

the total emissions allowed beyond 2030 in the global market are set with reference to stabilisation targets and that society seeks to make reductions where they are most desirable or efficient across the global economy. The carbon-traded forecasts assume that carbon is traded at a price equal to DECC's central long run forecast of carbon prices (September 2013 version) for appraisal.

1.6 'Carbon-capped' – These forecasts represent the level of aviation demand consistent with the Committee on Climate Change's (CCC) current assessment of how UK climate change targets can most effectively be met. The Climate Change Act 2008 set a target for total UK greenhouse gas emissions to be reduced by 80 per cent by 2050, relative to a 1990 baseline. Analysis by the CCC of how this can be achieved proposes that emissions of carbon dioxide (CO_2) from UK aviation in 2050 should be at or below 2005 levels. As such the carbon-capped forecasts assume no trading of aviation emissions either within the UK economy or internationally i.e. that the total carbon emissions from aviation cannot exceed the 37.5MtCO_2 limit set by the CCC.

1.7 The objective of considering both approaches is not to identify a single 'correct' forecast, but rather to understand the varying effects on aviation demand of constraining and pricing carbon emissions. In effect the two worlds set out above represent a range of possible ways in which aviation in the UK may contribute to achieving stabilisation of the global climate.

1.8 At one end of the range, the capped approach assumes a limit on UK aviation emissions. It reflects the CCC's concern that aviation emissions exceeding 37.5MtCO_2 in 2050 imply a near 85% reduction in the CO_2 emissions of other sectors. It therefore takes a static view of what the relative effort between sectors and economies should be on the basis that this may be at the limit of what is feasible. As the CCC notes, it is a planning assumption that should be kept under review, to allow for policy changes and new information about technology and abatement potential in different sectors.

1.9 The other end of the range assumes the total emissions allowed beyond 2030 in the global market are set with reference to stabilisation targets and that society seeks to make reductions where they are most efficient across the global economy. Therefore, it is assumed that any aviation emissions target can be met in part through buying credits from other sectors, without reference to national boundaries or other concerns that characterise international negotiations.

1.10 The carbon-capped forecasts described in chapters 4, 5 and 6 of *Strategic Fit: Updated Forecasts* use an approach to forecasting, which treats carbon emissions as a constraint, rather than as an output of the model. The CCC's planning assumption is modelled by supplementing the DECC price of traded carbon in the passenger demand model, NAPDM,[2] until demand is reduced to a level consistent with the emissions of 37.5MtCO_2 in 2050. This does not represent a new forecast of carbon prices, but is simply the value required, in the assumed absence of any other mechanism, to achieve the target of no more than 37.5MtCO_2 from aircraft departing UK airports in 2050.

1.11 Modelling the carbon-capped case only through carbon pricing is a simplifying assumption. It is likely that high carbon prices would drive further technological improvement in aircraft fuel efficiency or in the operational practices of airlines. Considering such responses is a primary objective of this sensitivity.

1.12 Analysis by the CCC and the DfT has demonstrated that the planning assumption could be achieved by mechanisms other than the carbon price.[3] In addition to the effect of controlling UK airport capacity, these earlier analyses assessed the effectiveness and costs and benefits of measures such as:

- mandatory CO_2 standards for aircraft;
- further investment in fuel efficiency and the modernisation of the fleet beyond that in the baseline assumptions;
- changing operational practices (e.g. further air traffic management measures, or flying at different altitudes and velocities);
- encouraging a greater uptake of biofuels; and
- limiting demand through effecting behavioural change in the public.

1.13 This report explores these policy mechanisms and tests the impact of one possible mix of policies.

2 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/360323/20141001_Supporting_Tables_for_DECC-HMT_Supplementary_Appraisal_Guidance.xlsx. These are in practice the DECC 2012 published values.

3 Committee on Climate Change, Meeting the UK aviation target – options for reducing emissions to 2050, (2009) http://www.theccc.org.uk/reports/aviation-report http://www.theccc.org.uk/reports/aviation-report and EMRC & AEA, A marginal abatement cost curve model for the UK aviation sector, (August 2011) http://assets.dft.gov.uk/publications/response-ccc-report/mac-report.pdf

The carbon policy sensitivity test

1.14 This sensitivity test presents a hybrid policy approach. As with the carbon-traded scenario, it assumes that carbon emissions from flights departing UK airports are traded as part of a liberal international carbon market. However, the price of carbon assumed in the trading scheme is not sufficient to ensure emissions do not exceed the CCC planning assumption, therefore it is assumed that the government incentivises further carbon abatement measures.

1.15 The approach of applying carbon abatement measures was first used by the CCC in their 2009 report on aviation.[4] The method was taken a step further in the Government's response to that report in 2011 consisting principally of a marginal abatement cost ('MAC') study,[5] which accompanied the DfT 2011 aviation forecasts.[6]

1.16 Both the CCC and DfT studies considered a large number of abatement measures which included increased use of biofuels, improvements in air traffic management, behavioural change by passengers, restricted airport capacity, more fuel efficient airline operations and encouraging the development of more fuel efficient aircraft. In developing this sensitivity test, the Commission has considered all of these options, and all are discussed in this report.

1.17 In order to minimise the reliance in this sensitivity on policy measures defined by the CCC as 'optimistic' or 'speculative', this test makes the maximum possible use of demand management through an emissions trading scheme. Since adding capacity increases demand and this in turn increases emissions, the price of permits have been defined so that emissions in the do minimum option are limited to the CCC planning assumption of 37.5MtCO_2 in 2050.

1.18 With the higher carbon price included in fares, only a subset of these potential carbon policy measures are required to abate the capacity option forecasts to the CCC's planning assumption. For the purpose of this sensitivity test, a mix of technological and operational policy measures has been applied.

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

5 EMRC & AEA, A marginal abatement cost curve model for the UK aviation sector, (August 2011) https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/4209/mac-report.pdf

6 Department for Transport, UK Aviation Forecasts, August 2011 https://www.gov.uk/government/publications/uk-aviation-forecasts-2011

1.19 This report provides the passenger forecasts under the carbon trading scheme that would be required in order to abate emissions to the CCC's planning assumption in 2050 without capacity expansion. It presents the additional measures that are required to abate emissions in the capacity options so that they are also consistent with the planning assumption. Finally, the report provides the economic appraisal of each scheme including the estimated costs associated with the abatement measures.

Demand growth scenario

1.20 To be consistent with the other sensitivity tests considered by the Commission in *Strategic Fit: Updated Forecasts*, this sensitivity test focuses on the *assessment of need* demand case. Where possible, this scenario uses economic inputs sourced from the Office for Budgetary Responsibility, OECD and IMF. A full description of this demand scenario is available in **Chapter 3** of *Strategic Fit: Updated Forecasts.*

Capacity development options

1.21 Airport usage forecasts are provided for the do minimum of no added capacity (the do minimum) and the three additional capacity options:

Do minimum — *The 'baseline' case where no new runway capacity is added.*

LGW 2R — *Gatwick Airport Second Runway doubling the airport capacity from 280,000 to 560,000 ATMs per annum from 2025. The scheme promoted by Gatwick Airport Limited (GAL).*

LHR NWR — *Heathrow Airport North West Runway increasing the airport capacity from 480,000 to 740,000 ATMs per annum from 2026. The scheme promoted by Heathrow Airport Limited (HAL).*

LHR ENR — *Heathrow Airport Extended Northern Runway permitting simultaneous take-offs and landings and increasing the airport capacity from 480,000 to 700,000 ATMs per annum from 2026. The scheme promoted by Heathrow Hub Limited (HH).*

Terminology

1.22 Throughout this report the following terminology is used to differentiate how the different elements of the forecasts are described:

'Scenario'	A specific set of future demand assumptions and forecasts.
'Carbon case'	A variant on each of the demand scenarios where carbon is either 'traded' as part of an emissions trading scheme or 'capped' to a specific target.
'Option'	A shortlisted scheme for adding runway capacity e.g. 'LGW 2R', 'LHR NWR' and 'LHR ENR'.

2. Carbon policy forecasting methodology

2.1 This chapter provides an outline of the methodology for producing aviation forecasts and carbon policy measures in this sensitivity test. The forecasts have been provided using the Airports Commission's version of the Department for Transport's (DfT) aviation forecasting model. More information of the model methodology is contained in the *Strategic Fit: Updated Forecasts* report.

2.2 There are three important earlier source documents referenced for the selection and evaluation of aviation carbon abatement measures.

1. The report by the CCC *Meeting the UK aviation target: options for reducing emissions to 2050* (2009).[7] The CCC modelled aviation demand in the presence of a range of carbon abatement measures. A summary of the assumptions made in the modelling of carbon abatement measures is provided in **Appendix 1**.

2. The Government's response to the CCC published in 2011, which consisted principally of a marginal abatement cost curve (MACC) study for the aviation sector undertaken by consultants EMRC and AEAT for the DfT *A marginal abatement cost curve model for the UK aviation sector*,[8] accompanied by the DfT 2011 aviation forecasts.[9] In this study, aviation demand was modelled in the presence of a range of carbon policy measures. A summary of the DfT's 2011 carbon policy abatement measure assumptions is provided in **Appendix 2.** The associated costs of the policy measures were also estimated.

3. Recent research, soon to be published, undertaken by the UCL Energy Institute led by Professor Andreas Schäfer ('UCL') and made available to the Airports Commission: *The Costs for Mitigating CO2 Emissions from Narrow Body Passenger Aircraft – An Analysis of the US Domestic Air Transportation Sector, December 2014.*[10] In this study estimates are made of the associated costs of

7 http://www.theccc.org.uk/publication/meeting-the-uk-aviation-target-options-for-reducing-emissions-to-2050/
8 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/4209/mac-report.pdf
9 https://www.gov.uk/government/publications/uk-aviation-forecasts-2011
10 Schäfer A., Evans A., Reynolds T.G., Dray L. "The Costs for Mitigating CO_2 Emissions from Narrow Body Passenger Aircraft – An Analysis of the UK Domestic Air Transportation Sector", December 2014 (unpublished draft)

carbon policy abatement measures available to narrow bodied aircraft in the US domestic aviation sector.

2.3 The first part of this chapter outlines the modelling approach and input assumptions in relation to the carbon policy measures. The second part reviews the other possible abatement measures that have not been used for the purposes of this sensitivity test.

2.4 The identification of these carbon abatement measures is not an assessment by the Airports Commission of the likely developments in this area. As with other areas of the Commission's appraisal this sensitivity provides one plausible version of the future in order to test the potential costs of limiting emissions to meet the planning assumption of 37.5MtCO_2 in 2050.

Input assumptions

2.5 As set out in **Chapter 1**, this test presents a hybrid policy approach in which a carbon trading scheme is combined with further carbon abatement measures. It has been designed such that the forecast emissions in the three shortlisted schemes and do minimum option do not exceed the CCC's planning assumption 37.5MtCO_2 in 2050.

2.6 In order to minimise this test's reliance on policy measures defined by the CCC as 'optimistic' or 'speculative', it makes the maximum possible use of demand management through an emissions trading scheme.

2.7 Therefore, as a starting point, this sensitivity test assumes a carbon price of £334/tonne in 2050 to control CO_2 emissions to 37.5MtCO_2 in the do minimum (2008 prices). This carbon price is taken from the carbon-capped *assessment of need* forecast and reduces emissions of 39.9MtCO_2 when carbon is traded and priced at £196/tonne to 37.5MtCO_2 in the do minimum.

2.8 When runway capacity is added and there is more carbon to be abated, two broad groups of abatement measures have been modelled. The groups of measures can be classified:

- biofuels
- airline operational practices

Biofuels

2.9 In the do minimum, biofuel uptake is assumed to account for 0.5% of aviation fuel burnt in 2030, rising to 2.5% by 2050. This uptake follows a lead-in period 2021-2025 when demonstration projects are funded. Thereafter, it is assumed that there is an industry wide agreement or regulation to mandate a set amount of biofuel.

2.10 The 5% biofuels uptake assumption for the CCC 'Likely' scenario in **Table 2.1** is equivalent to the 10% reported by the CCC, but uses a different metric. For easier comparison with other forecasts, the biofuel uptake assumptions are reported using the same metric as the EU ETS and IPCC. This is consistent with biofuels reducing emissions to zero and does not account for lifetime or full production cycle emissions. In using this reporting standard, the Commission has therefore lowered the uptake rates to compensate.[11] After adjusting for lifetime emissions, the uptake of biofuels assumed by the Commission in the do minimum forecast is half that adopted by the CCC in the 'Likely' scenario.

2.11 For the purposes of this test, two levels of policies to incentivise increased uptake of biofuels have been defined. In the lower level, the subsidising of biofuels demonstration plants and the subsequent mandatory usage of biofuels are assumed to increase to a level consistent with the CCC's 'Likely' scenario. This is equivalent to doubling the share of aviation fuel burnt accounted for by biofuels by 2050. In the higher level, the scale of the policy is increased to be consistent with the DfT's 'medium' policy scenario. In practice, the upper limit is theoretical, as no more than 8.1% biofuels uptake is assumed under the capacity options. **Table 2.1** summarises the assumed uptake of biofuels associated with these levels of policy compared to the baseline in the do minimum.[12]

11 This was consistent with the accounting of biofuel use in the UK's carbon budget, the EU ETS and with the latest guidance from the International Panel for Climate Change (IPCC).

12 Note that the profile to before 2050 (see **Table 2.1**) is not an exact replica of CCC assumptions in the early years but the final 2050 setting is.

Table 2.1: Biofuel uptake assumptions

	2030	2050
Baseline	**0.50%**	**2.50%**
CCC 'Likely' inherited from baseline	0.50%	2.50%
CCC 'Likely' demonstration	1.00%	1.00%
CCC 'Likely' mandatory	0.12%	1.50%
CCC 'Likely' total	**1.62%**	**5.00%**
Policy test inherited from baseline	0.50%	2.50%
Policy test demonstration	1.00%	1.00%
Policy test mandatory	0.50%	6.50%
Policy test total	**2.00%**	**10.00%**

Airline operational measures

2.12 In the studies by the CCC and DfT, there is some overlap between carbon abatement measures implemented through air traffic control and airline operational practices. For the purpose of this test it is assumed that fuel efficiencies achieved through air traffic control are required to accommodate future traffic growth while maintaining current levels of service. As this removes the scope for further efficiencies, the Commission have not considered any specifically air traffic management abatement measures.

2.13 In the do minimum, the Commission does not assume that the government implements any policies to incentivise more efficient airline operations. However, there are a variety of operational measures available to airlines to reduce fuel costs. For this test three operational measures have been defined:

- *Fuel efficient cruising speeds*
- *Powering of airfield taxiing (such as electric)*
- *Reductions in contingency fuel*

2.14 In 2010, a report by independent experts for ICAO-CAEP suggested that by **reducing cruising speed** by 14%, from 0.86Mach to 0.74Mach (654 to 564mph), fuel consumption could be reduced by 11.7% but efficiencies would fall away quickly beyond that speed reduction.[13] The CCC and DfT studies took place before this report and did not explicitly identify the potential for cruise speed efficiency gain.

13 EMRC/AEAT 2010, p.57 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/4209/mac-report.pdf and ICAO/CAEP: Report of the Independent Experts on the Medium and Long Term Goals for Aviation Fuel Burn Reduction From Technology, 2010 (Doc 9963)

2.15 The Commission has assumed that a policy of enforcing lower cruising speeds would enable a gain in fuel efficiency of up to 1.7%. This is consistent with the medium policy scenario for operational efficiency defined by the DfT. In congested UK airspace, air traffic control also exercise some influence on flight speed so there may also be an element of this measure counted under air traffic management in the earlier studies. Therefore, the assumed efficiency gain in this policy measure shown in **Table 2.2** is substantially below the potential gains identified by the ICAO Expert Panel.

Table 2.2: Assumptions on fuel efficiency gains through reductions in aircraft cruising speeds, cumulative overall efficiency gain

	2020	2030	2040
Baseline	0.00%	0.00%	0.00%
Policy test	0.00%	0.90%	1.70%

2.16 The potential options for mitigating aircraft emissions in **airfield taxiing** include electric-powered taxiing, single-engine taxiing or towing. Studies completed by QinetiQ and UCL contained estimates of the potential emissions savings from adopting these measures, which ranged between 2% and 3% and assumed that these efficiencies are applicable to only 50% of airfield taxiing due to manoeuvrability issues.[14] Taking account of these studies, **Table 2.3** shows the potential airfield taxiing efficiency gains that have been defined in this test. These gains are cautious in light of the research evidence.

Table 2.3: Assumptions on fuel efficiency gains through change of airfield taxiing practice, cumulative overall efficiency gain

	2020	2030	2040
Baseline	0.00%	0.00%	0.00%
Policy test	0.00%	0.50%	1.00%

2.17 **Reducing contingency fuel,** while ensuring that ICAO and local regulatory safety standards are still met, has the potential to reduce up to 1% of fuel burn per flight according to the studies considered.[15] The measure has been further enabled in

14 QinetiQ 2008 study for CCC; Schafer A., Evans A., Reynolds T.G., Dray L. "The Costs for Mitigating CO_2 Emissions from Narrow Body Passenger Aircraft – An Analysis of the UK Domestic Air Transportation Sector", December 2014 (unpublished draft)

15 *ANA Fuel Conservation – Reserve Fuel Optimization*, 2005, www.smartcockpit.com/download.php%3Fpath%3Ddocs/%26file%3DFuel_Conservation_and_Fuel_Reserve_Optimization.pdf+&cd=4&hl=en&ct=clnk&gl=uk

recent years by emerging technology, which now offers more opportunity for optimised flight plans. For the purpose of this test, the Commission has defined the potential fuel efficiencies from this measure outlined in **Table 2.4**, which is informed by UCL research.[16]

Table 2.4: Assumptions on fuel efficiency gains through less contingency fuel, cumulative overall efficiency gain

	2020	2030	2040
Baseline	0.00%	0.00%	0.00%
Policy test	0.00%	0.20%	0.40%

2.18 The three airline operational measures identified above (speed, airfield taxiing and contingency fuel) can be reasonably added as their interactions would be minimal.[17] The overall operational gains shown in **Table 2.5** are adopted for the baseline and this sensitivity test.

Table 2.5: Combined airline operational measure settings – cumulative overall efficiency gain

	2020	2030	2040
Baseline	0.00%	0.00%	0.00%
Policy test	0.00%	1.60%	3.10%

Modelling methodology

2.19 This test presents a hybrid policy approach in which a carbon trading scheme is combined with further carbon abatement measures, and has been designed such that the forecast emissions in the three shortlisted schemes and do minimum option do not exceed the CCC's planning assumption 37.5MtCO_2 in 2050.

2.20 As set out earlier in this chapter, this sensitivity test assumes a carbon price of £334/tonne in 2050 to control CO_2 emissions to 37.5MtCO_2 in the do minimum (2008 prices).

2.21 With the higher carbon price included in fares, only a subset of the potential carbon policy measures that have previously been considered by the DfT and CCC are required to abate the capacity option emissions to the planning assumption.

16 Schäfer et al *ibid*.

17 E.g. in the high measure case, a 1% reduction in fuel carried is not going to materially affect the gains which could be derived from speed optimisation etc.

2.22 The first policy measure to be modelled is the incentivising of biofuel uptake from both demonstration plants and subsequent mandatory biofuels up to the level that is consistent with the CCC's 'Likely' baseline scenario. If the planning assumption has not been met by using the CCC biofuel uptake assumption, the policy measures outlined above are applied as required until the 37.5MtCO_2 in 2050 emissions threshold is met. The sequence in which measures have been introduced was determined by their cost-effectiveness in abating carbon emissions in earlier studies as this should also equate to the willingness of airlines to implement the measure.[18] The sequence adopted is:

1. Demonstration + mandatory biofuel (uptake to CCC 'Likely')
2. Operational measures
3. Mandatory biofuels (policy test)

2.23 Where modelled CO_2 emissions in 2050 exceed the planning assumption, the measures are applied in turn until they reach the thresholds defined in the previous section. If the measure leads to emissions below the planning assumption, then it is partially implemented so that emissions fall to the limit of 37.5MtCO_2 in 2050.

Other possible policy measures

2.24 The introductory section set out that only a subset of the carbon abatement measures identified in previous studies has been adopted for the purpose of this sensitivity. This test provides one plausible version of the future in order to test the potential costs of limiting emissions to meet the planning assumption of 37.5MtCO_2 in 2050, however there are many other measures that could have been assessed. Therefore, the emission savings that could be made from policy measures in the aviation sector could potentially be greater, although these would need to be offset by the associated costs. This sections explores some of these potential measures, and provides the rationale for why they have not been adopted.

Airline operational measures

2.25 **Engine washing** on a more regular basis is defined as a very cost-effective measure on the UCL marginal abatement cost curve.[19] In the UCL study, it is estimated to deliver a 0.25% fuel efficiency gain with negative net costs, which

18 However, more recent research does suggest reversing operational measures and mandatory biofuels. A test of this alternative order has been adopted and described in Chapter 4 on appraisal.

19 Schäfer A., Evans A., Reynolds T.G., Dray L. "The Costs for Mitigating CO_2 Emissions from Narrow Body Passenger Aircraft – An Analysis of the UK Domestic Air Transportation Sector", December 2014 (unpublished draft)

implies that theoretically airlines should be implementing it already. Offsetting this potential, the average fuel-burn efficiency of an aircraft is estimated to decline by 0.2% a year.[20] The Commission's forecasts exclude this deterioration on the grounds that this measure cancels out the benefits of enhanced maintenance routines.

2.26 **Improved matching of aircraft type to mission flown.** According to the earlier studies, this measure can potentially achieve significant abatement. It accounts for nearly all the cumulative abatement by 2050 in the DfT's low policy scenario (a total of 6.4%), and a 0.3% reduction in fuel consumption per flight in the UCL model. There are three reasons why it has not been incorporated into this sensitivity test.

- The reluctance on cost and operational grounds of most airlines to operate a very mixed fleet and multi-version aircraft. Homogenous types are fundamental to the LCC business model (e.g. all current easyJet and Ryanair orders are all of one type).
- It proved the least cost efficient of all measures in the UCL study.
- With the exception of the LCC fleets, the DfT 'Larame' module, which calculates size of aircraft to meet demand, goes some way to internalising the effect within the forecasts.

2.27 **Maximising payload/Maximum Take-Off Weight**. The CCC concluded that the scope for reducing freight-only flights by achieving the optimum balance between belly-hold freight and passenger loads was limited. Many airlines (e.g. LCCs) do not carry freight and the abatement from reduced freighter flights was minimal relative to other measures.

2.28 **Increased load factors through reduced frequencies**. This measure was estimated by UCL to deliver a 0.84% efficiency improvement and could be applicable to all flights. But it does not readily apply to CCC and DfT fuel efficiency metrics, where fuel efficiency is measured in terms of seat-kms per tonne of fuel.

2.29 **Reducing cabin dead-weight**. The CCC have suggested that this might achieve a 1% reduction fuel burn per flight. Removing cabin weight is a cost effective operational measure and LCCs in particular have already made many of the savings to be had. Furthermore, given the convergence between LCC and other scheduled carriers in the UK short-haul markets the scope for further savings would be small. There is less scope for this efficiency in the long-haul passenger markets because

20 Morrell P.,Dray L., *Environmental Aspects of Fleet Rollover, Retirement and Life Cycle, Final Report*, Cranfield, 2009.

of the greater need for on-board catering facilities. The greater fuel efficiency associated with new aircraft types to some extent also captures the new lighter materials used in airframe fixtures.

2.30 **Reduced tankering.** This is the practice of airlines carrying excess fuel after re-fuelling at the cheapest location. There are great difficulties in understanding how much tankering currently occurs. Furthermore, tankering is difficult to predict in the future and its effectiveness is reduced by high mitigation costs (carrying extra fuel costs money). UCL gave it a low net abatement potential (0.26%), and this was applicable to only 15% of flights, making it one of the least cost effective abatement measures in the UCL's marginal abatement cost curve.

2.31 **Surface polish** (unpainted aircraft). UCL gave this an abatement potential of only 0.09% per flight and it is unlikely to be adopted by the UK fleet for marketing and branding reasons. For example easyJet are currently repainting their fleet and BA have experienced political sensitivities in the past over fleet livery. Overall it was one of the least cost effective abatement measures in the UCL marginal abatement cost curve.

Aircraft technology

2.32 The Commission considered including the policy measure termed by the DfT in 2011 '**achievement of ICAO-CAEP fuel burn goals from international collaboration'**. This measure refers to encouraging long term international collaboration in R&D investment to achieve goals for fuel burn technologies to be agreed by ICAO-CAEP independent experts.[21] Similar measures were included in the CCC's scenarios. By way of illustration, **Table 2.6** shows the policy measures adopted by the DfT in 2011 which increase the baseline efficiency of next generation aircraft only expected to enter service in the late 2020s onwards.

2.33 The baseline assumptions do include the effect of introducing new aircraft already in production such as wide-bodied Airbus A380s, Boeing 787s and Airbus 350s and new technology Airbus-320NEO, Boeing 737MAX and new Bombardier Canadair jets. The greatest part of the reduction in fuel consumption will come from these aircraft. The Commission have adopted the baseline fleet turnover assumptions from the most recent DfT forecasts. These are described in more detail in the DfT 2013 *Aviation Forecasts*.[22]

21 Note that this measure is distinct from setting a regulatory CO_2 standard for certifying the current fleet (similar to the noise regulatory standard) as currently being discussed by ICAO-CAEP.

22 See DfT UK Aviation forecasts, January 2013, Chapter 3, paragraphs 3.54-3.68, https://www.gov.uk/government/publications/uk-aviation-forecasts-2013.

2.34 After some deliberation the Commission decided that no further technological measures beyond the baseline would be considered because of the considerable difficulty and uncertainty of costing the investment required to make these further efficiency gains.

Table 2.6: fuel efficiency gains of 'G' future generation aircraft compared to aircraft in operation in 2008

	DfT (2011) Policy Levers			
	Base	**Low**	**Medium**	**High**
Up to 250 seats				
G1 2020s	**21.50%**	21.50%	27.00%	31.00%
G2 2030s	**24.50%**	26.00%	31.50%	36.00%
G3 2040s	**31.50%**	36.00%	41.00%	45.50%*
Over 250 seats				
G1 2020s	**17.50%**	17.50%	23.00%	27.00%
G2 2030s	**27.50%**	30.50%	36.00%	41.00%
G3 2040s	**29.50%**	33.20%	38.50%	43.20%

*>71 seats = 45.50%

2.35 Other fleet technology and fleet turnover policy measures have been previously considered by the CCC, DfT and UCL. These include regulating a CO_2 standard for aircraft in service, retiring aircraft earlier, and retrofitting older airframes with new engines or other fuel saving devices. These have not been included in this sensitivity test for a variety of reasons.

2.36 An **ICAO-CAEP regulatory CO_2** standard, akin to the standard introduced ICAO-CAEP noise certification, could be introduced in the short term, meaning that aircraft that fail to meet the standard are taken out of production and removed from the supply pool. DfT found that it had a very low abatement potential in the long term, because in the UK almost all the affected types had already been removed from the supply pool, and all aircraft would have passed the standards being discussed by ICAO.

2.37 **Early retirement** of less fuel efficient types was one of the less cost-effective abatement measures in the UCL marginal abatement cost curve. DfT research showed that the current fleet using UK airports was noticeably younger than observed internationally, with an average retirement age of 22 years (compared to the 25 years for international fleet used by the CCC).[23] As the Commission have adopted the retirement age of 22 years, there was relatively little scope for this measure to be used for any further abatement.

2.38 **Retro-fitting** of engines, engine components, winglets and riblets was both the least cost effective measure on the DfT 2011 MAC curve and among the least effective on the UCL MAC curve. New engines on old airframes do not deliver the same fuel efficiency as when they are fitted on an airframe designed specifically for those engine types. The returns on the investment have been found to be limited by the design life of the retained older airframe. In practice, the benefits of retro-fitting are superseded by the aircraft manufacturers making incremental changes to the new models of the existing aircraft types and smoothing out the 'lumpiness' in production cycles. For example, winglets are now fitted as standard on all new Boeing 737 and Airbus A320 family aircraft.

Air traffic management (ATM)

2.39 Potential fuel efficiencies by air traffic controllers and Air Navigation Service Providers (ANSP) can include reducing:

- horizontal inefficiencies i.e. not being able to fly the most direct Great Circle Distance because of airspace restrictions;
- vertical inefficiencies (staged ascents and descents, cruising at sub-optimal altitudes); and
- stacking and taxiing delays at congested airports.

2.40 In the Commission's forecasts an 8% uplift has been applied to all flight distances over the Great Circle Distance to allow for stacking and sub-optimal routeing. It is assumed that no reduction to this uplift should be made because ATM and ANSP improvements are needed to maintain service levels while accommodating traffic growth. A second reason for excluding ATM measures is that airlines have some control over altitude and speed optimisation for part of the flight. This introduces a degree of overlap with operational measures in which speed optimisation is included as one of the efficiency measures.

23 See EMRC/AEAT 2011, Figure 4
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/4209/mac-report.pdf

Capacity constraint

2.41 The purpose of this sensitivity test is to examine whether the specific additional capacity options being assessed by the Commission can be compatible with the CCC carbon targets.

2.42 The sensitivity test uses a common carbon price in all options which limits emissions to the level of the do minimum of no additional capacity. In order to offset the increased emissions resulting from a greater share of long-haul connections making use of the new capacity, such a policy would have to go further than simply balancing the runway ATM capacity added with ATM reductions at other UK airports where short-haul predominated. Defining a policy of this nature was not considered suitable for this sensitivity test.

3. Passenger demand and CO_2 forecasts

3.1 This chapter provides the passenger demand and CO_2 forecasts in this sensitivity test. As set out in **Chapter 1** and **Chapter 2**, this test presents a hybrid policy approach in which a carbon trading scheme is combined with further carbon abatement measures.

3.2 The first part of this chapter sets out the passenger and CO_2 forecasts as a result of the global carbon trading scheme. The second part contains the forecasts of CO_2 as a result of the further carbon abatement measures, holding passenger demand constant.

Passenger forecasts with the carbon trading scheme

3.3 This sensitivity shows the impact of a global carbon trading scheme in which the carbon price is set at £334/tonne in 2050 to control CO_2 emissions from aviation to 37.5MtCO_2 in the do minimum option (2008 prices). The carbon price has been taken from the carbon-capped *assessment of need* forecast. This price compares to the central DECC 2050 value of £196/tonne which results in emissions of 39.9MtCO_2 in the carbon-traded scenario and the high DECC value of £294/tonne which results in emissions of 38.4MtCO_2.

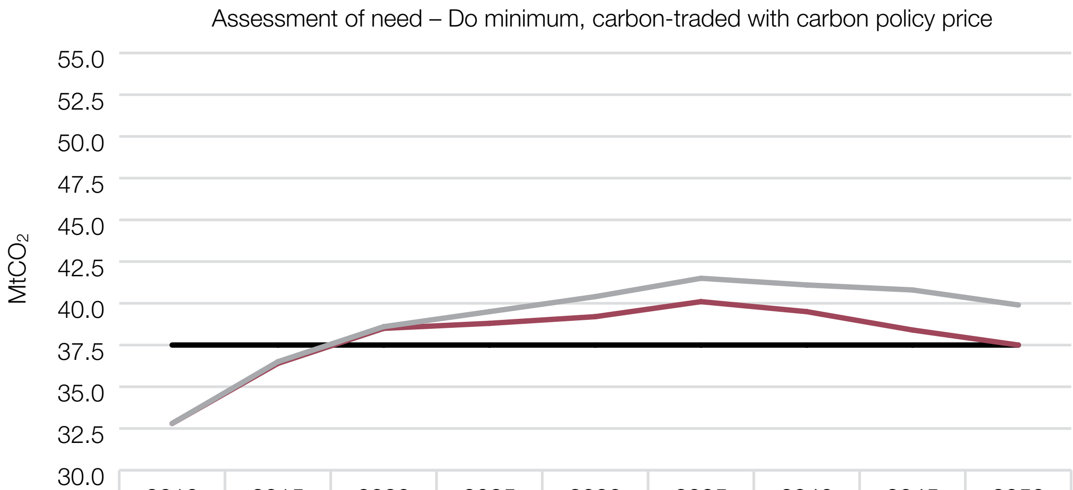
3.4 The passenger forecasts for the baseline carbon-traded and carbon policy price test for the do minimum of no added capacity are shown in **Table 3.1** and the profiles of CO_2 emissions in **Figure 3.1**. In the do minimum option, these are simply the carbon-traded and carbon-capped results from *Strategic Fit: Updated Forecasts.*

Table 3.1: Do minimum carbon-traded and carbon policy price passenger forecasts and CO_2 emissions

Do minimum							
Assessment of need		**Carbon-traded**			**Carbon policy price**		
mppa	**2011**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Heathrow	70	85	90	95	85	89	94
Gatwick	34	42	46	47	41	44	47
Stansted	18	35	35	35	34	35	35
Luton	10	14	18	18	14	18	18
London City	3	8	7	7	7	7	7
London	135	184	196	203	180	193	201
Other modelled UK	83	129	163	207	123	148	185
UK Total	**218**	**314**	**360**	**411**	**303**	**341**	**386**

		Carbon-traded			**Carbon policy price**		
UK	**2011**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
$MtCO_2$	34.4	40.4	41.1	39.9	39.2	39.5	37.5
Aircraft kms (millions)	3270.9	4288.7	4826.3	5529.3	4150.8	4596.5	5182.2

Figure 3.1: Do minimum carbon-traded and carbon policy price CO2 emissions



	2010	2015	2020	2025	2030	2035	2040	2045	2050
Assessment of need, carbon-traded, Do minimum	32.8	36.5	38.6	39.5	40.4	41.5	41.1	40.8	39.9
Assessment of need, carbon-policy price, Do minimum	32.8	36.4	38.5	38.8	39.2	40.1	39.5	38.4	37.5
Target	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5

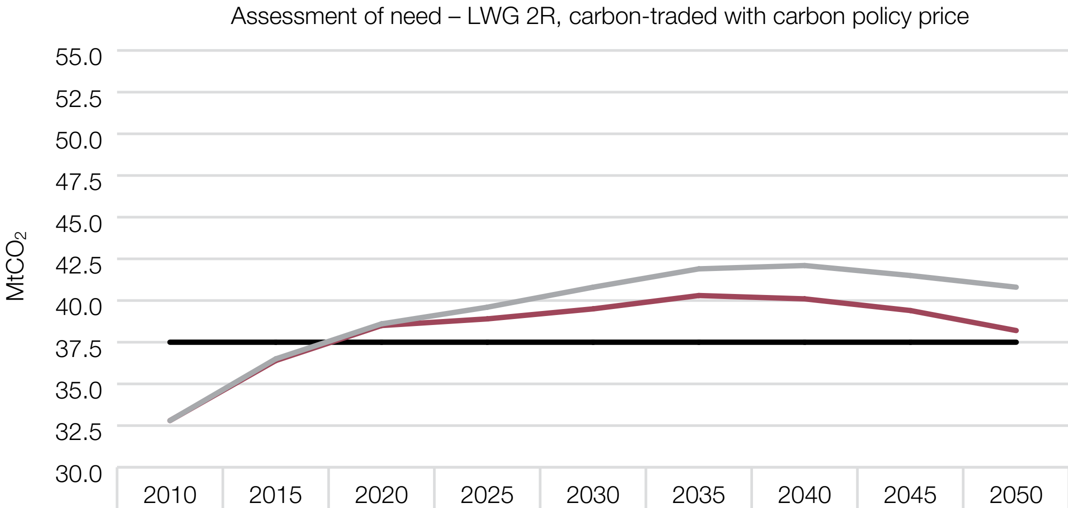
3.5 Forecasts have then been made for the three runway capacity options using the carbon price which limits the emissions to 37.5MtCO_2 in the do minimum. Since adding capacity increases demand and this in turn increases emissions, it follows that in these options emissions will exceed 37.5MtCO_2 with the emissions trading scheme in place.

Table 3.2: Gatwick Airport Second Runway carbon-traded and carbon policy price passenger forecasts and CO_2 emissions

LGW 2R							
Assessment of need		**Carbon-traded**			**Carbon policy price**		
mppa	**2011**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Heathrow	70	85	91	96	86	90	94
Gatwick	34	50	62	82	46	56	71
Stansted	18	33	35	35	32	35	35
Luton	10	13	17	18	13	15	18
London City	3	7	7	8	6	7	7
London	135	188	213	238	183	203	226
Other modelled UK	83	128	156	188	122	144	171
UK Total	**218**	**316**	**368**	**426**	**305**	**348**	**397**

		Carbon-traded			**Carbon policy price**		
UK	**2011**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
MtCO_2	34.4	40.8	42.1	40.8	39.5	40.1	38.2
Aircraft kms (millions)	3270.9	4325.5	4916.1	5694.2	4172.6	4668.0	5326.2

Figure 3.2: Gatwick Airport Second Runway carbon-traded and carbon policy price CO_2 emissions



	2010	2015	2020	2025	2030	2035	2040	2045	2050
Assessment of need, carbon-traded, Do minimum	32.8	36.5	38.6	39.6	40.8	41.9	42.1	41.5	40.8
Assessment of need, carbon-policy price, Do minimum	32.8	36.4	38.5	38.9	39.5	40.3	40.1	39.4	38.2
Target	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5

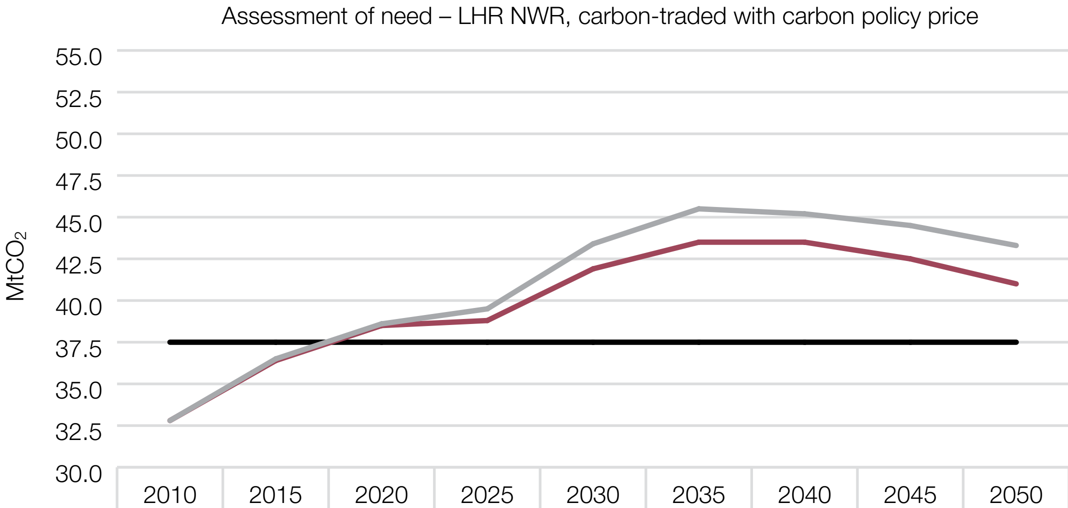
3.6 **Table 3.2** shows that when the 2050 carbon price is raised from £196/tonne to £334/tonne, forecast passenger demand at an expanded Gatwick airport drops from 82 million to 71 million passengers. National demand drops by 29 million passengers. **Figure 3.2** illustrates that with demand lowered to meet the carbon target in the do minimum of no additional capacity, national carbon emissions drop by 2.6MtCO_2 to 38.2MtCO_2 with the new capacity. Therefore adding the second runway leaves a further 0.7MtCO_2 to be abated by further policy measures.

Table 3.3: Heathrow Northwest Runway carbon-traded and carbon policy price passenger forecasts and CO_2 emissions

LHR NWR							
Assessment of need		**Carbon-traded**			**Carbon policy price**		
mppa	**2011**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Heathrow	70	116	134	138	114	133	137
Gatwick	34	39	43	47	38	42	45
Stansted	18	32	35	35	30	33	35
Luton	10	12	14	18	12	13	18
London City	3	5	8	8	4	7	7
London	135	205	234	245	198	227	242
Other modelled UK	83	126	153	190	120	141	169
UK Total	**218**	**331**	**387**	**435**	**319**	**368**	**412**

		Carbon-traded			**Carbon policy price**		
UK	**2011**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
$MtCO_2$	34.4	43.4	45.2	43.3	41.9	43.5	41.0
Aircraft kms (millions)	3270.9	4527.1	5173.8	5799.9	4359.1	4939.7	5512.7

Figure 3.3: Heathrow Northwest Runway carbon-traded and carbon policy price CO_2 emissions



	2010	2015	2020	2025	2030	2035	2040	2045	2050
Assessment of need, carbon-traded, Do minimum	32.8	36.5	38.6	39.5	43.4	45.5	45.2	44.5	43.3
Assessment of need, carbon-policy price, Do minimum	32.8	36.4	38.5	38.8	41.9	43.5	43.5	42.5	41.0
Target	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5

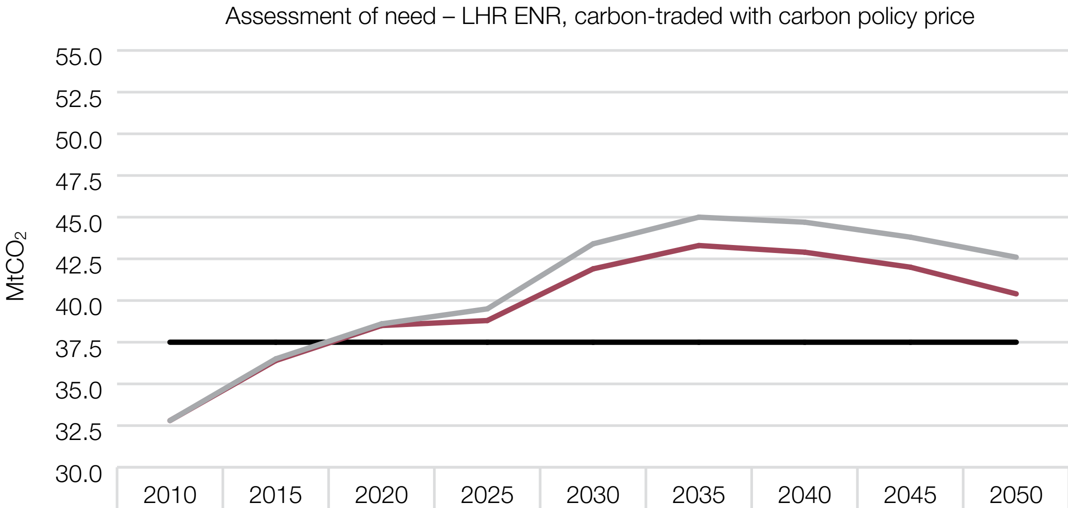
3.7 **Table 3.3** shows that when the 2050 carbon price is raised from £196/tonne to £334/tonne, passenger demand at Heathrow with a new Northwest Runway drops from 138 million to 137 million passengers. National demand drops by 23 million passengers. **Figure 3.3** illustrates that with demand lowered to meet the carbon target in the do minimum of no additional capacity, national carbon emissions drop by 2.3MtCO_2 to 41.0MtCO_2 with the new capacity. Therefore adding the new runway leaves a further 3.5MtCO_2 to be abated by further policy measures.

Table 3.4: Heathrow Extended Northern Runway carbon-traded and carbon policy price passenger forecasts and CO_2 emissions

LHR ENR							
Assessment of need		Carbon-traded			Carbon policy price		
mppa	2011	2030	2040	2050	2030	2040	2050
Heathrow	70	116	127	131	114	126	131
Gatwick	34	39	44	46	38	43	45
Stansted	18	32	35	35	30	34	35
Luton	10	12	15	18	12	13	18
London City	3	5	7	8	4	7	7
London	135	205	229	238	198	223	237
Other modelled UK	83	126	154	193	120	141	170
UK Total	**218**	**331**	**383**	**430**	**319**	**364**	**407**

		Carbon-traded			Carbon policy price		
UK	2011	2030	2040	2050	2030	2040	2050
$MtCO_2$	34.4	43.4	44.7	42.6	41.9	42.9	40.4
Aircraft kms (millions)	3270.9	4525.7	5124.8	5751.3	4357.2	4893.4	5449.3

Figure 3.4: Heathrow Extended Northern Runway carbon-traded and carbon policy price CO_2 emissions



	2010	2015	2020	2025	2030	2035	2040	2045	2050
Assessment of need, carbon-traded, Do minimum	32.8	36.5	38.6	39.5	43.4	45.0	44.7	43.8	42.6
Assessment of need, carbon-policy price, Do minimum	32.8	36.4	38.5	38.8	41.9	43.3	42.9	42.0	40.4
Target	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5

3.8 **Table 3.4** shows that when the 2050 carbon price is raised from £196/tonne to £334/tonne, passenger demand at Heathrow with an Extended Northern Runway remains at 131 million passengers. National demand drops by 23 million passengers. **Figure 3.4** illustrates that with demand lowered to meet the carbon target in the do minimum of no additional capacity, national carbon emissions drop by 2.2$MtCO_2$ to 40.4$MtCO_2$ with the new capacity. Therefore adding the extended Northern runway leaves 2.9$MtCO_2$ to be abated by further policy measures.

Carbon abatement with further policy measures

3.9 Having first reduced carbon emissions through higher carbon prices within an emissions trading scheme, these results focus on the further policy measures that are required in order to bring emissions down to reach 37.5$MtCO_2$ by 2050 in each capacity development option. The resulting modelled improvement in fuel efficiency is also reported. But it should be noted that monitoring the metric of fuel efficiency does not reflect the cut in carbon emissions delivered by an increased proportion of biofuels in total aviation fuel consumption. The effects of carbon policy measures are shown relative to the do minimum capacity option with baseline carbon policy assumptions.

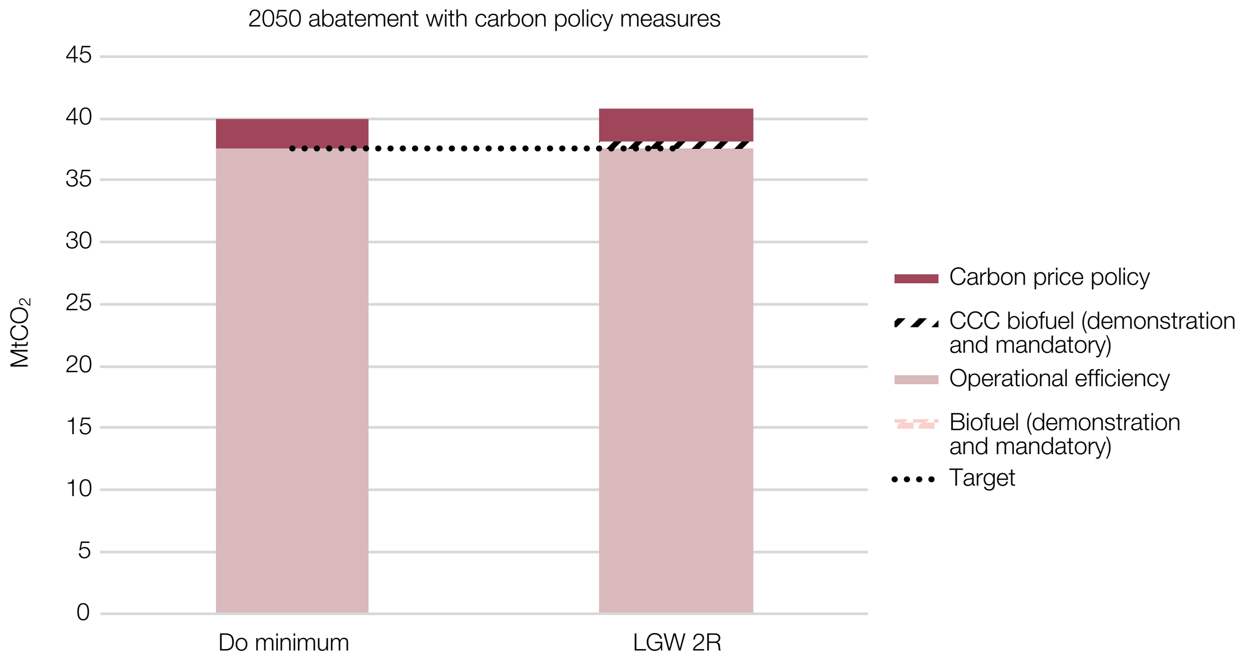
3.10 In the Gatwick Airport Second Runway option, a further 0.7MtCO_2 of further abatement is required in addition to the emissions trading scheme. **Table 3.5** and **Figure 3.5** show that only partial adoption (4.2%) of the CCC 'Likely' baseline assumption of 5% biofuel uptake is required to complete the abatement down to 37.5MtCO_2 in 2050.[24]

Table 3.5: Gatwick Airport Second Runway, effect of CO_2 abatement measures

Effect of policy measures on CO_2 levels in 2050		
Option	**Do minimum**	**LGW 2R**
2050 carbon-traded base (MtCO_2)	39.9	40.8
2050 carbon price policy (MtCO_2)	37.5	38.2
Operational efficiency measures applied	None	None
Biofuel measures applied	None	Partial CCC 'Likely'
2050 Operational measures cumulative fuel efficiency gain %	0.0%	0.0%
2050 Biofuel demonstration, % biofuel uptake	0.0%	1.0%
2050 Biofuel mandatory, % biofuel uptake	0.0%	0.7%
2050 Biofuel measures total, % biofuel uptake	0.0%	1.7%
2050 Operational efficiency abatement (MtCO_2)	–	–
2050 Biofuel demonstration abatement (MtCO_2)	–	0.4
2050 Biofuel mandatory abatement (MtCO_2)	–	0.3
2050 Biofuel total abatement (MtCO_2)	–	0.7
2050 Final CO_2 level after carbon policy measures (MtCO_2)	37.5	37.5

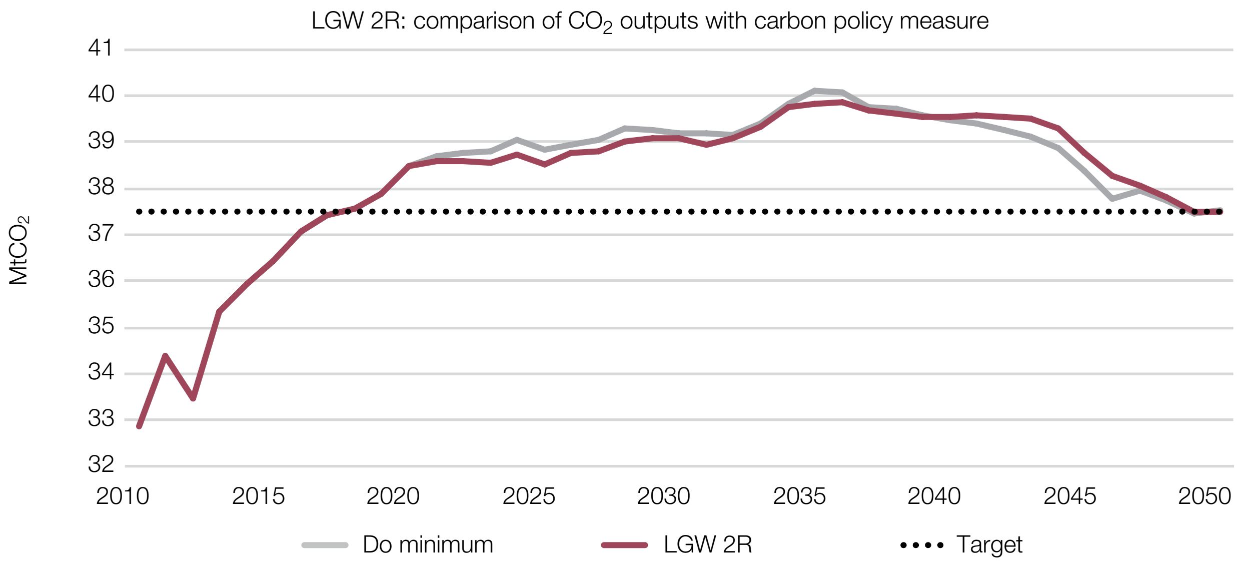
24 Note that this is the ETS accounting units of 0% biofuel carbon emissions, the CCC actually assume a 'Likely' 10% biofuel use but with only 50% emissions savings.

Figure 3.5: Gatwick Airport Second Runway, measures required



3.11 **Figure 3.6** shows the profile of total modelled emissions throughout the modelled period for the do minimum and Gatwick Second Runway option with the abatement measures required to meet the planning assumption.

Figure 3.6: Gatwick Airport Second Runway CO_2 emissions 2010-2050 with abatement measures



3.12 **Table 3.6** shows the change in fuel efficiency required to accommodate the new capacity of the Gatwick Second Runway within the emissions planning assumption. Biofuels do not contribute to the fuel efficiency metric and carbon price policy has only a very indirect effect through reducing passenger demand. As only an increase from the Commission's biofuel assumption to a level just below the CCC's baseline biofuel assumption is required, there is no change from the 1.1%pa fuel efficiency required to limit emissions to 37.5MtCO_2 in 2050.[25]

Table 3.6: Gatwick Airport Second Runway CO_2 annual rate of improvement in fuel efficiency to meet planning assumption

Fuel efficiency improvement per annum after carbon policy measures			
Option	**Baseline (no extra policy measures)**	**Carbon price policy**	**Operational efficiency policy**
Do minimum	1.07%	1.08%	–
LGW 2R	1.10%	1.10%	–

3.13 In the Heathrow North West Runway option, a further 3.5MtCO_2 of abatement is required in addition to the emissions trading scheme. **Table 3.7** and **Figure 3.7** show that adoption of the baseline CCC biofuel assumption, a full introduction of the operational policy measure and a partial adoption (8.1%) of the 10% biofuel uptake measure are required to limit emissions to 37.5MtCO_2 in 2050.

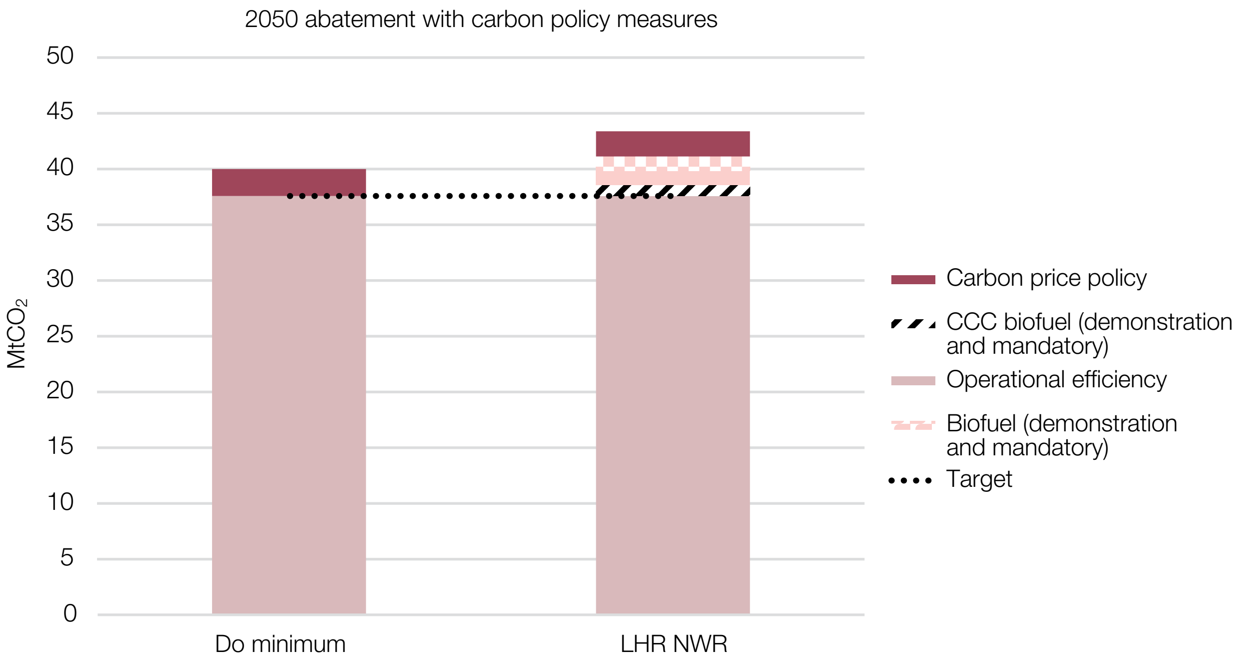
25 Note that increased biofuel uptake does not contribute to this measure of fuel efficiency improvement.

3.14

Table 3.7: Heathrow Airport North West Runway, effect of CO_2 abatement measures

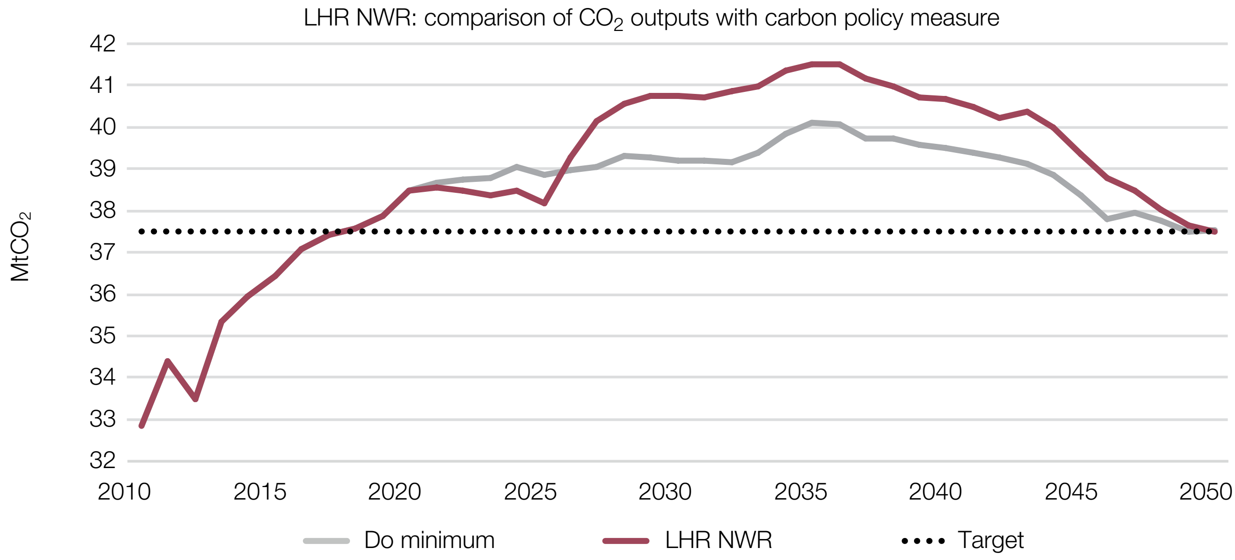
Effect of policy measures on CO_2 levels in 2050		
Option	**Do minimum**	**LHR NWR**
2050 carbon-traded base ($MtCO_2$)	39.9	43.3
2050 carbon price policy ($MtCO_2$)	37.5	41.0
Operational efficiency measures applied	None	Full
Biofuel measures applied	None	Partial
2050 Operational measures cumulative fuel efficiency gain %	0.0%	3.1%
2050 Biofuel demonstration, % biofuel uptake	0.0%	1.0%
2050 Biofuel mandatory, % biofuel uptake	0.0%	4.6%
2050 Biofuel measures total, % biofuel uptake	0.0%	5.6%
2050 Operational efficiency abatement ($MtCO_2$)	–	1.2
2050 Biofuel demonstration abatement ($MtCO_2$)	–	0.4
2050 Biofuel mandatory abatement ($MtCO_2$)	–	1.9
2050 Biofuel total abatement ($MtCO_2$)	–	2.3
2050 Final CO_2 level after carbon policy measures ($MtCO_2$)	37.5	37.5

Figure 3.7: Heathrow Airport North West Runway, measures required



3.15 **Figure 3.8** shows the profile of total modelled emissions throughout the modelled period for the do minimum and Heathrow North West Runway option with the abatement measures required to meet the emissions planning assumption.

Figure 3.8: Heathrow Airport North West Runway CO_2 emissions 2010-2050 with abatement measures



3.16 **Table 3.8** shows the change in fuel efficiency required to accommodate the new capacity of the Heathrow North West Runway within the emissions limit. Biofuels do not contribute to the fuel efficiency metric and carbon price policy has only a very indirect effect through reducing passenger demand. Fuel efficiency would need to improve from 1.07% to 1.15%pa to limit emissions to 37.5MtCO_2 in 2050.

Table 3.8: Heathrow Airport North West Runway CO_2 annual rate of improvement in fuel efficiency to meet planning assumption

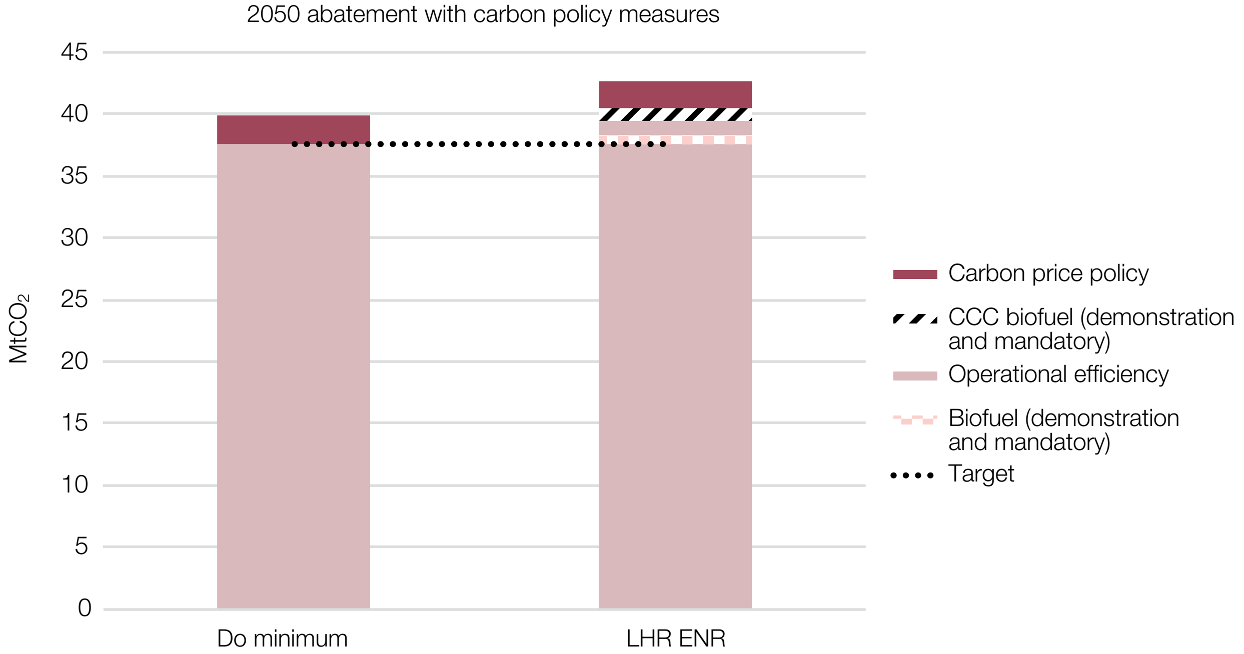
Fuel efficiency improvement per annum after carbon policy measures			
Option	**Baseline (no extra policy measures)**	**Carbon price policy**	**Operational efficiency policy**
Do minimum	1.07%	1.08%	–
LHR NWR	1.06%	1.07%	1.15%

3.17 In the Heathrow Extended Northern Runway option, a further 2.9MtCO_2 of abatement is required in addition to the emissions trading scheme. **Table 3.9** and **Figure 3.9** show that adoption of the baseline CCC biofuel assumption, a full incorporation of the operational policy measure and a partial adoption (6.9%) of the 10% biofuel uptake measure are required to limit emissions to 37.5MtCO_2 in 2050.

Table 3.9: Heathrow Airport Extended Northern Runway, effect of CO_2 abatement measures

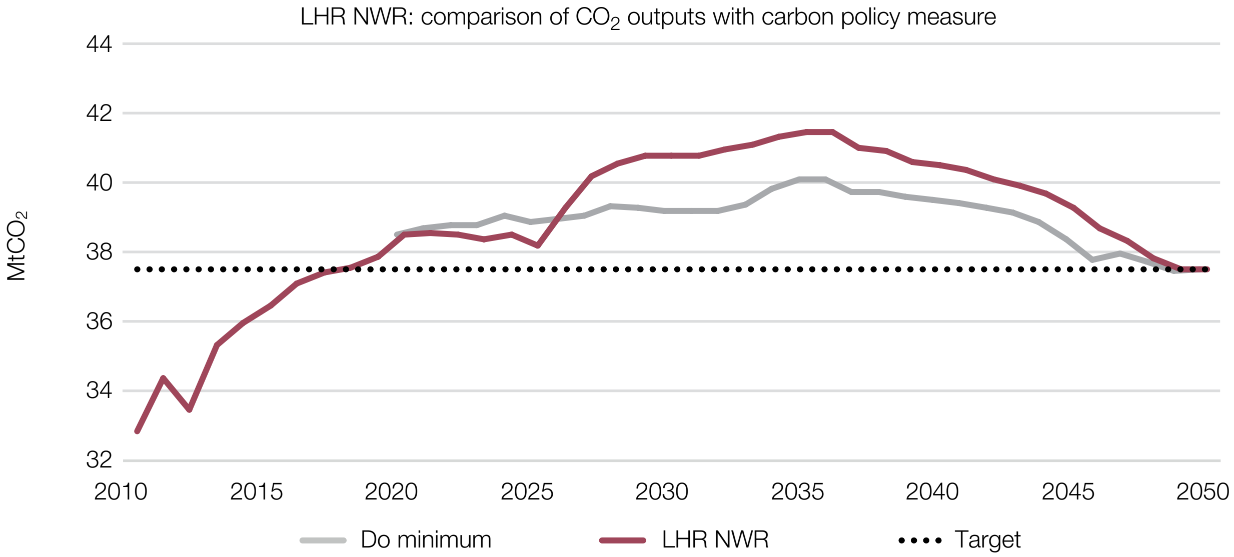
Effect of policy measures on CO_2 levels in 2050		
Option	**Do minimum**	**LHR ENR**
2050 carbon-traded base (MtCO_2)	39.9	42.6
2050 carbon price policy (MtCO_2)	37.5	40.4
Operational efficiency measures applied	None	Full
Biofuel measures applied	None	Partial
2050 Operational measures cumulative fuel efficiency gain %	0.0%	3.1%
2050 Biofuel demonstration, % biofuel uptake	0.0%	1.0%
2050 Biofuel mandatory, % biofuel uptake	0.0%	3.4%
2050 Biofuel measures total, % biofuel uptake	0.0%	4.4%
2050 Operational efficiency abatement (MtCO_2)	–	1.2
2050 Biofuel demonstration abatement (MtCO_2)	–	0.4
2050 Biofuel mandatory abatement (MtCO_2)	–	1.4
2050 Biofuel total abatement (MtCO_2)	–	1.8
2050 Final CO_2 level after carbon policy measures (MtCO_2)	37.5	37.5

Figure 3.9: Heathrow Airport Extended Northern Runway, measures required



3.18 **Figure 3.10** shows the profile of total modelled emissions throughout the modelled period for the do minimum and Heathrow Extended Northern Runway option with the abatement measures required to meet the CCC's planning assumption.

Figure 3.10: Heathrow Airport Extended Northern Runway CO_2 emissions 2010-2050 with abatement measures



3.19 **Table 3.10** shows the change in fuel efficiency required to accommodate the new capacity of the Heathrow Extended Northern Runway within the emissions limit. Biofuels do not contribute to the fuel efficiency metric and carbon price policy has only a very indirect effect through reducing passenger demand. Fuel efficiency would need to improve from 1.07% to 1.15%pa to limit emissions to 37.5MtCO_2 in 2050.

Table 3.10: Heathrow Airport Extended Northern Runway CO_2 annual rate of improvement in fuel efficiency to meet planning assumption

Fuel efficiency improvement per annum after carbon policy measures			
Option	Baseline (no extra policy measures)	Carbon price policy	Operational efficiency policy
Do minimum	1.07%	1.08%	–
LHR ENR	1.05%	1.07%	1.15%

4. Economic appraisal

4.1 This chapter outlines the methodology used to estimate the costs associated with the carbon policy sensitivity test and the associated appraisal results.

Methodology

Summary

4.2 The appraisal is divided into three parts:

- the estimation of the costs of implementing the carbon abatement measures described in **Chapter 2**;
- the calculation of the transport economic efficiency benefits associated with the schemes, given the demand forecasts and other model outputs set out in **Chapter 3**; and
- The calculation of the wider economic benefits associated with the schemes.

4.3 Not all economic impacts are included in this report. Infrastructure costs, delay, freight and noise impacts are covered elsewhere in the appraisal.

4.4 Transport economic efficiency benefits are estimated using the Teeasa model, following DfT WebTAG guidance. Details of the Teeasa methodology and assumptions are provided in *Economy: Transport Economic Efficiency Impacts (2015)*. The transport economic efficiency results are presented in the results section of this chapter.

4.5 This approach ensures that the impact of higher carbon prices (relative to the equivalent carbon-traded scenario) are reflected in the appraisal: higher carbon prices increase fares, lower demand and lower the benefits attached to additional capacity. As the carbon price is identical in the do minimum and in each of the capacity options there is no need to cost this item further.

4.6 For the purpose of this sensitivity, the higher carbon price is assumed to reflect a higher cost of buying carbon credits, and therefore a higher carbon externality. Because it is treated as an additional resource cost, there are no government revenue benefits attached to the higher carbon price. And, as the carbon externality is internalised, there is no need to monetise the carbon disbenefits attached to higher emissions following expansion. This approach is set out in Chapter 3 of *Economy: Updated Transport Economic Efficiency Impacts*, which in turn draws on WebTAG Unit A3.[26]

4.7 Wider economic benefits have been estimated using a welfare-type approach. The approach is based on impacts identified in DfT's WebTAG Wider Economic Impacts guidance but has been reinterpreted and extended for relevance to airport expansion. Details of the methodology and assumptions of the approach used are provided in *Economy: Wider Economic Impacts Assessment.* The wider economic impact results are also presented in the results section of this chapter.

4.8 The costs of the carbon abatement measures have been estimated separately. They are calculated from when they are first used to the end of the appraisal period i.e. 60 years after the scheme opening date.

4.9 There is no allowance for the costs of using the measures feeding back into fares and the demand model – this is equivalent to assuming that the costs are not borne by passengers. If such an allowance were made, it is likely that there would be two impacts on the results. Firstly, demand would be reduced cutting the transport economic efficiency benefits associated with expansion. Secondly, this assumption would lower the amount of abatement required, cutting the cost of such measures. Therefore the overall effect on changing this assumption is uncertain.

4.10 The estimate of the costs of the abatement measures draws heavily on DfT 'MAC' analysis undertaken in 2011 (see **Chapter 2**),[27] and the update undertaken for some of the measures in **Appendix 3** published alongside this report**.** As set out below, there is significant uncertainty attached to the estimated costs and in some cases further sensitivity testing has been undertaken.

26 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/313826/webtag-a3-environmental-impact-appraisal-may2014.pdf

27 EMRC & AEA, A marginal abatement cost curve model for the UK aviation sector, August 2011 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/4209/mac-report.pdf and Department for Transport, UK Aviation Forecasts, August 2011 https://www.gov.uk/government/publications/uk-aviation-forecasts-2011

4.11 Cost estimates included in this chapter relate to the three elements of policy measures beyond price that have been used to abate emissions to the CCC's planning assumption of 37.5MtCO_2 by 2050, as set out in **Chapter 2**:

- supporting biofuel demonstration plants;
- mandatory biofuel uptake; and
- airline operational measures.

In each case the costs refer to those incurred over and above the baseline.

Costs of biofuel demonstration plants

4.12 In line with DfT (2011), it is assumed that a public subsidy of 25% of the cost of each plant is provided. Jacobs has reviewed this assumption and found it to be "in line with current funding criteria". But there is significant uncertainty around the 25% public subsidy assumption. The report into costs in **Appendix 3** (published alongside this report) notes that a feasibility study by Arup/URS (2014) states that the publically funded proportion for such technical readiness level 7 (TRL-7) demonstration plants is in the range of 10-30%, although it also provides examples of plants in the EU that have received public funding from 17% to more than 50% of costs.[28]

4.13 Each demonstration plant is assumed to have a capacity of 100 million litres per annum. Additionally, and also in line with DfT's 2011 assumptions, revenues from the biofuels produced are assumed to be sufficient for producers to earn a return on investment such that no further subsidy is required.

4.14 The estimated cost of each demonstration plant has been updated from the DfT analysis. Based on TRL7 indicative cost ranges – drawing on Arup URS (2014) – Jacobs has estimated that the cost of delivering one 100 million litre demonstration plant is £409 million in 2014 prices. This is a significant increase from the estimated cost of $250 million (£158 million, in 2010 prices) used in the DfT analysis, demonstrating the high level of uncertainty in making cost estimates of developing this technology. This assessment assumes a public subsidy of 25%. Spreading the cost over three years, this implies a cost of £34 million per plant in each of 2020, 2021 and 2022.

28 Arup URS Consortium, Advanced Biofuel Demonstration Competition Feasibility Study, 2014, available online at: https://www.gov.uk/government/publications/advanced-biofuels-demonstration-competition-feasibility-study

4.15 As in the DfT analysis the quantity of fuel required from these plants is rounded up in multiples of 100 million litres (the assumed capacity) to account approximately for downtime. The use of this measure to the policy test level described in **Chapter 3** requires two demonstration plants under each runway capacity option.

Costs of increased use of biofuels (mandatory uptake)

4.16 The costs of this measure are driven by the difference in prices (if any) between kerosene and biofuels, adjusted for the forecast price of carbon taking into account the assumed carbon intensity of the two fuels. Once biofuel is forecast to be no more expensive than kerosene (inclusive of carbon costs), the incremental cost of using biofuel (as opposed to kerosene) falls to zero – it is never assumed to become negative. The increased use of biofuels – over and above that included in the baseline (without further policy measures) and that associated with the demonstration plants – is assumed to start in 2026.

4.17 Biofuel price forecasts are taken from DfT (2011) analysis, updated to 2014 prices. This shows a cost of £0.86/litre in 2026, rising to £0.91/litre in 2030. Costs are held constant after 2030.

4.18 Kerosene prices (exclusive of the carbon price) are based on the update provided by Jacobs in **Appendix 3**, published alongside this report. These are in turn determined primarily by the forecast price of oil associated with the *assessment of need* scenario.[29] This results in a cost of £0.55/litre in 2026, rising to £0.62 in 2040.

4.19 Carbon price assumptions are provided in **Chapter 2**. As with the CO_2 component of the aviation model, it is assumed that kerosene has a carbon dioxide content per kilogram of fuel of 3.15. This results in the carbon price increasing the cost of kerosene by £0.21/litre in 2026, rising steeply to £0.65/litre in 2040.

4.20 As the DfT 2011 analysis sets out, guidance from the Intergovernmental Panel on Climate Change (IPCC) is that the use of biofuels as a fuel by the transport sector should be allocated zero emissions for accounting purposes.[30] But it is recognised that although biofuel use would be expected to result in lower levels of emissions than the use of kerosene, it would not reduce emissions to zero. To reflect this, in the costing of this measure for appraisal purposes only, it is assumed that biofuels have half the carbon content of kerosene.[31] This assumption increases the cost

29 As explained in Chapter 3 of *Strategic Fit: Updated Forecasts*, this is based on the 'IEA New Policies Scenario' scenario.

30 EMRCAEA for DfT 2011, p. 64.

31 See CCC (2009) Chapter 5.

relative to what it would have been had the assumption of zero carbon content been maintained.

4.21 These forecasts result in a differential cost per litre (of using biofuel rather than kerosene) of £0.21/litre in 2026, falling to zero by 2039. If the carbon content of biofuel were instead assumed to be zero, then the differential would fall to zero by 2031.

Cost of operational measures

4.22 **Chapter 2** explains that a number of potential operational measures available to airlines that were assessed in the DfT 2011 analysis were not applied in this sensitivity test. The remaining three applied are:

1. fuel efficient cruising speeds
2. powering of airfield taxiing
3. reductions in contingency fuel.

4.23 Of these, only the measure of fuel efficient cruising speeds was previously a component of the DfT (2011) operational measures package. Taken together this revised package generates estimated abatement of 1.2MtCO_2 in 2050, compared with 2.8MtCO_2 in the low policy demand case in the DfT analysis.

4.24 This redefinition of the package of operational measures presents a challenge in relation to estimating its cost, since the previous analysis is less transferable. Two approaches have been explored and reported:

1. Applying the previous estimate that the low policy case would cost the equivalent of 1% of per annum airline direct operating costs (DOC), excluding fuel costs.[32] This might be considered to be an upper bound, given the reduced package of measures and lower abatement potential.

2. Re-estimating the costings associated with the revised package of three measures, drawing on the DfT 2011 work. (1) The previous **cruising speed** costing estimated that increased equipment and crew requirements of lower speeds would cost 2.5% of non-fuel direct operating costs (DOC).[33] In practice, the policy case examined in this sensitivity involves a reduction in speed of only

32 See page 60 of EMRCAEA report for DfT https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/4209/mac-report.pdf

33 Ibid., pp.60-61.

one-sixth of that associated with the DfT assumption.[34] Assuming that the costs are proportionate to the reduction in speed results in a cost estimate of about 0.4% of per annum non-fuel DOC. (2) The powering of **airfield taxiing** was previously a component of the separate DfT air traffic management (ATM) efficiency package. This package as a whole resulted in high net cost savings, and so it could reasonably be assumed as having zero cost in this sensitivity. (3) Similarly, and as set out earlier in paragraph 2.17, **reducing fuel contingency** is unlikely to be costly to operators, particularly as the high carbon price associated with this sensitivity test would generate further savings.

4.25 Thus this second approach would imply a total cost of about 0.4% of per annum non-fuel DOC, or about 40% of the equivalent DfT 2011 estimate. Given that this revised package is estimated to deliver about 40% of the abatement of the first approach (i.e. the full DfT 2011 package), this does not seem an unreasonable estimate.

4.26 The DfT 2011 estimate of costs equivalent to 1% of non-fuel DOC is applied as the central estimate in this sensitivity to provide a cautious cost estimate, although results are also presented where 0.4% is assumed instead. The 1% estimate is subject to significant uncertainty.

4.27 This approach necessitates a forecast of non-fuel DOC from departing flights. The starting level of such costs is taken from 2008 which is the base year of the national demand model (NAPDM). This results in an estimated total cost in 2008 of £9.8 billion in 2014 prices. This is then uplifted in line with seat-kilometre growth as forecast by the passenger allocation and ATM model (NAPAM) in each scenario. This results in estimates of total non-fuel costs of between £17.3 billion and £17.6 billion by the final NAPAM modelled year (2050), depending on the capacity option. As the appraisal period extends to up to 2085, this cost estimate is then uplifted by the forecast demand growth rate (post 2050) in NAPDM of 1.2% per annum. This represents a change to the approach taken by DfT in 2011, which first inferred non-fuel costs by calculating fuel costs and then assuming non-fuel costs were three times this level.

4.28 The 1% DOC penalty is then applied to the Commission's estimate of total non-fuel costs. This results in costs in 2050 of £173 million in the Heathrow Airport Extended Northern Runway scheme, and £176 million in the Heathrow Airport North West Runway scheme, before applying any discounting or tax adjustments. This measure

34 This assumption about flying speeds was only used in the DfT 'high' policy case. The DfT 2011 measure settings are shown in **Appendix 2**.

is not applied in the Gatwick Airport Second Runway option, as the total abatement required is lower.

4.29 Consistent with the DfT 2011 analysis, fuel and carbon costs savings associated with use of this measure are not calculated – it is assumed that the 1% DOC penalty is net of such savings.

Results

4.30 This section presents the combined present value results of introducing the three shortlisted schemes while offsetting the additional emissions generated by each scheme through a range of aviation-specific abatement measures such that emissions from the aviation sector in 2050 are 37.5MtCO_2. All results are presented relative to the do minimum option of not adding airport capacity, and with no carbon abatement beyond the carbon price required to keep emissions to the target in the do minimum.

4.31 All impacts are estimated up to 60 years after scheme opening. Results are shown in 2014 market prices (using an indirect tax correction factor of 1.19),[35] and discounted to 2014 using a rate of 3.5% until and including 2044, and 3% thereafter as set out in HM Treasury's *Green Book*.[36]

Transport Economic Efficiency Results

4.32 The report *Economy: Updated Transport Economic Efficiency Impacts* provides details on the model used, Teeasa, and the drivers of results. A brief summary is provided below.

4.33 Following new airport capacity, passengers benefit from higher frequency, new routes and lower shadow costs (which act like a congestion charge on capacity constrained airports). These help stimulate new demand, and shifts in passengers to the expanded airport. Benefits to international to international (I to I) passengers are reported separately for reasons set out in Chapter 2 of *Economy: Updated Transport Economic Efficiency Impacts.*

4.34 Lower shadow costs for passengers reduce producer (airline) surpluses – much of the lower shadow cost gain for passengers is a transfer from producers. But some of this producer disbenefit can be offset by new shadow cost revenue if shadow costs return at the expanded airport.

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35 As set out in the TAG Data Book, https://www.gov.uk/transport-analysis-guidance-webtag

36 See Annex 6 of https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/220541/green_book_complete.pdf

4.35 Government revenues are impacted by expansion in two ways.

- Increased Air Passenger Duty (APD) revenue can be collected from new traffic.
- Indirect tax revenue will be foregone when passenger demand transfers expenditure from other goods and services in the economy, many of which are subject to VAT; thus reducing indirect tax revenue. Offsetting this, lower shadow costs (and therefore air fares) reduce the indirect tax revenue loss per passenger.

4.36 As set out in paragraph 4.3, not all economic impacts are included in this report.

Table 4.1: Transport economic efficiency results, passenger, producer and government impacts, present value (£billion)

	Gatwick Airport Second Runway	Heathrow Airport Northwest Runway	Heathrow Airport Extended Northern Runway
Passenger benefits excluding I to I	30.0	39.1	35.0
Producer shadow cost impact	(27.4)	(32.6)	(28.4)
Government revenue impact	1.0	1.5	1.2
Total excluding I to I	3.6	8.0	7.8
Passenger benefits to I to I	1.2	6.6	5.5
Total including I to I	4.7	14.6	13.3

4.37 The total transport economic efficiency benefits associated with each option are around £3 billion to £4 billion lower than the carbon-traded equivalent results shown in *Economy: Updated Transport Economic Efficiency Impacts.*[37] This is to be expected as the higher carbon price applied in this sensitivity reduces demand and therefore the benefit attached to new airport capacity.

37 See tables 4.2, 4.4 and 4.6 of that Report.

Table 4.2: Cost of carbon abatement measures, present value (£billion)

	Gatwick Airport Second Runway	Heathrow Airport Northwest Runway	Heathrow Airport Extended Northern Runway
Demonstration biofuels plants	0.19	0.19	0.19
Mandatory biofuels	0.01	0.09	0.07
Operational measures	–	4.17	4.13
Total	0.21	4.45	4.39

4.38 The Gatwick Airport Second Runway option requires less abatement than the other options – 0.7MtCO_2, compared with up to 3.5MtCO_2 for the Heathrow options. As a result the most expensive of the three abatement measures – operational measures – is not required; this is the primary reason for the abatement costs being lower. Compounding this, there is also less need to use biofuels.

4.39 As discussed in paragraphs 4.24 to 4.26, there is a case for using an alternative approach with a lower cost estimate for operational measures. Assuming that non-fuel DOC increase by 0.4% rather than 1% as a result of this measure, abatement costs in the Heathrow Extended Northern Runway option would reduce by £2.3 billion, and by £2.4 billion in the Heathrow Airport North West Runway option. It would have no impact on the Gatwick Airport Second Runway option since this option does not require this measure.

4.40 If the 2011 DfT methodology relating to the use of carbon content of biofuels had been adopted (that is, it is set to zero), then the cost of mandatory biofuels would fall to less than £10m under each of the capacity options.

Table 4.3: Abatement cost over and above carbon price, £/tCO_2, 2020-2050

	Gatwick Airport Second Runway	Heathrow Airport Northwest Runway	Heathrow Airport Extended Northern Runway
Demonstration biofuels plants	14	14	14
Mandatory biofuels	4	4	4
Operational measures		52	53

4.41 **Table 4.3** shows the costs over and above the prevailing carbon price (£334/tonne by 2050) using each of the three measures, under each of the capacity options. This is calculated by summing the total discounted cost up to 2050 and dividing that by the sum of abatement up to 2050.

4.42 The DfT 2011 analysis estimated the demonstration biofuel plants as costing £4/tCO_2 over and above the carbon price used in that study.[38] This new estimate reflects the higher estimated capital costs described in paragraph 4.14. The costs of mandatory biofuels are now lower (the previous DfT estimate was £8/tCO_2), despite a more cautious assumption concerning the carbon content of biofuels. The higher estimate relates to higher forecast oil and carbon prices, making the incremental cost of biofuels relative to kerosene lower.

4.43 Operational measures were estimated by DfT to cost £31/tCO_2. The higher estimate in this updated analysis reflects the new more limited scope of the measure – in that it delivers less abatement – combined with the cautious central assumption that use of the measure continues to incur a cost of 1% of non-fuel DOC.

Table 4.4: Combined results, present value (£billion)

	Gatwick Airport Second Runway	Heathrow Airport Northwest Runway	Heathrow Airport Extended Northern Runway
Total transport economic efficiency benefit excluding I to I	3.6	8.0	7.8
minus carbon abatement cost	(0.2)	(4.5)	(4.4)
Total benefit (excluding I to I) net of carbon abatement cost	3.4	3.6	3.4
Total transport economic effiency benefit to I to I	1.2	6.6	5.5
Total benefit (including I to I) net of carbon abatement cost	4.5	10.2	8.9

4.44 **Table 4.4** shows the combined results, taking into account the transport economic efficiency benefits and the costs of undertaking aviation-specific carbon abatement measures to offset the additional emissions associated with adding airport capacity. The differences in benefits between the options reduces once additional carbon measures are made and costed. This is because under this sensitivity test the

38 All DfT cost estimates described in this section relate to the low policy case, central demand scenario.

capacity options with the highest benefit increase emissions by the most and so incur the most carbon abatement costs.

Wider Economic Impact Results

4.45 In addition to the transport economic efficiency impacts, airport expansion has impacts on the wider economy. The Commission has monetised the wider economic benefits of airport expansion using a welfare-based approach. The report *Economy: Wider Economic Impacts* provides details on the methodology used and the drivers of the results. A brief summary is provided below.

4.46 The increase in connectivity from expansion brings about an increase in international trade. The trade impacts on the wider economy have been considered for both **imports** and **exports**. Imports generates gains from trade through knowledge transfers and access to technology where these firms would bring new practices and skills to the UK, and can also drive out inefficient firms, increasing overall efficiency in the market. Gains from trade for exports feed through increased access to markets as a result of increased connectivity with airport expansion, allowing greater economies of scale. Knowledge transfers demonstrate the strong multiplier effects with the creation of knowledge based industries, production of higher value goods, attracting skilled workers along with the greater access to higher value markets.

4.47 Where expansion provides increased connectivity and lower access costs to these connections, it will also attract businesses to cluster around the airport, along with those in the supply chain. This clustering delivers knowledge and technology transfers, which in turn creates **agglomeration** benefits from the implied increase in productivity.

4.48 The additional clustering of businesses attracts labour. Workers anticipate higher wages in return for their higher productivity, and these higher wages generate government revenue from the increased income **tax**.

4.49 In imperfectly competitive markets, the fall in the cost of a unit of output also allows firms to increase production and reduce the price they offer to consumers while still keeping their profit margins. This increase in output provides additional **business output benefits**.

Table 4.5: Wider economic impact results, present value (£million)

	Imports	Exports	Agglomeration	Tax Wedge	Business Output Benefits	Total
LGW 2R	1,193	5,895	385	70	684	8,226
LHR NWR	1,394	6,966	1,592	1,069	822	11,844
LHR ENR	1,292	6,495	1,427	982	726	10,921

4.50 Table 4.5 shows total wider economic benefits of the shortlisted schemes range between £8.2bn and £11.8bn. These are around £0.1bn to £0.9bn higher than the carbon-traded equivalent results shown in *Economy: Wider Economic Impacts.* This is due to the higher carbon price applied in this sensitivity, which reduces demand from leisure passengers, who are relatively more price sensitive than business passengers. The increased share of business passengers leads to a rise in the benefits of expansion.

Appendix 1: CCC (2009) Report Carbon Abatement Measure Settings

	Likely Scenario	Optimistic Scenario	Speculative Scenario
Mandatory CO_2 standard	N/K	N/K	N/K
Fleet retirement	25 years	25 years	25 years
Improvement in fuel burn/fleet efficiency			
2020 future generation (compared to 2000 tech) 2030 future generation (compared to 2000 tech) 2040 future generation (compared to 2000 tech)	0.7% annual improvement in fleet fuel efficiency from engines and airframes on a seat-km basis.	0.9% annual improvement in fleet fuel efficiency from engines and airframes on a seat-km basis.	1.2% annual improvement in fleet fuel efficiency from engines and airframes on a seat-km basis.
Biofuels	**CCC assume 50% lifetime carbon, so CCC stated values ( ) are double**		
2020-2030	1% (2%)	1.5 (3%)	2.5 (5%)
2030-2040	N/K	N/K	N/K
2040-2050	5% (10%)	10% (20%)	15 (30%)
Retrofitting of engines (fleet fuel eff)	not stated	not stated	not stated
Airline operational efficiency	1%	2%	4%
Air Traffic Management (ATM) 2010-2050	5%	7-8%	9-10%
Video conferencing	No net impact	Reduces business aviation demand in 2050 by 10%	Reduces business aviation demand in 2050 by 30%
Modal shift, behavioural change	Reduces demand by 1% of pax and 2% of ATMs	In combination with video conferencing reduces demand by 7% of pax and 10% of ATMs	In combination with video conferencing reduces demand by 16% of pax and 19% of ATMs

Appendix 2: DfT (2011) Carbon Abatement Measure Settings

	Baseline (central)	Low policy lever	Medium policy lever	High policy lever
Mandatory CO_2 standard	No	Yes	Yes	Yes
Fleet retirement	22 years +	22 years	21 years	19 years
Improvement in fuel burn/ fleet efficiency				
2020 future generation (compared to 2000 tech)	17.5-21.5%	21.5%	27.0%	27.0%
2030 future generation (compared to 2000 tech)	24.5-27.5%	26.0%	31.5%	36.0%
2040 future generation (compared to 2000 tech)	29.5-31.5%	36.0%	41.0%	43.2%
Biofuels				
2020-2030	0.5%	2.0%	3.0%	6.0%
2030-2040	1.5%	6.0%	11.5%	23.0%
2040-2050	2.5%	10.0%	20.0%	40.0%
Retrofitting of engines (fleet fuel eff)	0.00%	0.06%	0.22%	0.47%
Airline operational efficiency	0%	6.4%	11.1%	17.6%
Air Traffic Management (ATM) 2010-2050	0%	2.0%	4.0%	6.0%
Video conferencing	0%	0%	2% reduction in business demand	5% reduction in business demand
Modal shift, behavioural change	0%	0%	2% reduction in leisure demand & 5% of long haul switches to short-haul	5% reduction in leisure demand & 10% of long haul switches to short-haul

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