ECONOMIC RESEARCH ON THE IMPACTS OF CARBON PRICING ON THE UK AVIATION SECTOR

Final Report

February 2022

CONTENTS

DISCLAIMER

Although this report was jointly commissioned by the Department for Transport (DfT) and the Department for Business, Energy, and Industrial Strategy (BEIS), the findings and recommendations are those of the authors and do not necessarily represent the views of DfT or of BEIS. The information or guidance in this document (including third-party information, products and services) is provided by DfT and BEIS on an ‘as is’ basis, without any representation or endorsement made and without warranty of any kind whether express or implied.

Department for Transport
Great Minster House
33 Horseferry Road
London
SW1P 4DR

Department for Business, Energy, and Industrial Strategy
1 Victoria Street
London
SW1H 0ET

This publication is also available on our website at www.gov.uk/government/organisations/department-for-transport

Any enquiries regarding this publication should be sent to us at www.gov.uk/government/organisations/department-for-transport

GLOSSARY OF ABBREVIATIONS

AIM	Aviation Integrated Model
APD	Air Passenger Duty
ATM	Air Traffic Management
BEIS	Department for Business, Energy and Industrial Strategy
CAA	Civil Aviation Authority
CCC	Climate Change Committee
CEU	CORSIA Eligible Unit
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
DfT	Department for Transport
DG CLIMA	Directorate-General for Climate Action
DOC	Direct Operating Costs
EC	European Commission
EEA	European Economic Area
ETS	Emissions Trading Scheme
EUA	European Union Allowance
EUAA	European Union Aviation Allowance
EU ETS	EU Emissions Trading System
FRT	Freight Flows
FTK	Freight Tonne-Kilometres
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HHI	Herfindahl-Hirschmann Index
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LCAF	Lower Carbon Aviation Fuel
LCC	Low Cost Carrier
LRF	Linear Reduction Factor
MAG	Manchester Airport Group
MRV	Monitoring, Reporting and Verification
O/D	Origin/Destination

OMR	Outermost Region
PAX	Passenger Flows
POF	Property and Operational Facilities
PPP	Purchasing Power Parity
R&D	Research & Development
RCP	Retail and Car Parking
RED	Renewable Energy Directive
RPK	Revenue Passenger-Kilometres
RTK	Revenue Tonne-Kilometres
SAF	Sustainable Aviation Fuel
VFR	Visiting Friends and Relatives
VOT	Value of Time

GLOSSARY OF KEY TERMS

Competitiveness: the capacity and ability of a firm or sector to gain and maintain a profitable, sustainable market share relative to rivals[1].

Competitive disadvantage: where a carbon mitigation policy increases costs for operations within the policy area (e.g. geography, sector, jurisdiction) and (some) businesses in the policy area experience a significant adverse impact on their ability to compete. This systematically disadvantages companies with a larger share of their operations in the policy area compared to airlines with a smaller share of their operations within the policy area.

Carbon leakage: positive carbon leakage occurs where a climate mitigation policy implemented in one area (e.g. geography, sector, jurisdiction) leads to an increase in emissions outside of the policy area. Negative carbon leakage occurs where a climate mitigation policy implemented in one area leads to a decrease in emissions outside of the policy area.

Shielding: aspects of climate policy that act to mitigate carbon leakage and competitive disadvantage impacts.

Free allocation: emissions allowances within an ETS that are distributed to firms for free under a determined methodology.

---

[1] BEIS, 2020a.

EXECUTIVE SUMMARY

The objectives of this study, jointly conducted by Frontier Economics and Air Transportation Analytics (ATA), are to develop a robust evidence base on the extent to which potential aviation carbon pricing policies could lead to competitive disadvantage and carbon leakage; to review the UK Emissions Trading Scheme (UK ETS) aviation free allocation methodology and consider how refinements to its design may help to mitigate these risks; and to assess the UK ETS design under potential future carbon pricing scenarios. Mitigating risk of carbon leakage and competitive disadvantage could be achieved either through the UK ETS design or through separate policy, but the focus of this study is UK ETS design.

This study is composed of two main sets of analyses:

- Identification and qualitative assessment of design options for free allocation of allowances in emissions trading schemes in the context of the UK ETS.
- Quantitative modelling of UK ETS illustrative policy options to test how competitive disadvantage and carbon leakage vary under different circumstances.

The qualitative analysis and quantitative modelling are complementary. The qualitative analysis allows a wider range of issues to be considered than those which are formally modelled.

Both sets of analyses in this study are subject to uncertainty. The most significant sources of uncertainty are future trends in UK ETS, EU ETS, and CORSIA carbon prices and future aviation demand after the COVID-19 pandemic recovery period. Because future aviation system outcomes can be sensitive to developments in uncertain future trends, the outcomes of the different policy options were assessed under a range of different assumptions.

If data is collected, then airline’s responses to higher carbon prices or a change in free allowances may add to the empirical evidence and be used to refine the UK ETS policy design, in particular considering how to support the decarbonisation investments necessary to ensure the long-term sustainability of the sector.

Key findings are summarised below.

Qualitative assessment of design options

An assessment framework was developed to enable UK ETS design options to be assessed against government objectives for effective carbon pricing policy, adapted for the aviation sector. Key policy objectives for carbon pricing include: reduce emissions through incentivising abatement, mitigate carbon leakage risk, support a viable market, and encourage climate action outside the current policy scope and the UK.

Free allocation is the main focus of the qualitative assessment, as it is the principal shielding mechanism within an ETS. The qualitative assessment considers a more detailed set of free allocation design issues than is possible in the model, and in some cases a wider set of competitiveness impacts, for example the impact of free allocation on the overall level of competition in the UK market. Other shielding methods that could be used in the UK aviation sector are also summarised. These are presented to inform initial thinking and are at an early stage of development so are assessed at a high level.

A set of six illustrative design features were developed based on a literature review and discussions with BEIS and DfT officials. These features represent aspects of the free allocation design that can be varied. Within each design feature, a set of design options were evaluated against the assessment framework. Potential interactions with other ETS design features and data availability were also assessed.

The assessment highlighted the trade-off between abatement and competitiveness: ETS is an additional cost item designed to incentivise abatement. **If the cost to airlines of UK ETS compliance increases, all else equal, this will likely increase incentives to reduce emissions** both within and outside the policy scope, **and reduce the competitiveness of the UK as an aviation market**. The magnitude of the loss of competitiveness depends on the size of the costs imposed by the ETS, the cost of aviation decarbonisation investments, and the ability of airlines to withstand reduced profitability and remain in the UK aviation market.

Free allocation can be used in theory to offset the impacts of higher costs from the UK ETS and affects airlines' business models in a way that is distinct from the carbon price, but in practice these impacts are subject to caveats. Free allowances do not impact airlines' marginal costs and retain the marginal decarbonisation incentive arising from the UK ETS. Free allowances do increase total revenue. Where airlines participate in the market with low profitability, free allowances will increase the likelihood that those airlines can remain in the UK aviation market. In practice, there is a spectrum of financial difficulty that may lead airlines to adjust scale rather than fully exit the market. Under some circumstances, where airlines operate low profitability routes that may otherwise not be backfilled, free allocation may increase competition in the market by increasing the number of players in the market, leading to increased capacity.

The analysis finds that **there is minimal risk of a trade-off between strengthening abatement incentives and reducing carbon leakage**, under the current scope of the UK ETS due to the symmetric nature of aviation itineraries. This result draws on the findings of the quantitative modelling in this study: in general a reduction in emissions within the policy area is associated with a reduction in emissions outside the policy area. This finding is specific to aviation and the current UK ETS scope, as other sectors that do not have the same symmetries can face a trade-off between achieving decarbonisation within the policy area and mitigating carbon leakage.

Free allowances have the potential to create competitive distortions between airlines within the UK aviation market. For example, particular airlines may receive a proportionately larger or smaller share of free allowances relative to the scale of their current operations, as the UK ETS free allocation is currently predominantly based on 2010 activity data. However, these distortions can be reduced by combining design features such as reserve permits to support market competition (e.g. reserves for new entrants or fast growers) or by updating activity data baseline years to reflect current market conditions.

In updating free allocation to more closely reflect current market conditions, on a one-off or regular basis, there is a risk of greater loss of competitiveness among regional airlines given that they have seen lower growth relative to the market average in the last decade. Regional airlines are likely to be relatively sensitive to free allocation policy, as a large portion of their operations fall under UK ETS scope. If maintaining the profitability of regional airlines contributes to government objectives, then the risk to regional airlines' profitability could be mitigated by defining short-haul and medium-haul subsectors within the free allocation mechanism to reflect that short-haul routes are more emissions-intensive, as take-off and landing form a larger proportion of the flight.

Quantitative modelling of policy options

To quantitatively assess the extent to which different design decisions for aviation in the UK ETS might cause carbon leakage and competitive disadvantage to UK airlines and airports, a set of 20 illustrative policy scenarios combining different UK ETS design options were assessed. These were chosen on the basis of combinations of:

- UK ETS carbon price;
- The methodology used for interaction between the UK ETS and ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA); and
- UK ETS free allocation methodology.

The outcomes of the different policy options are assessed against each other, as well as a 'no UK ETS' baseline using the global aviation systems model AIM. The options assessed covered UK ETS carbon prices from half to 1.5 times EU ETS carbon prices, CORSIA interaction options ranging from both schemes applied in full to no CORSIA on UK ETS routes, and levels of free allocation ranging from a continuation of current methodology to removing all UK ETS aviation free allocation.

Under nearly all combinations of policy options, CO_2 emissions are projected to decrease both inside and outside UK ETS scope compared to a no UK ETS case. This is because the most prominent impact of the UK ETS on aviation is to increase airline costs and ticket prices on flights from the UK to EEA countries. Most passengers on these routes are flying round-trip journeys with a return journey in the opposite direction, so demand and emissions decrease in both directions. This means that leakage is almost always negative[2]. However, the vast majority of emissions changes outside the UK ETS policy area are on EU ETS or CORSIA routes[3]. In practice, these changes will reduce airline obligations under the EU ETS and/or CORSIA. For example, emissions on EEA-UK flights are covered by the EU ETS and count towards total EU ETS emissions. For a given year, total EU ETS emissions are capped at a set value. Where the UK ETS causes reductions in emissions on these flights, this means that less emissions mitigation

---

[2] Negative leakage means that a CO_2 emissions decrease inside the policy area is associated with a CO_2 emissions decrease outside the policy area.

[3] ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) scheme applies on international routes between CORSIA-participating countries (apart from routes covered by the EU ETS). This includes most UK arriving and departing intercontinental flights.

is required elsewhere in the EU ETS (by an amount equal to the reduction in flight emissions). As such, the net emissions impact outside the UK ETS policy area is likely close to zero across all policy options.

None of the different combinations of UK ETS design options assessed produces substantially different outcomes between UK and non-UK airlines that are in competition with each other. As such, **we would not expect UK airlines to be significantly disadvantaged compared to their non-UK competitors under any of the options assessed here**.

The absolute level of impacts differs by type of airline. UK regional airlines have a larger fraction of their route network covered by the UK ETS than low-cost carriers or network airlines. As such, they are likely to be more affected by changes to the UK ETS which increase airline costs (e.g. increases in carbon price or reductions in free allowances). Network airlines have more flights on intercontinental routes where the UK ETS does not apply. **As such, the impact of the UK ETS on network airline costs is projected to be smaller than for other airline types, as a proportion of their total costs.**

However, regional airlines may have a greater ability to pass through costs onto ticket prices. This is because they typically operate routes from smaller airports without capacity constraints, and estimates of cost pass-through are typically higher for these types of route.

Similarly, **we do not project a large impact on the number of passengers transferring through UK hub airports** from any of the UK ETS options examined here. This is because most of these passengers are travelling on intercontinental journeys for which the UK ETS has only a small (or no) impact on costs. Because we also assume that cost pass-through is lower at congested airports, we project relatively little airport-level demand or revenue impact in general for UK hub airports. **Impacts on airport passenger demand and profits are projected to be higher for airports outside London.** This is because airports outside London are less likely to be congested (higher cost passthrough, leading to larger changes in ticket price) and have fewer intercontinental flights (so a higher proportion of their flights are covered by the UK ETS).

For the relative impacts of the different UK ETS characteristics examined, we find:

- **Carbon price:** UK ETS carbon price has the largest impact on outcomes of the different characteristics examined**. Higher carbon prices are associated with greater and earlier adoption of alternative technologies and fuels and greater reductions in demand.** For example, under mid-range input assumptions for uncertain future trends, the modelling suggests that passenger aircraft tonne-km on UK-EEA routes is 0.9-3.4% lower than in a no UK ETS scenario, depending mainly on carbon price. Higher carbon prices are also associated with larger decreases in aviation emissions both inside and outside the policy area. At low carbon prices, direct emissions decreases both inside and outside the policy area may be small (under 0.25 $MtCO_2$ at a global level under mid-range input assumptions for uncertain future trends). **The absolute level of UK ETS carbon price is more important in determining outcomes than the relative level of the UK ETS carbon price compared to the EU ETS carbon price.** This is because impacts which depend on relative carbon prices (for example, passengers choosing to transfer via hubs in EEA countries rather than in the UK) are relatively small compared to those which depend on absolute carbon prices (for example, reductions in UK-EEA passenger demand for direct flights).

- **CORSIA interaction:** The different CORSIA interaction options have a smaller impact on airline costs and operations. For example, the combination of UK ETS carbon prices equal to EU ETS carbon prices and a range of different CORSIA interaction options result in reductions in UK-EEA passenger flight tonne-km of between 1.8 and 2%. Six potential CORSIA interaction options were identified in DfT's 2021 consultation on how the UK ETS and CORSIA could interact (Options 1-6). Recognising that there are a wide range of options for CORSIA and UK ETS interaction that might be taken forward, we selected three options (Options 2, 4 and 6) for modelling from among those included in DfT's consultation. This was done simply as a proportionate and broadly representative means of illustrating the range of impacts that the wide variety of interaction options could have. Fully applying CORSIA and the UK ETS on UK-EEA routes (Option 4) would require airlines operating on these routes to both surrender UK ETS allowances and purchase CORSIA eligible units for a proportion of their emissions on these routes. This is the highest-cost option for airlines and has the largest impact on demand. Reducing airlines' UK ETS obligations to account for their CORSIA obligations on UK-EEA routes (Option 2) reduces average airline carbon costs on these routes, though outcomes may be dependent on the exact design of Option 2. This is because CORSIA carbon prices are below UK ETS carbon prices and are forecast to remain so for the foreseeable future. If CORSIA is not applied at all on UK-EEA routes (Option 6), costs are likely to be similar to those in Option 4, again because CORSIA carbon prices are projected to be relatively small.
- **Free allowances:** Free allowance allocation impacts primarily on the balance of airline operating costs and airline revenues. **Yearly cost changes in all phase-out cases are projected to remain below those airlines have experienced in recent years due to fluctuations in fuel price.** We assume that airlines set ticket prices based on marginal costs; potential deviations from this assumption are examined further in the qualitative assessment. This means that changes in free allocation do not have a significant impact on carbon leakage or on route-level competitive disadvantage in model outcomes. However, they do affect airline profitability. **If the free allowance allocation methodology remains as at present, we project that airline increases in carbon costs after adjustment for free allowances will typically be similar to the amount of carbon costs they are able to pass through onto ticket prices after the pandemic recovery period**, i.e., airline profitability would be similar to a case without the UK ETS in this specific case. If free allowances are phased out, under the assumptions used in this study it is likely that airline profitability (for both UK and non-UK airlines on UK ETS routes) will decrease. More rapid phase-outs increase the rate at which airline costs change per year, increasing the risks to participating airlines of exiting the market. Changing free allowance allocation to a more recent baseline mainly acts to shift free allowances from UK domestic to international routes, because international demand has grown more rapidly than domestic demand since the current

baseline was established; however, the exact impact is uncertain due to uncertainties in how airline networks will develop.

1 INTRODUCTION

1.1 Background

The UK aviation sector is responsible for approximately 38 $MtCO_2e$ of annual greenhouse gas (GHG) emissions, equivalent to approximately 8% of total UK emissions[4]. Absolute aviation emissions have been relatively stable since 2005 (outside of the COVID-19 period), with increases in commercial demand mitigated by increased load factors and improvements in fleet efficiency. As aviation faces a relatively high cost of carbon abatement compared to other sectors with significant contributions to UK emissions, the proportional contribution of aviation to UK emissions is expected to increase over time[5].

Aviation has been included since 2012 in the EU ETS, a greenhouse gas emissions trading market that covers power plants, industry factories, and the aviation sector. From 2013 to 2020, the EU ETS applied to emissions associated with flights departing from an aerodrome in the UK and arriving in:

- The UK;
- A European Economic Area (EEA) state (excluding outermost regions);
- Gibraltar, Ceuta and Melilla, the Åland Islands, Jan Mayen; or
- An offshore structure in the UK or EEA continental shelves[6].

Airlines were required to monitor and report on relevant emissions and surrender European Union Allowances (EUAs) against these emissions[7].

Since January 2021, these flights, as well as flights from Gibraltar to the UK, have been subject to the UK ETS[8] [9].

- Aviation Phase I(a) of UK ETS will run from 2021 to 2023 and will largely mirror the previous EU ETS, with important differences. Specifically, the UK ETS does not distinguish between aviation and non-aviation emissions allowances; as such there is no separate aviation cap. The UK also imposes an auction reserve price of £22/tCO_2e below which the UK ETS price cannot fall at auctions[10]. The UK has also capped allowances 5% below the UK's notional share of the EU ETS Phase IV cap.
- Aviation Phase I(b) will run from 2024 to 2030[11], allowing the government to introduce changes in the design of the scheme for the aviation sector based on the outcome of its net-zero consistent cap and free allocation review, as well

---

[4] 2019 estimate from BEIS, 2021b. UK aviation emissions include GHG domestic civil aviation emissions (cruise, take-off and landing) and international civil aviation bunker emissions but exclude military aviation and non-GHG climate forcing.

[5] For example, see CCC, 2020.

[6] European Commission, 2021c.

[7] In this report an airline refers to an organization providing a regular public service of passenger and/or freight air transport on one or more routes. A UK airline in this report is defined as an airline which currently holds a Type A operating license in the UK.

[8] Environment Agency, 2021; Before 2020, Gibraltar was a member of the EU and the EEA.

[9] Emissions associated with flights departing from an aerodrome in the EEA and arriving in the UK continue to be subject to the EU ETS.

[10] BEIS, 2021a.

[11] Changes to free allocation will be introduced at the latest from 2024, and may be introduced in 2023.

as any amendments required for CORSIA, a global carbon offsetting scheme for aviation administered by the International Civil Aviation Organisation (ICAO). CORSIA covers international flights between participating countries. This includes UK-EEA routes[12].

The UK is considering options for how the UK ETS and CORSIA could interact[13]. Candidate options include:

- Option 1: Simple hybrid scheme. Airline UK ETS obligations would be reduced by an amount equivalent to their CORSIA obligations. In effect, this means that the UK ETS would apply to emissions on these flights unless they are covered by CORSIA.
- Option 2: Supply-adjusted hybrid scheme. Airline UK ETS obligations would be reduced by an amount equivalent to their CORSIA obligations, but the UK ETS cap would also be adjusted to take account of this. For analytical purposes, for every tonne of CO_2 removed from the UK ETS obligations of an airline due to CORSIA, we have assumed a tonne of CO_2 in UK ETS allowances would be removed from the auctioning pot.
- Option 3: Restricted hybrid scheme. Airlines would be able to use CORSIA eligible units against their UK ETS obligations, but only if those eligible units meet additional quality criteria. This would likely be reflected in the carbon price (in this case, the carbon price paid by airlines for CORSIA eligible units on UK ETS routes).
- Option 4: UK ETS and CORSIA. This option would implement both schemes independently, i.e. airlines flying UK to EEA routes would be required to comply with both schemes for emissions above the CORSIA baseline and therefore have overlapping obligations on these flights.
- Option 5: Domestic offsetting scheme. CORSIA would apply to international flights, and the UK ETS would be replaced by a CORSIA-style domestic offsetting scheme. As a UK policy, this scheme could have a more stringent baseline than CORSIA, include UK domestic flights and apply separate emissions unit criteria, but would generally use the same monitoring, reporting and verification framework as CORSIA and align with CORSIA on other administrative details.
- Option 6: UK ETS only. Only the UK ETS would apply to flights from the UK to EEA countries. CORSIA would continue to apply to other international flights in scope of the scheme.

DfT and BEIS are conducting a series of reviews to inform these potential changes. Specifically, the government recognises that unilateral climate action that reduces emissions in the UK aviation sector could result in carbon leakage and/or competitive disadvantage.

---

[12] The EC's 'Fit for 55' package (EC, 2021) indicates that the EC does not plan to implement CORSIA on EU ETS routes. As such, we assume that EEA-UK routes are not subject to CORSIA. However, CORSIA will still apply on other routes to and from the EEA.

[13] DfT, 2021.

1.2 Report objective and structure

The objective of this study is to develop a robust evidence base on the extent to which potential aviation carbon pricing policies could lead to competitive disadvantage and carbon leakage; to review the UK ETS aviation free allocation methodology and consider how refinements to its design may help to mitigate these risks; and to assess the current UK ETS under future carbon pricing scenarios.

This study is composed of two main sets of analyses, summarised below in Figure 1.

The first set of analyses aims to articulate and assess design options for ETS shielding policies in the context of the UK ETS. This includes a qualitative analysis of the channels through which ETS schemes can impact leakage and competitive disadvantage; a desk-based review of new and existing mechanisms for allocating free allowances in ETS; an assessment of the effectiveness of each type of mechanism against a theoretical framework and in comparison to the EU ETS free allocation mechanism; and a description of metrics and data sources that should be used to implement the mechanism in the context of the UK ETS.

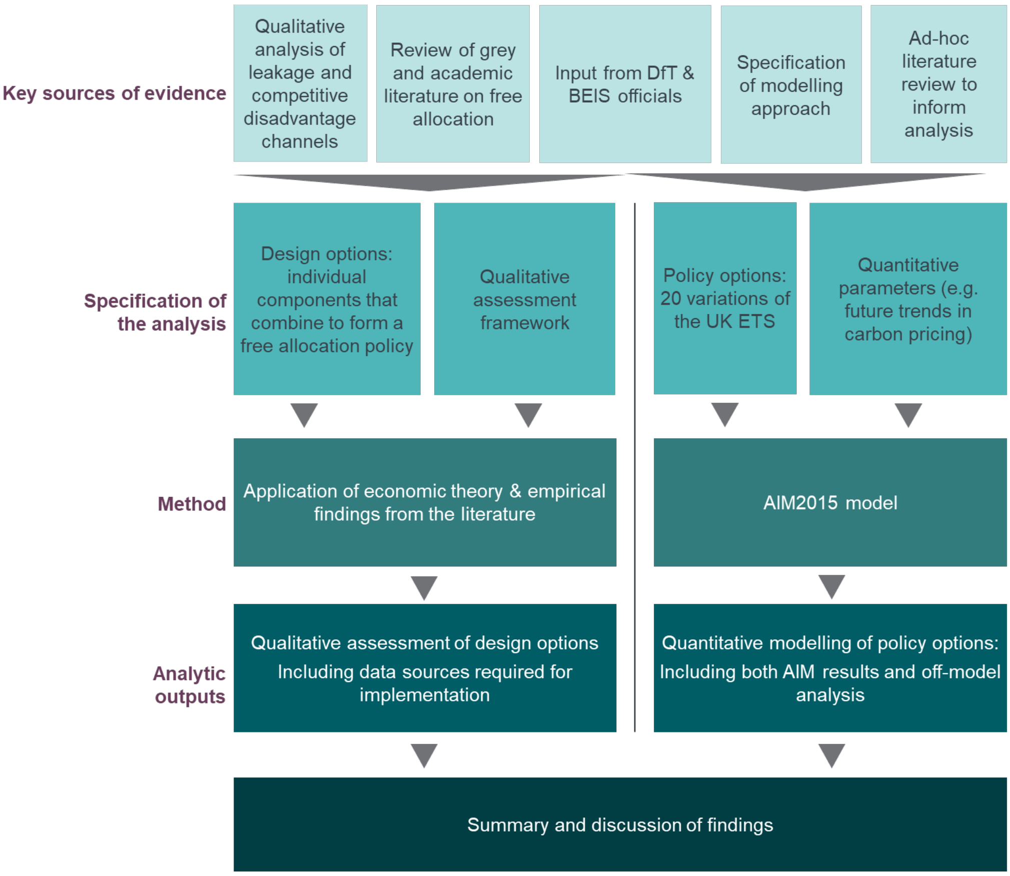
The second set of analyses quantitatively models UK ETS policy options. This includes specifying input policy and uncertain scenario variables, adjusting the aviation model[14] for use in this study, conducting the quantitative modelling of policy options, and supplementing this with qualitative modelling where necessary to assess potential channels of leakage that are not fully covered by the quantitative modelling. The supplemental qualitative modelling of leakage channels is separate to the qualitative assessment of free allocation outlined above.

Input from DfT and BEIS informed the structure and content of the work throughout.

---

[14] The analysis uses the Aviation Integrated Model 2015, described in detail in Section 5.

Figure 1 Organisation of the study



Source: *Frontier Economics*

The rest of this report is structured as follows:

- **Section 2** includes a description of the nature of competition faced by the UK aviation sector and the causal channels linking carbon pricing to competitive disadvantage and carbon leakage
- **Section 3** describes the framework and methodology used for the qualitative assessment of individual design options that could form part of the UK ETS free allocation approach
- **Section 4** presents the results from the qualitative assessment, including data requirements of design options
- **Section 5** describes the methodology for the quantitative assessment of the policy scenarios that could represent future UK carbon pricing policy
- **Section 6** presents the results from the carbon pricing policy quantitative assessment
- **Section 7** concludes by summarising key findings from the qualitative and quantitative analyses.
- **Annex A** summarises literature review findings and additional detail for the assessment of free allocation approaches

- **Annex B** provides additional detail on methodology for the modelling components of this study
- **Annex C** provides detail on Quality Assurance for the modelling components of this study
- **Annex D** additional output metrics for the assessment of carbon pricing policy scenarios

2 INTRODUCTION TO CARBON PRICING IMPACTS ON LEAKAGE AND COMPETITIVE DISADVANTAGE

This section presents an overview of the aviation market and aviation carbon pricing which will inform subsequent modelling. **Section 2.1** discusses the nature of competition faced by the UK aviation sector. **Section 2.2** proposes metrics to measure competitive disadvantage and leakage. **Section 2.3** sets out causal mechanisms linking carbon pricing to competitive disadvantage and leakage, including a visual theory of change.

In the remainder of the report we then explore how the UK ETS design could be modified to help mitigate the positive carbon leakage and competitive disadvantage channels described below, while continuing to incentivise emissions abatement.

2.1 The nature of UK aviation competition

This section summarises the nature of competition in the principal markets within the aviation sector:

- Competition between airlines
- Competition between airports
- Competition between upstream suppliers

2.1.1 Airline competition

Airlines compete with each other for passengers and for freight.

2.1.1.1 Airline competition for passengers

Airlines compete in those services that are regarded as interchangeable or substitutable by the consumer[15]. Some important dimensions of consumer preferences include: fare price; origin/destination (O/D) locations; arrival time and date; travel time; direct vs. indirect flight; booking flexibility; and quality of service. Passengers may increasingly also consider the environmental impact of different itinerary options[16].

Different passenger types tend to have different preferences over these dimensions[17]:

- **Business** passengers tend to have relatively low price sensitivity. They have relatively high sensitivity to the arrival time/date and high valuation of travel time (e.g. strong preference for direct over connecting itineraries). They have low location substitutability (unwilling to switch to a different destination). They

---

[15] Lijesen et al., 2002.

[16] Mayer, 2018.

[17] Li, 2016; Swarbrooke, 2012.

may have relatively high-quality sensitivity (e.g. availability of business lounges).

- **Leisure** passengers tend to have relatively high price sensitivity and relatively low sensitivity to arrival time/date and travel time, and may have some location substitutability (e.g. willingness to switch between different beach destinations).
- **Visiting friends and relatives (VFR)** passengers tend to have high price sensitivity, low sensitivity to arrival time and travel time, and strong location preferences.

As a result, a passenger aviation market definition must take account of the fare price (which also captures perceived quality of service); appropriate temporal units to capture substitutable arrival times; substitutable travel time (which in the case of transfer traffic determines substitute intermediate destinations); and a spatial unit to capture substitutable origin, destination and intermediate locations.

There are four main categories of airlines that compete for passengers[18]:

- **Network carriers** operate hub-and-spoke networks, which connect origins and destinations through one or more hub airports. They tend to offer a wide range of services. These include long-haul intercontinental services that compete with other network carriers, as well as short-and medium-haul services that compete with low-cost carriers (LCCs) (see below) for point-to-point services. To offer this range in a hub-and-spoke configuration, they often operate very diverse fleets. Examples include British Airways and Air France. A recent trend has been an increase in competition from low-cost carriers for not only leisure and VFR but also for business passengers. Network carriers may be part of an airline group (e.g. British Airways is a part of IAG), and groups can shift aircraft between their members. Network carriers have formed global alliances in order to take advantage of economies of scale and scope while complying with nationality-based ownership rules relating to traffic rights that prevent global mergers (e.g. SkyTeam, Star Alliance and OneWorld). The alliances form multi hub-and-spoke systems with a set of inter-airline agreements and can increase network operational efficiency.
- **Low-cost carriers (LCCs)** offer point-to-point connections, low fare prices and basic levels of service. They tend to reduce costs by operating out of secondary airports with lower aviation charges – although some serve major airports – and by operating a single medium-sized aircraft type with high utilisation. UK examples include easyJet and Jet2's scheduled services. Some network carriers have launched LCC services out of secondary hubs in order to compete in these markets (for example, the British Airways subsidiary BA CityFlyer).
- **Regional carriers** offer short-haul routes serving regional airports. They tend to operate smaller aircraft that can land on short runways, and airports with short runways protect regional routes from LCC competition. UK examples include Loganair and Eastern Airways. Regional carriers compete with LCCs and have lost substantial market share to them[19]; recent UK regional carriers ceasing operations include Flybmi (2019) and Flybe (2020).

---

[18] Alderighi et al., 2012; Lijesen et al., 2002.

[19] Niestadt, 2021.

- **Holiday/leisure carriers** offer air transport bundled with other holiday/leisure services. In the UK, examples include the charter services from TUI and Jet2. These carriers are also in competition with LCCs and have also lost market share to them in recent years; recent UK leisure carriers that have ceased operations include Monarch (2017) and Thomas Cook (2019).

Airlines employ a variety of strategies to compete. As airlines must commit to flight schedules in advance, they initially compete on capacity, and subsequently compete on price (see Section 4.1.1.3 for a more detailed discussion of this point). Airlines also employ various methods of vertical quality differentiation including: economy/business/first-class seating, in-flight entertainment, airport lounges, expedited ground service and check-in, and ticket refundability. Airlines also offer price discounts based on purchase volume, for example with frequent flyer programmes.

In addition to competition between airlines, there is also intermodal competition with surface transport. Competition with high-speed rail and road transport is primarily on short-haul routes where the total travel time (including airport access time) is comparable across modes. In particular, there is competition between rail and short-haul flights on this type of itinerary[20]. In some cases, air and surface transport play complementary rather than competitive roles. High-speed rail, commuter rail and motorway links to hub airports increase airport accessibility and increase the catchment area for an airport[21].

Different characteristics of an airport can strengthen or weaken competition among airlines. In general, competition is stronger if new airlines can quickly enter into a market without incurring significant upfront expansion costs. Congestion at airports reduces the threat of new entrants, as can slot unavailability due to legacy commercial arrangements, and these can limit competition among airlines. In the UK, Heathrow and Gatwick had pre-pandemic congestion. Heathrow operated at capacity from the mid-2000s through 2019, and Elliott & Cuttle (2019) estimated that ticket fares at Heathrow were 25% higher than they would be if Heathrow were not operating at capacity.

2.1.1.2 Airline competition for freight

Air freight demand is largely in high-value goods such as pharmaceuticals and electronics, and in perishables such as fresh produce. In addition, there has been recent growth in the market attributable to growth in e-commerce and just-in-time logistics (Feng et al., 2015).

Non-perishables are not sensitive to travel time to the same extent as passengers. As a result, more stopovers are viable on a given O/D route. The routes are also typically longer distance than for passenger transport.

There are two types of airlines in the freight market:

- **Combination carriers,** which provide both passenger and freight services. They may operate dedicated freight services and/or transport freight in the belly hold of passenger aircraft. Belly hold freight tends to be used more on long-

---

[20] Behrens & Pels, 2012.

[21] Albalate, 2015.

haul flights, due to the impact on aircraft turnaround times. UK examples of combination carriers include International Airlines Group Cargo and Virgin Atlantic Cargo. In recent years there has been an increase in freight value on passenger long-haul flights due to an increase in the cargo capacity of passenger jets[22]. The routes served by combination carriers tend to be dictated by passenger demand.

- **Freight-only carriers,** which specialise in cargo services. These can be **integrated carriers** which provide a door-to-door service (e.g. FedEx or DHL) or they can be **non-integrated** and not provide customer-facing operations. Non-integrated carriers collaborate with freight forwarders that act as an intermediary between the shipper/customer and the carrier. For example, DHL also has freight forwarding services that contract with other non-integrated carriers. Freight carriers tend to choose secondary airports, comparable to LCCs.

  Integrated carriers compete for freight from shippers/customers, and non-integrated carriers compete for freight from forwarders. Forwarders vary in terms of characteristics, which can affect their value to the carrier. These characteristics include[23]:

  - Robust history of outturn: this is evidence of future cargo demand from the forwarder;
  - History of demand for return flights (back-cargo): increases average load factor and therefore the carrier's profitability;
  - Return of unused capacity: forwarders book carrier capacity in advance and often do not suffer penalties for unused capacity; and
  - Cancellation, no-show records and payment reputation: other aspects of operational reliability.

Carriers offer services that are differentiated by priority (speed) and by cargo type, such as perishable foods, live animals, dangerous goods and high-value items. Carriers also offer different contract types to forwarders (short-run capacity with dynamic prices and long-run capacity with a fixed price discount), with varying levels of booking flexibility offered to the forwarder.

Freight differs from passenger transport in key respects: volatility for capacity and bookings is higher, and more complex itineraries with more stopovers are possible[24].

Fuel is a higher fraction of operating costs for freight than for passenger services, as freight flights are less labour-intensive. Freight carriers also tend to operate older and less fuel-efficient aircraft, and so they are typically more sensitive to changes in fuel costs[25].

---

[22] Van Asch et al., 2019.

[23] Feng et al., 2015.

[24] Feng et al., 2015.

[25] ATA and Clarity 2018; Dray 2013.

2.1.2 Airport competition

Airports generate revenue from both airlines (passenger and freight services) and from passengers.

2.1.2.1 Airport competition for airlines

Airports compete for airline capacity, which provides them with revenue from landing and passenger charges. Airlines can switch capacity between airports by changing seat capacity on a route (by shifting frequency or aircraft type). They can also change capacity by closing and opening routes.

Airports publish a list of airport charges, and airlines may negotiate discounts to these prices. The airport's charges may be structured to allow different charges to different airlines, such as allowing the flexibility to attract LCC traffic. For example, airports alter the balance of charges per movement or per passenger, or offer optional services such as add-on charges. A subset of the largest UK airports is subject to Airport Charges Regulation[26] of conduct in setting airport charges. In a few cases (i.e. at London Heathrow and London Gatwick), airport charges are subject to economic regulation, as the Civil Aviation Authority (CAA) has determined that they exert significant market power[27].

When the airline can switch capacity away from the airport, particularly to other airports in the same geographic market (O/D traffic) or competitor hubs (transfer traffic), this exerts downward competitive pressure (i.e. downward price pressure) on airport charges. In general, LCCs operating point-to-point services are better able to switch capacity between airports than network carriers. At some airports, LCCs have a very significant share of flights, which can imply countervailing market power. Network carriers that operate multiple hubs tend to sustain higher competitive pressure on their hub airports, via a credible threat of de-hubbing, compared with network carriers with a single hub[28].

Another dimension that improves an airline's bargaining position is the profitability of the airline's routes to the airport. An airline's schedule is more profitable to the airport if it has many flights, if each flight has many passengers (increasing the per-passenger charge and contributing to airport concession revenue), and if each passenger has high retail spend at the airport. Therefore, customer preferences and demand for airlines are important drivers of airport competition for airlines.

Airport congestion will likely reduce airlines' market power. If the airport is congested, demand for capacity exceeds the supply. Then, it tends to be the case that if an airline threatens to switch capacity to another airport, the airport will be able to replace the capacity using another airline.

2.1.2.2 Airport competition for freight airlines

Freight airlines often make use of different airports to passenger airports, for example the freight operations at Stansted, which are large in comparison with its

---

[26] Civil Aviation Authority, 2021c.

[27] Maertens, 2012.

[28] Thelle & la Cour Sonne, 2018.

passenger operations. Freight airlines also have a different distribution of flight departure/arrival times. Many freight flights occur at night, and so airport curfews are a constraint for airlines.

Airports compete for integrated and non-integrated freight carriers, and negotiate landing charges with carriers. There are various factors that impact an airport's competitiveness for freight[29].

A key factor is demand for the airport's location. For O/D freight, this translates to freight demand in the catchment area of the airport. For hub traffic, demand is higher for central locations that minimise the total flight kilometres within the airline's network.

Freight forwarders consolidate smaller shipments into larger consignments. In general, a higher volume of shipments helps forwarders to efficiently consolidate shipments. This creates returns to scale (i.e. lower costs to freight forwarders at larger airports), and larger airports may be more competitive in attracting freight forwarders' traffic compared to smaller airports. Other factors that increase an airport's competitiveness are a high volume of wide-bodied aircraft (that can be used for belly hold freight); speed and reliability of ground handling services; ground access; and presence of specialised freight-handling facilities.

2.1.2.3 Airport competition for passengers

In addition to aeronautical revenue, airports also generate non-aeronautical revenue (e.g. concessions from airport retailers, parking charges).

Passengers exert competitive pressure on airports by switching away from an airport if there is a viable outside alternative. This competitive pressure may vary by passenger type (e.g. leisure passengers may exert greater price pressure on airports due to higher price sensitivity) and by route length (passengers who originate or destine at the airport tend to consider a smaller catchment area around the airport for short- and medium-haul flights relative to long-haul flights).

The ability to switch away from an airport has different characteristics for O/D passengers and for transfer passengers, which impacts competition.

Competition with other airports for **O/D passengers** is primarily with other airports serving the same catchment area. This competition depends on airport access (time and cost), itinerary travel time, the flight schedule frequency and airport amenities. As discussed above, air travel competes with surface transport primarily on short-haul routes: in the UK, domestic and Channel Tunnel routes[30]. In some cases O/D airports may compete with airports in distant geographic areas (e.g. competition for business passengers choosing conference centres co-located with airports, or competition among airports serving beach areas).

Competition with other airports for **transfer passengers** may be with geographically distant airports. An example is competition between London Heathrow and Dubai International Airport for transcontinental traffic between Europe and Asia. As a result, hub airports may compete with a larger number of other airports for transfer passengers than airports compete for O/D passengers.

---

[29] Van Asch, 2019.

[30] A limitation on competition from Channel Tunnel transport is the capacity constraints of the tunnel.

Transfer passengers arguably incur greater airport costs due to the more complex baggage handling requirements compared to non-transfer passengers. However, transfer passengers typically have lower airport charges compared with non-transfer passengers. This implies a higher level of competition for transfer compared with O/D traffic[31]. The competition among airports for transfer passengers travelling between a particular origin and destination depends on the itinerary travel time, the flight schedule frequency, airport amenities and on them offering a higher quality of transfer services (to reduce the stopover time). Transfer traffic represents a small fraction of UK operations; however, at London Heathrow it represents an unusually large proportion of traffic[32].

A range of other factors may also impact airport competition for passengers. Taxes such as the Air Passenger Duty (APD) that are passed through to passengers can impact an airport's competitiveness. In addition, barriers to airport entry can impact competition. There may be significant restrictions on new airport construction or capacity expansion, for example due to planning legislation, geographic constraints and long build times. These barriers may weaken airport competition, particularly in markets served by congested airports[33]. Lastly, airports may have 'intangible' value to passengers, which impacts their competitiveness. For example, London Heathrow sustains a brand value that may help to sustain high fare and concession prices[34].

2.1.3 Competition among upstream suppliers

A range of suppliers compete to provide services to airlines and airports. These include suppliers of fuel, ground handling services, catering services, air traffic management, maintenance services, aircraft parts, interior installations, instruments and avionics, as well as the manufacture, sale and leasing of aircraft.

The nature of competition varies across these sectors. Markets are generally fragmented, with low barriers to entry and suppliers selling to multiple airports or airlines. The exceptions are air traffic management (ATM) and aircraft manufacture and leasing.

- **Air navigation service providers** are generally the sole providers of ATM services to an airport or country. In practice, they are often subject to economic regulation (e.g. NATS in the UK) or are state-owned (e.g. Deutsche Flugsicherung in Germany) or an agency of the government (e.g. DSNA in France). There can be competition in this market, for example in tendering the right to run the service.
- The **manufacture** of passenger and freight aircraft is an effective duopoly, with Airbus and Boeing accounting for 99% of the commercial aircraft market[35]. Airlines either purchase aircraft directly from manufacturers or **lease** from intermediaries. Prior to the COVID-19 pandemic, half of the aircraft in operation

---

[31] Zuidberg, 2014.

[32] ATA and Clarity, 2018.

[33] Polk & Bilotkach, 2013.

[34] Starkie, 2020.

[35] Duddu, 2020.

were leased[36]. The largest lessors – AerCap, GECAS, Avolon and Air Lease Corporation – control around one-quarter of the global leased fleet, and the proposed merger between AerCap and GECAS (the largest two lessors) would lead to further market consolidation[37].

2.2 Definitions of leakage and competitive disadvantage

This study examine the effect of carbon pricing policies on two outcomes of interest:

- **Carbon leakage**: where a carbon mitigation policy implemented in one area (e.g. geography, sector, jurisdiction) leads to an change in emissions outside of the policy area. Positive leakage occurs when a mechanism that decreases emissions within the policy area induces an increase in emissions outside the policy area. Negative leakage occurs when a mechanism that decreases emissions within the policy area induces a decrease in emissions outside the policy area. These definitions may differ slightly from those used in the UK Government's Net Zero Strategy, but are consistent with the definitions found in the literature.
- **Competitive disadvantage**: where a carbon mitigation policy increases costs for operations within the policy area (e.g. geography, sector, jurisdiction) and (some) businesses in the policy area experience a significant adverse impact on their ability to compete. This systematically disadvantages companies with a larger share of their operations in the policy area compared to airlines with a smaller share of their operations within the policy area[38].

Leakage and competitive disadvantage are a function of sector **conditions** and **conduct**[39]. Conditions associated with leakage and competitive disadvantage include sectors and firms with large carbon cost exposure (emissions-intensive sectors, price-sensitive demand and globalised product market). Conduct associated with leakage and competitive disadvantage includes a lack of opportunities to reduce emissions and low capacity to pass costs on to buyers.

This section outlines a set of metrics for competitive disadvantage and leakage in the context of the UK aviation sector. These metrics form the basis of our discussion of competitive disadvantage and leakage in Section 4 and the methodology specification for the quantitative modelling in Section 6. Leakage

This study defines leakage in terms of the emissions increase outside the policy area attributable to the emissions decrease inside the policy area over time (ATA and Clarity, 2018):

---

[36] Centre for Aviation, 2021.

[37] IBA, 2021.

[38] It is important to note that carbon pricing does not always lead to solely negative outcomes for competitiveness in the long-term. For example, pushing airlines to innovate in a green way could be beneficial in the long-term if green considerations become increasingly important for consumers in the future.

[39] BEIS, 2020a.

$$Leakage = \frac{-\Delta CO_{2,outside\ policy}}{\Delta CO_{2,inside\ policy}}$$, where

$$\Delta CO_2 = \Delta CO_{2,outside\ policy} + \Delta CO_{2,inside\ policy}$$

Emissions inside and outside the policy area are classed according to whether the policy applies to the particular flight generating the emissions. The definition therefore depends on the accounting boundaries and methodology for the scheme. The boundaries will need to consider issues such as:

- Whether the policy applies to UK-departing flights or to UK-arriving and UK-departing jointly;
- The interaction between CORSIA Emissions Units and UK ETS allowances; and
- The accounting for fuel lifecycle emissions of sustainable aviation fuels.

The policy area in this case is UK ETS eligible flights, i.e. UK domestic and UK-EEA flights (excluding those to EU outermost regions).

A positive value implies that a CO_2 emissions decrease inside the policy area is accompanied by a CO_2 emissions increase outside the policy area. For example, leakage of 100% would mean that CO_2 emissions increase outside the policy area by the same amount that they decrease inside the policy area, and there is no impact on emissions at a global level. A negative value for leakage implies that CO_2 emissions decrease inside and outside the policy area. Leakage of -100% would mean that the policy reduces CO_2 emissions inside and outside the policy area by a similar amount.

A large positive or large negative carbon leakage value could be due to a relatively large change in emissions outside the policy area, or a relatively small change in emissions inside the policy area (or both). This point is important for interpretation of the quantitative modelling results in Section 6.

2.2.1.1 Competitive disadvantage

Competitive disadvantage can be measured in a variety of ways. This study uses a suite of metrics in order to capture effects that would likely occur on a range of timescales, from the perspective of airlines and from the perspective of airports[40]:

- **Short-run competitiveness effect**: companies that are impacted by the policy lose capacity relative to companies that are not impacted by the policy; and
- **Long-run (investment) competitiveness effect**: companies shift operations to areas outside the policy area.

This approach is consistent with BEIS (2020a), which recommends measuring competitive impacts using a combination of metrics to capture a ‘holistic and long-term view of competitiveness’.

---

[40] See e.g. Vivid Economics, 2015.

To construct these measures, we define a subset of airlines and airports of interest, which we compare against a reference group. We use the following working definitions in the quantitative and qualitative analyses:

- **Route type:** flight legs divided into UK domestic, UK originating/EEA destinating, EEA originating/UK destinating, originating/destinating between UK and non-EEA, originating/destinating between EEA and non-UK country, and segmented by passenger vs. freight;
- **Airline type:** the airlines of interest are those impacted by the policy holding a Type A operating licence issued in the UK[41], excluding helicopter-only airlines (see Section B.4)[42]. We further segment by passenger vs. freight; and
- **Airport type:** the airports of interest are those impacted by the policy which are located within the UK.

We report a set of **intermediate outcomes** by route type in order to provide context for the competitiveness outcomes:

- Airlines
  - Costs: direct operating costs (DOCs) per revenue tonne kilometre (RTK), by route type
  - Emissions intensity: route-level fuel lifecycle CO_2/RTK
  - Volume: RTK and passengers, by route type
  - Value: average cost passthrough and load factor, by route type
- Airports
  - The change in O/D passengers passing through UK airports vs. non-UK airports
  - The change in transfer passengers passing through UK airports vs. non-UK airports

We examine **airline competitiveness** by estimating these metrics by airline type:

- Costs: DOC per RTK, by airline type
- Volume: RTK, by airline type
- Value: average cost passthrough, by airline type

Airline competitive disadvantage will be measured as the change in each of these metrics for UK vs. competing non-UK airlines.

We examine **airport competitiveness** by estimating two complementary measures of turnover:

- Volume: the number of passengers per airport

---

[41] This is required by airlines with aircraft with 20 or more seats.

[42] Note that this definition introduces uncertainty related to airline subsidiary organisation post Brexit. Some UK airlines may introduce new EU-based subsidiaries, and others may change whether their UK-based or EU-based subsidiary operates particular routes.

Helicopter-only airlines are excluded because they contribute a very small, non-material share of aviation traffic.

- Value: the airport revenue (aeronautical and non-aeronautical) for hub airports

Airport competitive disadvantage will be measured as the change in each of these metrics for UK vs. competing non-UK airports.

2.3 Causal mechanisms linking carbon pricing to leakage and competitive disadvantage

This section sets out the causal channels connecting carbon pricing policies to carbon leakage and competitive disadvantage. This conceptual framework frames the qualitative and quantitative analyses in this study.

In outlining these channels, we consider the potential differential effects of policies on subtypes of agents. These subtypes are for the purposes of our theoretical discussion, which includes a range of breakdowns that are tailored to each causal channel. The breakdowns include but are not limited to:

- **Passenger types**: business vs. leisure; originating within or outside the policy area; passengers with domestic vs. international itineraries; passengers with direct vs. indirect itineraries;
- **Airline types**: airlines with substantial policy area operations vs. all others; network airlines vs. LCCs vs. regional airlines[43]; passenger airlines vs. freight airlines; and
- **Airport types**: hub vs. non-hub airports; congested vs. non-congested airports; slot-controlled vs. non-slot-controlled[44].

For each causal mechanism we discuss principal drivers of uncertainty and where the effect of the policy would vary depending on the design of the policy (e.g. the approach to free allocation). Here, the carbon price level is a key source of uncertainty for all causal channels below, impacting the magnitude of each causal effect. We also discuss the effect of underlying levels of aviation demand and the economic performance on policy impacts where relevant.

Section 2.3.1 describes the set of customer (demand-side) reactions, and 2.3.2 describes the set of airline (supply-side) reactions. We have defined these reactions to be disjoint activities at the level of the agent (consumer or airline), but in aggregate all channels are likely to occur simultaneously and iteratively following the introduction of a carbon price.

Importantly, there are a range of distributional consequences of emissions pricing policies which occur before airlines or passengers respond. In general, the larger the share of revenues accounted for by fossil Jet A[45], the larger the impact of emissions pricing policies will be and the more likely an airline is to experience a competitive disadvantage. For example, airlines with less efficient fleets are likely to be disadvantaged relative to those with more efficient fleets. Some of these distributional consequences will be reflected in the quantitative modelling in

---

[43] Note that holiday airlines will be impacted by those channels that impact leisure passengers.

[44] For UK carbon pricing, another element of uncertainty for Heathrow is that there may be non-rational responses to carbon pricing due to brand value (‘premium status’) or intangible benefits to consumers.

[45] Fossil fuel suitable for most jet aircraft (kerosene).

Section 6, but they will not be explicitly examined in this section as they are distinct from competitive disadvantages associated with leakage channels.

Below we discuss customer (demand-side) and airline (supply-side) reactions to carbon policy. The dynamics of how costs are passed through to prices is discussed in more detail in Section 4.1.1.3.

2.3.1 Customer reactions

Airlines pass through some share of the policy cost to customers in the form of higher fares.

In reaction to an increase in fares, customers would be expected to reduce demand on a given aviation route with some combination of substitutions:

- No substitution;
- Substitute to ground transport;
- Substitute to a different aviation route; or
- Substitute to another activity outside the policy area which produces non-priced carbon emissions[46].

The magnitude of these customer reactions in each case depends on the degree to which airlines are able to pass the carbon price through to ticket fares. In perfectly competitive markets, air fares will adjust over time in order to pass through 100% of the carbon cost to customers. In markets not characterised by perfect competition, the passthrough rate will depend on a number of factors, including the number of airlines competing in a market, the commercial strategies of those airlines and how customer demand responds to price changes[47].

In addition, if the airport is operating at capacity, ticket prices are largely determined by passenger willingness-to-pay (i.e. ticket prices adjust so that customer demand fills the fixed capacity). In this case, fare prices likely include economic rents (supernormal airline profit). If an airline's marginal costs rise, they will be able to profitably supply the same capacity as before, until the point that marginal costs rise enough so that route-level profits are zero. In other words, capacity constraints likely limit an airline's ability to pass through carbon costs to fare prices.

Where carbon costs are imposed using an ETS, economic theory predicts that cost passthrough is independent of the free allocation policy; regardless of whether allowances are auctioned or distributed for free, airlines will account for the carbon price as part of their cost functions[48]. This is because, by surrendering the allowance, the airline makes the decision to forgo the opportunity of selling it on the secondary market at the prevailing price[49]. This theory applies even if the

---

[46] For example, a passenger originating outside the UK may substitute a trip to the UK with increased energy usage at their origin, in a jurisdiction where the associated emissions are not subject to carbon pricing. Substituting to an activity where emissions are equivalently priced may not imply leakage, even if it does impose a competitive disadvantage on the UK aviation sector. See e.g. BEIS, 2020a.

[47] Vivid Economics, 2007.

[48] This assumes zero transaction costs, which is discussed later in Section 4.1.1.7.

[49] See e.g. Hepburn et al., 2013; Ernst & Young and York Aviation, 2008; CE Delft, 2005; Vivid Economics, 2007; Frontier Economics, 2006; Anger & Köhler, 2010.

supply of allowances is high relative to demand and the secondary market price is very low.

This assumption also informed the 2006 EU ETS Aviation Impact Assessment[50]. The subsequent EU ETS impact assessment[51] revised this, assuming instead that ticket 'prices are reduced in proportion to the reductions in incurred EU ETS costs (i.e. expenses for acquired allowances and international credits)'[52]. However, the impact assessment does not cite any academic evidence to support this conclusion and therefore its validity cannot be verified. We return to this point in the assessment of free allocation mechanisms in Section 4.

The remainder of this section discusses each channel in turn.

2.3.1.1 Reduce demand for air transport (no substitution)

In the simplest customer reaction, customers reduce demand for air transport and do not replace this demand with any activity that generates emissions.

Passenger itineraries often have emissions attributable to multiple countries, and changes in aviation emissions within a policy area are associated with changes outside of the policy area, for example:

- A reduction in customer demand for departing flights in the policy area also reduces demand for arriving flights from outside of the policy area; and
- A reduction in the demand for multi-leg flights departing in the policy area also reduces demand for subsequent legs.

For this reason, this channel would likely produce 'negative' leakage: each unit of emissions reduction within the policy area is associated with a reduction outside the policy area. The magnitude of the leakage would depend on the specific boundaries of the carbon pricing policy.

This channel would competitively disadvantage airlines with routes in the policy area and airports in the policy area.

There are a number of key uncertainties affecting the magnitude of the impact, including:

- **The level of the passenger price elasticity of demand**[53]. This channel would disproportionately impact carriers that tend to serve price-sensitive customers in the policy area, for example policy area LCCs serving leisure passengers. Passengers at Heathrow and Gatwick may be less price-elastic than passengers at other policy area airports, and so Heathrow and Gatwick airports may be relatively less affected by this channel. Therefore, customers' price elasticity of demand is an important area of uncertainty in these channels.
- **The degree of cost passthrough.** As discussed above incomplete passthrough would reduce the policy impact through this channel.

---

[50] SEC, 2006.

[51] European Commission, 2013a.

[52] In other words, the impact assessment assumed that cost passthrough to ticket prices depends on expense of the allowances incurred by the airline, which in turn depends on the level of the airline's free allocation.

[53] Price elasticity is the degree to which demand or supply changes in response to a change in price, where high elasticity corresponds to a larger response

- **The level of underlying demand post-COVID-19 recovery.** If there is a higher level of counterfactual demand in the policy area, then this would scale up the volume of traffic that is subject to the impacts of carbon pricing. This would likely imply a larger effect of the carbon policy in absolute level terms.
- **Counterfactual carbon prices (EU ETS and CORSIA), and the interaction between carbon pricing schemes.** For a particular route, the policy impact will depend on the fare price increase due to the carbon policy. Therefore, the baseline carbon price in absence of the policy (i.e. due to another scheme), impacts the leakage effects of the policy. This uncertainty is also relevant for each of the customer reaction channels described below.

Freight airlines have lower labour costs and a higher proportion of fuel costs compared with passenger transport. They generally use less fuel-efficient aircraft; freighter aircraft are often converted from older passenger aircraft and reflect passenger airline technology decisions with a 15- to 20-year time lag. Therefore, freight will be relatively more sensitive to carbon pricing. The reduction in freight demand will disproportionately impact lower-value and less time-sensitive goods for which shippers have higher price sensitivity. This is likely to impact air cargo that is used to minimise inventories and support just-in-time production[54].

Another factor is the cargo market size at the airport, as shipments are easier to manage efficiently at higher scales[55]. Therefore cargo at smaller airports may be more price sensitive.

2.3.1.2 Substitute to surface transport

As discussed above, surface transport via road, rail or sea may be a substitute for passenger air travel for short-distance itineraries (for example, rail trips under 200 minutes)[56].

Sea cargo may be a viable substitute for air cargo, especially for heavier goods (where air transport may be relatively more expensive) and less time-sensitive goods (where the longer delivery time is acceptable to customers).

The emissions impact of this channel would depend on the vehicle occupancy of the surface mode that the passenger substituted towards. It would disproportionately impact particular types of agents:

- The main effect would likely be for **domestic policy area passengers** and passengers on international routes with strong competition from rail/road. International itineraries in which a UK international rail leg connects with air travel outside the policy area are also possible, but due to the incremental travel time this is more likely to be taken up by leisure passengers, who tend to be less sensitive to itinerary time[57].

---

[54] Saghir & Hoekman, 2009.

[55] Kupfer et al., 2016.

[56] See e.g. Behrens & Pels, 2012.

[57] See e.g. Brons et al., 2002; InterVistas, 2007

- **Airlines with policy area domestic routes** would likely be competitively disadvantaged relative to rail airlines and relative to airlines with long-haul routes facing little competition from surface transport.
- This channel would likely disproportionately disadvantage **policy area regional airports**, as these airports have a larger share of short-haul routes that are feasible substitutes for surface transport.

There are several key uncertainties. As before, the magnitude of this channel depends on baseline policy area demand, cost passthrough and interaction with other carbon pricing policies. In addition, the implementation of the High Speed 2 rail network (HS2) is a key source of uncertainty around customers' future ability to viably switch away from domestic aviation routes.

In the freight market, carbon pricing would likely encourage more integrated multimodal supply chains. In general, greater utilisation of multimodal itineraries in cargo does not face the limitation in the passenger market of customer aversion to stopovers. Substituting for surface transport is relatively likely for shorter distances as air routes have higher fuel intensities per kilometre because a greater part of the leg is spent ascending and descending[58]. The overall emissions impact on cargo would depend on the type of substitution for surface transport. Substituting an air cargo itinerary for a surface itinerary could reduce emissions. However, substituting an air itinerary for an itinerary composed of a surface leg within the policy area connected to an air leg outside of the policy area would create positive leakage.

2.3.1.3 Substitute to a different aviation route

Another possibility is that customers substitute away from a route in the policy area to another aviation route. There are several ways in which this substitution could in theory occur.

- **Destination substitution:** a customer not originating in the policy area substitutes a route destined in the policy area for a route not destined in the policy area. This is more likely for leisure customers, who have weaker destination preferences. This would lead to positive leakage.
- **Hub substitution**: the customer substitutes a journey that is connecting (but is not originating or destined) in the policy area for a journey that does not connect in the policy area. In this case leakage will be positive, although the total change in emissions has an ambiguous sign depending on the relative total distance and the carbon intensity of the alternative itinerary.
- **Gateway substitution**: the customer substitutes long-haul direct flights originating or destined in the policy area for short-haul flights to non-policy-area hubs to connect to a long-haul flight. This would lead to positive leakage.
- **Surface gateway substitution**: the customer substitutes long-haul direct flights originating or destined in the policy area for a surface transport link from the policy area to a non-policy-area hub and then connects to a long-haul flight.

---

[58] Saghir & Hoekman, 2009.

As this would substantially increase transport time, it is more likely for non-business customers. This would lead to positive leakage.

These channels would be likely to competitively disadvantage airlines hubbed in the policy area operating long-haul flights as well as policy area hub airports. Congestion at UK hubs may mitigate the effect of this channel if they have lower cost passthrough.

For cargo, because fuel is a relatively larger part of the airline's cost base, viable route substitution is limited to the extent that it would increase an itinerary's total distance, which would be weighed against the potential carbon cost savings of the route substitution. At the same time, a customer may substitute between cargo orders from different origins based on their relative shipping prices. This will depend on the substitutability of goods from other origins; some high-value cargo will likely have low substitutability (e.g. initial deliveries of a product, critical spare parts, high-end electronics).

This channel is subject to several key uncertainties around customer demand including itinerary/route substitutability and baseline levels of aviation demand in the policy area.

2.3.1.4 Substitute to another activity outside the policy area that produces non-priced carbon emissions

Customers could, in theory, substitute aviation demand for some other non-transport activity that is not subject to carbon pricing. Examples could include substituting away from business travel destined in the policy area by investing in telecoms infrastructure to support remote working or substituting leisure itineraries with expenditure on non-travel leisure goods.

For freight transport, customers could substitute air-transported goods for a different locally manufactured good which may be more carbon intensive.

The scale of this substitution is likely to be small and, given that many alternative emissions-intensive activities are covered by the UK ETS, carbon price support and/or small/ultra-small emitter targets, positive leakage through this channel is likely to be negligible.

2.3.2 Airline reactions

Below we discuss how leakage could in principle arise via airline reactions to carbon pricing. We discuss the likelihood of these channels leading to material impacts on carbon leakage and competitive disadvantage in Section 6.

As fuel costs represent a substantial share of airline costs, airlines already experience significant incentives to increase fuel efficiency. Aside from reducing capacity, the greatest future emissions reductions are likely to come from aircraft technological developments or fuel switching. There is only a small potential for emissions reduction from other types of operational changes or from air traffic management changes[59].

---

[59] ATA and Ellondee, 2018; For example, this study estimates that the combined effect of high-likelihood operational and air traffic management changes would decrease fuel consumption by less than 6%.

Airlines may react to a carbon price via a number of different channels:

- Change capacity on routes;
- Hold capacity constant and reallocate aircraft between routes;
- Hold capacity constant and replace high-emissions aircraft with low-emissions models;
- Tankering, taking on additional fuel outside of the policy region in order to reduce refuelling inside the policy area; and
- Invest in and adopt low-emissions technologies or operational processes, including sustainable aviation fuel (SAF).

The remainder of this section discusses these five channels in turn.

2.3.2.1 Change capacity on routes

Airlines can shift capacity on routes by scaling frequency and aircraft type up or down, by dropping policy area routes if the route's rate of return drops below a viable minimum, or by adding routes that avoid the policy area. In general, LCCs have greater ability to drop and add routes than network carriers due to their point-to-point structure, and so this may competitively disadvantage network carriers.

In principle there could be positive leakage if capacity is redeployed outside the policy area. There will also be differential impacts on airlines and airports:

- **Volume effect**: airlines and airports with a smaller proportion of impacted capacity will have a smaller overall cost impact.
- **Cross-subsidisation effect**: airlines and airport groups with a smaller proportion of impacted capacity will have greater ability to cover overheads using routes outside of the policy region. There is some uncertainty associated with the willingness and ability of airlines and groups to cross-subsidise in this way, particularly among airline groups that have complex corporate structures.

Both of these effects could disadvantage policy area airlines and policy area airports that have a larger proportion of their capacity impacted by the policy. An important area of uncertainty for these effects is the parameters of other carbon price schemes: the carbon price level in different jurisdictions, the carbon price evolution over time and country participation in CORSIA. The economic performance of the sector and the free allocation methodology also impact airline behaviour: an airline that has a stronger balance sheet due to higher consumer demand, or due to cost savings from free allocation, will have greater financial ability to sustain routes that have low or volatile profits. The decision to sustain a less reliably profitable route will depend on a number of factors such as future expectations of cost base, profitability and importance in the airline's network.

Higher aviation demand outside the policy area would increase the impact of this channel (on both leakage and competitive disadvantage) by supporting an increase in capacity outside the policy area.

In the medium term, these changes in capacity, combined with the customer reactions described above, will lead to a new set of flight schedules[60]. In principle this could lead to airlines increasing capacity outside the policy area (for example, to meet demand for an indirect itinerary in place of a direct flight in order to shift RPKs outside of the policy area). This in turn may lead to new airlines or subsidiaries establishing outside the UK or relocating outside the policy area. Another possibility is relocating hubs from inside to outside the policy area. Whether these effects would materialise in practice is dependent on the areas of uncertainty discussed above, including the relative carbon prices in different jurisdictions. We discuss this further in Sections 4 and 6.

2.3.2.2 Hold capacity constant and reallocate aircraft between routes

Airlines may have the ability to reassign low-emissions aircraft to policy area routes and high-emissions aircraft to other routes. This carbon cost mitigation strategy will be primarily available to those airlines with sufficient capacity outside of the policy area. This will competitively disadvantage, for example, regional airlines within the policy area (whose operations are concentrated inside of the policy area and therefore do not have the capacity to reassign high-emissions aircraft outside of the policy area). In cargo, this may competitively advantage global integrated airlines with a small proportion of operations within the policy area. The channel will have positive leakage. The extent to which airlines are able to reallocate fleet is uncertain, but it is likely to have a relatively small impact on leakage and competitiveness in this case. This is due to the small difference in effective carbon prices between different types of aircraft affected by the policy, which means that the incentives to reallocate different types of aircraft between routes will be small[61].

2.3.2.3 Hold capacity constant and replace high-emissions aircraft with low-emissions models

Airlines manage fleet composition by considering a range of factors, including new aircraft purchases, alterations to aircraft in the fleet, and retirements. When purchasing new aircraft, airlines tend to place orders with lower fuel burn when new models become available with significantly lower emissions intensity. High-fuel burn aircraft may be retired relatively early in periods with high fuel prices[62].

Rather than utilise and retire high-emissions aircraft, airlines in the policy area could instead sell or lease aircraft to airlines for routes outside of the policy area. Airlines with an older fleet may have a competitive advantage as they would be closer to retiring their older aircraft and could take the opportunity to acquire new aircraft with lower emissions intensity. The leakage associated with this channel depends on the emissions intensity of the other aircraft that are replaced.

Cargo airlines tend to use older and less fuel-efficient fleets. This indicates that their cost minimisation approach tends to favour the cost savings associated with buying and leasing older aircraft over the cost savings associated with operating more fuel-efficient aircraft. Therefore, they would be less likely to pursue this

---

[60] Equilibrium denotes when market participants have finished reacting to a change in the market.

[61] ATA and Clarity, 2018.

[62] Morrell & Dray, 2009.

strategy compared to passenger airlines, whose cost minimisation strategy is more likely to favour opportunities to improve the fuel efficiency of the fleet.

This channel depends on the level of global aviation demand and on global carbon pricing. If there is a larger carbon price differential between the policy area and other regions, then there is greater potential for this channel.

ATA and Clarity (2018) found that the impacts of this channel in the UK were likely to be minimal. This was because the cost savings from selling off older aircraft and replacing them with newer models accrued through fuel efficiency at around a 20% efficiency improvement was not enough to compensate for the increase in capital costs.

2.3.2.4 Fuel tankering

If carbon pricing is based on refuelling within the policy area, then this may create a discrepancy between a refuelling pattern that minimises the fuel consumption of an itinerary and one that minimises fuel costs. Tankering occurs when an airline takes on additional fuel outside of the policy area to reduce the refuelling that occurs within the policy area. This will create positive leakage by increasing the aircraft weight. The strategy will be most profitably available to aircraft on short-haul routes that originate in the policy area and destine outside of the policy area (or vice-versa), and so would competitively disadvantage airlines who do not operate these routes.

Tankering is most profitable on short-haul routes, because taking on additional fuel weight incurs a smaller fuel burn cost on a short-haul route compared to on a long-haul route. At the same time, cargo routes tend to be longer distance than passenger routes. Because tankering is most profitable on short-haul routes, cargo airlines would likely have fewer opportunities to profitably tanker on their routes compared to passenger airlines. As a result, tankering is likely to have a lesser impact on cargo emissions compared to passenger emissions.

2.3.2.5 Invest in and adopt low-emissions technology or operational processes

Dray et al. (2018) found that a combination of technological and operational measures undertaken at fuel prices of £35 to £70 per barrel could reduce carbon emissions per RPK for North American narrowbody aircraft by 2% per year to 2050. This is consistent with the ICAO Destination Green roadmap[63]. However there are many sources of uncertainty in this channel. Future emissions per RPK are dependent on future SAF carbon efficiency, which is uncertain, and which may account for over half of carbon efficiency gains and in particular drive carbon efficiency gains for long-haul flights. The carbon pricing impact on SAF usage will also depend on the carbon accounting applied to SAF. Likewise, the ability of airlines to invest in low-emissions technologies is a function of underlying demand, the economic performance of the aviation sector and the availability of investors.

The ability of airlines to invest in future low-emissions technologies may be related to their historic tendency to operate a newer and more fuel-efficient fleet. In other

---

[63] ICAO, 2019d.

cases, new technological developments may open opportunities for different airlines to profitably invest in low-emissions technologies than those airlines who have done so historically. These factors will determine whether this strategy competitively advantages airlines that currently have newer and more fuel-efficient fleets.

As discussed above, cargo airlines have a cost minimisation approach that tends to favour the cost savings associated with buying and leasing older aircraft over the cost savings associated with operating more fuel-efficient aircraft. As a result, cargo airlines are less likely to invest in new technologies compared to passenger airlines.

In general, these measures would be expected to have negative leakage, because there would be technology spillovers that would reduce carbon emissions for aircraft operations outside of the policy area. There may be some exceptions in certain cases where inputs are rivalrous, for example Renewable Energy Directive II (REDII) compliant biofuels.

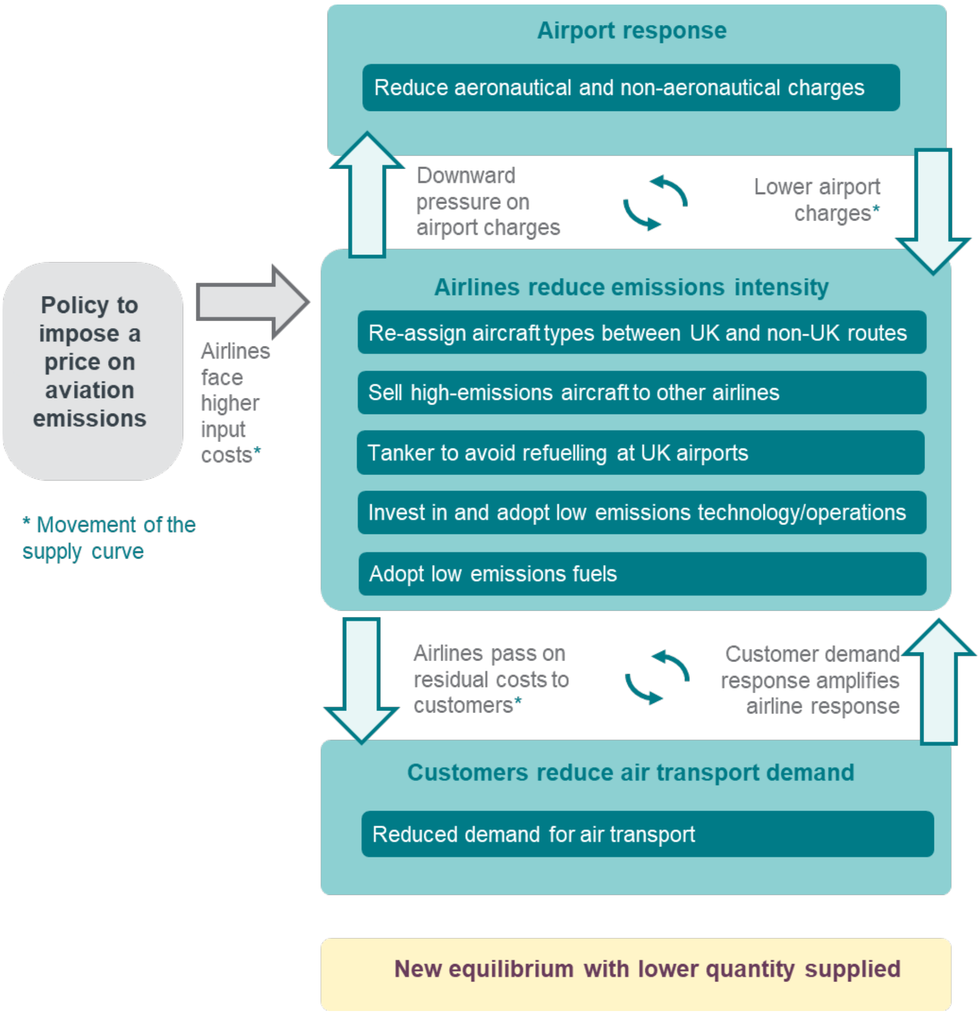
2.3.2.6 Second-order effects

The first-order airline reactions described above may create second-order macroeconomic effects. These could include:

- **An energy effect**: this could occur both with fossil fuels and with SAF.
  - **Fossil Jet A**: a reduction in demand for fossil Jet A fuel inside the policy area could lead to a reduction in global fuel prices and an increase in demand for fuel outside the policy area. The magnitude of this effect depends on the policy impact on fossil Jet A fuel demand. As UK fuel consumption accounts for a small share of global fuel demand, this effect is unlikely to be material.
  - **SAF**: an increase in demand for SAF inside the policy area could lead to an increase in global SAF prices and a decrease in demand outside the policy area, generating positive leakage in the short-term. This will depend on the level of future SAF supply constraints and the magnitude of UK SAF demand. As SAF supply is substantially smaller than fossil Jet A supply, a UK policy is more likely to materially impact the SAF market than the fossil Jet A market. This effect could competitively disadvantage airlines for whom SAF represents a higher share of their fuel, as opposed to fossil Jet A fuel. Refer to Section 6.5.1.4 for further discussion.
- **An aircraft effect:** A glut in the supply of high-emissions aircraft, resulting from airlines changing their fleet structure, could lower the price of high-emissions aircraft outside of the policy region and thereby reduce the operating costs of flights outside the policy region. Similarly to the energy effect above, the magnitude of this impact is likely to be small, because the impact of the aircraft supply due to the policy compared to the global supply of aircraft would be small.

2.3.3 Theory of change

Figure 2 Aviation sector response to a carbon pricing policy

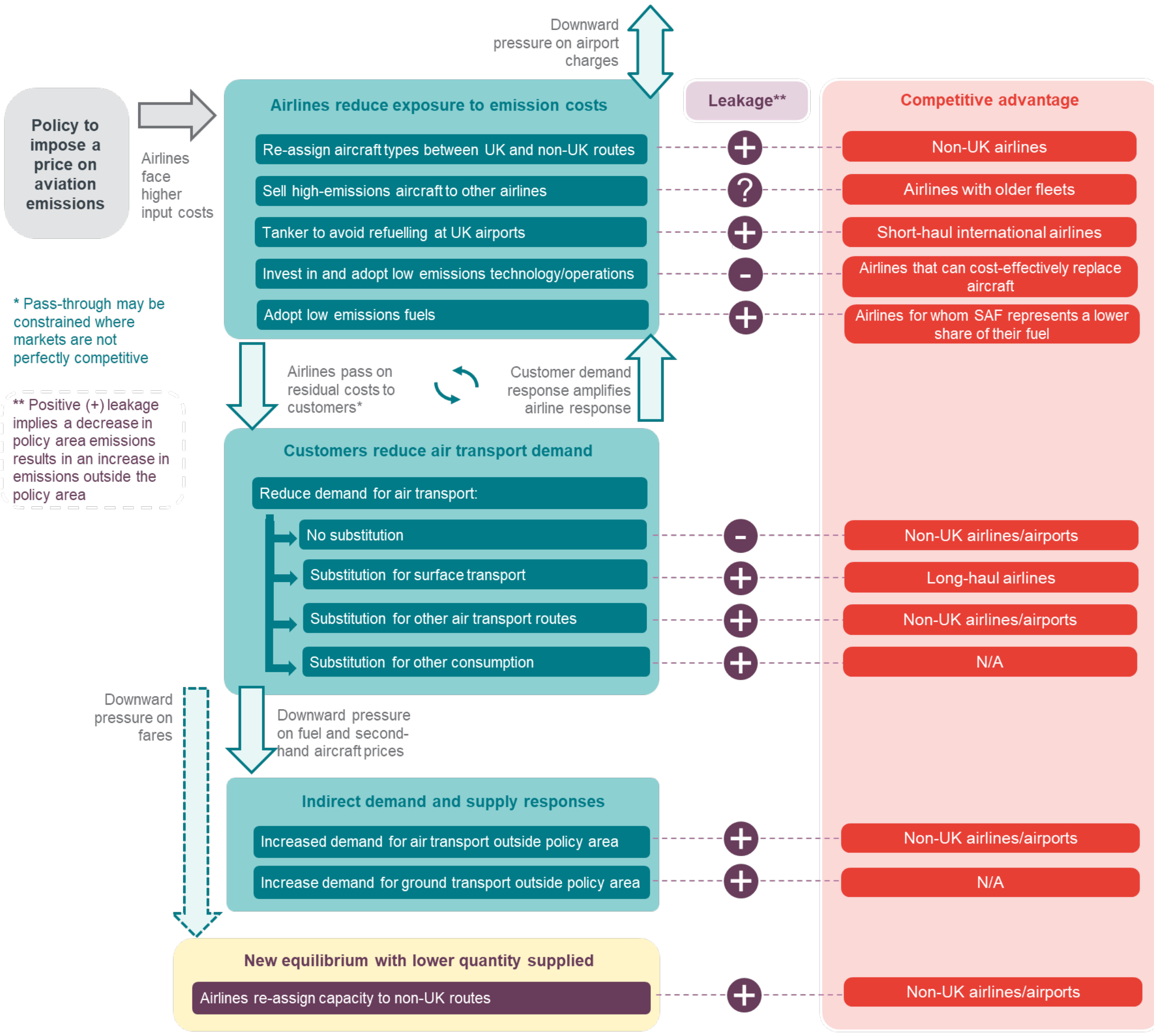


Source: Frontier Economics

The theoretical dynamics of the aviation sector response to a carbon pricing policy can be summarised as shown in Figure 2. The carbon price means that airlines face higher operating costs. They can reduce these costs by reducing the emissions intensity of their activities or by negotiating lower airport charges (for airports where landing charges are not regulated), and pass on some share of the residual costs to customers in the form of higher fares. Customers in turn reduce their demand for air transport and decrease load factors, leading airlines to reduce capacity in order to increase load factors, resulting in a new equilibrium with higher fares and a lower quantity of air transport relative to the pre-policy baseline.

This framework can be adapted to represent the causal channels driving leakage and competitive advantage (see Figure 3).

Figure 3 Channels of policy impact



Source: Frontier Economics and ATA

3 FRAMEWORK FOR ASSESSING DESIGN OPTIONS OF AN ETS

3.1 Introduction

Markets are well-functioning when they are allocatively, productively and dynamically efficient[64]. Aviation, as in other sectors, is subject to market failure where there are costs to society of pollution which the polluters do not bear.

An ETS scheme can be introduced in order to correct market failure, however its design and implementation should seek to avoid distortions that lead to inefficiencies. For example, the ETS should align with dynamic efficiency, such that firms can invest in low-carbon technologies and reduce the cost of carbon abatement in the future.

The particular focus of this study is how ETS design can mitigate risk of positive carbon leakage and competitive disadvantage. The discussion in the previous section highlighted that carbon leakage and competitive advantage can in theory act through a variety of channels. These channels have different impacts on airlines, airports, consumers, and government; and different implications for decarbonisation and market objectives. Some of these objectives in practice may tend to covary and others present trade-offs.

To formalise the range of outcomes and set up our later discussion of these trade-offs, we provide an assessment framework (**Section 3.2**) that summarises a set of key objectives for aviation carbon policy. This approach aligns with Green Book[65] guidance to assess social outcomes of policies under appraisal as set out subsequently.

This framework includes high-level objectives, each of which is composed of more granular outcomes, and so the framework can be used both for high-level and also for detailed assessment of particular carbon policies.

We then outline a range of policies that could be used to mitigate risk the of carbon leakage and competitive disadvantage channels set out above (**Section 3.3**). This is divided into two parts. First we develop a detailed list of design options for free allocation. Second we outline other shielding policies at a high level.

3.2 Assessment framework

Our assessment framework consists of a set of assessment criteria and a 6-point qualitative scale.

---

[64] Allocative efficiency refers to a market in which different goods and services are provided at optimal levels given consumer preferences. Productive efficiency is achieved when a firm makes optimal use of inputs in order to produce goods and services. A firm is dynamically efficiency when it optimally invests in new production processes over time in order to reduce costs.

[65] HM Treasury, 2020.

3.2.1.1 Assessment Criteria

The assessment criteria are based on the overarching principles for the UK ETS objectives. These principles are:

- **Reducing emissions through incentivising abatement:** In co-ordination with the wider suite of decarbonisation policies, the principal aim is to drive cost-efficient abatement, in line with the UK's pathway to achieving its domestic and international climate targets. This supports the objectives of the Paris Agreement. Relevant targets include the Sixth Carbon Budget, the UK's Nationally Determined Contribution under the Paris Agreement, and the UK's 2050 net zero emissions target.
- **Appropriately mitigate carbon leakage risk:** In effectively mitigating competitiveness distortions and reducing carbon leakage risk, the policy contributes to reducing global emissions through changes in production, demand or activity.
- **Support a viable market:** This objective has two aims. The first is to provide certainty for market participants by setting clearly defined rules and parameters for the operation of the market, including on the discretion of government to intervene in the market. The second aim is to ensure a smooth continuation of emissions trading for market participants, reducing the risk of negative impacts from unexpected changes in the market, including in price, demand and liquidity.
- **Encourage climate action outside the current scope and the UK:** Making the best use of the UK ETS across the economy acts as a tool for demonstrating global leadership on climate change, and as a means for practical forms of co-operation wherever possible.

These four principles have been adjusted for application to the aviation sector and the focus of this assessment, to form six high-level assessment criteria. Within each criterion sit a number of sub-questions. Consistent with Green Book guidance, these criteria are aligned with high-level UK ETS policy objectives, and they are framed as social outcomes.

Table 1 Assessment criteria

Criteria	Subcriteria
1. Reduce emissions through incentivising abatement	a. How does the design option impact on the incentives for supply-side (including emissions and emission-intensity) and demand-side abatement in UK aviation? b. Does the design option facilitate investment in aviation decarbonisations (to bring down abatement costs in the future)? c. Is the design option likely to lead to allocative efficiency (where least-cost abatement options are used first)? d. How will this design option interact with other parts of the UK ETS?
2a. Appropriately mitigate carbon leakage risk	a. How effective is the design option in mitigating carbon leakage both in the end state and during the transition?
2b. Appropriately mitigate risk of competitiveness distortions	a. How effective is the design option in mitigating competitive disadvantage in the UK (including location decision and UK hub airports) both in the end state and during the transition? b. Does the design option affect the relative competitiveness of new entrants and incumbent firms in the UK aviation sector?
3a. Support a viable market – operator perspective	a. Is this design option likely to lead to unjustified windfall gains for some players in the markets (an effective transfer from other players)? b. Will the design option allow the market to respond to shocks? c. What are the impacts of the design option and implementation on aircraft operators administrative costs? d. Does the design option punish early action? e. Is the design option transparent and easy to understand for players in the market (with low compliance costs)? f. Is the design option likely to lead to disproportionate or regressive distributional impacts for operators?
3b. Support a viable market – government perspective	a. Is the design option likely to impact revenue generation for HMT? b. Is the design option likely to lead to distortions in the market for aviation (beyond affecting UK competitiveness) including perverse incentives for passengers or operators either during its transition or afterwards? c. Does the design option easily allow pre-specified or reactive adjustments by government? d. Is the design option likely to lead to an increase in airfares, and will these have disproportionate or regressive distributional impacts on consumers? e. Is the design option easy to introduce and monitor for government, with low data requirements and admin costs? f. Is the design option likely to expose the UK to risks in the upstream and downstream parts of the value chain (e.g. maintenance, tourism)? g. Is the design policy likely to lead to employment impacts in the UK aviation sector?
4. Encourage climate action outside the current scope and the UK	a. How will this design option interact with other international aviation mechanisms such as CORSIA? b. Is this design option compatible with WTO rules?

Source: Frontier Economics

3.2.1.2 Qualitative scale

In the assessment we use a qualitative scale with levels 0-5. For each of the above high-level assessment criteria, the levels and their interpretation are outlined below.

Figure 4 Qualitative assessment scale

	1 - Reduce emissions through incentivising abatement	2a - Appropriately mitigate carbon leakage risk	2b - Appropriately mitigate risk of competitiveness distortions	3a - Support a viable market: airline perspective	3b - Support a viable market: government perspective	4 – Align with climate action outside the current scope and the UK
5	Substantially reduces sector-level emissions compared to the baseline	Substantially reduces carbon leakage across the sector as a whole compared to the baseline	Substantially reduces risk of competitive disadvantage compared to the baseline	Market is significantly improved from an airline perspective compared to the baseline	Market is significantly improved from a government perspective compared to the baseline	UK ETS is significantly more aligned with other decarbonisation mechanisms and international rules compared to the baseline
4	Moderately reduces sector-level emissions compared to the baseline	Moderately reduces carbon leakage across the sector as a whole compared to the baseline	Moderately reduces risk of competitive disadvantage compared to the baseline	Market is moderately improved from an airline perspective compared to the baseline	Market is moderately improved from a government perspective compared to the baseline	UK ETS is moderately more aligned with other decarbonisation mechanisms and international rules compared to the baseline
3	Ambiguous overall effect on sector-level emissions compared to the baseline	Ambiguous overall effect on carbon leakage across the sector as a whole compared to the baseline	Ambiguous overall effect on competitive disadvantage compared to the baseline	Ambiguous overall effect on market viability from an airline perspective compared to the baseline	Ambiguous overall effect on market viability from a government perspective compared to the baseline	Ambiguous overall effect on UK ETS alignment with other decarbonisation mechanisms or international rules compared to the baseline
2	Moderately increases sector-level emissions compared to the baseline	Moderately increases carbon leakage across the sector as a whole compared to the baseline	Moderately increases risk of competitive disadvantage compared to the baseline	Market is moderately worsened from an airline perspective compared to the baseline	Market is moderately worsened from a government perspective compared to the baseline	UK ETS is moderately less aligned with other decarbonisation mechanisms and international rules compared to the baseline
1	Substantially increases sector-level emissions compared to the baseline	Substantially increases carbon leakage across the sector as a whole compared to the baseline	Substantially increases risk of competitive disadvantage compared to the baseline	Market is significantly worsened from an airline perspective compared to the baseline	Market is significantly worsened from a government perspective compared to the baseline	UK ETS is significantly less aligned with other decarbonisation mechanisms and international rules compared to the baseline
N/A	Minimal causal impact on sector-level emissions	Minimal causal impact on carbon leakage	Minimal causal impact on competitive disadvantage	Minimal causal impact on market from airline perspective	Minimal causal impact on market from government perspective	Minimal causal impact on UK ETS alignment with other decarbonisation mechanism or international rules

Source: Frontier Economics

Please note that there is a distinction between rating 3 (amber) and rating 0 (grey): rating 3 indicates that there is a clear causal channel between the design option and the outcomes of interest (but the direction of overall effect is ambiguous), whereas rating 0 indicates that there is not a clear causal channel between the design option and the outcomes of interest.

3.3 Design options for assessment

3.3.1 Approach to selecting free allocation as the primary focus of the assessment

In order to select policy design features to be included in the qualitative assessment, we engaged with BEIS and DfT officials.

In this process, we first proposed a wide range of potential policy solutions within the scope of policies and responsibilities of the relevant public bodies, as recommended by the Green Book. These initial discussions included different aspects of ETS design such as free allocation mechanisms, fungibility of permits, carbon price stability mechanisms, compliance enforcement, and interaction with other carbon pricing policies; as well as non-ETS carbon policies.

Given that free allocation is the primary shielding mechanism across most ETS, and based on DfT and BEIS feedback, we selected free allocation design as the primary focus of the study. We then developed a detailed list of free allocation design options (**Section 3.3.2**).

A secondary interest in this study was other shielding mechanisms aside from free allocation, including mechanisms that might be included within ETS design or be implemented as a separate policy. We discuss potential non-free allocation shielding mechanisms at a high level (**Section 3.3.3**); these policies are relatively prospective and might be considered in the medium to long term.

3.3.2 Free allocation

This section summarises the current free allocation mechanism for the UK ETS, and then develops design options—a set of variations on the current policy—to be included in the free allocation assessment.

3.3.2.1 Current UK ETS free allocation mechanism

Below we summarise the aviation free allocation mechanism in place in 2021 during Phase I(a) of the UK ETS. The Aviation Allocation Table has been published for the 2021 to 2025 allocation period, with figures for airline's allocation entitlements, and indicative figures for the period 2023-2025 which are currently subject to review.

Free allocation is currently based on each airline's 2010 tonne-km activity data (TKM) which is the distance that a plane flies multiplied by the weight of its contents[66] (or 2014 TKM data for those benefiting from EU ETS special reserve for new entrants or fast growers) for flights within scope of the UK ETS (see Section 1.1 for scope definition).

A free allowance entitlement for an individual airline is calculated by multiplying that airline's TKM figure by the aviation benchmark. The benchmark used currently is the EU ETS free allocation benchmark. This figure is approximately 0.64 allowances per 1000 TKM; see below for explanation of the EU ETS benchmark calculation.

In line with EU ETS Phase IV, from 2021 a linear reduction factor of 2.2% is annually applied to free allocation entitlement, reducing eligible participants' allocation by 2.2% year on year.

---

[66] TKM is defined as (great circle distance between departure and arrival aerodrome + fixed factor of 95km) x (payload of freight, mail and passengers carried).

CALCULATION OF EU ETS BENCHMARK

The EU ETS benchmark was calculated in stages:

- **Aviation cap.** The cap on aviation allowances was set at 95% of average emissions in 2004 to 2006. This was originally calculated based on the original scope of the EU ETS. This cap was then adjusted downward to reflect the reduction in EU ETS aviation scope to intra-EEA flights[67].
- **Total annual free allowances**. Of the aviation cap for the reduced scope, 82% of allowances were issued free of charge, 3% held in reserve, and 15% auctioned[68].
- **Benchmark.** The EU ETS benchmark was calculated by dividing total annual free allowances by the sum of all airlines' submitted 2010 TKM data i.e. the sector TKM.

3.3.2.2 Framework for free allocation

At a very high level, the allocation is composed of three terms: an activity measure, a benchmark, and an adjustment factor. For these components one can consider the following issues:

- Defining subsectors;
- Updating terms over time, either through updates to the data or through policy-driven rescaling; and
- The units or formula for calculating each term.

The below framework aims to be generic (suitable for the design of a free allocation mechanism "from the ground up"). However, a number of specific historical factors contributed to the development of the EU ETS benchmark. In order to keep the framework generic, below we define the benchmark in a different way to how it is defined in the aviation EU ETS. In the remainder of this report, we refer to the 'benchmark' as we have defined it, distinct from the 'EU ETS benchmark'.

Consider a set of airlines in a sector, and each airline i conducts some measured activity $activity_{i,j,t|s}$ in subsector j, for a time period s in which the activity is measured (one year or multiple years), to be used for free allowances allocated in year t. For example, $activity_{i,j,2020|2010}$ would indicate activity data collected in 2010 and then used for the 2020 allocation.

If the free allocation mechanism does not include any subsector definitions, then all airlines are in the same sector j.

These units of activity need to be converted into units of emissions (allowances): this is the purpose of the benchmark. Each subsector benchmark, $benchmark_{j,t|r}$, implemented in year t based on data in time period r, is a measure of emissions intensity (emissions per unit of activity). r may include one year or multiple years

---

[67] European Commission, 2021.

[68] European Commission, 2009b.

of data. $benchmark_{j,t|r}$ is a function b_j of historical emissions data and historical activity data for the subsector:

$$benchmark_{j,t|r} = b_j(activity_{1,\dots,I;j,r}, emissions_{1,\dots,I;j,r})$$

$benchmark_{j,t|r}$ is in units of emissions per activity: $(emissions)/(activity)$. For example, the benchmark could be 0.5 tCO2 per 1,000 TKM.

The third component of the mechanism is an adjustment factor applied to each subsector. The adjustment factor can be used to shift the total number of free allowances in each subsector upwards or downwards, in line with policy objectives. The adjustment factor can be considered as the product of separate terms:

$$AF_{j,t} = \left(1 - initialAF_j\right) \times \prod_{u=initial\ year+1}^{t} (1 - annualAF_{j,u})$$

The adjustment factor $AF_{j,t}$ in year t for subsector j is the product of an initial adjustment factor (which can be used to adjust the total free allocation in the initial year for the subsector) and subsequent annual adjustment factors. For example, the initial adjustment factor might be calibrated so that free allocation represents 50% of historical subsector emissions, and the annual adjustment factor could be set at a 5% annual reduction. The initial adjustment factor is primarily calculated to address the quantity of free allocation determined optimal for the ETS in the starting year.

These terms can be combined to calculate free allowances. To do this, we distinguish between non-reserve free allowances (i.e. the main pool of allowances) and also reserve free allowances. Reserve allowances may be desirable if airlines' historical activity data from period s does not accurately reflect their scale of operations in period t, such that a correction is needed to mitigate risk of market distortions arising from the particular airlines receiving systematically fewer free permits relative to other airlines. For example, if an airline entered the market after the activity data has last been updated, they will not receive free allowances until the next activity data update unless a special provision is made.

For non-reserve free allowances, we combine the terms from above:

$$nonreserveFA_{i,t} = \sum_j (activity_{i,j,t|s} \times benchmark_{j,t|s} \times AF_{j,t})$$

where $nonreserveFA_{i,t}$ are the total non-reserve free allowances awarded to airline i for year t.

The reserve allocation is based on the non-reserve allocation calculation, with some additional steps. To develop a reserve mechanism for a particular category k (e.g. a new entrant reserve) in subsector j, the policy must establish a set of rules specifying how the airline's subsector activity qualifies for type k reserve permits. We define the activity that qualifies for reserves $R_{k,j,t}(activity_{i,j;1\dots t})$ which is a function of the history of an airline's activity. In the example of a new entrant reserve, $R_{k,j,t}(activity_{i,j;1\dots t})$ could be set to 0 for all airlines aside from the new entrants, where it might be set to their activity level in the year after they entered the market.

The total permits allocated from reserves is the sum across each type of reserve type k and subsector j:

$$reserveFA_{i,t} = \sum_{j} \sum_{k} (R_{k,j,t}(activity_{i,j;1\ldots t}) \times benchmark_{j,t|s} \times AF_{j,t})$$

Total free allocation is the sum of non-reserve and reserve allocation:

$$FA_{i,t} = nonreserveFA_{i,t} + reserveFA_{i,t}$$

We note that this framework differs from the current UK ETS in the calculation of the benchmark. The EU ETS benchmark combines data on emissions intensity and also policy decisions to adjust the level of free allocation. However, the purpose of our approach is to conceptually distinguish between the component of free allocation that is data-driven (our definition of the benchmark) versus the component that is driven by government policy to control the total free allocation level (our definition of the adjustment factor). Our assessment of benchmark design options focuses specifically on how free allocation can be designed in order to reflect variation in emissions intensity in aviation. The adjustment factor design options focus on policy-driven adjustments to the level of free allocation.

Below we summarise the design features that comprise this calculation, and how these features are implemented in the current UK ETS. We also highlight whether this is a design feature that can be individually varied, or whether it must match other design features and is therefore not a ‘free’ decision variable.

Figure 5 Non-reserve free allocation design features

Notation	Design feature	Current UK ETS design	Free variable
$\boldsymbol{activity_{i,j,t\|s}}$	Unit of activity measure	Tonnes-kilometres	Free
$activity_{i,\boldsymbol{j},t\|s}$	Subsector definition	Sector-level (no subsectors)	Free
$activity_{i,j,\boldsymbol{t\|s}}$	S is they year the activity data was collected, which is used to allocate free permits in year t	The activity data is from 2010 (from 2014, if applicable for the airline)	Free
$\boldsymbol{b_j}(activity_{1,\dots,I;j,r}, emissions_{1,\dots,I;j,r})$	Statistic to calculate the benchmark	Please see note on EU ETS benchmark above	Free
$b_j(\boldsymbol{activity}_{1,\dots,I;j,r}, emissions_{1,\dots,I;j,r})$	Activity units used in the benchmark calculation	Tonnes-kilometres	This should correspond to the unit of activity measure (see above)
$b_j(activity_{1,\dots,I;j,r}, \boldsymbol{emissions}_{1,\dots,I;j,r})$	Emissions units used in benchmark calculation	Tonnes of carbon dioxide	In order to align with inter-sector permit fungibility, this should match the emissions units used for the entirety of the ETS
$b_{\boldsymbol{j}}(activity_{1,\dots,I;\boldsymbol{j},r}, emissions_{1,\dots,I;\boldsymbol{j},r})$	Subsector definition in benchmark	Sector-level (no subsectors)	This should correspond to the subsector definition used in the activity measure (see above)
$b_j(activity_{1,\dots,I;j,\boldsymbol{r}}, emissions_{1,\dots,I;j,\boldsymbol{r}})$	Time period of the data used in the benchmark	Please see note on EU ETS benchmark above	Free
$\boldsymbol{initialAF}_j$	Initial adjustment level to calibrate the initial level of free allocation	Initial adjustment factor required to set the UK ETS total free allowances in 2021 to 4.4 MtCO2[69]	Free
$\boldsymbol{annualAF}_{j,u}$	Annual trend component of adjustment factor	The level of free allocation currently declines by 2.2%	Free
$AF_{\boldsymbol{j},t}$	Any variation in adjustment factor by subsector	Sector-level (no subsectors)	Free
$R_{\boldsymbol{k},j,t}(activity_{i,j;1\dots t})$	Types of reserve allocation	UK ETS commits to honouring fast growth between 2010 and 2014 that was in receipt of EU ETS reserves (if applicable); other reserves not currently implemented	Free
$\boldsymbol{R}_{k,j,t}(activity_{i,j;1\dots t})$	Rules to determine allocation from reserve		Free

Source: Frontier Economics

3.3.2.3 Selection of design options

Given the above longlist of design features, we considered which of these to include in the shortlist of design features for assessment, and which design options within each design feature to include.

---

[69] BEIS, 2021b.

The focus of this study is on high-level policy design, and detailed implementation aspects are outside of scope. Therefore, the selection of design options for assessment, within each of the above design features, focusses on key decisions that can be assessed using the framework in Section 3.2.

In the selection of design options, we have considered the following criteria:

CRITERIA FOR INCLUSION OF DESIGN OPTIONS IN THE ASSESSMENT

- **Ease of implementation**. We retained design options that had plausibly feasible data collection, administration, and enforcement.
- **Legal considerations**. We included design options that align with UK and international laws and regulations.
- **Precedent**. The design options are focussed on methods that have precedent in other ETS's.
- **Materiality**. We included options that were likely to have material impacts on the level and/or distribution of free allocation.
- **Policy objectives**. We assessed design options that supported at least one or some of the assessment criteria (see Section 3.2.1.1). These are:
  - Reducing emissions through incentivising abatement
  - Appropriately mitigating carbon leakage risk
  - Appropriately mitigating risk of competitiveness distortions
  - Support a viable market: airline and government perspectives
  - Aligning with climate action outside the current scope and the UK
- **Strategic priorities**. We added design options that are focused on strategic priorities that DfT and BEIS officials identified.

For particular design features, specific criteria from among the above are especially relevant. We include these key points in the discussion below.

We discuss options within each of the following design features:

- Activity:
  - Unit of activity measure
  - Updating year of activity data
- Benchmark:
  - Defining benchmark subsectors
  - Statistic for estimating the benchmark
  - Updating the year of benchmark data
- Adjustment factor:
  - Initial adjustment factor and annual adjustment factor
  - Variation in the adjustment factor by subsector

- Reserves:
    - ☐ Types of reserve allowances
    - ☐ Rules to determine allocation from reserves

3.3.2.4 Unit of activity measure

The two typical choices for units in a free allocation mechanism are activity measures (in the cases of fixed sector benchmarking and output-based allocation) and emissions.

If the mechanism uses an activity measure, key issues for aviation include:

- The measure should capture a key output of the sector or subsector that is associated with emissions
- The measure should capture passenger and freight activity in an equitable way
- The measure should have proportionate ease of implementation, taking into account administrative costs to airlines and government

There are a number of standard measures of aviation transport activity that do not capture both passenger and freight activity, and therefore do not offer advantages relative to the current tonnes-kilometre measure. These include revenue passenger kilometres and available seat kilometres (relevant for passenger activity only), cargo tonnes-kilometres (relevant for freight activity only). We have eliminated these measures from consideration.

We have considered fuel usage as a measure of activity. However fuel usage closely tracks emissions, and may risk distortions by incentivising tankering, depending on the fuel monitoring regime. Therefore we conclude that fuel usage does not offer substantial advantages over emissions as a measure of activity, and have not included this option in the assessment.

The current measure of TKM is based on (distance)x(payload), where payload includes the mass of passengers, freight, and mail. This measure does not include aircraft and fuel weight. This raises a question about whether the activity measure could include aircraft and fuel weight. We note that airlines are already heavily incentivised to minimise excess weight associated with aircraft and fuel, to reduce fuel costs. Moreover, conceptually, the output of the sector is captured by the payload transported, rather than total mass transported. Therefore we have not included an alternate TKM measure that include aircraft and fuel weight, and only include the current TKM measure in the assessment.

The only remaining activity unit that could be assessed is using historical emissions. Using emissions as an activity unit would punish early action, reward carbon intensive airlines, and reduce abatement incentives. This design option would therefore not meet the objectives of the UK ETS, and therefore is not assessed further in this report.

Defining benchmark subsectors

If the free allocation mechanism had a sector-wide mechanism with no defined subsectors, there may be a particular subsector at greater risk compared to other subsectors of carbon leakage (to other routes) or competitive disadvantage. This could occur if:

- A subsector has lower ability to pass through costs to customers than other subsectors and as a result are at higher risk of losing market share; or
- A subsector has higher emissions intensity per unit of activity due to operational factors relative to other subsectors.

We note that the subsector definition should not introduce disproportionate administrative costs to airlines and government, and should seek to avoid introducing market distortions by increasing the profitability of one subsector relative to another subsector.

In the context of UK aviation, the greatest risk of incomplete cost passthrough is at congested UK hub airports (see Section 2.3.1.1 for discussion of cost passthrough and airport congestion). The incomplete passthrough at congested airports is due to airport capacity constraints. These constraints also act to increase profitability on impacted routes relative to non-capacity-constrained routes. Given that the capacity-constrained routes are relatively profitable and therefore at lower risk of competitive disadvantage due to carbon pricing, we do not find justification to provide additional shielding mechanisms on these routes.

Public Service Obligation (PSO) routes are another subsector that has more limited ability to pass through costs. This is due to the lower demand and lower profitability for these routes relative to other routes, which may limit airline’s ability to pass through costs while continuing to operate the route to minimum required level of profitability. However, public service obligation routes receive government subsidies to ensure continued service. The future subsidisation of PSO routes may need adjustment due to the impacts of carbon pricing on demand on these routes. As the subsidy provides an existing policy mechanism to support continued PSO service, we do not propose including PSOs as a defined subsector in the free allocation mechanism. A subsidy is also likely to be a more appropriate approach as it can be better targeted. Carbon pricing may introduce additional cost volatility for PSO services, which may be considered in the design of the subsidy.

We have also considered defining subsectors based on the emissions intensity of different aviation activities. We have identified potential subsectors of short-haul versus medium-haul flights, where the distinction is based on a distance threshold (e.g. 800 km). Short-haul flights tend to have higher emissions per TKM relative to medium-haul flights, as take-off and landing have higher emissions per TKM relative to cruising, and for short-haul flights, take-off and landing represent a larger fraction of the flight relative to medium-haul flights. Passenger flights have an estimated 35% higher tCO2 per RPK compared with medium-haul flights[70]. Therefore if short-haul activity and medium-haul activity are subject to the same free allocation mechanism, airlines with a disproportionate share of short-haul activity may receive a lower intensity of shielding relative to other UK airlines.

We assess the following design option for subsector definitions against the current policy:

---

[70] Graver, Rutherford, and Zheng, 2020.

- Short-haul routes versus medium-haul routes, based on a distance threshold

3.3.2.5 Updating the activity data year

In the literature and among existing ETSs, there is a wide range of updating frequency for activity data. At one extreme, output-based allocation updates the activity data every year or every few years (examples that adjust free allocation based on recent activity include Québec ETS, California ETS, Australia ETS). At another extreme, the activity data is very rarely updated, or has not been updated since the inception of the present scheme (e.g. the aviation EU ETS).

We assess the following design options for updating the activity data year, in order to capture the possible range of data updating frequency:

- A one-off update of the activity data year
- Regular updating of the activity data, where the updating could be more or less frequent

3.3.2.6 Statistic for calculating the benchmark

We have reviewed methods for benchmark calculation in large ETS schemes, in different sectors. The statistics used in these schemes fall into two main categories:

1. **A measure of average sector or subsector performance**. Typical benchmark statistics in this category include:
   - (total subsector free allowances)/(total subsector activity); and
   - (X% of total subsector emissions)/(total subsector activity), where the scaling factor X is determined by policy.

   Examples of this category of statistic include the South Korea ETS, the EU ETS (aviation), subsectors in the California ETS, subsectors in the New Zealand ETS, and subsectors in the Quebec ETS.

2. **A measure of high-performing emissions efficiency**, based on the firm-level distribution of emissions efficiency. Firm-level emissions efficiency is measured as (firm emissions)/(firm activity). Examples include:
   - the Xth percentile of firm-level emissions efficiency (e.g. applied to industrial installations in the EU ETS)
   - Best-in-class firm-level emissions efficiency (e.g. applied to some subsectors in the California ETS).

The current UK ETS uses a benchmark statistic that falls into category (1) described above.

We considered whether a benchmark statistic from category (2) should be included in the assessment. Category (2) relies on a key assumption: that the comparison of firm-level data is on a like-for-like basis, i.e. the firm-level distribution of emissions intensity reflects differences in emissions efficiency largely under management control, rather than differences in the type of output produced. In aviation, we find that this assumption is not suitable. In aviation, differences in airline-level emissions intensity reflect a combination of the lengths of routes, fleet fuel efficiency, and operational practice.

Therefore we find that the approach of using a sector or subsector-wide statistic (category 1 above) is more appropriate for an aviation policy similar to the UK ETS. Further deviations from the current UK ETS – such as separate sub-sector level benchmarks - would need to be combined with changing the benchmark statistics to avoid distributing permits based on factors outside of management control. We do not include alternate types of statistics in the assessment.

3.3.2.7 Updating benchmark data year

The benchmark data year can be updated simultaneously with the activity data year. In theory, the benchmark can be updated over time with the explicit aim of tracking developments in the emissions efficiency in the sector or subsector. It can therefore be updated at different times to the activity data. This would lower the level of free allocation in line with technological and operational advances. However, this same policy objective can also be accomplished via the adjustment factor, which can be used to taper free allocation over time (see below). For this reason, we do not include updating the benchmark year separately in the assessment.

3.3.2.8 Level of and time trend in the adjustment factor

We include the following design options in the assessment, to capture the two main types of ways in which the adjustment factor can be used to reduce free allocation over time:

- A one-off change to decrease the initial free allocation level in the ETS phase
- A change in the annual adjustment factor, to reduce free allocation more rapidly over time

3.3.2.9 Variation in adjustment factor by subsector

The free allocation mechanism could vary between subsectors either by varying the benchmark or varying the adjustment factor between subsectors. As discussed above, we include short-haul activity and medium-haul activity as a subsector definition in the assessment. In theory shielding by subsector could also be achieved by varying the adjustment factor by subsector, and the policy choice of adjustment factors for short-haul and for medium-haul activity would determine the relative intensity of shielding provided to these subsectors. We note that this is an alternative design option, but do not include it as design option in the assessment, as the results would be very similar to the design option of varying the benchmark by subsector (see Section 4.3 for these results).

3.3.2.10 Types of reserve allowances

If the activity data is not updated annually, there may be circumstances under which an airline's historical activity data will substantially deviate from current activity data. These include the following:

- An airline enters the UK aviation market. New entrants since 2014 do not currently receive an allocation entitlement. We note that there is precedent for this type of reserve in the EU ETS (aviation). We include a new entrant reserve option in the assessment.
- An airline exits the UK aviation market. Airlines that have exited the UK aviation market no longer qualify for receipt of free allowances. We do not assess any alternative reserve allocation design options for market exit.
- An airline has substantially increased aviation activity. There is currently no UK ETS reserve for allocation but there is precedent for this type of reserve in the EU ETS (aviation) for 2010-2014. We include a fast growth reserve option in the assessment.
- An airline has substantially decreased aviation activity. Currently, airlines whose activity falls below certain minimum thresholds are not covered by the UK ETS[71]. This does not address the case where an airline's activity shrinks substantially but is still above this minimum threshold. We do not assess alternative design options that adjust free allocation specifically for decreased aviation activity. Conceptually, a downward adjustment of this type is a partial update of the activity data. We find that this issue could be addressed by updating the activity data, this is already assessed in Section 4.4.
- Airlines merge together or split into separate business entities. The free allocation of airlines who have undergone mergers or have split is reallocated according to the business reorganisation[72]. We do not assess alternatives to this policy.
- Airlines have transferred operation of routes (without a merger or split). Currently UK ETS free allocation is not adjusted to reflect transferred operation of routes. Qualitatively this shares key features with updating the activity data (see assessment of updating the activity data Section 4.4).

We assess the following types of reserve allocation:

- Reserve for fast growth
- Reserve for new entrants

3.3.2.11 Rule to determine portion of airline activity that qualifies for reserve allowances

For the two types of reserve allocation above that we assess, there are a range of possible rules that could be used to determine the level of reserve allocation. We therefore do not pick out specific rules to be formally assessed; instead our assessment discusses the themes that should be considered when setting up reserve allowances. For example, in terms of assessing the policy outcomes associated with the shielding mechanism, a key dimension of the reserve policy is whether the reserve is more or less generous in allocating permits, and therefore the strength of the incentive delivered. We discuss different design options to vary the reserve allocation in Section 4.7, but without a formal assessment.

---

[71] National Archives, 2020.

[72] National Archives, 2020.

3.3.2.12 Shortlist of design options

Based on the above selection process, we assess the following design options in Section 4:

Table 2 Design options for qualitative assessment

Design feature	Design options to be assessed against the current UK ETS design
Defining benchmark subsectors	Short-haul and medium-haul subsectors
Updating the activity data	One-off update; regular update
Initial adjustment factor and annual adjustment factor	Change in initial adjustment factor; change in annual adjustment factor
Introducing reserve groups	New entrant reserve; fast growth reserve
Rules for reserve group allocation	Discuss range of rules to increase the allowances allocated from reserves

3.3.3 Other shielding mechanisms

The main focus of the qualitative assessment is free allocation in the context of the UK ETS. In this section we consider alternative shielding policies to free allocation, which could be included as a part of the ETS design or function as a separate policy. As in the rest of the study, we consider shielding mechanisms for air transportation services. Shielding the upstream markets in manufacturing and infrastructure are outside the scope of this study.

We consider two broad categories of policies:

- Carbon Border Adjustment Mechanisms (CBAMs)
- Product standards and other decarbonisation incentives

These categories do not represent a comprehensive list of possible shielding mechanisms. They have been selected to help develop an understanding of how key policies that have been considered in other sectors may be applied in the aviation market.

The following discussion is a high-level overview of relevant issues, and represents an earlier stage of development relative to the assessment of free allocation. Further assessment of alternative shielding mechanisms, in the context of reduced future levels of free allocation, is an area for future research.

3.3.3.1 Carbon border adjustment mechanisms

CBAMs have been considered in sectors with point (stationary) emissions (e.g. industrial plants) to mitigate competitive disadvantage and leakage risks due to carbon cost differences between (domestically) produced goods and services that are subject to carbon pricing (e.g. a carbon tax or ETS) and imported goods that are subject to lower carbon pricing.

In this discussion we focus on CBAMs that could mitigate the effects of differences in the stringency of carbon pricing between different categories of UK aviation activities. A CBAM policy would seek to raise the effective carbon price on flights that are not subject to other carbon pricing mechanisms (UK ETS, EU ETS, CORSIA) or are affected by them but at a much lower level.

At present, the UK ETS carbon price and EU ETS carbon price are relatively similar, and the CORSIA carbon price is substantially lower than both the UK and EU ETS prices.

The CBAM policy may need to specify policy interactions with CORSIA. The treatment of CORSIA obligations under the CBAM could be designed to be consistent with any UK ETS policy interaction with CORSIA that is in place in future.

While CBAMs may allow equalisation of carbon prices they can also suffer from disadvantages. They are likely to be difficult to implement in practice because they need a consistent and non-discriminatory way to accurately measure the carbon content of alternative routes. For example, calculating the appropriate CBAM for passengers travelling through a non-UK hub airport may be complex and without it risks distorting travel choices. There are few if any real-world applications of CBAMs to-date. The application of CBAMs involves trade and related international considerations and challenges that domestic carbon taxes do not face.

We note that other carbon pricing mechanisms aside from a CBAM could in theory be used to raise the effective carbon price on flights that are currently subject to relatively low or no carbon price. These related mechanisms include:

- Requirement to purchase UK ETS allowances;
- Requirement to purchase offsets meeting specified standards

3.3.3.2 Product standards and related decarbonisation incentives

There are a range of other policy mechanisms that could be used to provide shielding where they are paired with a fiscal policy that ensures equivalent treatment on all routes involving a UK aerodrome.

Incentives could include:

1. **Product standards for aircraft.** Product standards would place fiscal or regulatory incentives on the use of particular standards of carbon efficient aircraft. They could mandate the type of aircraft allowed to land in the UK, or potentially (based on international negotiations) to fly through UK airspace. The standards could be based on aircraft type and/or engine type.
2. **Investment in and use of sustainable aviation fuel (SAF).** The receipt of a fiscal incentive could be tied to a commitment to use a proportion of aviation biofuel in fleet refuelling by a particular year.
3. **Investment in R&D in low-carbon technologies**. An additional option is to tie a fiscal incentive to investments in low-carbon R&D, to promote the development and commercialisation of these technologies and future reductions. This could be used to support risky investments that would not otherwise be made in technologies such as electric and hydrogen powered aircraft.

4. **Following recommendations of external energy / emissions audits.** In line with the planned approach to free allowances for industrial installations in the EU ETS, a fiscal incentive could be made conditional on implementing emissions reduction recommendations by an independent, third party auditor.[73] For such a policy, it would be important to agree a terms of reference for the audit to ensure recommendations appropriate to climate and aviation markets.

Each of these options could help to ‘level the playing field’ (product standards, audits) or provide additional funding (new investment support) where carbon prices risk reducing the competitiveness of some firms. In doing so they could help to shield firms subject to carbon prices. However, they may also suffer from a number of disadvantages. Most notably, with the exception of audits, they are linked to particular technological choices – they require government or related bodies to pick the right standards, fuels or approach to R&D. Audits in an aviation context would be significantly complicated by existing regulations and the international rules governing aviation.

---

[73] See European Commission, 2021h.

4 FINDINGS FROM ASSESSMENT OF DESIGN OPTIONS OF AN ETS

4.1 Background for the assessment

Below we summarise key points about free allocation in the context of the aviation market that are relevant for our findings across design options, summarised later in this section.

The background material below covers the following:

- Free allocation and the ETS carbon price are independent components of the ETS design
- The carbon price and free allocation impact different types of airline costs
- Airlines react differently to changes in the carbon price and changes in free allocation
- Impacts of changes in carbon pricing and free allocation on carbon leakage
- Caveats to the theoretical results.

This material builds on the discussion in Section 2. Whereas Section 2 focused on the impact of the carbon price on leakage and competitive disadvantage, here our discussion builds toward the assessment of free allocation, the main focus of the design options.

In the following, we consider the impact of carbon policy in the medium-term, after market participants adjust to new conditions (i.e. this is a study of comparative statics). In the short-run there may be market fluctuations whilst airlines, airports, and customers learn information, make decisions, and implement changes, before converging to a new equilibrium.

4.1.1.1 Free allocation and the ETS carbon price are independent components of the ETS design

In theory, free allocation and the ETS carbon price are two separate and independent components of the policy design. In other words, changes in the level and/or distribution of free allocation will not impact the carbon price when zero transaction costs are assumed[74] [75]. We explain this theoretical finding below.

In a well-functioning ETS, the carbon price that clears the market (i.e. the price of permits obtained through auction or secondary markets) is the marginal abatement cost for the set of activities within the scope of the scheme. In other words, if the cap on the ETS were set at 100 tonnes, then the price of a permit would equilibrize to the cost of abating the 101st least costly tonne of carbon to abate. To see why this is, consider if the carbon price were higher or lower than this level. If the carbon price were lower, then there would be an airline in the market emitting a tonne of carbon that is cheaper to cover with a permit rather

---

[74] Coase Theorem, Coase (1960).

[75] This is discussed later in Section 4.1.1.7.

than abate, leading to an overdemand of permits. If the carbon price were higher, then there would be an airline in the ETS emitting a tonne of carbon that they could more cheaply abate than cover with a permit, leading to an oversupply of permits. In both of these cases, the market would not be in equilibrium and the carbon price would adjust (adjust upward if overdemand, adjust downward if oversupply). As permits are tradable between sectors, the relevant price is the marginal abatement cost of the whole ETS, rather than within the aviation sector.

The ETS cap impacts the carbon price, as this affects which tonne of emissions is the marginal tonne. Typically, a higher cap lowers the carbon price, and a lower cap raises the carbon price. But changing the number or distribution of free allowances does not impact the cap or impact the carbon price, as long as the total number of free permits in circulation is less than the current level of emissions. Therefore, it does not impact the firm’s decision about the tonnes of carbon it will abate versus cover with permits (the firm’s marginal abatement decisions).

4.1.1.2 The carbon price and free allocation impact different types of airline costs

In Section 2 we summarised how a change in the carbon price impacts airline’s marginal abatement decisions. We now compare the impacts of a change in carbon price with the impacts of a change in free allocation.

The carbon price and free allocation translate into different types of costs to airlines:

- A change in the ETS carbon price is a change in direct marginal costs. This is because the carbon price affects the cost of fuel consumption by increasing the price of burning fuel, which affects the cost of adding capacity.
- A change in an airline’s level of free allocation is a change in their fixed costs. This is because free allocation represents a lump-sum endowment to the airline that does not vary depending on whether the airline adds or subtracts capacity in the future[76].

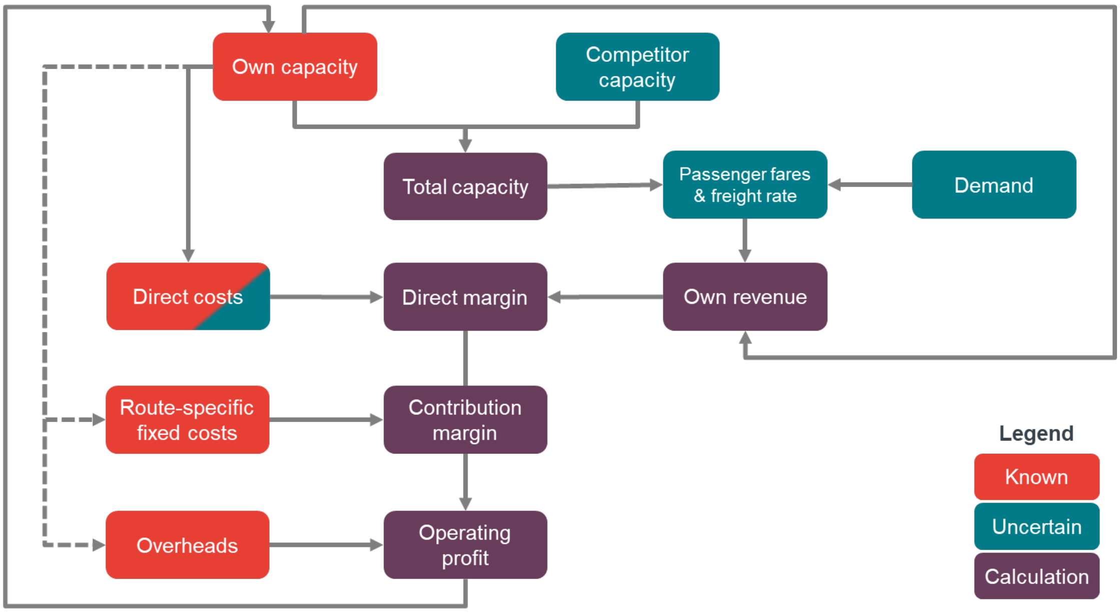
4.1.1.3 Airlines react differently to changes in the carbon price and changes in free allocation

The diagram below provides a high level illustration of the airline business model.

---

[76] By treating free allocation as a change in fixed costs, we assume that airlines cannot anticipate/influence how their operations may change the free allocation they receive now or in the future. If airlines can influence their free allocation, then free allocation represents a marginal cost then this may lead to distortions. We discuss this issue later in this section.

Figure 6 Airline business model



Source: Frontier Economics

We describe these dynamics below and then discuss how airlines would react to a change in the carbon price (marginal costs) versus a change in free allocation (fixed costs).

- Airlines initially compete on capacity: An airline must decide how much capacity to commit to a particular route for an upcoming season. This decision must be made in advance – typically at least 6 months before the schedule comes into operation – based on what the airline anticipates will happen many months down the line, including how much capacity its competitors will decide to commit to the route, the expected level of demand on the route, and the expected level of certain variable costs (while airport charges are known in advance and are predictable, other costs such as fuel and currency movements can be very volatile). Capacity is not perfectly divisible, and there may be operational considerations too. For example, an airline may only decide to operate a route if it can operate at least a minimum number of flights per season, and it may have a homogenous fleet such that it cannot vary aircraft size. The ability to increase capacity also depends on whether there are spare slots at the airports in question, and also whether the airline itself has enough aircraft capacity, albeit it is able to switch its existing capacity (slots and aircraft) from one route to another, if required.
- Ticket prices are determined by capacity: After competing on capacity, airlines compete on price. If there is an abundance of spare capacity on a route, including both the airline in question and its rivals, then for a given level of demand, ticket prices may be low. If in reality demand turns out higher than anticipated and seats are scarce, ticket prices will be high[77].

---

[77] We note that capacity on a given route may not be perfectly homogeneous across competitors. Differentiating factors include: time of day and day of the week; airline type; airport location in cities with multiple airports, etc. The stronger the degree of differentiation, the weaker the link between an airline's own

- Direct margins: The direct margin of a flight is the total revenue that is generated minus the direct cost of operating it. Revenue includes ticket fares and ancillary revenues, such as any on-flight sales, priority boarding, seat allocation, checked in bags, and commissions for car rentals and hotels, etc. Direct costs are those which would be avoided if a particular flight did not go ahead. These include airport charges (assuming that the airline pays per use rather than has a fixed contract), fuel (including ETS costs), ground handling costs, and salary costs for crew and pilots (depending on how its contracts labour). If the direct margin on a particular route is high, and this is anticipated to continue, then competitive pressures should result in capacity increasing – as long as there is spare capacity available to do so (slots and aircraft). Increasing capacity leads to prices decreasing, costs increasing, and as a result, the direct margin would fall. Conversely, if it were negative, airlines should decrease capacity, which would lead to prices increasing, costs decreasing and direct margins therefore improving. The competitive outcome is a route where direct margins are relatively low. If they were any higher, a new entrant may enter, provided there is spare capacity. An airline may be recovering its direct costs on a route, but the route may make no contribution to covering other costs.
- Contribution margins & operating profits: Airlines need to recover all costs in the long run, including aircraft financing costs and route marketing costs, as well as overheads. In the short run, competitive pressures may push direct margins very low such that airlines are not recovering their route-specific costs or head office costs. Airlines typically recover fixed costs during peak times and aim to recover at least direct costs during off peak periods, or otherwise they would find it more profitable to just ground their aircraft. If a route does not recover route-specific costs, then in the long run it is not profitable, and airlines have the incentive to drop it, and deploy the aircraft elsewhere. If an airline does not recover its head office costs, then it will need to downsize, or it will go out of business.

Given the above, if marginal costs increase due to carbon pricing, then direct costs will increase, which will result in airlines reducing capacity on the route, which will result in higher prices. In practice this means that we would expect ETS costs to be passed through to customers in the form of higher ticket prices. However, at congested airports, where ticket prices may be based more on willingness to pay rather than cost, we might expect to see less cost passthrough. Higher marginal costs from carbon pricing may also strengthen incentives to make larger decarbonisation investments; these are discussed in Section 4.

Free allowances are a lump-sum annual payment that effectively reduce airlines' fixed costs. If fixed costs increase due to a reduction in free allocation, then overhead costs increase but the profitability of any given route within the policy area is unaffected. In theory, assuming the market is in equilibrium, airlines are already operating at the optimum capacity on each route, meaning they are not operating on loss-making routes and any increases or decreases in capacity on any given route would be loss-making. As a result, airlines will continue to operate

---

price and its competitors' capacity decisions. At an extreme, if two airlines' offerings were so differentiated that they were effectively in different markets, one airline increasing their capacity would have no impact on the other airline's ticket price.

the same capacity as before. However, if fixed costs increase to such an extent that airlines have negative profit, or high risk of negative profit, the airline may choose to exit the market entirely. In practice airline's decisions are not necessarily binary, and there is a spectrum of financial difficulty that may lead airlines to reduce scale rather than fully exit immediately. In other words, a reduction in free allowances increases the fixed costs that airlines need to recover to stay in the market.

This impact is more likely for airlines with a high proportion of capacity within the policy region, as proportionally higher fraction of their fixed costs will be impacted by a change in free allocation policy.

4.1.1.4 Effect of market exit on capacity and ticket prices

As described above, a substantial reduction in free allowances may reduce the number of airlines that stay in the market. Below we discuss the impact of market exit on capacity and ticket prices.

If aviation were a perfectly competitive market, then ticket prices would be based on marginal costs. As free allowances affect overheads rather than marginal costs, ticket prices would not change after a reduction in free allowances, even if an airline were to exit the market, as the market would remain perfectly competitive. This is equivalent to assuming that free allocation will not substantially impact airlines' market power, and aligns with the assumptions made in the quantitative modelling in Section 6.

If aviation is not a perfectly competitive market, then it is likely that competitor airlines will react to market exit on routes that have experienced exit by increasing capacity to meet the excess demand created by the market exit. If a given route experiences capacity expansion from existing airlines but there are no new entrants, there will be a net loss in the number of airlines on the route, and therefore a loss of competition. The decrease in competition would lead to a net reduction in capacity across all airlines on the route and an increase in ticket prices. This would differ from the approach in the quantitative modelling. It is possible that a new entrant to the route will come in and add capacity, in which case there may be minimal impact on competition, capacity, and ticket prices.

It is therefore important to understand whether there are likely to be new entrants on routes that have experienced market exit due to the changes in free allowance allocation. This will depend on the size of the reduction in free allowances experienced by the exiting airlines, but the market exit likely indicates that some of the impacted routes may have only been marginally profitable before the market exit. Hence new airlines may be less likely to enter onto these routes, meaning that loss of competition is more likely. Marginally profitable routes could include routes with low/decreasing demand and routes that had many competitors before the market exit. Routes through congested airports would be less likely to be impacted by the market exit (in terms of ticket prices or capacity).

4.1.1.5 Cost passthrough and free allocation

As discussed in Sections 3.3.2.3 and 4.1.1.3, incomplete cost passthrough can indicate that a sector, subsector, or airline is at risk of carbon leakage or competitive disadvantage, particularly under higher carbon prices. In the UK aviation market, routes at congested airports are likely the most material area of incomplete cost passthrough (please see Section 2.3.1.1 for discussion). In this case, the incomplete cost passthrough is due to capacity constraints: capacity is lower and ticket prices are elevated compared to case where airport capacity were unconstrained. On these routes, airlines tend to achieve supernormal profits, and so the risk of competitive disadvantage and carbon leakage is lower than on other routes.

Although incomplete cost passthrough can inform the design of a free allocation mechanism as it can be an indication of where shielding may be needed, the free allocation mechanism is unlikely to directly interact with cost passthrough. This is because while both free allocation and cost passthrough have impacts on airline profitability, free allocation impacts airlines’ fixed costs, and incomplete cost passthrough relates to marginal costs.

EMPIRICAL FINDINGS ON THE RELATIONSHIP BETWEEN FREE ALLOCATION AND MARGINAL ABATEMENT INCENTIVES

Some studies have found that in practice initial allocation of free permits is correlated with ex post emissions. Studying Phase 1 and Phase 2 of the EU ETS, Abrell et al. (2011) found that the initial free allocation is correlated with ex post emissions of regulated firms. De Vivo and Marin (2018) find that firms with more generous allowances are less likely to abate than firms with the same abatement costs but less generous allowances. This could indicate that markets are deviating from optimal market behaviour. This could arise for a number of reasons:

- Poorly functioning auctioning or secondary markets for permits, so that obtaining permits from auctions or markets is difficult or has uncertain pricing
- High concentration of initial allocation among a few airlines
- Organisational barriers that prevent airlines from making optimal decisions, for example due to decentralised decision-making
- Endowment effect on permits. This is a type of decision-making bias where airlines conduct fewer market transactions than is optimal, such that it appears that airlines place higher value on assets that they own versus assets that they would acquire by auctions or markets.

However the above findings are for stationary sectors, and do not provide direct evidence on airline behaviour – though it is possible that some behaviour may transfer to airlines. Moreover, these impacts are likely to be second-order effects.

In the medium- to long-term, under a higher ETS carbon price, the cost of any deviations from optimal market behaviour will increase. Airlines will likely become increasingly adept at optimising their decarbonisation strategies and converge toward rational behaviour.

For these reasons, our analysis assumes that airlines behave rationally and fully internalise the opportunity costs of free allocation, and that there are no transaction costs. Please see Section 4.1.1.7 for summary of caveats to these assumptions.

4.1.1.6 Impacts of changes in carbon pricing and free allocation on abatement and carbon leakage

When assessing the impact of free allocation on abatement incentives, this assessment primarily considers impacts of free allocation on abatement in the short run. On this time scale, there will likely be limited opportunities for airlines to implement measures to improve their emissions efficiency (ATA & Ellondee, 2018). Therefore, the below discussion, in the remainder of Section 4, tends to focus on capacity reduction as the main abatement measure available. In the medium and long term, other strategies will become cost-effective, and the discussion in Section 4.9.1.2 considers policies that could support decarbonisation investment.

In Section 2 we summarised different potential channels through which an ETS can impact leakage. Free allocation indirectly impacts carbon leakage through its impact on abatement within the policy area. Free allocation does not have a direct impact on carbon leakage, or an independent impact on carbon leakage beyond that outlined below. A key feature of the UK ETS scope is that it includes flights departing from the UK to the EEA, but it does not include flights returning from the EEA to the UK. Given that the majority of itineraries are return trips, a reduction in flights in the policy area (departing from the UK) would lead to a similar reduction in flights outside the policy area (arriving in the UK). This reduction could be the result of airline reactions to either an increase in the carbon price or a decrease in free allocation. In carbon leakage terms this would reflect a value of close to -100%. Section 6 provides modelling results on leakage that offer greater detail on the negative leakage estimates.

4.1.1.7 Caveats to the theoretical results

The above discussion relies on a number of key assumptions that are standard in the economics literature. We summarise these assumptions below, note where we are likely in practice to observe deviations from these assumptions, and how the assumptions compare with those in the quantitative modelling.

We assume airlines can react flexibly to market changes. In practice, time lags in airline reactions may lead the market to deviate from what the theory would predict. For example, customers purchase tickets in advance, airlines place aircraft orders in advance, and airlines and airports have medium-run contracts with one another and with other parts of the supply chain. This could lead to time delays in the impacts of environmental interventions. For example, airlines have two 6-month seasons and schedule on this basis, so would most likely take at least 6 months to react to a sudden sharp shock by changing capacity. While presumably changes in the UK ETS would be communicated in advance so airlines could adjust their capacity decisions in time, the exact impact of the change in the UK ETS may be unknown, and therefore it may be hard for airlines to correctly predict.

In the quantitative modelling, we note that AIM models some time lag-related effects, including an effective lag to the fuel prices that airlines experience due to fuel price hedging, lagged effects in ticket pricing, and time lags in technology acquisition for new aircraft designs. Other effects, such as lags due to medium-run contracts between airlines and airports, are not modelled.

We assume that market participants make optimal decisions. We have assumed that airlines, airports, and customers act optimally to achieve their aims. For airlines and airports this implies optimal profit maximisation, and for customers that they make optimal purchasing choices given their preferences.

This assumption is consistent with the approach in the quantitative modelling, that economically optimal decisions closely approximate airline and customer behaviour.

In practice, market participants may not be perfectly ‘rational’ in this sense.

Airlines and airports may make decisions with a range of behavioural characteristics. They may have a status-quo bias in which they are reluctant to change operating or investment practices. This could act to slow their adoption of abatement strategies. In some cases they may face uncertainty and have imperfect forecasts about particular routes and markets, or they may find it challenging to react optimally to information about events that will occur further in the future. Again, this may slow their reactions to new policies and decarbonisation opportunities. In addition, airlines and airports may disproportionately favour short-term over medium- or long-term profits which may slow early decarbonisation action.

Customers also may deviate from rationality. They may make purchasing decisions without full information about the market (e.g. knowledge of competitor services or market trends). This may lead to short-run fluctuations while customers adapt to new market conditions.

We assume there are no transaction costs to selling UK ETS allowances on the secondary market. This means that airlines fully internalise the opportunity cost of free allocation, as noted above. Were positive and significant transaction costs assumed, this would mean firms would treat free allowances differently from permits that they would need to purchase, and therefore would be less likely to abate earlier tonnes of CO2 (that are still within their free allowance allocation) than later tonnes. In practice transaction costs are likely to be positive but minimal, and therefore assuming zero transaction costs is a simplifying assumption that does not distort the findings of the analysis.

Unless otherwise noted, we assume that airlines cannot anticipate how their activity in current and future periods will impact future free allocation. However, this assumption will not hold if airlines know that their free allocation will be based on airline data gathered in an upcoming year (for example, in the design option where activity data is regularly updated, see Section 4.4). In this case they could strategically alter their activities during the upcoming year in order to affect their free allocation. This may benefit larger airlines who may have a greater ability to incur losses to realise future gains. However, airlines would only pursue such a strategy if it were advantageous. This would depend on several factors:

- If the ETS carbon price is predicted to rise in the future, this increases the value of future permits relative to current permits. This would increase the likelihood that airlines would increase the permits they must obtain in the current year in order to reduce the permits that they must purchase in the future. Therefore a predicted rise in the carbon price increases the likelihood of distortive behaviour.
- If the cost of abatement rises in the future for the airline, this raises the value of permits in future years relative to permits in the current year. In general, the cost of abatement should fall over time as new decarbonisation technologies develop. However, a rise in abatement costs could occur in certain circumstances, for example if there is an anticipated future shortage in SAF. An anticipated rise in the cost of abatement in the future increases the likelihood of distortive behaviour.
- The likelihood of distortive behaviour is higher if a given change in the airline's activity has a large impact on the airline's future free allocation. For example, if the overall level of free allocation is relatively low, then a given change in airline activity will provide relatively low free allocation benefits in future, decreasing risk of distortive behaviour.

- The cost of increasing capacity in the short-term is not prohibitively high, such that even a large windfall gain in the future could not be justified in terms of current costs.

Assuming that capacity on routes today matches demand (which we would expect given the airline business model described above), increasing capacity on routes today to get more free permits in future would be loss making at the route level. And the loss here could potentially be greater than the financial gains made in the future from free allowances, in which case it would be loss making overall. It is not clear what the net effect is. This will depend on the carbon price, as well as discount rates and how long the free allocation will be set for: for instance, if the free allocation for the next 10 years will be determined by activity next year, airlines could accept a short-run loss for higher windfall gains in future. We discuss this issue in the design option for updating the activity data (Section 4.4).

The quantitative modelling does not include policy options where airlines would be able to anticipate effects of their current activity on their future free allocation.

Dynamics may be different at congested airports. In Figure 7 we described how airlines respond to changes in direct costs and profitability by adjusting capacity on routes, meaning that changes in costs are generally passed through to customers in full. However, at congested airports, where demand exceeds available capacity, ticket prices may be based more on willingness to pay and less on costs. This means that at congested airports we might expect to see less than full cost passthrough. The quantitative analysis models complete passthrough for routes at non-congested airports, and partial passthrough for routes at congested airports.

In the following subsections, we draw on the above theoretical findings to evaluate each design option in turn.

4.2 Summary assessment of current UK ETS free allocation mechanism

The free allocation mechanism within the current UK ETS was described above in Section 3.3.2.1.

In the remainder of the free allocation assessment, design options will be compared relative to the current UK ETS design, and the assessment framework in Section 3.2 is designed for this comparison.

As background for this assessment of design options, we consider key advantages and disadvantages of the current UK ETS free allocation design, organised by design feature. The below summary is focussed on key points, and additional detail on the below issues is discussed via comparison between the current approach and design options in Section 4.3-4.7. We do not score the current UK ETS using the 6-point rating system outlined in Section 0 as we do for other design options. This rating system uses the baseline as a comparator, which would not be appropriate when assessing the baseline itself.

The quantitative results in Section 6 show that carbon leakage from UK ETS policy is expected to be negative. This follows from the symmetric nature of aviation where the majority of flights are return flights and therefore a reduction in flights outbound from the UK leads to a reduction of flights inbound into the UK. Therefore a reduction in emissions within the UK is expected to lead to a reduction in emissions outside of the UK, i.e. negative carbon leakage. In other words, there is low risk of more stringent UK ETS policy leading to an increase in emissions outside the policy area. Below, we therefore discuss shielding in terms of mitigating risk of competitive disadvantage.

4.2.1.1 Sector-wide free allocation mechanism.

A sector-wide mechanism is comparatively simple to communicate to stakeholders. The disadvantage is that particular subsectors may be relatively more at risk of competitive disadvantage, and therefore a sector-wide benchmark is not adjusting the level of shielding towards those most at risk of competitive disadvantage and therefore in need.

4.2.1.2 Activity data dates from 2010 (EU ETS reserve allocation from 2014).

In continuing to use a relatively old year of activity data, the current design does not reflect recent changes to airline capacity.

A disadvantage is that the distribution of free allowances does not reflect changes in capacity in the sector over the last ten years, including the increase in international flights in comparison to domestic flights, and increase in low cost carrier flights. Subsidies given to airlines that are not based on recent activity levels could lead to distortions in the market.

However, better aligning free allocation with the distribution of current trends in sector activity, so that free allocation reflects current sector activity, may in other ways support the UK aviation market as a whole. Airlines and activity that have experienced growth over the last decade may be best equipped to contribute to the future competitiveness of the market, and to address decarbonisation challenges.

Currently, free allocation does not have a mechanism to quickly adapt to market shocks. This risks the oversupply of free allocation if there is a substantial decrease in aviation demand, as during the COVID-19 pandemic. Although negative demand shocks have historically been transitory, greater flexibility in free allocation may have advantages in terms of allowing government to adjust the design more rapidly in view of market developments.

4.2.1.3 Level and tapering of free allocation

Assessing the level of free allocation in the context of broader UK decarbonisation policy is outside the scope of this study.

4.2.1.4 Reserve allocation

The UK ETS does not currently allocate reserves for activity. Reserve allocation can be used to support competition and innovation in the sector, and considering reserve allocation could be an area of UK ETS refinement. However reserves are likely to represent a small proportion of free allocation, and so the overall impact of reserves is likely to be small relative to policy decisions such as the speed of tapering free allocation.

Figure 8 Summary table of design options to be assessed

Design feature	Current UK ETS	Design options
Level of market segmentation	No segmentation of aviation market within the free allocation mechanism	Separate benchmarks for short-haul vs. medium-haul flights
Updating the year of the activity data	No committed activity data update	One-of update; regular update
Change in adjustment factor	2.2% trend increase in adjustment factor (decrease in free allowances)	One-off change; different trend
Reserve group	No new reserve allocations (honouring legacy EU ETS reserve allocations)	New entrants reserve; fast growers reserve
Reserve group allocation	No new reserve allocations	Discussion of different levels of allowances awarded per activity unit for reserve group

Source: Frontier Economics

4.3 Defining benchmark subsectors

The UK ETS currently has a sector-wide aviation benchmark that applies to all airlines. In this section we consider applying different benchmarks to aviation subsectors. We assess the design option of defining two subsectors[78], where activity is classed as either short-haul or medium-haul based on a particular distance threshold for the flight (e.g. 800km). This would mean that a different number of free permits would be allocated per unit of short-haul activity than per unit of medium-haul activity. Airlines would therefore be required to submit separate emissions and activity data for short-haul and for medium-haul flights.

To isolate the effect of this design option, we suppose that a certain annual schedule of total free allowances were determined for the next aviation phase of the UK ETS (2024)[79]. We consider the impact of calculating the benchmark by subsector versus the case where the benchmark were sector-wide (the ‘baseline policy’). Defining subsectors would lead to a redistribution of free allocation relative to the current design, without changing the total level of free allocation.

As short-haul flights tend to be more emissions-intensive than medium-haul flights the benchmark for short-haul activity (allowances per activity unit) would be higher than the current sector-wide benchmark, which would be higher than the

---

[78] As the current scope of the UK ETS consists of UK domestic and UK-EEA flights, the flights within scope are short-haul and medium-haul.

[79] This assumption allows us to isolate the effect of the redistribution in our assessment, without simultaneously assessing an increase in permits. We isolate the effect of a change in the total number of permits later in our discussion of altering the adjustment factor (Section 4.5).

benchmark for medium-haul activity. Airlines with proportionately more short-haul activity would receive more free allowances relative to the baseline policy, and airlines with proportionately less short-haul activity would receive fewer free allowances relative to the baseline policy.

4.3.1.1 Key strengths and weaknesses of defining separate sub-sector benchmarks

Under this change, firms with relatively more short-haul flights are more likely to experience an increase in profitability, while those with relatively more medium-haul flights are more likely to experience a reduction in profitability.

These shifts in profitability would impact capacity (and therefore emissions) only if the reduction in profitability for a particular airline were great enough to induce market exit. Negative profitability impacts would be concentrated among airlines that only operate medium-haul UK-EEA routes, and no short-haul routes within scope, for example airlines domiciled in the EEA. However these airlines tend to operate proportionately more routes outside of UK ETS scope and so proportionately less of their profits would be impacted by UK ETS free allocation policy, rendering market exit unlikely.

If market capacity were altered, it would be away from medium-haul flights (that are less carbon-intensive) and towards short-haul flights (that are more carbon-intensive), perhaps marginally increasing overall emissions.

However, even if market exit were to occur on some routes, some of the capacity reduction would likely be met with increases in other airline capacity on these routes. Therefore capacity reductions may be transitional rather than permanent, and may end up being limited in size.

Assessment criterion	**Assessment**
1: reduce emissions through incentivising abatement	Rating: 3 ▪ As discussed above, while market capacity may be redistributed between airlines and routes it is unlikely that market capacity overall would be altered significantly, and we find that this design option may impact individual airline emissions but would be unlikely to materially impact whole sector emissions compared to the status quo. ▪ This option would be unlikely to impact incentives to invest in decarbonisation technology, which is more likely to be driven by the current and expected future carbon price.
2: appropriately mitigate carbon leakage risk	Rating: 3 ▪ Due to the factors explained above, this option may impact airline capacity but would be unlikely to materially impact overall capacity within the policy area. Due to the round-trip nature of aviation, there are unlikely to be substantial changes in overall capacity outside of the policy area, though capacity may be redistributed between airlines and routes.
3: appropriately mitigate risk of competitiveness distortions	Rating: 4 ▪ May offer some protection for airlines with a large share of operations that are short-haul and under UK ETS scope, including regional UK airlines, and minimal negative competitiveness impacts for airlines with medium-haul routes given UK ETS flights are likely to be a small part of their overall portfolio.
4: support a viable market: airline perspective	Rating: 3 ▪ This option would redistribute profits among airlines, increasing profits for airlines with proportionately more short-haul activity, and decreasing profits for airlines with proportionately more medium-haul activity. From an airline perspective this option creates both winners and losers. ▪ May benefit regional airports that serve proportionately more short-haul activity by supporting these routes. ▪ This option involves a slight increase in data granularity that airlines must provide in their free allocation applications, but is unlikely to be a material increase in administrative costs.
5: support a viable market: government perspective	Rating 3: ▪ The greatest risk of ticket price increases is among medium-haul routes, where (as explained above) capacity changes may occur and airlines may exit leaving fewer airlines in the market – potentially impacting ticket prices. ▪ By protecting the competitiveness of short-haul activity, this option may increase employment and other parts of the value chain for regional airlines (e.g. regional aircraft suppliers)
6: align with climate action outside the current scope and the UK	Rating: 2 ▪ Different airlines will have proportionately more or less short-haul and medium-haul activity. If airlines receive different levels of free allowances per activity unit due to their different mixes of short- and long-haul activity, this could be seen as applying differential treatment to airlines and could conflict with WTO rules. This has not yet been tested, and the likelihood of a conflict depends on the interpretation of WTO rules.

4.3.1.2 Key distributional impacts and sensitivities relevant to the UK-specific aviation context

As explained in the table above, segmenting the market based on flight distance would likely increase profitability of airlines with a greater share of short-haul routes, and decrease profitability among airlines with a greater share of medium-haul routes. This is unlikely to materially impact overall capacity and emissions both within and outside of the policy area, but may redistribute capacity amongst routes and airlines. The increase in profitability associated with short-haul routes would likely benefit regional UK airlines and decrease risk of regional airline market exit. The positive impact on regional UK airlines is likely to be more significant than for network or LCC airlines, and would potentially have positive spillover effects for regional airports and customers of regional routes. Network and LCC airlines with a large share of medium-haul flights are unlikely to be significantly competitively disadvantaged as flights within UK ETS scope likely form a relatively small portion of their operations.

4.3.1.3 Key interactions with other elements of free allocation and carbon pricing policy

Carbon price: The magnitude of the effect on airlines (and any knock-on effects on airports and customers) depends on the carbon price level. Introducing separate benchmarks redistributes free allowances from medium-haul airlines to short-haul airlines. While this does not impact marginal costs, and therefore the profitability of individual routes, it impacts the profitability of airlines by changing their fixed costs. The higher the carbon price, the larger the increase in profitability for airlines with predominantly short-haul routes and the larger the decrease in profitability for airlines with predominantly medium-haul routes.

Other design aspects of free allocation: Calculating the benchmark by subsector should only be considered in conjunction with using TKM activity data, and not with using emissions activity data (grandfathering[80]). If emissions activity data is used, then there is no need for a benchmark (the benchmark is fixed at 1).

If the activity data were updated (see Section 4.4 for this design option), then it would be appropriate to also update the TKM and emissions data used to calculate the benchmark, so that all data that inputs into the free allocation mechanism is internally consistent, to support clarity and transparency of the mechanism to airlines and other market participants.

Data requirements: This option would require airlines to submit activity and emissions data segmented into short-haul and medium-haul categories for each year in which the benchmark/activity data is updated. Given that route-level TKM data was submitted as a part of the Phase III EU ETS free allocation applications, this design option would not increase the administrative burden on airlines relative to that application.

4.3.1.4 Summary of key trade-offs relative to the current UK ETS design

Calculating the benchmark by short-haul versus long-haul activity is not likely to have a significant positive or negative impact on emissions or carbon leakage. This option could offer some protection of competitiveness for regional airlines (and regional airports and customers). However this design option risks being seen to

---

[80] Grandfathering is when historic levels of emissions are used to determine current levels of free allocation.

offer differential treatment to different airlines, and this risk should be weighed against the potential shielding benefits.

4.4 Updating activity data

This design feature would involve updating the activity data from its current base year of 2010 to a later year (or updating to an average of multiple later years). The update would reflect market changes that have occurred since that time, so that free allocation more accurately reflects the current relative scale of airlines.

This design feature could either consist of a one-off update to the activity baseline year or regular updates. Regular updating could be as frequent as annual updates, or less frequent (biannual, every 5 years, etc). Regular updates to activity data in the aviation sector would mirror the current system for stationary installations[81] in the UK ETS, where free allowance allocation is updated annually once installation have submitted verified Activity Level Data Reports for the previous calendar year.

If the level of free allowances varied in proportion to activity data updates (e.g. if an airline had 30% more activity in the update year than they had in 2010, then this would translate to 30% more free allocation), then free allocation could increase in line with total increases in sector activity. Therefore, to assess this design feature, we suppose that a certain annual schedule of total free allowances were determined for the next aviation phase of the UK ETS (2024)[82], but that the activity data updates affect the distribution of free allocation among airlines. Practically, this would involve simultaneous updates to the activity data and the adjustment factor.

The impact of this option would depend on the choice of the new baseline year[83] for the activity data ("baseline year") and the frequency of updating.

In choosing a **baseline year (or time period)**, there are several considerations:

- The new baseline year should be relatively recent to reflect the current distribution of activity among airlines.
- It would be sensible to avoid choosing a baseline year containing significant shocks, such as COVID-19 impacts, in order that the activity data reflects permanent trends in the sector rather than transitory changes. Averaging together multiple years to form a new activity baseline may help to 'smooth' any of these transitory shocks occurring in particular years.
- In theory, if the baseline year is announced in advance, then airlines can anticipate how their activity will impact free allocation. This creates the potential

---

[81] Installations are non-moving technical units where one or more activities under the scope of an ETS are carried out, or where other activities that have a direct connection with the activities carried out on that site that could also have an effect on emissions and pollution.

[82] This assumption allows us to isolate the effect of the redistribution in our assessment, without simultaneously assessing an increase in permits. We isolate the effect of a change in the total number of permits later in our discussion of altering the adjustment factor (Section 4.5).

[83] It is important to distinguish between the benchmark and the activity data baseline year. The benchmark is the measure of average emissions intensity in the sector, calculated by dividing total sector emissions by total sector activity, at one point in time. The benchmark has a baseline year, i.e. the year the total sector emissions and total sector activity were measured and used to calculate the baseline. The activity data separately has its own baseline year, which is the year that individual airlines' activity data was measured to calculate their free allowance allocation. The benchmark and activity data could have the same baseline year – and this may be desirable - but it would be possible for them to have different baseline years.

for 'gaming' behaviour, as airlines may have the incentive to increase activity so that they receive higher free allowances in the future. Gaming behaviour would likely include distorted capacity decisions around the particular update year. These could include airlines delaying planned decreases in capacity or bringing forward planned increases around an anticipated activity update year, in order to increase their free allocation. More detail on this type of behaviour is provided below.

In choosing the **frequency of updating** the activity data, one may consider:

- An update to the activity data benefits airlines that have experienced capacity growth relative to the market average. Therefore, updating the activity data weakens the incentive for airlines to abate through capacity reductions. Several factors contribute to the size of this effect:
  - All else equal, the more frequently the activity data is updated, the faster airlines are rewarded for increasing capacity, and the weaker the ongoing incentive to reduce capacity over time. In this way, frequent activity data updates effectively links free allowances and marginal costs.
  - If the level of free allocation is high, an airline receives more free permits for every additional unit of activity. This means that free allowances can have a larger impact on airlines' capacity decisions.
- Frequent updating of activity data creates some financial uncertainty from the perspective of an individual airline, and also revenue uncertainty from the perspective of government.
- There is some administrative burden associated with every update of the activity data (data collection, verification, submission, free allowance calculation).

With a regular schedule of updates, there is a risk that a future update year is by chance anomalous. For example, an unanticipated shock to aviation demand could shift the distribution of activity in the update year in a way that is not representative of medium-run sector trends. One way to mitigate this risk is to average together multiple years of recent data in the update.

In the above discussion of incentives, we mention the possibility of 'gaming behaviour'. In practice, airlines would only be incentivised to 'game' free allowances in some cases, where (a) the value of the incremental free permits gained in the future is high relative to (b) the incremental cost of the inflated activity in the year of the data update. Factors that increase the risk of 'gaming' behaviour, by increasing the value of (a) relative to (b), include:

- Infrequent updating of the activity data (long data update period), so that one year of elevated activity determines more years of free permits. If the activity data is updated annually, there is negligible risk of this type of 'gaming'[84].

---

[84] In other words, if the activity data is infrequently updated, then:

- First-order effect: the free allocation mechanism only weakly rewards increases in activity over time
- Second-order effect: in the particular year of the activity data update, there may be a 'gaming' incentive to inflate capacity in that year only. This effect is likely to be small relative to the first-order effect.

.

- An expected increase in the carbon price over the period, e.g. due to reductions in the emissions cap, so that future permits are more valuable than today's permits

Factors that lower the risk of 'gaming' behaviour, by decreasing the value of (a) relative to (b), include:

- A decrease in the cost of abatement over time, e.g. due to advancements and investments in decarbonisation technology
- A decrease in the level of free allocation over time

Averaging together multiple years to form a new activity baseline may also help reduce these 'gaming' incentives.

The policy scenarios analysed in the quantitative modelling do not create risks of gaming behaviour, and so this issue is outside the scope of that analysis.

4.4.1.1 Key strengths and weaknesses of updating the activity data

Assessment criterion	Assessment: one-off update	Assessment: regular update
1: reduce emissions through incentivising abatement	Rating: 3 - A one-off update would benefit airlines that have experienced relatively higher growth since the update year, this is likely to be international airlines. The subsequent loss of profitability for domestic airlines may lead to loss of capacity and hence an emissions reduction only if the reduction in profitability for a particular airline were great enough to induce market exit. These impacts are unlikely to have material impact on emissions abatement. airline	Rating: 2 - A regular update of the activity data would benefit increases in activity relative to the market average on an ongoing basis, which would provide a link between free allowances and marginal cost and therefore slightly weaken incentives to abate through capacity reductions. The risk of weakened incentives is higher with more frequent updating.
2: appropriately mitigate carbon leakage risk	Rating: 3 - As UK airlines with international routes have experienced activity growth since 2010 relative to airlines with regional routes, they may tend to receive more free allowances. For the reasons detailed in Section 4.1.1.6, they may see a corresponding increase in profitability and capacity. Due to the symmetric nature of aviation itineraries this in theory would reduce capacity and emissions within the policy area but increase emissions outside the policy area – leading to carbon leakage. - However the above effects are likely to be small in magnitude; the impact of this option would be unlikely to materially impact capacity and carbon leakage.	Rating: 2 - If regular updating weakens the incentive for ongoing capacity reductions on international flights within the policy area, this may slightly increase capacity within the policy area, which would also lead to an increase in capacity outside of the policy area (the return flights). - Annual updating may lead to some volatility in free allocation.
3: appropriately mitigate risk of competitiveness distortions	Rating: 4 - UK airlines with international routes have experienced activity growth since 2010 relative to airlines with regional routes. A one-off update to the activity data would shield faster growing airlines more and slower growing airlines less, relative to the current policy. This brings free allocation in line with current activity.	Rating: 5 - Regular updates could reduce any existing distortions between new entrants versus incumbent airlines, and fast versus slow growers, resulting from allocative inefficiencies in new entrant or fast grower provisions. Regular updating would benefit airlines with increases in UK capacity. This may help to incentivise new entrants and innovative firms to invest in the UK market. This incentive would likely be stronger with more frequent updating.

Assessment criterion	Assessment: one-off update	Assessment: regular update
4: support a viable market: airline perspective	Rating: 3 ▪ Benefits those that have relatively increased activity, at a cost to those that have reduced activity (or increased capacity by less than the average), as outlined above. ▪ Regular updating risks that transient shocks that occur in the update year impact free allowances in the period after the shock occurs, after the shock has ceased to impact the market ▪ May increase airlines' administrative costs; costs may increase with frequency of updates.	Rating: 3 ▪ See assessment for one-off update ▪ In addition, regular updating increases responsiveness of free allocation to sector- and airline-level developments
5: support a viable market: government perspective	Rating: 3 ▪ Assuming no impact on the level of free allocation, there is no impact on revenue to HMT. There may be some potential for distortive behaviour if airlines can anticipate an update, and can delay decreases in capacity or accelerate increases in capacity around the update year. ▪ By reducing incentive for capacity reduction and benefiting growing firms, this option may increase employment and demand in other parts of the value chain. ▪ Increased administrative burden to recalculate free allowance allocation; this burden is greater with more frequent updates	Rating: 3 ▪ See assessment for one-off update ▪ Regular activity updates may facilitate government enacting other adjustments to the free allocation design on an ongoing basis.
6: align with climate action outside the current scope and the UK	Rating N/A: ▪ Unlikely to have significant impact	Rating N/A: ▪ Unlikely to have significant impact

4.4.1.2 Key distributional impacts and sensitivities relevant to the UK-specific aviation context

As UK domestic flights have relatively decreased since 2010, updating the activity baseline year from its current baseline would redistribute free allocation toward airlines with relatively more international flights. Regional airlines' profitability is relatively sensitive to free allocation, compared with network and LCC profitability, as a larger share of regional airline capacity is within UK ETS scope. This design option would also shift allocation toward LCCs, who have on the whole gained UK market share over the last decade, risking greater market concentration.

Negative impacts on regional airlines' capacity could have spillover effects for regional airports and regional connectivity.

4.4.1.3 Key interactions with other elements of free allocation and carbon pricing policy

Carbon price: The impact of the redistribution of free permits on airlines' profitability will be greater if the carbon price is higher.

Other design aspects of free allocation:

If the activity data update is frequently updated, then this lessens the impact of any design decisions around new entrant and fast grower reserves, as free allocation from the reserves would only be in effect until the next activity data update. If there is an annual activity data update, there is no need for new entrant and fast grower reserves. An annual activity data update also eliminates the need for transfer provisions (i.e. transferring the allocation associated with a set of routes transferred between airlines).

If government has determined an annual schedule of free allowances, then the adjustment factor would need to be updated at the same time as the activity data to achieve the scheduled level of free allowances.

Annual updates of the activity data should not be combined with a change of the activity units to historical emissions as it affects the marginal abatement incentive by directly rewarding increases in emissions with additional free permits. For example, if there were annual activity data updating and the benchmark were set at 0.6 allowances per tCO2 emitted and the price of a permit was £100, then airlines would receive 0.6 additional allowances in the following year (worth £60) for each additional tonne of CO2 emitted in the current year. Factoring this future benefit would mean that the cost of emitting an additional tonne of CO2 this year is £40 (or approximately £40, factoring in any cost of borrowing) rather than the carbon price of £100. This would distort marginal decisions around capacity and investing in decarbonisation technology.

Data requirements: This option requires airlines to submit activity data for every year in which the activity data is updated.

4.4.1.4 Summary of key trade-offs relative to the current UK ETS design

There could be several benefits to updating the activity data from the 2010 data currently used in the UK ETS. Updating the activity year would bring the distribution of free allocation into closer alignment with activity levels in the sector. Regular updating of activity data would also allow free permits to adjust to sector-, subsector- and airline-level developments or shocks that impact capacity, and help to avoid abrupt shifts in the level of free allocation relative to current sector activity.

Updating the activity year will inevitably lead to winners and losers relative to the current UK ETS design. Faster growing airlines and new entrants will benefit from this update, while slower growing airlines (including regional carriers) and incumbents may experience negative impacts on profitability and potentially capacity. This is likely to have a positive impact on UK competitiveness by incentivising growth and rewarding innovative airlines that succeed in the market.

Regular updating would peg free allocation distribution to relative activity levels among airlines, so that positive and negative impacts on profitability to fast- and slow-growers would be repeated on an ongoing basis. This would reward capacity growth and may weaken the incentive to abate emissions via reductions in capacity by creating a link between free allowances and marginal costs. Any regular or anticipated one-off updating of the activity year should seek to avoid the possibility of distortive or ‘gaming’ behaviour among airlines; this could include choosing a baseline year before the announcement date or averaging together multiple years of activity to form a new baseline.

Activity data updating may be associated with some incremental airline and government administrative costs relative to the current UK ETS.

4.5 Change in adjustment factor

As described in Section 3.3.2.2, the adjustment factor is used to set the total amount of free allowances available in any given year, including setting total free allowances in the initial year of the ETS phase, and the speed at which free allowances are phased out. Currently, in 2021 there are 4.4 MtCO2 of UK ETS free allowances to aviation airlines, and the free allowances for each airline decrease by 2.2% per year.

It would be possible to change the adjustment factor in either direction – i.e. an increase or a decrease. Illustratively, we assess an increase in the adjustment factor below. To avoid duplication, we do not also assess a decrease in the adjustment factor, as an assessment of this would contain the same information as the assessment of an increase but in the reverse direction.

We therefore assess two design options: a one-off increase in the adjustment factor, and an increase in the annual adjustment factor to taper free allocation more rapidly over time.

Increasing the adjustment factor would reduce the number of free allowances received by all airlines in the sector, increasing their fixed costs and reducing profitability. As discussed in more detail in Section 4.1, this increases risk of loss of competition and risk of some reduction in capacity.

4.5.1.1 Key strengths and weaknesses of increasing the adjustment factor

Assessment criterion	**Assessment**
1: reduce emissions through incentivising abatement	Rating: 3* - Increasing the adjustment factor would reduce free allowances, but not impact the carbon price; there would be no change to marginal abatement incentives. - Reducing free allowances increases the likelihood of a reduction in capacity (see Section 4.1.1.4), decreasing emissions. This reduction in emissions may be mitigated by second-order effects where remaining airlines backfill with their own capacity.
2: appropriately mitigate carbon leakage risk	Rating: 3* - This option increases likelihood of a reduction in capacity within the policy area. Due to the round trip nature of aviation and scope of the UK ETS, this would be associated with a decrease in emissions outside of the policy area – i.e. negative carbon leakage.
3: appropriately mitigate risk of competitiveness distortions	Rating: 2 - An increase in the adjustment factor leads to proportionately fewer free allowances across airlines, decreasing their profitability. Airlines with a large proportion of operations within UK ETS policy scope, and who tend to operate with lower margins (e.g. at uncongested airports), are most likely to experience a loss of competitiveness.
4: support a viable market: airline perspective	Rating: 3 - No change in administrative costs, and easy for market players to understand. - A steeper annual reduction in free allocation may be easier to rationalise to airlines, rather than a larger one-off change in the level of free allocation.
5: support a viable market: government perspective	Rating 2: - Decreasing free allocation would increase government revenue. - A decrease in the level of free allocation increases risk of increases in ticket prices from loss of airlines (see Section 4.1.1.4). This reduction in airlines may be mitigated by second-order effects where remaining airlines backfill with their own capacity. This risk would also be associated with negative impacts on employment and other parts of the value chain.
6: align with climate action outside the current scope and the UK	Rating N/A: - Unlikely to have significant impact

**This rating reflects that reducing emissions through capacity reduction is not a UK ETS policy objective.*

4.5.1.2 Key distributional impacts and sensitivities relevant to the UK-specific aviation context

Altering the adjustment factor impacts the level of free allowances but not the distribution of allowances among airlines. For a detailed discussion of the impact of a decrease in free allocation, please see Section 4.1. A substantial decrease in free allocation may increase risk of loss of competition in the aviation market (as explained in detail in Section 4.1.1.4), and this risk is likely concentrated among those airlines with a high proportion of operations within UK ETS scope, including regional airlines. This increased risk of loss of competition is associated with a risk of higher ticket prices. Higher ticket prices would affect demand from leisure passengers to a greater degree due to their greater price sensitivity.

As a larger fraction of freight airlines' costs are fuel costs compared with passenger airlines, a sector-level reduction in free allocation will tend to have a proportionately larger negative impact on freight airlines' profitability than passenger airlines' profitability.

4.5.1.3 Key interactions with other elements of free allocation and carbon pricing policy

Carbon price: The risk of negative impacts on airport revenue and on consumers is higher under a higher carbon price.

Other design aspects of free allocation: No significant other interactions with other design aspects of free allocation have been identified.

Data requirements: This option has no additional data requirements relative to the baseline policy.

4.5.1.4 Summary of key trade-offs relative to the current UK ETS design

Increasing the adjustment factor reduces free allowances proportionately for all airlines in the market. This reduces airline profitability and potentially capacity across the sector, decreasing emissions both inside and outside of the policy area but increasing risk of competitive disadvantage for airlines with greater proportion of airlines inside the policy area or with lower baseline profitability, including airlines that are not at congested airports.

4.6 Introducing reserve groups

The UK ETS has a provision to honour reserve allocation that was granted through the EU ETS, based on 2014 data. The current design does not include provisions for new reserve allocation.

Below we assess two design options for reserve groups: a reserve for fast growth and a reserve for new entrants. The purpose of these reserves is to account for significant change in activity since the last update year of the activity data, and therefore act to some degree as an alternative to updating the activity baseline year. Instead of more recent activity data being submitted by all airlines and used in determining the free allowance allocation, more recent activity data is only submitted by a specified group of airlines that the government may want to promote. This allows some of the benefits of updating the activity data, without the same level of administrative cost for both airlines and the government. However it adds some level of complexity as multiple free allocation mechanisms operate simultaneously.

When thinking about why the government may want to support certain groups of airlines, an example is airlines experiencing fast growth and new market entrants which may contribute to competition and innovation in the aviation market.

We assume that the pool of reserve allocation is separate from the pool of non-reserve allocation. That is, we assume that if more reserve allowances are distributed in a particular year, this does not impact the number of non-reserve allowances distributed in that year. Determining the size of the reserve pool is an implementation decision, and outside the scope of this study.

The below effects are contingent on material uptake of reserve permits. If there is little or no activity by new market entrants, and/or the criteria for fast growth reserve allowances are very stringent, then the reserves would have no material impacts.

4.6.1.1 Key strengths and weaknesses of introducing reserve groups

Assessment criterion	Assessment
1: reduce emissions through incentivising abatement	Rating: 3* ▪ Incentivises capacity growth and new entry which would increase emissions relative to the current policy. ▪ However reserves may tend to benefit smaller airlines; small airlines are likely to have a relatively small impact on sector-wide emissions
2: appropriately mitigate carbon leakage risk	Rating: 3* ▪ Incentivises capacity growth within the policy area. Increases within the policy area are associated with increases in capacity (and therefore emissions) outside the policy area.
3: appropriately mitigate risk of competitiveness distortions	Rating: 4 ▪ Reduces new entrant overheads and increases profitability of activity growth inside the policy area. ▪ Reduces possible distortion to competition to the extent that the reserve group better reflects current activity levels.
4: support a viable market: airline perspective **New entrant reserve**	Rating: 4 ▪ Reduces differential treatment in which free allocation does not proportionately contribute to the overheads of new entrants and incumbents. ▪ Introduces some additional administrative costs to airlines
4: support a viable market: airline perspective **Fast grower reserve**	Rating: 3 ▪ Reduces differential treatment of earlier capacity growth and recent capacity growth. ▪ May benefit smaller airlines that can likely achieve higher levels of growth relative to large airlines ▪ Introduces some additional administrative costs to airlines ▪ Definition of fast growth may be seen as arbitrary if not clearly communicated with stakeholders.
5: support a viable market: government perspective	Rating 4: ▪ If the reserve is drawn from permits that would otherwise be auctioned, this may reduce revenue to HMT. Creates more equitable free allocation to airlines of a given size who have experienced faster or slower activity growth or entered the market more or less recently. ▪ Increase in capacity would also increase employment and other parts of the value chain.
6: align with climate action outside the current scope and the UK	Rating N/A: ▪ Unlikely to have significant impact

**This rating reflects that emissions changes through changes in capacity are not a UK ETS policy objective.*

4.6.1.2 Key distributional impacts and sensitivities relevant to the UK-specific aviation context

New entrant and fast growth reserves would likely benefit airlines with small UK operations. They would also likely benefit routes that are areas of growth or emerging markets. Introducing these reserves would reduce the risk to airlines of adding new capacity, as the required return on the routes for commercial viability would be reduced. Reserves may therefore provide a particular incentive when costs and revenue for some additional capacity is relatively uncertain. Impact on overall emissions is likely to be small, as the affected airlines and activity would likely be small relative to the size of the aviation market.

The above effects depend on the qualification criteria and the rate of uptake of the reserves, which we discuss in Section 4.7.

4.6.1.3 Key interactions with other elements of free allocation and carbon pricing policy

Carbon price: The impact of these reserves will be greater if the carbon price is higher.

Other design aspects of free allocation: If the activity data is updated on an annual basis, there is no need for either a new entrants or fast grower reserve. If the activity data is updated regularly and frequently, the impacts of either a new entrants or fast grower reserve is likely to be minimal.

Data requirements: New entrants and fast growers would be required to submit activity data for the years they are applying for reserve permits.

4.6.1.4 Summary of key trade-offs relative to the current UK ETS design

New entrant and fast growth reserves can help to support small airlines that may receive proportionately fewer allowances compared with larger incumbents. This may help to support competition, although this may incentivise some small increase in emissions within and outside the policy area[85].

4.7 Rules for reserve group allocation

For the two types of reserves discussed above—new entrants and fast growth—we discuss different rules that could vary the number of reserve allowances distributed. This is a key design decision that varies the strength of the incentive.

Qualitatively, the impact of strengthening the incentive is similar to the impact of including the reserve at all (the design options above in Section 4.6). For this reason, in this subsection we do not repeat the formal assessment. Instead we describe different possible options to reserve allocation, and discuss advantages and disadvantages of each.

---

[85] For example, a sharp annual growth cut-off for the fast growers reserve could lead airlines close to that cut-off to artificially inflate capacity to reach the threshold and therefore qualify for additional 'fast-grower' reserves.

4.7.1.1 Fast growth reserve

There are several methods by which a reserve could reward fast growth to a greater or lesser degree. These include the following.

Lower/raise the requirements for activity growth that qualifies an airline for reserve permits. The lower the requirements for activity growth to qualify for reserve permits, the closer the mechanism resembles activity data updating, with the associated advantages and disadvantages. Please see Section 4.4 for the assessment of activity data updating.

Vary the requirements for activity growth by time elapsed since last activity data update. For example, 15% average year-on-year growth could be required if it has been one year since the last activity data update, 10% average year-on-year growth if it has been two years since the last activity data update, etc. Airlines are likely able to sustain particularly high growth for a shorter period of time, before reverting to a slower long-run growth trajectory. If the requirements for fast growth are set high, then this may advantage airlines who happen to experience fast growth around the year of activity data updating, which may not be representative of the airlines who experience sustained growth over a longer period of time. Taking this into account would likely improve medium-run uptake of a fast growth reserve.

Vary allowances per activity unit. If an airline qualifies for reserve allowances, the airline's activity growth could translate into relatively more or fewer reserve permits. A variety of rules could be used to determine the reserve permits received for a given level of activity growth. For example, all TKM growth above a threshold could receive the same allowances per TKM as in non-reserve free allocation.

In deciding these implementation details, some general principles apply:

- The update year of the activity data could impact uptake of a fast growth reserve. If an update year is chosen with anomalously low activity, then airlines will more easily achieve year-on-year growth in the following years. This may not be representative of long-run trends.
- The criteria for reserve permits should assess growth since the last activity data update year, as the purpose of the reserve is to 'correct' for substantial activity changes that are not reflected in the free allocation activity data.
- The more complex the criteria for the reserve permits, the greater the need for clear justification to and communication with airlines.
- Introducing hard thresholds may create distortions around the threshold. For example, introducing an activity growth threshold that creates a large discontinuity in free allowances may distort airline behaviour for airlines near the threshold.
- Rewarding activity growth can be achieved through reserve permits, but also through updating the activity data (see Section 4.4). Updating activity data applies a consistent free allocation update across all airlines, whereas a fast growth reserve can be tailored to reward high performing airlines. These design features can be combined in order to achieve a balance of shielding higher growth versus lower growth airlines.

- Fast growth reserve criteria that are likely to benefit a substantial proportion of airlines may achieve similar objectives to updating activity data. Updating the activity data may be simpler to implement and communicate to airlines relative to complex fast growth reserve criteria.

4.7.1.2 New entrant reserve

A new entrant reserve could allocate free permits relatively more or less generously, to strengthen or diminish the free allocation support to new entrant profitability.

The definition of a new entrant would specify the number of years after market entry that a new entrant airline can submit new activity data for free allocation. If a new entrant can only submit activity data in the year of market entry, this will likely result in a lower free allocation to new entrants compared with a policy that allows new market entrants to submit activity data in additional subsequent years after market entry. The decision about the length of time that an airline would qualify as a new entrant would depend on the frequency of activity data updating (if activity data is updated relatively frequently then new entrants' data will be updated along with other airlines, and the criteria for a new entrant will have lower impact).

Vary allowances per activity unit. If an airline qualifies for reserve allowances, the airline's activity levels could translate into relatively more or fewer reserve permits. If a new entrant receives more permits per TKM than other airlines, this increases market entrance profitability, incentivising market entry.

4.7.1.3 Conclusions

Defining a fast growing airline involves a suite of design decisions, as outlined above, for which there may be multiple viable alternatives, requiring justification in order to avoid arbitrariness. By comparison, a new entrant reserve could likely be designed in such a way as to be relatively simple to communicate to airlines.

In previous sections of the report (e.g. Section 4.6) that reserve allowances are separate from non-reserve allowances, to isolate the effect of introducing reserves, reserve allowances could in theory also be allocated from the pool of free allowances. If reserve permits are allocated from the pool of free allowances, then other airlines bear some downside risk associated with this (if reserve permits in a year are unexpectedly high, then other airlines would receive slightly lower free allocation). However in practice we would expect the downside risk to be small given that reserve permits are generally a very small proportion of total free allowances. If reserve permits are allocated from a separate pool, then airlines do not bear this risk. The way in which permits are held in reserve and released for free allocation or auction is an implementation issue that is outside the scope of this study.

4.8 Free allocation assessment summary

Below we summarise main findings of the assessment across design features. Figure 9 outlines the key design options that achieve desired policy outcomes, (organised by outcome), and Figure 10 outlines design options that would most likely risk adverse policy outcomes. These policy outcomes are based on the assessment criteria. Some assessment criteria contain multiple policy outcomes within them, which can make it challenging to highlight individual design options that perform particularly well or badly against the entire criteria. Therefore instead of using the assessment criteria, we have summarised the key outcomes in the tables below.

There are three main policy outcomes included within our assessment:

1. Incentivising abatement within the policy area;
2. Reducing carbon leakage; and
3. Protecting against competitive disadvantage.

We have found that there are minimal trade-offs between the first two of these objectives, due to the negative leakage effects of UK ETS carbon pricing; design options that are likely to reduce emissions within the policy area (abatement) tend to also reduce emissions outside of the policy area. Therefore we have aggregated these objectives in the summary tables below.

In addition to the above objectives, we have selected key sub-criteria from within the assessment criterion of supporting a viable market (airline and government perspectives), which includes a diverse range of policy outcomes.

Figure 9 Key positive policy outcomes

Specific policy outcomes	Design features that support this outcome	Reasoning	Distribution of outcome among market participants
Incentivise emission abatement both within and outside the policy region (abatement and carbon leakage)	One-off increase in adjustment factor; Higher trend in adjustment factor	Reduction in number of free permits (rather than a redistribution) would lead to greater capacity and emissions reductions in the market	Reductions in capacity and increases in ticket prices are more likely for routes with low demand, including some regional routes
Reduce risk of competitive disadvantage (1)	New entrants reserve; Fast-growers reserve	Supports increases in number of market competitors and route competition	May benefit consumers through reduced ticket prices, due to greater competition
Reduce risk of competitive disadvantage (2)	One-off update of activity data; Regular update of activity data	Redistributes permits toward airlines that have achieved activity growth (relative to market average) shields competitive operations	Disadvantages airlines with declines in activity relative to the market average, which will tend to include regional airlines
Minimise risk of disproportionate or regressive distributional impacts for airlines or consumers	Separate benchmarks for short-haul and medium-haul flights	Increases shielding for airlines with short-haul routes, who face higher carbon costs per TKM	Benefits short-haul airlines, especially regional airlines, along with the airports they operate from, and disadvantages carriers that tend to operate medium-haul routes

Figure 10 Key adverse policy outcomes

Specific policy outcomes	Design features that risk this outcome	Reasoning	Distribution of outcome among market participants
Weaken emission abatement incentives both within and outside the policy region (abatement and carbon leakage)	Frequent regular update of activity data	Increase in activity since 2010 would mean more free allowances and increased capacity and emissions. Regular updating also creates link between activity and allowances, effectively reducing marginal costs	Benefiting airlines who have grown since 2010 (and the airports they use) and harming airlines who have shrunk since 2010 (and the airports they use)
Increase risk of competitive disadvantage	One-off increase in adjustment factor; Higher trend in adjustment factor	Reduction in number of free permits and therefore in shielding across all airlines	Does not alter distributional impacts from the current UK ETS as applied to all airlines equally
Increase in administrative costs	Regular update in activity data	Airlines would be required to submit activity data on an ongoing basis airline	Administrative overhead is increased may be proportionately larger for smaller airlines
Increase distorting behaviour in the aviation market	Regular update of activity data	Potential for gaming behaviour, where firms alter the timing of capacity decisions to be allocated more free allowances (distorting the market) Airline	

At a high level, the two main aspects of free allocation are the level of the allocation and the distribution of allowances among airlines.

Adjusting the level of free allocation downward (via the adjustment factor) has the potential to lead to emissions reductions caused by capacity reductions inside and outside the policy area. In theory this may increase risk of competitive disadvantage, but in practice any competitiveness impacts would likely be mitigated by second-order effects such as airlines backfilling their capacity. The risk of capacity reductions is concentrated among airlines with lower levels of profitability that serve routes with weaker demand, airlines that tend to serve non-congested airports that will passthrough their costs, and also airlines with a large share of domestic flights, as a larger fraction of their activity is covered by UK ETS policy. We note that reducing emissions through reductions in capacity is not an objective of UK ETS policy.

A range of options are available to alter the distribution of allowances among airlines to more closely reflect market conditions. Updating activity data and introducing reserve groups would all act to reduce differential treatment and competitive distortions between airlines. Calculating the benchmark by short-haul versus long-haul subsectors would increase the profitability of airlines with a large share of short-haul flights, shielding short-haul operations that are intrinsically more emissions intensive.

All of the one-off updates proposed above would introduce administrative costs that are no greater than the administrative costs of establishing the EU ETS Phase III free allowance mechanism. Updating the activity data on a regular basis would introduce additional administrative costs (for each data year update).

4.9 Assessment of other approaches to shielding

Below we provide a high-level discussion of advantages and disadvantages of a CBAM and product standards, as outlined in Section 3.3.3.

4.9.1.1 Carbon border adjustment mechanism

Over 70% of UK departing flight emissions are on intercontinental routes which are not covered by the UK ETS. While most of these flights are captured under CORSIA, CORSIA carbon prices tend to be significantly lower than the UK and EU ETS. CBAMs could be used to create a more level playing field – ensuring similar carbon prices are experienced on similar routes.

A CBAM of this type, all else equal, in the short-term could result in capacity reductions among airlines with international routes that are outside of the UK ETS policy area. The magnitude of this impact would depend on the magnitude of the CBAM. In the medium- to long-term, the CBAM could contribute to investments in decarbonisation technology as firms seek to reduce carbon content of flights.

For routes with incomplete cost passthrough, which is likely routes through congested airports, there is likely to be a more muted capacity reduction, and airlines may absorb some of the carbon costs. The CBAM may reduce supernormal profits on routes through congested hub airports, up to the point where the routes have competitive pricing, at which point airlines would pass through the remaining carbon costs to consumers.

The practical feasibility of CBAMs is significantly complicated by their need to comply with the relevant international agreements and law, including the Chicago Convention[86], the UK's Open Skies Agreement with the USA[87], and international air law. A CBAM would likely face significantly higher implementation challenges than the free allocation design options discussed above, as it increases the scope of UK aviation carbon pricing and requires compliance with international agreements.

---

[86] ICAO, 2006.

[87] US Department of State, 2017.

As discussed in Section 3.3.3.1, the effective carbon price could be raised on routes outside of UK ETS scope in various ways, which have different advantages and disadvantages:

- A carbon tax for the emissions associated with the departing flight. An advantage of this approach is that a carbon price can be specified in a way to provide certainty to airlines, or alternatively it can be pegged to the UK ETS carbon price, potentially in a way that reduces volatility;
- Requirement to purchase UK ETS allowances. This has the advantage of being aligned with the UK ETS carbon price. The UK ETS cap would need to be adjusted under this option;
- Requirement to purchase offsets meeting specified standards. These standards could include that the offset is geographically within the UK, for example. There may be complexity with specifying offset standards, and some risk that the corresponding carbon price are not in alignment with the UK ETS price.

These example illustrate some of the complexities of applying CBAMs despite their apparent appeal as alternatives to free allocation.

4.9.1.2 Product standards and other decarbonisation incentives

Aviation faces a high cost of abatement in the short and medium term. A potential risk of policies that impose a carbon price on some routes is that they incentivise short-term abatement primarily through capacity reduction rather than investment in decarbonising measures. Complementary policies can be used to shield and to incentivise the development and uptake of low carbon technology to support the medium- to long-term environmental sustainability of the sector.

As discussed in Section 3.3.3.2, these incentives could be delivered through a fiscal incentive or a regulatory requirement. An advantage of a fiscal incentive is that it can allow airlines flexibility in the intensity of uptake. This may be useful if airlines face different costs of uptake and if a cost-effective mix of decarbonisation measures varies substantially between airlines. A regulatory requirement can offer greater certainty to government, by stipulating minimum requirements, at the expense of (1) less flexibility to airlines and (2) potential international negotiation to ensure alignment with multi-lateral agreements. Regulatory standards can also be used to maintain a “level playing field” for competition among airlines by holding their carbon efficiency to some minimum standard.

Product standards for aircraft types or engine types could ensure a minimum level of current- and next-generation fleet technology. This type of policy could be used to incentivise carbon efficiency on UK routes outside of UK ETS or EU ETS scope. The precise impact would depend on the form of product standard and the composition of the relevant fleets (e.g carbon efficiency of the aircraft). One of the difficulties of product standards is this unequal impact based on the ‘starting position’ of different airlines.

A fiscal or regulatory incentive could subsidise **investment in SAF.** This type of policy would need to consider how fuel availability depends on airports, and how measures could incentivise airlines to participate with airports in developing SAF facilities. SAF availability is currently a constraint on SAF uptake[88]. A risk with this policy is that it could encourage tankering by discouraging refuelling at airports with low SAF provision. If the incentive is tied to SAF purchase credits, and these credits may be purchased outside the policy area, then design should consider interactions with international SAF subsidies or incentives.

To encourage uptake of other low-carbon technologies, a fiscal incentive could be tied to airlines' **low-carbon R&D** activities. This type of funding could be a grant mechanism, which has a benefit of stimulating competition to produce high quality grant applications. It could also be an airline requirement to reinvest part of a tax rebate or part of the value of free allowances in low-carbon R&D, in which case it will be important to consider how to ensure that airlines deliver high-value projects. R&D measures could incentivise riskier and more innovative activities than airlines might typically conduct. A drawback is that this incentive may be more efficiently targeted at aerospace research and manufacturing firms for research areas that are at an early stage of development. We note there are existing funding channels for low carbon aviation R&D, for example the Aerospace Technology Institute. Monitoring areas of low carbon aviation technology, to assess which have matured sufficiently to benefit from airline deployment incentives, is an important area of future work.

Airlines could also have requirements to submit to **external energy or emissions audits,** and to follow the auditors' recommendations. The cost to government would likely be low compared to funding SAF and low-carbon R&D. However the gains in terms of carbon efficiency may also be relatively low, as airlines are already heavily incentivised to minimise fuel burn. If the scope of the audit is operational practice, then the carbon efficiency gains are likely to be minimal. If the scope of the audit includes requirements for fleet improvements, then this would be a similar measure to the product standards discussed above. Furthermore, ensuring audit recommendations take into account wider regulatory requirements could complicate their application in practice.

---

[88] BEIS, 2021e.

5 POLICY OPTIONS AND ASSESSMENT METHODOLOGY IN THE QUANTITATIVE ANALYSIS

This section describes the quantitative methodology we use to assess the extent to which different options for the UK ETS impact upon carbon leakage and competitive disadvantage. First, we describe the characteristics of the illustrative UK ETS policy options that will be assessed (**Section 5.1**). Second, we describe the modelling methodology we use to project outcomes from applying these policy options over the period to 2035 (**Section 5.2**). Future projections are inherently uncertain and may be sensitive to assumptions about the development of uncertain future variables such as aviation demand growth rates or oil price. Section 5.2 also describes assumptions for future uncertain variables that may affect UK ETS impacts, both for a central (nominal) case and upper- and lower-end scenarios for sensitivity analysis. This section is supported by additional methodological detail in the report Annexes. **Annex B** gives additional details of the methodology used and of how values for uncertain scenario variables were derived. **ANNEX C** gives additional detail on the quality assurance processes that were carried out.

5.1 Selection of illustrative policy options to assess

The qualitative analysis in Section 4 addressed a range of key design options for the UK ETS for aviation. For the modelling analysis, we concentrate on assessing potential outcomes for a selection of 20 different combined UK ETS aviation policy scenarios. As such, a narrower range of three design characteristics are assessed than in the qualitative analysis and the focus is on how these characteristics may combine.

Based on the analysis in Section 4, we choose three key characteristics to vary across the different combined policy scenarios. These are:

- UK ETS carbon prices;
- UK ETS CORSIA interaction option; and
- The way that free allowances are allocated.

These characteristics complement the qualitative assessment. UK ETS carbon price was highlighted throughout the qualitative analysis as a key dependency, and free allocation was the specific focus of the qualitative analysis.

Scenarios for these variables, and for additional characteristics that are kept constant across all policy scenarios modelled, are discussed in turn below. In Section 5.1.5, we present the full set of 20 combined policy scenarios.

5.1.1 UK ETS carbon price options assessed

Carbon prices are a key determinant of both airline and passenger response to carbon trading policy in aviation. The level of carbon price is likely to have a strong impact on the extent of carbon leakage.[89] Although developments in carbon prices are uncertain, they are also affected by policy. For example, trading schemes with more stringent caps will typically have higher carbon prices. Because of this, carbon prices are included as a policy variable to be assessed.

The geographic scope of the UK ETS affects the type of carbon price scenarios that are appropriate. The UK ETS applies on UK domestic routes and UK-EEA routes. The EU ETS applies on EEA-UK routes and on intra-EEA routes. Each outbound international UK ETS-covered flight will typically have an EU ETS-covered return journey and, where airlines who operate UK ETS-covered flights have choices about where to add extra single-aisle capacity, these choices will likely be between UK ETS and EU ETS routes. As such, the difference between UK ETS and EU ETS price is important for outcomes. Currently, UK ETS and EU ETS carbon prices are close to each other[90], but there is the potential for carbon prices to diverge in future if the requirements, scope or cost of emissions mitigation for sectors within the two schemes diverge.

For the quantitative analysis, we therefore define three illustrative cases for UK ETS carbon price:

- Scenarios Equal (**E**): UK ETS carbon price remains equal to EU ETS carbon price.
- Scenarios Low (**L**): UK ETS price is 50% below EU ETS carbon price.
- Scenarios High (**H**): UK ETS price is 50% above EU ETS carbon price.

The intention of these scenarios is to explore what outcomes are possible over a wide range of potential futures, rather than to provide definitive predictions for future trends. EU ETS carbon prices are treated as uncertain variables, and form part of the study's sensitivity analysis. Nominal, upper and lower scenarios for their values are discussed in Section 5.2.3. The way that UK ETS carbon prices are used in the quantitative modelling is discussed in more detail in Section 5.2.1 and Section 5.2.3.

5.1.2 CORSIA implementation options assessed

As outlined in Section 1.1, DfT (2021)[91] discusses options for how the UK ETS and CORSIA could interact, including six illustrative interaction options (options 1-6). Recognising that there are a wide range of options that might be taken forward, we selected three options for analysis from among those included in DfT's consultation. This was done simply as a proportionate and broadly representative means of illustrating the range of impacts that the wide variety of interaction options could have. These are **Options 2, 4 and 6**. Under option 2, we assume UK ETS obligations on international routes are reduced by an amount equal to the route-level CORSIA obligation. We also assume the equivalent amount of allowances is retired from the UK ETS auction pot. Under option 4, both schemes apply at once, and airlines on UK-EEA routes are subject to full UK ETS and CORSIA costs.

---

[89] ATA and Clarity, 2018.

[90] Reuters, 2021.

[92] Aviation free allowance totals for the period to 2025 by airline have already been estimated and are available from BEIS (2021b).

Under option 6, CORSIA does not apply on UK-EEA routes. Option 6 additionally changes the global CORSIA baseline, as further discussed in Annex B.1.

Baseline assumptions about the UK ETS, EU ETS and CORSIA, and the way that they are handled in the quantitative modelling, are discussed in more detail in Section 5.2.1 and Annex B.

5.1.3 UK ETS free allocation options assessed

The allocation of free allowances reduces the additional costs imposed on airlines as a result of carbon trading. As with the EU ETS, UK ETS free allocation entitlements are currently calculated by multiplying the aviation benchmark[92] by the verified tonne-km data reported by airlines. This process is discussed further in Section 3.3.2.1. For the 2021 UK ETS scheme year, this amount has been reduced by 2.2% and distributed in proportion with airlines' UK ETS aviation activity. It will continue to be reduced by 2.2% each year. The European Commission plans to phase out EU ETS free aviation allowances by 2027[93].

The impact of free allowances on airline behaviour is currently uncertain, as highlighted in Section 4.1, with a wide range of assumptions used in the literature. This is discussed further in Annex B.7.5. Higher levels of free allocation are likely to result in lower levels of competitive disadvantage and may (depending on cost pass-through assumptions) increase airline profits compared to a case where no emissions trading is implemented. As free allocation is currently based on a historical airline tonne-km benchmark, it may also lead to slower-growing airlines with more operations in the benchmark year having a higher percentage of their emissions covered by of free allocation than faster-growing airlines, potentially leading to different levels of competitive disadvantage on routes used by different types of airlines.

Based on the analysis in Section 4, recognising the wide range of possible scenarios, we define five hypothetical scenarios for UK ETS free allocation options as a pragmatic means of testing the importance of the choice of UK ETS free allocation approach for the outcomes of interest:

- Option a: The current methodology is maintained.
- Option b: Airline allocation of free allowances stops in 2024.
- Option c: Free allowances are phased out using the same trajectory as the proposed EU ETS free allowance phase-out[94].
- Option d: Free allowances are phased out from 2024 to zero in 2031.
- Option e: The amount of free allowances issued follows current methodology, but from 2024 they are allocated based on the distribution of year-2019 RTK.

Note that options a to d vary the total volume of free allowances, and the results could be combined with qualitative options that consider the optimal allocation of

---

[92] Aviation free allowance totals for the period to 2025 by airline have already been estimated and are available from BEIS (2021b).

[93] EC, 2021.

[94] This phase-out is part of the EC 'Fit for 55' package (EC, 2021e). Under the proposal, EU ETS free aviation allowances will be reduced progressively from 2024, reaching full auctioning in 2027.

allowances (e.g. updating activity data, modifying the benchmark, and units of activity data). Option e is one example of a possible implementation of the design option of updating the activity data, assessed in Section 4.4.

As with the carbon price options described above, these are illustrative scenarios designed to examine outcomes across a range of possible allocation options, rather than a list of definitive options from which one will be chosen.

Baseline assumptions about free allowance allocation, and the way that it is handled in the quantitative modelling, are discussed in more detail in Section 5.2.1 and Annex B.

5.1.4 Characteristics kept constant in the quantitative modelling

This section describes the assumptions used in the quantitative modelling for some additional UK ETS characteristics that are kept constant across the set of policy options modelled.

5.1.4.1 Treatment of SAF

CORSIA and the EU ETS treat SAF differently. SAF can have a wide range of fuel lifecycle emissions, depending on the feedstock used and production process. Under CORSIA, an alternative fuel must deliver a minimum of a 10% reduction in fuel lifecycle GHG emissions compared to conventional fossil kerosene to be counted as a CORSIA-eligible fuel[95]. The ratio of the alternative fuel's lifecycle emissions to those of conventional fossil kerosene is used to calculate the amount by which an airline's offset obligations under CORSIA are reduced. For the EU ETS, SAF must meet the REDII qualification threshold of a 65% reduction in fuel lifecycle emissions[96]. If a fuel meets this target, it is exempt under the EU ETS.

For the UK ETS, the current treatment of SAF is based on the EU ETS alternative aviation fuel methodology. Future treatment of alternative fuels under the UK ETS is still under review. As such, we assume the UK ETS and EU ETS use the same alternative fuel exemption methodology for all model runs.

5.1.4.2 Caps, baselines, geographic and sectoral scope

The UK ETS, EU ETS and CORSIA are all subject to regular review. The EU ETS has already changed scope multiple times (from full to reduced scope initially, and then via adjustments, e.g. to include Croatia in the scheme). At present, CORSIA specifies plans to 2035; the UK ETS and EU ETS specify detailed plans to 2030 only. In practice, the evolution of all three schemes over the longer term depends on uncertain factors such as the level of climate ambition of individual participating states at the point of scheme review. Because carbon prices are affected by the level of stringency of a carbon trading scheme, different levels of carbon price can be considered as a proxy for these types of changes. However, we do not explicitly model scope changes for the UK ETS or EU ETS. Where characteristics are not

---

[95] ICAO, 2019c.

[96] European Parliament, 2020.

specified past 2030, we assume a continuation of previous trends. For CORSIA, scope changes are likely for the different phases of the scheme; this is discussed in Annex B.1.2.

5.1.5 Combined policy scenarios

Based on the selection of options for individual UK ETS characteristics described above, we define 20 combined policy scenarios covering a range of UK ETS carbon price, CORSIA interaction option, and free allowance allocation methodology combinations. These combined scenarios are shown in Table 3. For each scenario, the scenario name is a combination of the UK ETS carbon price option (E, L, H), the CORSIA option (2, 4, 6) and the free allowance allocation option (a, b, c, d, e). Where outcomes are presented that do not vary with changes in free allowance allocation, we group options by UK ETS carbon price scenario and CORSIA interaction option only (e.g Options E2, E4).

Table 3. Combined UK ETS policy scenarios to be assessed

Policy scenario	UK ETS carbon price	CORSIA option	UK ETS free allocation
E2a	Matches EU ETS carbon price	Option 2	Current approach
E2b	Matches EU ETS carbon price	Option 2	No free allocation (from 2024)
E4a	Matches EU ETS carbon price	Option 4	Current approach
E4b	Matches EU ETS carbon price	Option 4	No free allocation (from 2024)
E4c	Matches EU ETS carbon price	Option 4	Phase-out from 2024. No free allowances by 2027.
E4d	Matches EU ETS carbon price	Option 4	Phase-out from 2024. No free allowances by 2031.
E4e	Matches EU ETS carbon price	Option 4	2019 benchmark (from 2024)
E6a	Matches EU ETS carbon price	Option 6	Current approach
L2a	50% lower than EU ETS carbon price	Option 2	Current approach
L2b	50% lower than EU ETS carbon price	Option 2	No free allocation (from 2024)
L4a	50% lower than EU ETS carbon price	Option 4	Current approach
L4b	50% lower than EU ETS carbon price	Option 4	No free allocation (from 2024)
L4c	50% lower than EU ETS carbon price	Option 4	Phase-out from 2024. No free allowances by 2027.
L4d	50% lower than EU ETS carbon price	Option 4	Phase-out from 2024. No free allowances by 2031.
H2a	50% higher than EU ETS carbon price	Option 2	Current approach
H2b	50% higher than EU ETS carbon price	Option 2	No free allocation (from 2024)
H4a	50% higher than EU ETS carbon price	Option 4	Current approach
H4b	50% higher than EU ETS carbon price	Option 4	No free allocation (from 2024)
H4c	50% higher than EU ETS carbon price	Option 4	Phase-out from 2024. No free allowances by 2027.
H4d	50% higher than EU ETS carbon price	Option 4	Phase-out from 2024. No free allowances by 2031.

5.2 Summary of modelling methodology

To model the impact of the policy scenarios discussed above on carbon leakage and competitive disadvantage, we use the aviation systems model AIM. This section describes how AIM models the aviation sector, including a discussion of the model's approach to uncertainty and key limitations. It is supplemented by additional methodological detail in ANNEX B. First, we describe the basic methodology used in AIM (Section 5.2.1). Then, we discuss the output metrics that we use to capture carbon leakage and competitive disadvantage effects (Section 5.2.2). Finally, we describe how AIM is used in this study to carry out sensitivity analysis (Section 5.2.3).

5.2.1 The Aviation Integrated Model

The Aviation Integrated Model (AIM) is a global aviation systems model which simulates interactions between passengers, airlines, airports and other system actors from a 2015 base year into the future, with the goal of providing insight into how policy interventions and other projected system changes will affect aviation's environmental and economic impacts. The model was originally developed in 2006-2009 with UK Research Council funding (e.g. Reynolds et al., 2007; Dray et al. 2014),[97] and was updated as part of the ACCLAIM project (2015-2018) between University College London (UCL), Imperial College and Southampton University (e.g. Dray et al., 2019),[98] with additional input from Massachusetts Institute of Technology regarding alternative technologies (e.g. Schäfer et al., 2018).[99] The model is open source, with code, documentation and a simplified version of model databases available from the UCL Air Transportation Systems Group website.[100]

---

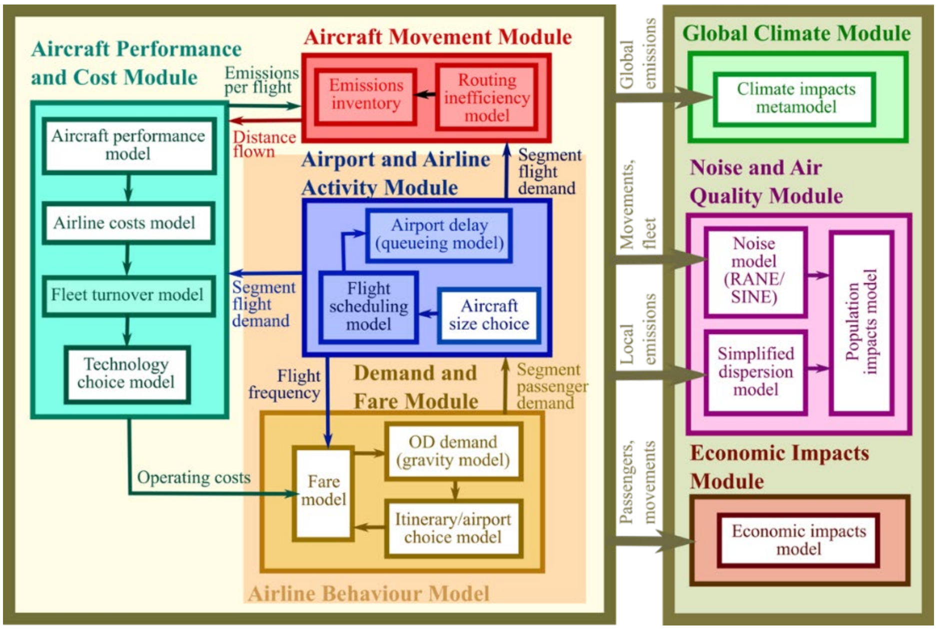
[97] Reynolds, 2014.

[98] Dray et al., 2019.

[99] Schäfer et al., 2018.

[100] http://www.atslab.org. Note that the version of the model used here is adapted from the version currently available on the website.

Figure 11 Aviation sector policy assessment structure (AIM)



Source: AIM

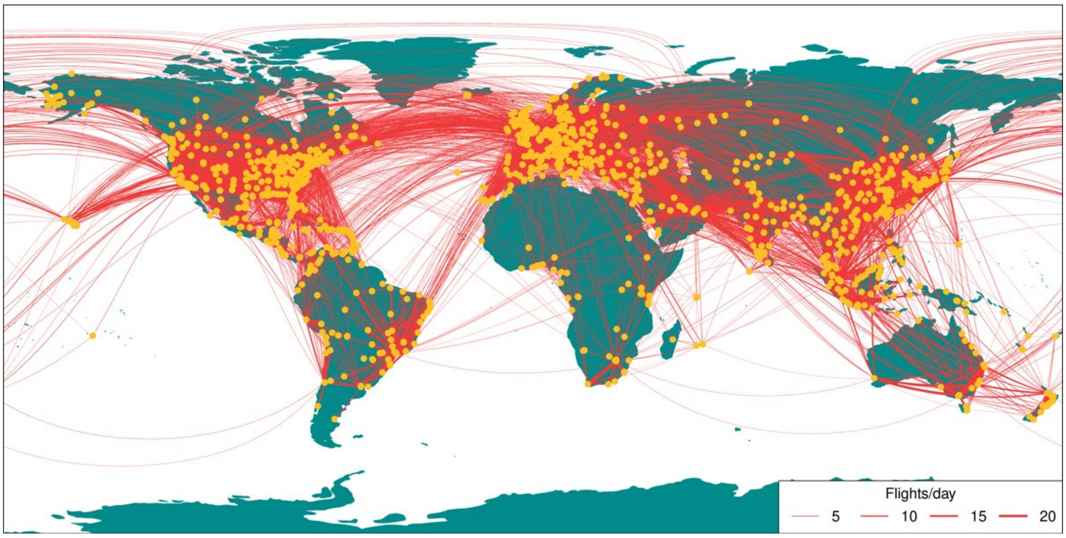
AIM and its individual modules have been used to assess the environmental and economic impacts of multiple actual and hypothetical policies down to the individual airport, flight segment or passenger itinerary level[101]. The structure of the model is shown in Figure 11.

AIM consists of seven interconnected modules. The Demand and Fare Module projects true origin-ultimate destination demand between 878 cities representing approximately 95% of global scheduled RPK and assesses which of the available 1,169 airports and routes passengers will use to take these journeys. Non-scheduled flights, and flights to airports outside the modelled airport set, are dealt with through the use of scaling factors and a dummy airport representing all other destinations, respectively. The methodologies used to estimate passenger demand and itinerary choice are discussed in detail in Annex B.3.

---

[101] This includes the 2020 assessment of the interaction of the EU ETS and CORSIA for European Commission Directorate-General for Climate Action (DG CLIMA) and a 2021 update to that study further exploring the impact of COVID-19 on the outcomes (ICF et al. 2020); assessment of carbon leakage and competitive impact of UK aviation policy for DfT (ATA & Clarity, 2018); and International Energy Agency (IEA) analysis of the impact of new aviation technologies to meet net-zero CO_2 requirements (IEA, 2020a).

Figure 12 Global modelled flight network and airport set, 2015



Source: AIM

A simple freight model incorporated into a recent version of AIM also captures country-pair level air freight flows, freight carriage in freighter aircraft and the holds of passenger aircraft, and changes in freighter aircraft operations resulting from changes in passenger aircraft hold capacity. Because non-scheduled flights and freight are modelled, CO_2 totals are representative of total civil aviation CO_2, allowing policies which rely on levels of growth above a given baseline (i.e. CORSIA) to be assessed. The year-2015 network and airport set modelled is shown in Figure 12. Fares are simulated using a fare model, based on airline costs, route-level competition and capacity metrics, and other factors (described in detail in Annex B.2).

The Airport and Airline Activity module assesses which aircraft will be used to fly these routes and at what frequency, what the resulting airport-level movements are and how this translates into delay at each airport. Aspects of this methodology that are important for carbon leakage and competitive disadvantage are discussed further in Annex B.2. The Aircraft Movement Module assesses the corresponding airborne routes and the consequent location of emissions.

The Aircraft Performance and Cost module assesses the size, composition, age and technology use of the aircraft fleet, which is split into nine size classes from small regional jets to very large aircraft, the resulting costs for airlines, and emissions implications. Aspects of this methodology that are important for carbon leakage and competitive disadvantage are also discussed further in Annex B.2. These four modules are run iteratively until a stable solution is reached. Data are then output, which can be used in the impact modules, shown on the right panel of Figure 11.

AIM simulates the development and policy response of multiple aviation externalities including CO_2, NO_x (and NO_2), PM2.5 and noise down to the individual airport level. Additionally, a first-order assessment of non-CO_2 climate impacts can be made via AIM's Global Climate Module. Outputs can also be used to assess other environmental impacts via post-processing. However, as the focus of this study is on carbon leakage and competitive disadvantage, metrics relating to other externalities are not included in outputs.

Key modelling areas which impact carbon leakage and airline competitiveness are discussed in detail in ANNEX B. This includes how the UK ETS, EU ETS and CORSIA are modelled. Further information about the assumptions and validation procedures for individual modules is provided in the AIM model documentation;[102] further information on model validation is provided in Dray et al. (2019)[103] and, where specifically relevant for this project, in ANNEX C.

5.2.2 Output metrics

For this study, we concentrate on metrics which capture carbon leakage and competitiveness impacts on UK airlines and airports, as outlined in Section 2.2. This includes metrics which capture the drivers of these impacts.

To assess the level of **carbon leakage**, we use the negative of the emissions change outside the UK ETS policy area divided by the emissions change inside the UK ETS policy area, as defined in Section 0. We assess this metric both in terms of direct and fuel lifecycle CO_2[104]. We also report global CO_2 by policy area (UK ETS, EU ETS, CORSIA) to assess the extent to which leakage affects airline obligations under other policies.

To assess the drivers behind carbon leakage, we additionally consider:

- Emissions intensity: route-level fuel lifecycle CO_2/RTK; and
- Changes in the number of O/D and transfer passengers passing through UK airports vs. non-UK airports.

To assess impacts on **airline competitiveness,** we use metrics examining how operations and costs change for UK and non-UK airlines.

- Costs: Direct Operating Costs (DOC) per revenue tonne kilometre (RTK), by route type and airline nationality;
- Volume: RTK and passengers, by route type and airline nationality;
- Value: average cost pass-through and load factor, by route type and airline nationality.

We additionally examine how costs and operations change by airline type (e.g. network, low-cost or regional airlines).

We examine **airport competitiveness** by estimating two complementary measures of turnover:

1. Volume: the numbers of O/D and transfer passengers per airport;[105] and
2. Value: the airport revenue (aeronautical and non-aeronautical) per airport.

---

[102] Available at http://www.atslab.org/data-tools/.

[103] Dray et al., 2019.

[104] Direct CO_2 is all CO_2 released by aircraft engines. Fuel lifecycle CO_2 additionally includes CO_2 associated with the production and distribution of the fuel used in aircraft engines. Where airlines use drop-in SAF, fuel lifecycle CO_2 decreases but direct CO_2 does not.

[105] The purpose of distinguishing between London and non-London is to capture that there may be differential competitiveness impacts for airports with more transfer traffic (i.e. London).

As well as the metrics given in the main body of the report, additional supporting metrics are shown in ANNEX D. For metrics which use airline nationality, we divide into UK and non-UK airlines. Defining a UK airline can be difficult because airlines operate internationally and are often part of internationally owned groups;[106] the definition used here is discussed in Section B.4.

5.2.3 Treatment of uncertainty and model sensitivity

The future impacts of aviation policy depend strongly on uncertain future socioeconomic and aviation system developments: for example, developments in global incomes, energy prices, attitudes to aviation and technology development. Modelling outcomes are also contingent on uncertainty in estimated model specification and parameters, and from unanticipated disruptive events. For example, the COVID-19 pandemic was not anticipated in the initial design of CORSIA. The combination of COVID-19 related decreases in passenger movements and CORSIA's subsequent pilot phase baseline update to 2019 may mean, in practice, that the CORSIA offset requirement for the pilot phase is zero[107].

A description of the general approach to sensitivity analysis in this report is given in Annex B.6. We identify seven key uncertain scenario variables or groups of variables which are likely to have a material effect on outcomes, and so need to be considered in the sensitivity analysis. These variables, and a summary of the expected system impacts of changing them, are shown in Table 4.

---

[106] ATA and Clarity, 2018.

[107] Dray & Schäfer, 2021; Schneider & Graichen, 2020.

Table 4. Summary of the expected changes in impacts of changing uncertain scenario variables.

Uncertain scenario variable	Impacts if lower than nominal	Impacts if higher than nominal
Demand growth	Higher fraction of CO_2 emissions covered by UK ETS free allowances. Lower/no CORSIA obligations.	Smaller fraction of CO_2 emissions covered by UK ETS free allowances. Higher CORSIA obligations and costs.
Capability of new technology to reduce fuel use	Higher airline fuel and carbon costs, leading to higher ticket prices.	Lower airline fuel and carbon costs, leading to lower ticket prices.
Oil price	Baseline ticket prices are lower. Carbon price is a higher fraction of airline costs.	Baseline ticket prices are higher. Carbon price is a smaller fraction of airline costs.
Alternative fuel supply	Airlines have less opportunity to reduce carbon costs by using alternative fuel.	Airlines have more opportunity to reduce carbon costs by using alternative fuel (if cost-effective).
Passenger price sensitivity	UK ETS-related ticket price increases have less impact on demand.	UK ETS-related ticket price increases have more impact on demand.
Cost pass-through	Higher likelihood airline profit per passenger will decrease. Smaller impact on demand.	Smaller impact on airline profits. Larger impact on demand.
EU ETS and CORSIA characteristics	Lower carbon prices or smaller scope would lead to lower impact of the EU ETS and CORSIA on demand and operations.	Higher carbon prices or larger scope would lead to larger impact of the EU ETS and CORSIA on demand and operations.

For each of the 20 policy options, we run one ‘central-case’ model run with all uncertain scenario variables set to ‘most-likely’ values and a corresponding set of sensitivity model runs using different trends for each uncertain scenario variable in turn. The values which are used for these variables are derived from analyses of projected trends in the available literature on each variable. For each of the seven identified uncertain scenario variables or combinations of variables, the derivation of input values for nominal, upper and lower cases is discussed in detail in Annex B.6. Table 5, below, gives a summary of key assumptions and their sources.

Table 5. Summary of key assumptions used for uncertain scenario variables

Variable	Lower*	Central (nominal)*	Upper*	Derived from
Demand growth	N/A[108]	Close to projections published by DfT in 2017	Close to industry projections	DfT, 2017; Airbus, 2019; Boeing, 2020; O'Neill et al. (2013).
Technology characteristics	'Pessimistic' literature values	'Most-likely' literature values	'Optimistic' literature values	ATA & Ellondee, 2018
Oil price, year 2015 USD/bbl	45.7	73.7	110.0	BEIS, 2019
SAF supply	Remains at current levels	Capped at 10%	Capped at 40%	BEIS, 2019
Cost pass-though at congested airports	0%	50%	100%	ATA & Clarity, 2018
Passenger demand elasticities	AIM baseline values - 0.115	AIM baseline values	AIM baseline values + 0.115	Dray et al. 2019; DfT, 2017; ATA & Clarity, 2018
EU ETS carbon price, year 2015 GBP/tCO2	39.6	79.2	118.8	BEIS, 2021a
CORSIA carbon price, year 2015 GBP/tCO2	1.22	1.22	21.6	Fearnehough et al., 2018; ICAO, 2015
CORSIA baseline year after pilot phase	Remains at 2019	Remains at 2019	Reverts to 2019/2020	ICAO, 2020

Source: ATA

** Year-2030 value or assumptions used*

In some cases, unexpected outcomes may arise because of combined uncertainty in several uncertain scenario variables at once. For example, ticket prices will be particularly high in the case that oil prices, EU ETS carbon prices and cost pass-through are all at the high end of what is expected, and this may then have an impact on outcomes related to the UK ETS. To explore potential risks from these situations, we additionally define eight scenarios which combine trends in different uncertain variables. These are shown in Table 6, for variables not related to policy. For variables related to the EU ETS and CORSIA, different assumptions are used for different individual policy characteristics in these combined scenarios. These are summarised in Table 7.

---

[108] Only two scenarios are used for demand growth, central (nominal) and upper.

Table 6. Combinations of uncertain scenario variables which are likely to produce extreme outcomes

Case	Demand growth	Tech. chars	Oil price	Alt. fuel chars	Price sensitivity	Cost pass-through
High emissions	High	Pessimistic	Low	Pessimistic	High	Low
Low emissions	Low	Optimistic	High	Optimistic	High	High
High ticket prices	Nom.	Pessimistic	High	Pessimistic	Low	High
Low ticket prices	Nom.	Optimistic	Low	Optimistic	High	Low
High risk of emissions increase outside the policy area	High	Pessimistic	Low	Pessimistic	High	High
Low risk of emissions increase outside the policy area	Low	Optimistic	High	Optimistic	Low	Low
High risk of competitive disadvantage	High	Pessimistic	Low	Pessimistic	High	Low
Low risk of competitive disadvantage	Low	Optimistic	High	Optimistic	Low	High

Source: ATA

Note that low oil price is associated with higher risk of carbon leakage and competitive disadvantage as, in this case, carbon costs are a larger fraction of total operating cost.

Table 7. Combinations of EU ETS and CORSIA characteristics in extreme outcome sensitivity cases

Case	EU ETS carbon price	CORSIA baseline	CORSIA carbon price
High emissions	Low	Remains at 2019	Low
Low emissions	High	Decreases	High
High ticket prices	High	Decreases	High
Low ticket prices	Low	Remains at 2019	Low
High risk of emissions increase outside the policy area	Lower than UK ETS carbon price	Remains at 2019	Low
Low risk of emissions increase outside the policy area	Higher than UK ETS carbon price	Decreases	High
High risk of competitive disadvantage	Lower than UK ETS carbon price	Remains at 2019	Low
Low risk of competitive disadvantage	Higher than UK ETS carbon price	Decreases	High

Source: ATA

6 FINDINGS OF THE QUANTITATIVE ANALYSIS

This section describes the results of assessing the different UK ETS policy options described in Section 5.1.5 using the methodology described in Section 5.2.1 and Annex B. We consider outcomes in terms of carbon leakage (Section 6.1), airline competitive disadvantage (Section 6.2) and airport competitive disadvantage (Section 6.3). In order to have a consistent basis for comparison which does not depend on UK ETS characteristics, we compare outcomes against each other and also against a situation where there is no UK ETS (‘No UK ETS’ scenario). Sensitivity analysis of outcomes is discussed in Section 6.4. Additionally, we discuss the potential impact of leakage channels that are not directly included in the quantitative analysis (Section 6.5).

6.1 Impacts of UK ETS carbon price and CORSIA interaction option on carbon leakage

KEY FINDINGS

- CO_2 emissions for all central-case options are projected to decrease both inside and outside UK ETS scope compared to a no UK ETS case.
- This is because passengers fly round-trip journeys, so the UK ETS reduces demand and emissions on both incoming and outgoing flights.
- Higher carbon prices may also lead to more use of SAF or changes in technologies or operational measures used, increasing the absolute level of emissions reductions.
- The vast majority of emissions changes outside the UK ETS policy area are on EU ETS or CORSIA routes. In practice, these changes will reduce airline obligations under the EU ETS and/or CORSIA. As such, the net emissions impact outside the UK ETS policy area is likely close to zero across all policy options.

This section discusses how the different UK ETS options examined in this report may result in carbon leakage. To assess the amount of leakage, we consider changes in direct and fuel lifecycle CO_2 emissions by policy scope. Because neither of these metrics considers the extent to which emissions may reduce in other sectors due to emissions trading (both under the UK ETS and EU ETS) or CORSIA offsets, we additionally discuss the location of these emissions changes by applicable policy.

As noted in the qualitative analysis in Section 4.1.1.6, because passengers typically make round-trip journeys, any policy which increases costs on UK-EEA departing flights is likely to reduce demand on a round-trip basis, i.e., equal reductions in UK-EEA international departing CO_2 (inside policy scope) and EEA-UK international arriving CO_2 (outside policy scope). In the simplest case, therefore, we would expect carbon leakage to be negative[109] and around -100%[110].

---

[109] Negative leakage implies that emissions decrease both inside and outside the policy area.

[110] ATA and Clarity, 2018.

Outcomes may deviate from this simple picture for several reasons, for example (outcomes which might increase the risk of positive leakage shown in **bold**):

- There will also be a reduction in UK domestic flight CO_2 (increasing emissions reductions within the policy area);
- There will be reductions in emissions associated with non-UK legs of UK departing transfer passengers (increasing emissions reductions outside the policy area);
- **Transfer passengers who hub through the UK may switch to hubbing through another country (emissions reduction inside the policy area, emissions increase outside the policy area);**
- Airline technology use and operational strategies may change (emissions reductions within the policy area with additional potential for emissions reductions outside the policy area);
- **Changes in the number of passenger flights may affect the number of freighter flights that are needed to supply air freight demand (emissions increases and decreases are possible depending on the routes affected);**
- **Airlines may increase use of SAF on UK-EEA routes (increased emissions reduction within the policy area), which may also affect SAF use on other routes due to supply limits and/or increased investment in production (direction of effect uncertain); and**
- **For options which involve an effective change in the geographic scope of the CORSIA baseline (i.e., Option 6), CORSIA costs may be different at a global level (emissions increase outside the policy area in the case that CORSIA costs decrease, and vice versa).**

Please see the discussion of leakage channels in Section 2.3 for further details on these outcomes.

For context, Table 8 shows projected global direct CO_2 by geographic scope and policy option in 2030, for all uncertain scenario variables set to nominal values. Direct CO_2 covers all CO_2 released from combustion in aircraft engines. It does not account for emissions reductions in other sectors which are stimulated by airlines' purchases of emissions allowances from those sectors.

Table 8. Global direct CO_2 by geographic scope and policy option, 2030.

Option	UK domestic	UK to EEA	EEA to UK	UK to/from other	Other domestic routes	Other international routes [111]	Total
Baseline direct CO_2, Mt	1.47	8.74	8.81	51.66	314.5	619.0	1004.1
Difference from baseline, Mt							
Options E2	-0.05	-0.18	-0.18	-0.07	0.0	-0.1	-0.55
Options E4	-0.05	-0.19	-0.19	-0.07	0.0	-0.1	-0.54
Options E6	-0.05	-0.19	-0.19	-0.07	0.0	0.0	-0.53
Options L2	-0.03	-0.09	-0.1	-0.04	0.0	0.0	-0.23
Options L4	-0.03	-0.1	-0.1	-0.04	0.0	0.0	-0.24
Options H2	-0.07	-0.26	-0.25	-0.09	0.0	0.0	-0.66
Options H4	-0.07	-0.28	-0.27	-0.07	0.0	0.0	-0.70

Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6).

These values illustrate several factors which define how the UK ETS affects demand and emissions in the model runs. First, UK domestic CO_2 emissions are small (around 0.1% of global CO_2 emissions and around 4% of UK departing flight emissions). Second, over 70% of UK departing flight CO_2 is on intercontinental routes which are not covered by the UK ETS or EU ETS. These routes have fewer passengers, but much higher CO_2 per passenger, than UK-EEA routes. The largest component of global CO_2 emissions is on international routes between other countries. The impact of the UK ETS on these routes is very small in percentage terms (direct CO2 changes by less than 0.02% across the different policy options) and reflects the impacts of multiple second-order effects in different directions, as further discussed in Section 6.1.1. However, because absolute CO_2 emissions on these routes are so high, a tiny percentage change in their CO_2 emissions can have an impact on overall leakage.

---

[111] Note that outcomes for ‘other international’ routes reflect a combination of second-order impacts acting to increase and decrease demand and emissions by small amounts, as discussed above.

Table 9. Absolute year-2030 direct CO_2 emissions* by scope, by policy option.

Option	UK ETS routes	UK departing CORSIA routes	Emissions covered by the UK ETS which also count towards the CORSIA baseline	Emissions for which airlines have both UK ETS allowance and CORSIA offset obligations	UK departing non-covered routes	EU ETS routes	Non UK departing CORSIA routes	Non UK departing non-covered routes[112]	Total[113]
Options E2	9.23	30.58	7.81	0	3.78	49.59	445.07	473.16	1003.6
Options E4	9.95	30.57	7.8	0.74	3.78	49.58	445.08	473.16	1003.6
Options E6	9.95	22.04	0	0	3.78	49.58	445.09	473.16	1003.6
Options L2	9.33	30.68	7.89	0	3.78	49.69	445.12	473.19	1003.9
Options L4	10.07	30.68	7.88	0.75	3.78	49.69	445.11	473.19	1003.9
Options H2	9.16	30.49	7.49	0	3.78	49.56	445.09	473.16	1003.5
Options H4	9.84	30.48	7.47	0.7	3.78	49.53	445.08	473.15	1003.4

**Policy option direct CO2, Mt*

Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6).

Table 9 shows modelled emissions impact by policy option and scope, for all uncertain variables set to nominal values[114]. Emissions totals under different policy scopes are different to those under the geographical scopes shown in Table 8 for several reasons:

- Routes to and from EU Outermost Regions[115] are exempt from both the UK and EU ETS. This means that UK ETS routes cover less CO_2 than the sum of UK domestic and UK-EEA flights.
- Where the UK ETS is not applied (baseline), UK domestic CO_2 is not covered by any policy (UK departing non-covered). UK-EEA flights which would be covered by the UK ETS and/or CORSIA are only covered by CORSIA.
- Under CORSIA interaction option 4, UK ETS international routes are also covered by CORSIA, i.e., airlines must submit both UK ETS allowances and CORSIA offsets for emissions above the CORSIA baseline.
- Under CORSIA interaction option 2, UK ETS international routes are covered by CORSIA, but UK ETS obligations are reduced by an amount equal to CORSIA obligations for airlines operating on these routes. This avoids airlines being charged twice for the same emissions.
- UK ETS international routes are used in calculating the CORSIA baseline and offset obligations for CORSIA interaction options 2 and 4. They are not used in CORSIA interaction option 6.

---

[112] Note this covers both domestic routes and international flights to and from CORSIA non-participants to which another policy does not apply.

[113] Total summed CO_2 emissions are equal to the sum of totals under all policies (columns in black) minus any overlap between scopes (columns in grey)

[114] Note that the grey-text columns in Table 8 count where CO_2 is covered by more than one policy at once. Global CO_2 is therefore the sum of totals in the black-text columns minus the sum of totals in the grey-text columns.

[115] This includes UK flights to the Canary Islands and Azores.

- CORSIA covers only international routes between participating countries, so all domestic flights (around 30% of global CO_2) are excluded, as are all flights to and from non-participating countries[116].

Because we assume ticket prices are based on marginal costs, different options for free allowance outcome do not have a significant impact on outcomes and we show only grouped policy options by carbon price and CORSIA option assumptions.

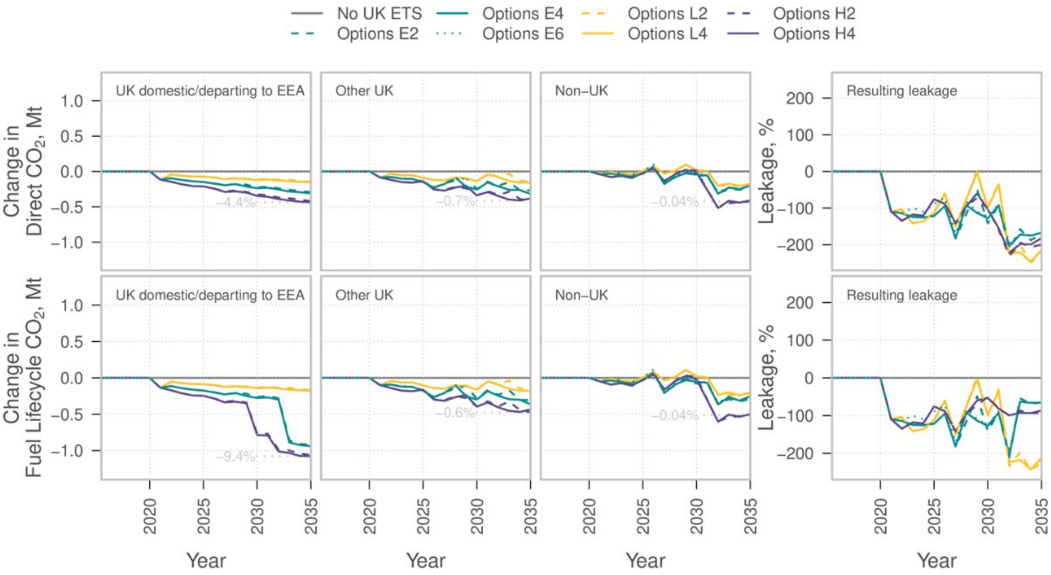
The different carbon price options mainly affect the magnitude of impacts. For example, lower carbon prices (Options L) are associated with smaller reductions in emissions from a no UK ETS baseline than higher carbon prices (Options H). The different CORSIA interaction options differ both by the scope of CORSIA coverage and in terms of average carbon costs. Under CORSIA option 2 (Options E2, H2 and L2) airline UK ETS obligations on UK-EEA routes are reduced by the amount of CORSIA obligations on those routes, leading to a smaller amount of emissions under UK ETS scope. Under CORSIA Option 4, CO_2 emissions above the CORSIA baseline are accounted for twice (once under CORSIA, once under the UK ETS). Under CORSIA option 6, UK-EEA routes are not included in CORSIA at all. This means that the CORSIA baseline is different at a global level, leading to slightly different offset obligations for all airlines who participate. In terms of impacts on airline carbon costs, which affect leakage calculated using direct and fuel lifecycle emissions:

- CORSIA option 4 has the highest effective carbon price of the different CORSIA options;
- Because baseline CORSIA prices are assumed to be low, CORSIA option 6 has very similar outcomes to option 4 (i.e., UK ETS carbon costs dominate on UK-EEA routes and option 6 has similar carbon costs to option 4); and
- Under CORSIA option 2, airlines experience a small reduction in carbon costs once CORSIA obligations rise above zero, as the carbon price of emissions above the CORSIA baseline is reduced.

---

[116] Annex B.1.2 discusses current CORSIA participation and how it may develop in future.

Figure 13. Changes in direct and fuel lifecycle CO_2 by UK ETS scope, and resulting carbon leakage, by policy option.



Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6).

Figure 13 shows emissions impacts of the different policy options by route type, and the resulting leakage, over time. Outcomes for 2030 are also shown in Table 10. Changes in direct CO_2 result mainly from changes in demand. After 2030, changes in technology choice also affect outcomes. For non-UK direct emissions, larger changes after 2030 arise mainly from airlines investing earlier in technologies which they use on both UK and non-UK routes. This applies particularly to larger narrowbody and smaller twin-aisle aircraft types which can be used on UK-EEA routes and EEA intercontinental routes. The magnitude of these changes is larger where the UK ETS carbon price is higher. Change in fuel lifecycle CO_2 additionally accounts for changes in SAF use. For example, policy area fuel lifecycle CO_2 decreases are larger in higher carbon price scenarios, and decreases begin at an earlier date, because of increased and earlier SAF use on UK-EEA routes in these scenarios. Step changes in fuel lifecycle CO_2 which are not seen in direct CO_2 occur at points when different SAF pathways become cost-effective to use on different route groups.

Table 10. Direct and fuel lifecycle CO_2 by UK ETS scope, and resulting carbon leakage, by policy option, 2030.

	Direct				Fuel Lifecycle			
Option	**UK domestic/ departing to EEA***	**Other UK***	**Non-UK***	**Resulting leakage,%**	**UK domestic/ departing to EEA***	**Other UK***	**Non-UK***	**Resulting leakage, %**
Baseline CO2, Mt	10.2	60.5	933.5	-	11.9	70.3	1085.5	-
Options E2	-0.226	-0.25	-0.069	-141	-0.263	-0.29	-0.081	-141
	(-2.2)	(-0.4)	(0.0)		(-2.2)	(-0.4)	(0.0)	
Options E4	-0.238	-0.257	-0.046	-128	-0.276	-0.299	-0.054	-128
	(-2.3)	(-0.4)	(0.0)		(-2.3)	(-0.4)	(0.0)	
Options E6	-0.237	-0.256	-0.038	-124	-0.276	-0.298	-0.044	-124
	(-2.3)	(-0.4)	(0.0)		(-2.3)	(-0.4)	(0.0)	
Options L2	-0.116	-0.135	0.019	-99.6	-0.134	-0.156	0.023	-99.6
	(-1.1)	(-0.2)	(0.0)		(-1.1)	(-0.2)	(0.0)	
Options L4	-0.122	-0.139	0.018	-99.5	-0.142	-0.162	0.02	-99.5
	(-1.2)	(-0.2)	(0.0)		(-1.2)	(-0.2)	(0.0)	
Options H2	-0.325	-0.34	0.01	-101	-0.762	-0.395	0.012	-50.3
	(-3.2)	(-0.6)	(0.0)		(-6.4)	(-0.6)	(0.0)	
Options H4	-0.346	-0.34	-0.019	-104	-0.785	-0.395	-0.021	-53.0
	(-3.4)	(-0.6)	(0.0)		(-6.6)	(-0.6)	(0.0)	

**For Options E2-H4, units are difference from baseline, Mt (%)*

Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6).

The changes in emissions by scope shown in Figure 13 and Table 10 are relatively small as a percentage of total emissions. Direct CO_2 on UK ETS routes in 2030 decreases by between 1.2 and 3.4% from a no UK ETS baseline, and fuel lifecycle CO_2 by between 1.1 and 6.6%. Of course, these figures do not include emissions reductions in other sectors which occur as a result of aviation participating in the UK ETS. For other UK routes, year-2030 emissions are almost unchanged. They decrease by 0.2-0.6% under both direct and fuel lifecycle scopes.

The change in non-UK emissions shown is under 0.05% of global aviation CO_2 on those routes in 2035. The drivers behind changes in emissions on these routes are further discussed in 6.1.1. Because multiple small impacts affect these routes, acting both to increase and decrease emissions, overall outcomes fluctuate and are uncertain.

Because of the way that carbon leakage is defined, a large value for leakage can mean both:

- A large change in emissions outside the policy area, or

- A small change in emissions within the policy area.

This means that a large value for leakage does not necessarily imply large overall emissions impacts.

Leakage outcomes, as anticipated and discussed in the qualitative assessment, are negative and typically close to -100% for direct CO_2. For CO_2 on a fuel lifecycle basis, there is more dependence on carbon price. If the carbon price is high enough to stimulate additional SAF use inside the policy area, this mainly acts to decrease emissions inside the policy area, reducing the resulting leakage metric. In the cases where UK ETS carbon price is below EU ETS carbon price (Options L), the demand and emissions impacts of applying the UK ETS to aviation are small both inside and outside the policy area. Carbon prices are also too small to stimulate additional SAF use or change technology choices for options L. In this case, leakage values may be large and sensitive to small second-order changes in operations, technology or fuel choice, as calculating leakage metrics involves dividing by a small number. This applies particularly to the post-2030 period when the scope for second-order impacts is greater. This leads to spikes and fluctuations in the leakage metrics plotted in Figure 13.Figure 13. Changes in direct and fuel lifecycle CO_2 by UK ETS scope, and resulting carbon leakage, by policy option.

For the options where the UK ETS price is equal to the EU ETS carbon price (Options E) or above it (Options H), emissions reductions within the policy area are larger and there is somewhat less variability in leakage metrics. Emissions reductions within the policy area are larger in later years (when carbon prices are higher, having a larger impact on demand, and more technology options are available to reduce emissions). This in turn leads to smaller values for carbon leakage. However, under the nominal-case assumptions used here, leakage remains negative throughout for all options. The impact on leakage of changing input assumptions for uncertain input variables is explored further in Section 6.4. Additional output metrics for variables which affect leakage outcomes (change in CO_2 per RTK and changes in load factors) are given in ANNEX D.

One further important consideration for carbon leakage is the extent to which emissions reductions on routes outside the main policy scope interact with other aviation policy. For example, emissions reductions on EU ETS routes will directly act to reduce an airline's EU ETS obligations. As a result, smaller emissions reductions will be made in other EU ETS sectors and the net impact may be close to zero. Similarly, emissions reductions on CORSIA routes will be balanced out by decreases in CORSIA offset requirements once CORSIA-eligible emissions rise above the CORSIA baseline. Table 9 also shows emission changes by policy area. If emissions changes on EU ETS and CORSIA-covered routes are assumed to have no net impact, carbon leakage is close to zero in all cases. This is because the impacts of the different UK ETS options on routes that are not covered by the UK ETS, EU ETS or CORSIA[117] is very small.

---

[117] Routes to and from CORSIA non-participants are not covered by CORSIA. Example UK departing routes which are not covered by the UK ETS, EU ETS or CORSIA in 2035 include London-Buenos Aires and London-Karachi. Example non-UK routes which are not covered by the UK ETS, EU ETS or CORSIA in 2035 include US and Chinese domestic routes.

6.1.1 Explaining impacts on non-UK flight legs

The analysis above suggests that changes in emissions on non-UK flight legs can have an impact on carbon leakage. To understand why this occurs, we need to consider the different ways that global aviation systems are interconnected.

Figure 14. Illustrative example of impacts on non-UK flight legs.

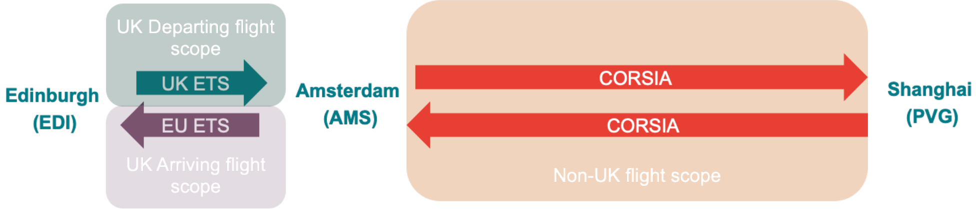


Figure 14 shows an example UK ETS-affected passenger itinerary: Edinburgh to Shanghai via Amsterdam. The round-trip journey contains four flight legs, two of which are short-haul (Edinburgh-Amsterdam and Amsterdam-Edinburgh) and two of which are long-haul (Amsterdam-Shanghai and Shanghai-Amsterdam). Of these flight legs, only Edinburgh-Amsterdam is in a UK departing flight scope. Amsterdam-Edinburgh is in a UK arriving flight scope, and the two flight legs between Amsterdam and Shanghai, which account for the majority of itinerary-level emissions, are not in any UK flight scope.

When the UK ETS is applied, costs for this itinerary will increase and demand is likely to go down. This includes on all of the flight legs in the itinerary. For this specific itinerary, therefore, applying the UK ETS is likely to produce a small reduction in UK departing emissions, a small reduction in UK arriving emissions, and a much larger reduction in non-UK associated emissions (as the long-haul flight legs are not associated with the UK). UK ETS costs may also slightly increase incentives to provide direct flights for these types of intercontinental origin-destination pair, since a direct Edinburgh-Shanghai flight would not be covered by the UK ETS[118]. Although these effects are small, in aggregate they lead to changes in emissions on non-UK scopes.

Some additional second-order impacts also affect emissions on non-UK associated flights:

- Where demand decreases such as the one described above reduce the number of passenger flights on a non-UK associated flight leg, this reduces the hold freight capacity on this flight leg. This may increase the number of freighter flights that are required to serve freight demand (increase in emissions outside the policy area).
- Where airlines use fleet across a network which includes both UK-associated and non UK-associated flights, they may invest in technology to reduce emissions and costs on UK routes, but also use that technology on other routes (decrease in emissions outside the policy area).

---

[118] This effect is included in the modelling for city-pairs where at least one airline already operates a direct flight at city-pair level, but the case where carbon prices cause an airline to add a city-pair connection which is not currently served by any other airline is not included.

These effects are discussed further in the section on airline competitive disadvantage, below.

6.2 Impacts of UK ETS carbon price, CORSIA interaction option and free allowance allocation on airline competitive disadvantage

KEY FINDINGS

- None of the different combinations of UK ETS design options assessed produces substantially different outcomes between UK and non-UK airlines that are in competition with each other.
- However, the absolute level of impacts differs by type of airline.
- UK regional airlines have a larger fraction of their route network covered by the UK ETS than low-cost carriers or network airlines, and so may be more vulnerable to high UK ETS carbon prices or rapid changes in costs.
- Network airlines have more flights on intercontinental routes where the UK ETS does not apply, so demand impacts at a whole-airline level are expected to be smaller for network airlines.
- However, regional airlines may have a greater ability to pass through costs onto ticket prices.

The different UK ETS policy options may have different impacts on the way that UK airlines compete with non-UK airlines. Several types of impact are possible. First, we discuss whether the level of impact (in terms of changes in passenger and freight demand, operating costs, and cost passthrough from a no UK ETS case) differs between UK and non-UK airlines[119]. Second, we discuss how impacts differ by type of passenger itinerary, concentrating particularly on differences between impacts on direct and transfer passengers. Third, we look at how impacts may differ by airline type (e.g. network, low-cost or regional operating models). Finally, we look at impacts related to transition speed, concentrating on the different cost impacts of different phase-out options and airlines' capacity to respond to these changes.

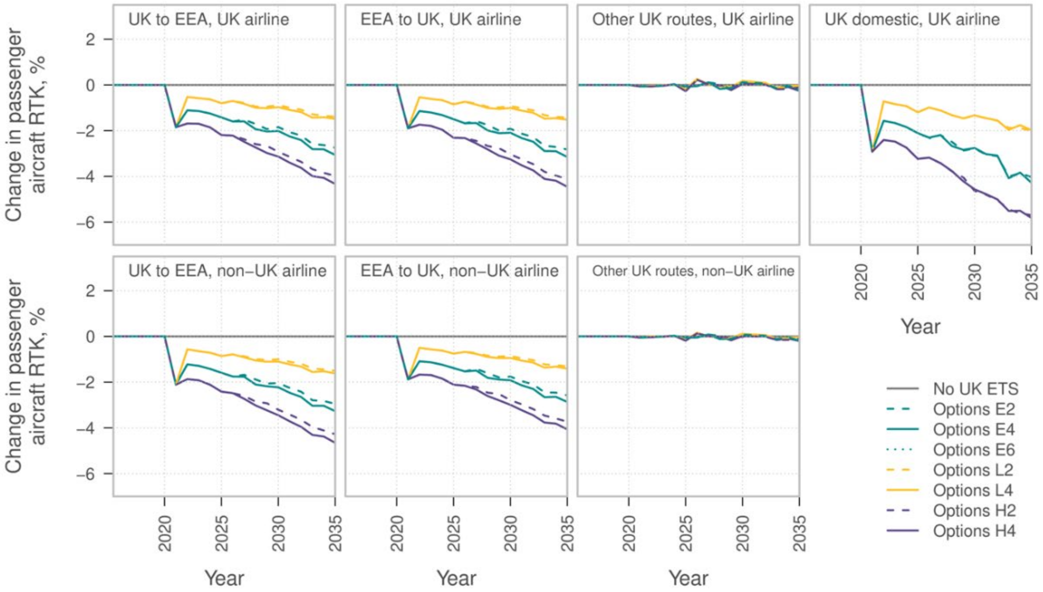
6.2.1 Impacts on UK and non-UK airlines

We define a UK airline as one which currently holds a Type A operating licence in the UK. Further discussion of how UK airlines are modelled, including a list of airlines which meet this definition, is given in Annex B.4. UK airlines dominate UK domestic routes. For routes between the UK and EEA, slightly over half of operations are carried out by UK airlines, and the rest by non-UK airlines. None of the policy options investigated here apply different rules to airlines based on nationality. However, impacts on airlines of different nationalities may occur where these airlines operate on different route groups, and these route groups are more or less affected by different UK ETS options.

---

[119] See also the discussion on how UK and non-UK airlines are defined in Section B.4.

Figure 15. Change in passenger aircraft RTK by airline nationality, route group and policy option.



Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6).

Figure 15 shows how passenger aircraft RTK changes from a no UK ETS baseline by policy option, geographic scope and airline nationality. For 2030, these values are also shown in Table 11. Because airlines are assumed to set ticket prices based on marginal costs, RTK outcomes do not differ significantly between different free allocation options, and policy options are shown grouped by carbon price and CORSIA interaction assumption only.

In general, impacts on UK and non-UK airlines are very similar across all geographic scopes where there is significant non-UK airline involvement. Where there are small differences, these reflect that UK and non-UK airlines operate a slightly different selection of routes. However, on similar route networks no significant difference in outcomes between UK and non-UK airlines is anticipated for any of the policy options examined[120]. Similarly to carbon leakage outcomes, reductions in RTK closely track UK ETS carbon price assumptions and are similar on inbound and outbound UK routes, reflecting that passengers typically make round-trip journeys. As discussed in the qualitative assessment, in percentage terms, RTK impacts are highest on UK domestic routes (1.3-4.6% decrease in 2030, depending mainly on carbon price assumptions). RTK impacts on routes between the UK and EEA countries are similar between airline types and outbound/inbound status and range between 0.9-3.5% in 2030, again depending mainly on carbon price. For other routes, outcomes are a combination of second-order effects as discussed above; although per-passenger impacts are very small, UK routes which are not domestic or to/from EEA countries are typically long-haul intercontinental routes with high RTK per passenger, amplifying these impacts.

---

[120] Note however that there are differences between airlines operating on different route networks. For example, as discussed in the next section, outcomes differ between UK regional airlines and non-UK regional airlines.

One consistent outcome on these routes is that reductions in UK-EEA demand reduces delay at UK airports, which may make them more attractive for non-UK ETS itineraries.

Table 11. Change in passenger RTK by policy option, airline nationality and route group, 2030

Option	UK domestic, UK airline	UK to EEA, UK airline	UK to EEA, non-UK airline	EEA to UK, UK airline	EEA to UK, non-UK airline	Other UK routes, UK airline	Other UK routes, non-UK airline
Baseline RTK, billion	1.353	7.46	6.068	6.967	6.554	31.33	39.538
Difference from baseline, percent							
Options E2	-2.78	-1.85	-2.04	-1.92	-1.76	0.10	0.06
Options E4	-2.76	-2.01	-2.23	-2.09	-1.92	0.11	0.08
Options E6	-2.76	-2.01	-2.22	-2.09	-1.92	0.11	0.08
Options L2	-1.34	-0.89	-1.00	-0.92	-0.86	0.17	0.11
Options L4	-1.33	-0.97	-1.10	-1.01	-0.94	0.18	0.11
Options H2	-4.64	-2.93	-3.21	-3.04	-2.79	-0.01	-0.02
Options H4	-4.57	-3.14	-3.45	-3.25	-2.99	0.05	0.02

Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6).

The corresponding outcomes for freighter aircraft are shown in Figure 16 and Table 12[121]. As discussed in Annex B.2, less information about freighter flights is available than for passengers, so outcomes are subject to higher uncertainty. Air freight may be carried in freighter aircraft or the holds of passenger aircraft. Globally, hold freight and freight carried in freighters have historically accounted for roughly similar tonne-km totals. Excluding 2020, when there were significant reductions in passenger flights, there is normally only around 1 freighter aircraft operating globally for every 10 passenger aircraft; in 2017, the largest component of UK air freight flows was hold freight in flights to and from Heathrow airport[122]. Freighter flights are more likely to operate from airports that specialise in freight[123]. Freighter aircraft RTK between the UK and EEA countries is small compared to passenger aircraft RTK and total freighter RTK in other world regions[124].

---

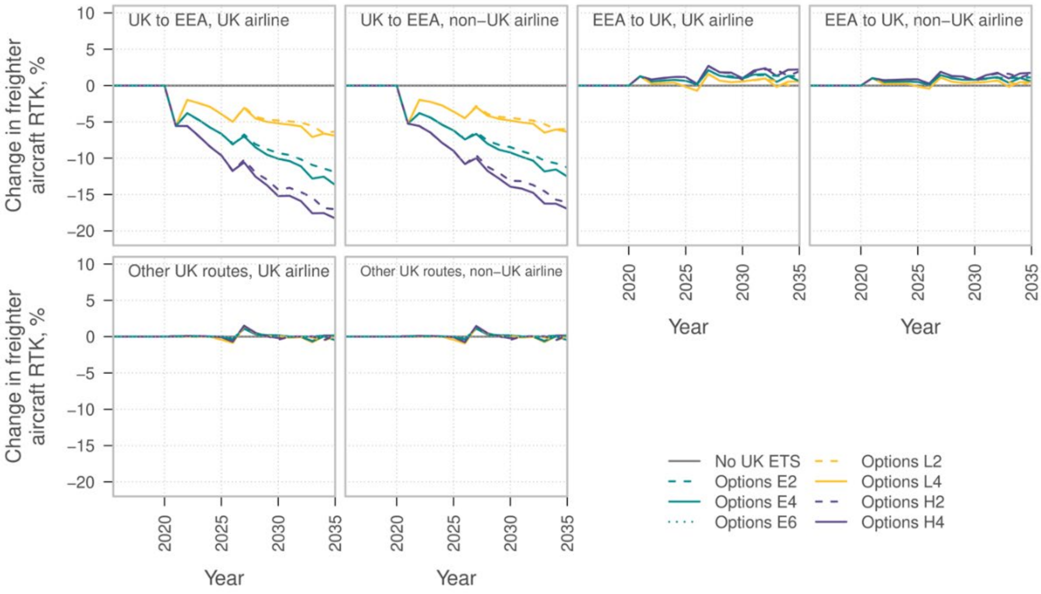
[121] For freighter flights, UK domestic outcomes are not shown. This is due to the small RTK totals involved and because we do not model factors that affect UK domestic freighter flights in detail.

[122] Steer, 2018.

[123] E.g. Steer, 2018; Budd & Ison, 2017.

[124] E.g. Eurostat, 2020; Steer, 2018.

Figure 16. Change in freighter aircraft RTK by airline nationality, route group and policy option.



Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6).

Freighter route networks are also not symmetric, with aircraft frequently flying triangular routes to take account of asymmetric freight flows[125]. These relationships affect the amount of RTK impact on freighter flights from the different policy options. When plotted on a similar scale to passenger RTK, absolute changes in freight RTK on UK-EEA routes are very small. In percentage terms, however, RTK impacts are larger than for passenger aircraft (up to 15% in 2030, depending on carbon price). This reflects that fuel and carbon are greater fractions of operating cost for freighters than for passenger aircraft, different typical destinations, and that where reductions in air freight demand are greater than those in passenger demand, a higher proportion of freight will travel in passenger aircraft holds. However, these reductions apply to a much smaller total RTK than for passengers.

---

[125] E.g. Budd & Ison, 2017.

Table 12. Change in freighter RTK by policy option, airline nationality and route group, 2030. Baseline passenger aircraft RTK is also shown for comparison.

Option	UK to EEA, UK airline	UK to EEA, non-UK airline	EEA to UK, UK airline	EEA to UK, non-UK airline	Other UK routes, UK airline	Other UK routes, non-UK airline
Baseline freighter RTK, billion	0.027	0.034	0.039	0.054	2.032	2.244
Baseline passenger aircraft RTK, billion	7.46	6.07	6.97	6,55	31.33	39.53
Freighter aircraft difference from baseline, percent						
Options E2	-9.3	-8.5	1.0	0.8	0.2	0.2
Options E4	-10.1	-9.2	1.0	0.8	0.2	0.2
Options E6	-10.1	-9.2	1.0	0.8	0.2	0.2
Options L2	-4.8	-4.4	0.5	0.4	0.1	0.1
Options L4	-5.2	-4.8	0.6	0.4	0.1	0.1
Options H2	-14.3	-13.1	0.8	0.5	-0.4	-0.4
Options H4	-15.2	-13.9	1.0	0.7	-0.2	-0.2

Because freighter aircraft flights are not assumed to be symmetric, much more limited impacts are envisaged for EEA-UK freighter flights. The main impact here is a small increase in RTK because hold freight capacity has decreased on EEA-UK routes. However, the largest freighter RTK impacts in absolute rather than percentage terms are on other UK routes. These routes are not subject to the UK ETS. However, several second-order impacts apply here. For example:

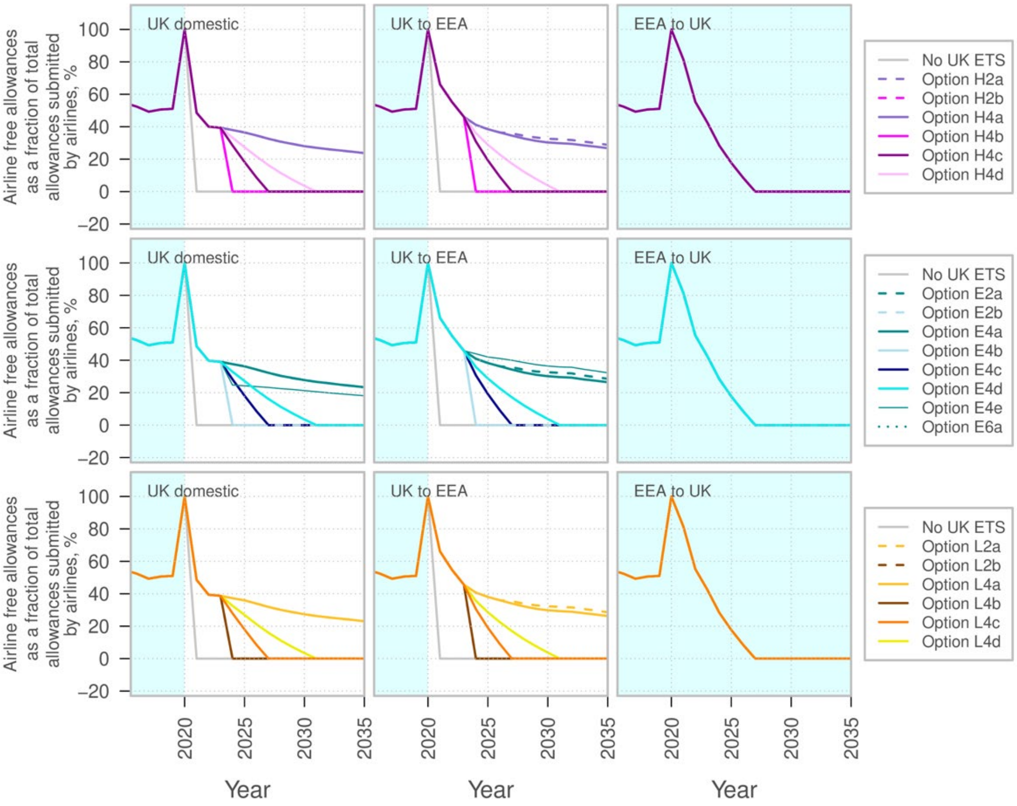
- Freighter aircraft RTK to and from non-EEA destinations is higher than to and from EEA destinations, magnifying the impact of small fluctuations in demand driven by second-order effects.
- Small reductions in passenger demand on other UK routes from reductions in transfer passengers lead to reductions in hold freight capacity, which may in turn translate to a larger number of freighter flights.
- Reductions in direct UK-EEA flight demand have the impact of reducing delays and congestion at UK airports. This can make them more attractive destinations for freighter flights.

However, the absolute magnitude of these impacts is still small compared to that from passenger flights. Similarly to passenger flights, outcomes are not anticipated to differ significantly by airline nationality. Additional discussion of freight-specific impacts is given in Section 6.5.1.

Additional metrics on number of passengers and freight RTK are given in ANNEX D.

The different policy options examined also differ by impacts on airline operating cost. Some of this cost will be passed through onto ticket prices, and some will be absorbed by airlines, resulting in decreases in profit. In the latter case, impacts may be mitigated somewhat by the allocation of free allowances. As discussed in Section 3, free allowances are distributed at an airline level. The number of aviation free allowances, and the way that they are distributed to airlines, are UK ETS design options that are being investigated in this study.

Figure 17. Typical airline UK ETS (non-shaded areas) or EU ETS (shaded areas) free allowance allocation as a fraction of total UK ETS or EU ETS allowances submitted by airlines on UK domestic and UK to/from EEA routes, by policy option and year.



Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances; e = benchmark update to 2019. Shaded areas show where the EU ETS applies, non-shaded areas show where the UK ETS applies.

Figure 17 shows the fraction of total allowances submitted by airlines which can be covered by free allowances by policy option and type of route (UK domestic, UK to EEA and EEA to UK; background shading shows regions and time periods when the EU ETS (blue) or UK ETS (no shading) applies). Where airlines operate on more than one type of route, we assume that their free allowances are split between route types based on the proportion of the airline's total CO_2 emitted on the different route types. Although free allowances are allocated at an airline level rather than a route level, this fraction gives an indication of the extent to which a typical airline operating on these routes can cover their carbon costs using their free allowance allocation. For the different phase-out options, incurred carbon costs per year change at different speeds, as discussed further in Section 6.2.4. By 2030, around 30% of total UK ETS allowances used in aviation are projected to be covered by free allowances in the case that the current free allocation methodology remains in place. Under the different phase-out options, the fraction of free allowances is zero or close to zero in 2030. A design option to vary the free allocation mechanism by short-haul versus long-haul activity, which would alter the distribution between regional and other airlines, is discussed in Section 4.3.

Total airline carbon costs can be divided into those that are covered by free allowance allocations, and those that are not. Because we assume that airlines set ticket prices based on marginal costs, the level of pass-through of total airline carbon costs is not affected by the level of free allocation. However, the level of free allowance allocation does affect the extent to which an airline's carbon costs which are not covered by free allowances are covered by the carbon costs it passes through. Table 13 shows typical passed through carbon cost divided by incurred carbon costs[126] by geographic scope, airline type and policy option in 2030. Values of this metric that are above 1 indicate that the average increase in ticket prices is greater than the average increase in incurred costs (i.e., that airlines are passing through some of the opportunity costs of free allowances). Values that are below 1 indicate that the average increase in ticket prices is below the average increase in incurred costs. In this situation, airlines absorb some of the increased costs as a decrease in profits.

---

[126] Incurred carbon costs are the total cost of allowances that are paid for by an airline, i.e., not including those that are covered by free allowances.

Table 13. Passed through carbon cost divided by incurred carbon costs by geographic scope, airline type and policy option, 2030.

Option	UK domestic, UK airline	UK to EEA, UK airline	UK to EEA, non-UK airline	EEA to UK, UK airline	EEA to UK, non-UK airline	Other UK routes, UK airline	Other UK routes, non-UK airline
Baseline passed through carbon cost/ auctioned carbon cost	0	0.697	0.743	0.652	0.698	0.545	0.545
Passed through carbon cost/auctioned carbon cost by policy option							
Option E2a	1.09	0.964	1.162	0.653	0.699	0.546	0.546
Option E2b	0.787	0.687	0.733	0.653	0.699	0.546	0.546
Option E4a	1.09	0.936	1.114	0.653	0.698	0.546	0.546
Option E4b	0.788	0.688	0.733	0.653	0.698	0.546	0.546
Option E4c	0.788	0.688	0.733	0.653	0.698	0.546	0.546
Option E4d	0.816	0.711	0.766	0.653	0.698	0.546	0.546
Option E4e	1	1.089	1.145	0.653	0.698	0.546	0.546
Option E6a	1.09	0.936	1.115	0.653	0.698	0.547	0.547
Option L2a	1.086	0.961	1.156	0.654	0.699	0.546	0.546
Option L2b	0.789	0.688	0.734	0.654	0.699	0.546	0.546
Option L4a	1.086	0.933	1.109	0.654	0.699	0.546	0.546
Option L4b	0.789	0.689	0.735	0.654	0.699	0.546	0.546
Option L4c	0.789	0.689	0.735	0.654	0.699	0.546	0.546
Option L4d	0.817	0.712	0.767	0.654	0.699	0.546	0.546
Option H2a	1.107	0.978	1.189	0.653	0.698	0.546	0.546
Option H2b	0.786	0.686	0.732	0.653	0.698	0.546	0.546
Option H4a	1.108	0.949	1.138	0.652	0.697	0.546	0.546
Option H4b	0.786	0.686	0.732	0.652	0.697	0.546	0.546
Option H4c	0.786	0.686	0.732	0.652	0.697	0.546	0.546
Option H4d	0.816	0.711	0.767	0.652	0.697	0.546	0.546

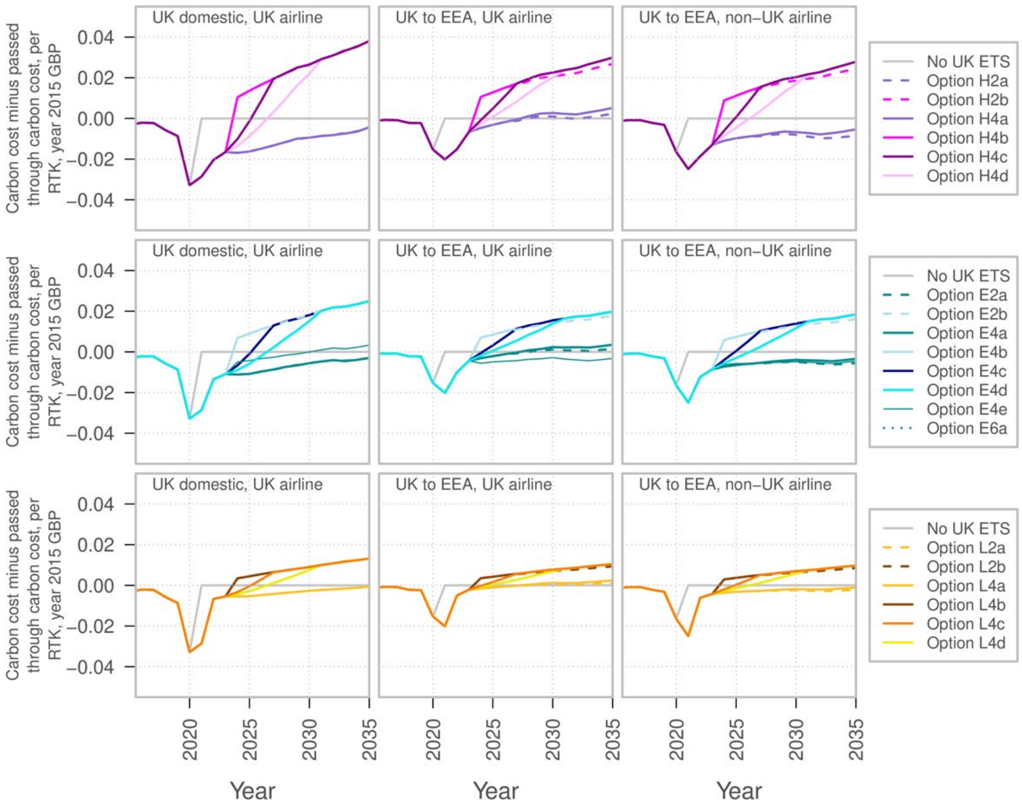
Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances; e = benchmark update to 2019.

Under the assumptions about cost passthrough used here, airlines that absorb significant carbon costs are typically those operating at congested airports, where airlines' ability to pass through costs is more limited[127]. The extent to which this occurs is not strongly impacted by carbon price (options L/E/H) under the assumptions used here, but in practice passthrough may be higher if carbon prices rise beyond airline's ability to absorb them. Sensitivities around cost passthrough are discussed in Section 6.4.1. Airlines are also more likely to absorb carbon costs in the case that fewer free allowances are available to them (e.g., where they have been phase out, as on Options b-d).

---

[127] See e.g. Dray et al. (2020). Although they have less ability to pass through additional carbon costs, airlines operating at congested airports are also typically able to charge higher baseline ticket prices.

Figure 18. Typical incurred carbon costs minus passed through carbon costs by year and policy option, for airlines operating passenger aircraft on different route groups.



Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances; e = benchmark update to 2019. Note that CORSIA options 2, 4 and 6 are identical for UK domestic routes because CORSIA does not apply on domestic routes.

Similarly, Figure 18 shows incurred carbon costs minus passed through carbon costs for typical airlines operating passenger aircraft on different route groups over time, for the different policy options[128]. Note that free allowances are assigned at an airline level, rather than being assigned to specific routes; as such, this figure is only intended to show indicative impacts for airlines which have a greater proportion of operations on each route group.

As for Figure 18, where airlines operate on more than one type of route, their free allowances are divided between route types for this figure based on the proportion of the airline's total CO_2 on the different route types. Values below 0 indicate that passed through costs are above incurred costs, i.e., that average airline profits are higher than they would be in the absence of the UK ETS.

---

[128] In this section, operating cost metrics are given on a per-RTK basis. This allows outcomes for passenger and freighter aircraft to be reported in a comparable way. Typically, the weight of a passenger plus their luggage is around 100kg. As such, direct operating costs per passenger-km are around 10% of direct operating costs per RTK. For example, an increase in carbon costs per RTK of £0.1 implies an increase in carbon costs per passenger-km of £0.01, or a £10 increase in the cost for one passenger on a 1000-km one-way trip.

In particular, for the period during and immediately after the COVID-19 pandemic, a relatively high fraction of aviation emissions is covered by free allowances because of pandemic-related decreases in demand. In this situation, it is more likely that passed-through carbon costs are greater than incurred carbon costs, because incurred carbon costs are lower. Over time, as demand grows, all policy options move towards greater incurred costs. In the policy options where the current UK ETS free allocation methodology is maintained (Options a), incurred carbon costs generally are close to passed through carbon costs in the 2030-2035 period, i.e., the UK ETS does not have a strong positive or negative impact on airline profit.

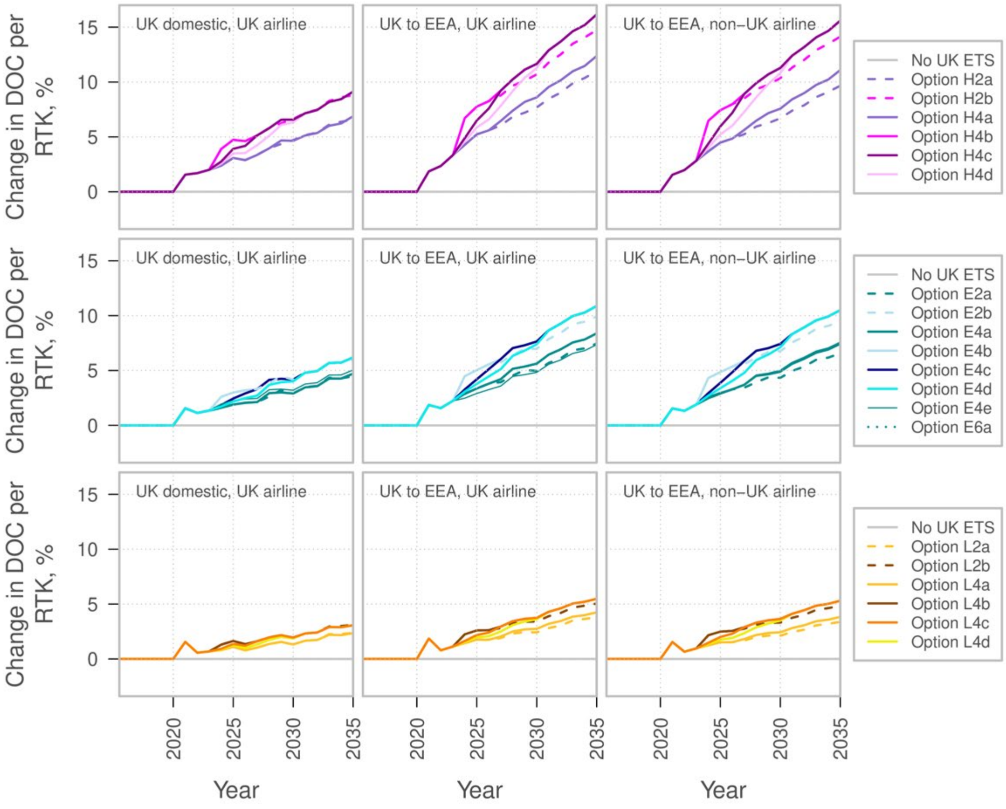
For the policy options where UK ETS free allowances are phased out, incurred carbon costs typically exceed passed through carbon costs in the 2030-2035 period, and airline profit may be smaller. The speed of change in airline costs depends on the speed of free allowance phase out in the different phase-out options. This is discussed further in Section 6.2.4. The differences between the different CORSIA interaction options on carbon cost passthrough is relatively small. Because baseline CORSIA carbon prices are assumed to be low, airlines have similar operating costs under CORSIA options 4 and 6. Under CORSIA option 2, airlines experience a reduction in UK ETS obligations on UK-EEA routes and hence a reduction in average carbon cost which increases over time as global CORSIA-eligible emissions rise above the CORSIA baseline. This in turn reduces their costs compared to the amount of costs they are able to pass through onto ticket prices.

For Option E4e, current methodology is used to set the overall level of UK ETS free allowance allocation, but the baseline year is updated to 2019. The main impact of this is to switch free allowances from domestic to international routes. This is because the number of UK domestic flights has decreased and the number of UK international flights increased since the original 2010 baseline year[129].

---

[129] CAA, 2021.

Figure 19. Passenger aircraft change in direct operating cost (DOC) per RTK, compared to a no UK ETS scenario, by year, geographic scope, airline type and policy option.



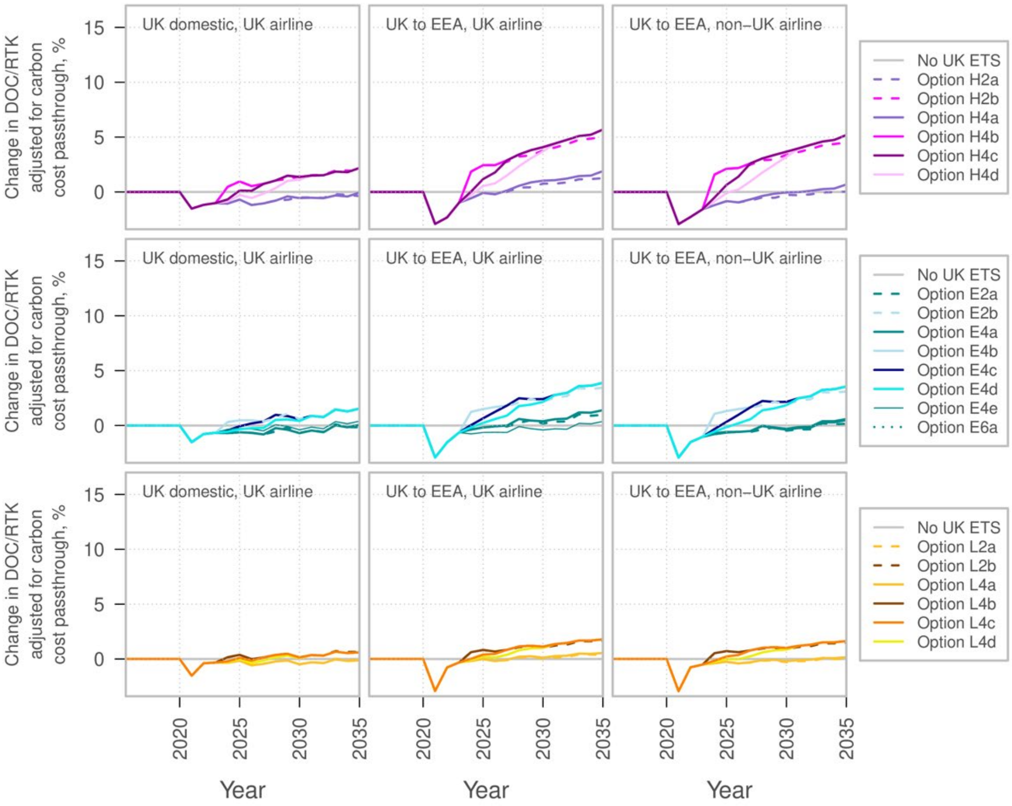
Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances; e = benchmark update to 2019.

Finally, we compare the outcome of the different policy options on passenger aircraft DOC per RTK[130]. Figure 19 shows DOC per RTK for the different policy options compared to a no UK ETS case, by year, airline type and geographic scope. These values are not adjusted for carbon cost passthrough. As well as changes in carbon costs, DOC/RTK also includes the impact of other changes in operating cost which may arise from changes in fleet or operations when the UK ETS is applied. For example, airlines which invest in technologies to reduce their emissions are effectively trading off capital or fuel costs against carbon costs. Detailed outcomes for 2030 are also included in Annex D.2. For UK domestic routes, costs change by 1.3-6.5% in 2030, depending on policy option. Costs are higher for policy options with fewer free allowances and where UK ETS carbon prices are higher.

---

[130] Note that direct operating costs do not include all airline costs - for example, costs associated with marketing, administration, overheads and ground equipment ownership (around 20% of totals; ICAO, 2017b) are excluded. In general, we would expect the direct impact of the UK ETS on these costs to be small.

Figure 20. Passenger aircraft change in direct operating cost (DOC) per RTK adjusted for carbon cost passthrough, compared to a no UK ETS scenario, by year, geographic scope, airline type and policy option.



Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances; e = benchmark update to 2019.

For UK-EEA routes, DOC/RTK increases by around 2.2-11.7% depending on policy option, with the high end of this range occurring only in policy options Hb - Hd where the UK ETS price is high and free allowances have been phased out. Percentage increases in costs are higher for UK international routes than UK domestic routes because fuel and carbon account for a higher percentage of total operating cost for longer-haul flights[131]. UK and non-UK airlines on these routes experience a similar level of cost increase, with small differences arising from the slightly different sets of routes operated by each type of airline. Costs are also slightly higher for CORSIA options 4 and 6 compared to option 2.

For UK-EEA and other routes, changes in operating cost arise only from second-order effects (e.g., changes in passenger numbers) are typically small, and may be decreases or increases.

---

[131] Note that, due to its geographic scope, almost all UK ETS routes are below 1,500 miles, which limits this effect. UK domestic routes are all under 500 miles.

Figure 20 shows change in operating cost per RTK from a no UK ETS scenario, similarly to Figure 19. but this time adjusted for carbon cost passthrough. This value may be negative if airlines are projected to pass through more carbon costs than they are incurring (i.e., if they are projected to pass through opportunity costs associated with free allowances). As discussed above, for options with continued free allowance allocation, under the assumptions used here incurred carbon costs are relatively close to passed through carbon costs in the 2030-2035 period. For options where free allowances are phased out, carbon cost passthrough accounts for around 65-80% of the increase in operating cost from the UK ETS – i.e., the majority of the change in operating cost is passed through onto ticket prices, with some differences between airlines which operate on different route networks (as discussed in Section 6.2.3).

The outcomes shown above are for passenger aircraft. However, outcomes for freighter aircraft display the same trends. The corresponding figures and tables for freighter aircraft are given in ANNEX D. In general, operating cost outcomes are particularly dependent on the input assumptions used. The outcomes shown here are sensitive to cost pass-through assumptions. Outcomes for different levels of cost pass-through are discussed further in the section on sensitivity analysis.

6.2.2 Impacts by type of passenger journey

Different types of passenger journey will experience different levels of impact from the UK ETS. In 2015, the most common itinerary type for passengers at UK airports was a direct international flight to an EEA country. For example, direct inbound and outbound international flights accounted for around 70 million scheduled passenger journeys each in 2015, of which around 80% were to EEA countries[132]. For comparison, there were around 19 million scheduled UK domestic direct passenger air trips over the same time period, around 10 million passengers took a UK departing itinerary hubbing via a non-UK airport (with a similar number of non-UK hubbing inbound trips), and around 9 million international-international transfers were made via a UK hub airport, with smaller demand for other journey types.

---

[132] Sabre, 2017.

Table 14. Impact of the different policy options on number of passengers by itinerary type, 2030

Option	UK domestic-only itineraries	UK international departing direct itineraries to EEA	UK international departing direct itineraries to non-EEA	UK international arriving direct itineraries from EEA	UK international arriving direct itineraries from non-EEA	UK departing via UK hub	UK arriving via UK hub	UK departing via non-UK hub	UK arriving via non-UK hub	International-international transfer via UK	International-international transfer via non-UK, where a UK transfer airport is available as a reasonable alternative
Baseline values, mppa	27	79.8	18.6	79.6	18.2	2.02	2.08	18.8	20.2	13.5	54.3
Difference from baseline, %											
Options E2	-3.4	-1.9	0.0	-1.8	0.0	-0.6	-0.8	-0.1	-0.3	0.3	0.0
Options E4	-3.4	-2.0	0.1	-2.0	0.1	-0.6	-0.9	-0.2	-0.3	0.3	0.0
Options E6	-3.4	-2.0	0.1	-2.0	0.1	-0.6	-0.9	-0.2	-0.3	0.3	0.0
Options L2	-1.7	-0.9	0.1	-0.9	0.1	-0.1	-0.2	-0.1	-0.2	0.5	0.0
Options L4	-1.7	-1.0	0.1	-1.0	0.1	-0.1	-0.2	-0.1	-0.2	0.5	0.0
Options H2	-5.5	-3.0	0.0	-2.9	0.0	-1.4	-1.7	-0.2	-0.5	-0.1	0.0
Options H4	-5.4	-3.2	0.1	-3.1	0.1	-1.3	-1.7	-0.3	-0.5	0	0.0

Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6).

For 2030, Table 14 shows the estimated impacts of the different UK ETS options on numbers of passengers by itinerary type (Baseline = no UK ETS). The largest impacts on passenger numbers in percentage terms is on UK domestic-only itineraries (up to around a 5.5% decrease, depending on carbon price assumptions). This reflects several factors. First, domestic flights are covered by the UK ETS on both the outbound and return journeys of a round-trip itinerary. Second, cost pass-through on domestic flights is likely to be relatively high, reflecting use of smaller and regional airports. Finally, flights with smaller aircraft have relatively high carbon intensity per passenger, and are more likely to be used on domestic routes. The largest impact in absolute terms is on direct itineraries between the UK and EEA countries. This primarily reflects the large number of passengers on these routes. For a typical round-trip journey, passengers on direct UK-EEA itineraries will experience UK ETS costs on the outbound leg only. However, any decrease in outbound demand will also be seen on the return leg.

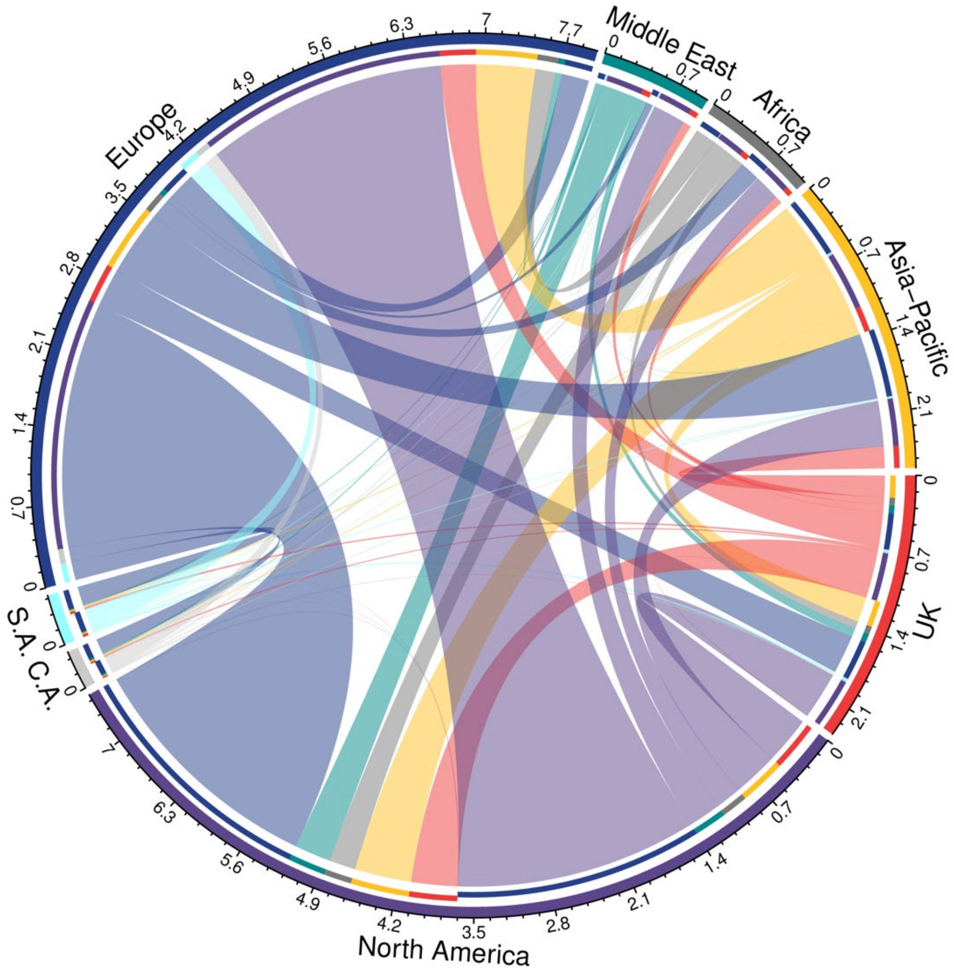


Figure 21. International-international transfer passenger flows through London Heathrow airport in 2015, showing region of origin and destination.

Data: Sabre, 2017. S.A. = South America, C.A. = Central America. The numbers shown indicate passenger movements in mppa.

For other itinerary types, impacts are small. This reflects both the smaller initial number of passengers on these itineraries, and the geographic scope of the UK ETS. In particular, impacts on UK international-international transfer passengers are minimal. This reflects the typical origin and destination of UK international-international transfer passengers. The vast majority of UK international-international transfer passengers travel through London Heathrow airport. Figure 21 shows year-2015 transfer passenger flows through Heathrow, using data from Sabre (2017)[133]. The thickness of the lines shown between each origin and destination region show the number of transfer passengers using Heathrow to travel between those regions. Because of the UK's geographic position, UK transfer passengers are typically travelling on long-haul intercontinental journeys. Very few of these trips are from a European location to another European location. More frequently, passengers who transfer in the UK combine a long-haul flight leg from North America or Asia with a short-haul flight leg onwards to a destination in Continental Europe. As a round-trip, these journeys consist of two long-haul trips

---

[133] Sabre, 2017.

which are subject either to CORSIA or to no policy, one short-haul trip which is subject to the EU ETS, and one short-haul trip which is subject to the UK ETS. Several factors combine to reduce demand impacts on these flight itineraries:

- Typically, itinerary-level costs are dominated by the cost of the long-haul flight legs. This reduces the relative impact of the UK ETS on costs.
- International-international transfers are typically at airports that are close to capacity, where cost pass-through is expected to be lower, further reducing the impact on fares.
- Reductions in UK-EEA and UK domestic direct demand also reduce delays and congestion at UK airports compared to a no UK ETS baseline. This in turn has a small upwards impact on demand for other itinerary types using UK airports.
- Some UK transfer passengers are travelling on routes with no UK ETS eligibility throughout (e.g., North America-Middle East or North America-Asia). For these passengers, the only impact of the UK ETS is a reduction in delays at UK hub airports.

The net outcome is that the impact of the different UK ETS options on the number of UK international-international transfer passengers, compared to a no UK ETS baseline, is small. As discussed below, this also decreases impacts on airports which are more reliant on transfer traffic.

There are also impacts on UK-originating passengers who transfer through UK airports. As shown in Figure 21, UK departing international passengers who transfer at a UK airport divide into two main groups of similar size: those whose final destination is continental Europe, and those whose final destination is in North America or Asia. The first group are impacted by the UK ETS at a similar level to UK-EEA departing direct passengers. The second group are impacted by the UK ETS at a similar level to international-international transfer passengers. The net impact on UK originating passengers who transfer in the UK is a decrease in demand of up to around 2% in the highest carbon price case.

For other itinerary types, impacts closely follow carbon price assumptions. Where UK ETS carbon prices are high (Scenarios H), demand impacts are larger; where they are low (Scenarios L), demand impacts are smaller (though there is still a reduction in UK domestic direct itinerary demand of around 2% in Scenarios L2 and L4). For UK domestic demand, there is no impact from the UK ETS CORSIA interaction option chosen; for passenger itineraries between the UK and EEA, CORSIA interaction option 2 has a slightly smaller impact on demand than options 4 and 6 because it effectively results in a decrease in carbon costs. Because airlines are assumed to set ticket prices based on marginal costs, the different free allocation options examined do not have different impacts on passenger numbers.

6.2.3 Impacts by airline type

As discussed in Section 2, impacts on different airlines will depend on their route network and business model. For this analysis, we consider three types of airline:

- **Network airlines** (e.g. British Airways, Air France-KLM). These airlines typically operate hub-and-spoke type networks with a mix of long- and short-haul flights, aircraft sizes, and passenger ticket classes.
- **Low-cost carriers** (e.g. EasyJet, Ryanair). These airlines typically operate short- and medium-haul flights on point-to-point networks, with more homogeneity in aircraft sizes, ticket classes, and typical flight distance.
- **Regional airlines** (e.g. LoganAir, Aurigny). These are smaller airlines who typically offer short-haul and domestic flights with small aircraft.

Typically, intercontinental routes are operated by network airlines, and international routes within Europe are operated by a mix of network and low-cost carriers, with a smaller amount of regional airline flights. Domestic flights can be divided into domestic trunk routes (for example, London-Edinburgh), which are operated by a mix of airline types with larger single-aisle aircraft, and regional routes (for example, Glasgow-Stornoway) which are often operated by regional carries using smaller single-aisle (often turboprop) aircraft.

To assess impacts on different airline types, we combined data on the year-2015 operations of different airlines by airline type[134] with projected operations from the central-case AIM model runs. We assume each flight segment continues to be operated by the same mix of airline types as it was in 2015 (i.e., routes operated by regional airlines continue to be operated by regional airlines, routes operated by low-cost carriers continue to be operated by low-cost carriers, etc.).

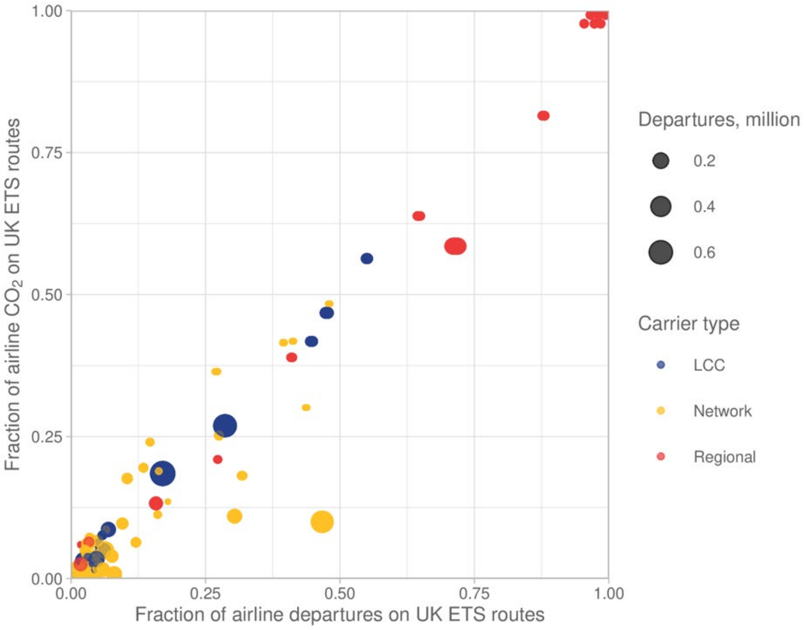


Figure 22. Fraction of total airline-level CO_2 and departures on UK ETS routes, by airline type and size.

---

[134] Sabre, 2017.

Airline-level analysis of future projections is uncertain. Airlines are often short-lived, may merge with each other or set up subsidiaries with different business models, and multiple UK-based airlines ceased trading over the 2015-2021 period. In Section 4.6, the qualitative assessment considered design options to better account for industry growth and new entrants. The airline-level impacts of different free allowance allocation options are uncertain and depend critically on which airlines take up operations on routes previously operated by airlines that have ceased trading. As such, this analysis should be considered as a broad appraisal of the type of impacts which might affect airlines with different types of route network, rather than as a detailed analysis of the impacts on individual airlines.

Two major factors are likely to affect the extent to which different types of airline are affected by the UK ETS. First, airlines differ in the extent to which their route networks are covered by the UK ETS. As shown in

Figure 22, UK-based regional airlines have UK ETS costs on most or all of their operations. For low-cost carriers, typically half or fewer of their operations are covered by the UK ETS, reflecting a high share of UK-EEA international routes with EEA-UK return trips. For network airlines, the share of airline departures covered by the UK ETS is typically under half, and the share of total CO_2 covered by the UK ETS is much lower, reflecting a larger share of long-haul, non-UK ETS routes.

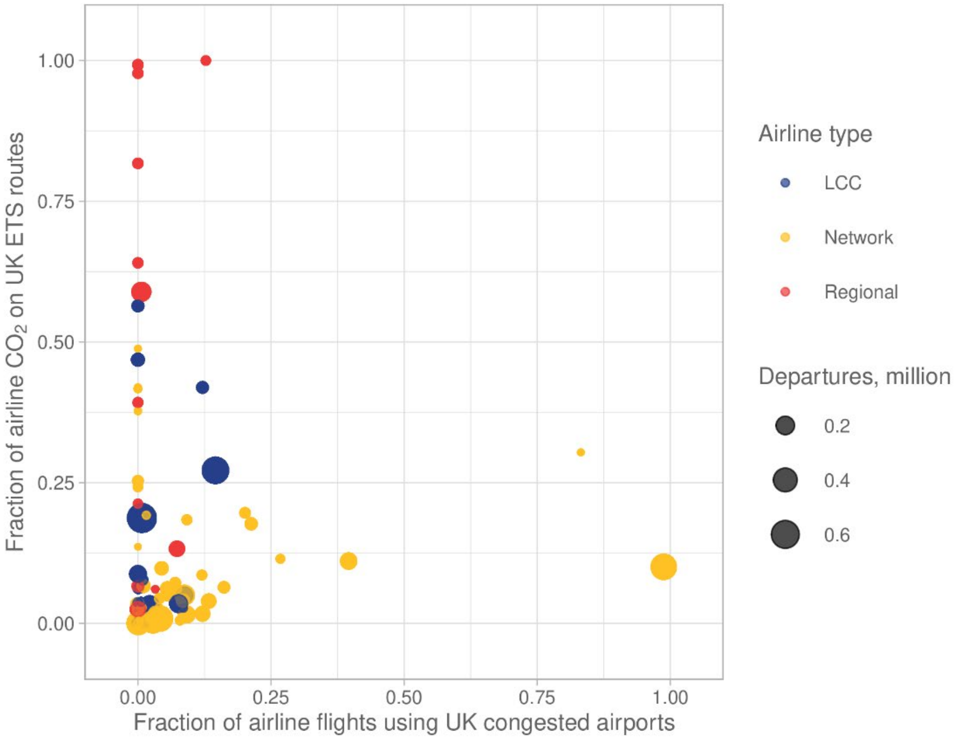


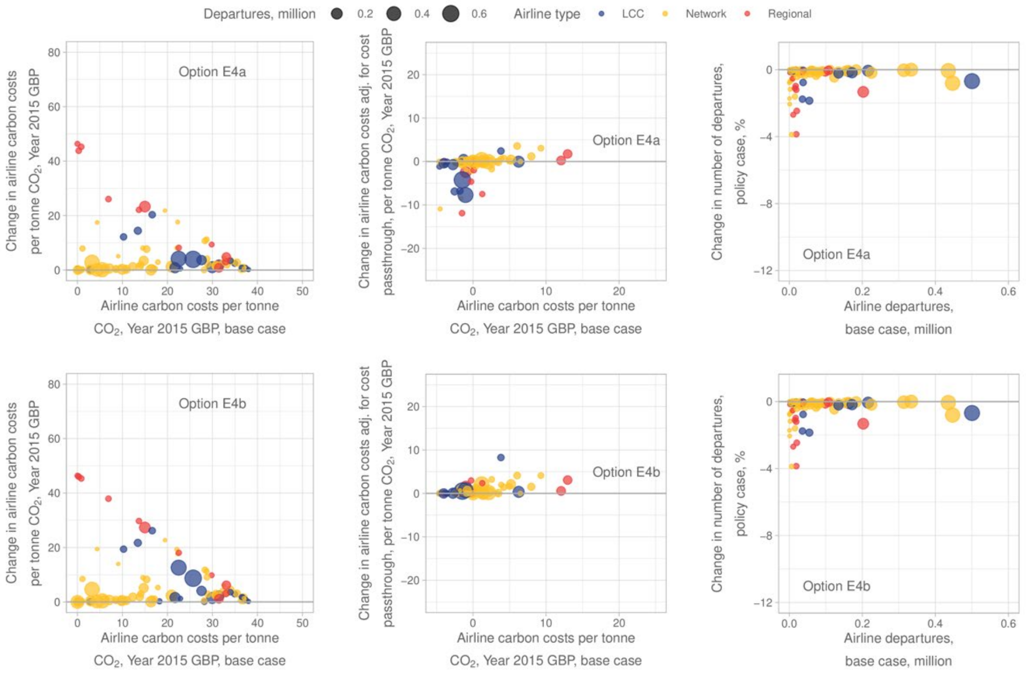
Figure 23. Fraction of departures at UK congested airports, by airline type and size.

Second, as discussed in Annex B.7.5, cost pass-through is typically lower at congested airports and is modelled as such in the central case model runs carried out for this study. Figure 23 shows the fraction of airline flights using UK congested airports by airline type. Typically, congested airports are dominated by network airlines, with a smaller number of low-cost carrier operations and almost no regional airline operations. This implies that network airlines are less likely to pass on their full UK ETS costs to passengers, compared to low-cost and regional airlines.

The largest difference between the different policy options is during the 2024-2031 period when different free allowance allocation phase-out conditions apply. As such, we compare outcomes for 2025. At this point, free allowances remain similar to current allocation in option a, have been fully eliminated in option b, are being phased out at different speeds for options c-d and are allocated according to a later benchmark in option e.

Figure 24 shows year-2025 airline-level average carbon costs by airline type, for policy cases E4a and E4b (UK ETS carbon price equal to EU ETS carbon price, current free allowance allocation methodology and 2024 end of free allowance allocation for aviation), compared to those in a non UK ETS case. The left-hand panels show outcomes without adjusting for carbon cost passthrough, and the central values the corresponding outcomes with adjusting for carbon cost passthrough. Right-hand panels show total airline-level demand impacts. Options E4a and E4b are chosen as they illustrate different extremes of free allowance allocation. Outcomes for the full set of policy options are shown in Annex D.2, but are generally similar to those for Options E4a and E4b shown here; for cases H and L, absolute levels of carbon cost differ but the relative levels of impact between different airline types remain the same. Airline-level averages are calculated across an airline's entire network, i.e an airline which has more routes covered by the UK ETS will experience a larger change in average carbon costs from application of the UK ETS. Only carbon costs above those covered by each airline's free allowance allocation are shown.

Figure 24. Comparison of year-2025 change in airline average carbon costs per tonne CO_2 (left-hand panels), change in airline average carbon costs adjusted for cost passthrough (central panels) and change in airline-level demand (right-hand panels), for Options E4a and E4b.



Note on option names: Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances; e = benchmark update to 2019.

As also demonstrated by Figure 22 and Figure 23, airline-level carbon cost impacts are largest on UK-based regional airlines when compared to a ‘No UK ETS’ case. Changes in costs for low-cost carriers are smaller (in percentage terms) at an airline level, and typically network airlines experience the smallest airline-level percentage changes in costs. Historically, the share of low-cost carrier operations has tended to grow over time. If low-cost carriers in future take over a greater proportion of routes currently operated by network or regional airlines, typical low-cost carrier outcomes may additionally be influenced by the characteristics of these routes[135]. In 2025, free allowances are projected to account for around 37% of total UK ETS aviation emissions in the case that the current allocation methodology continues to apply (options a). However, these allowances are not distributed equally between airlines and depend under all options except option e (year-2019 benchmark update) on the current (year-2010) benchmark. As such, there are a

---

[135] Changes arising from changes to low-cost carrier networks may be limited by the relative lack of success at present of long-haul low-cost business models (e.g., FlightGlobal, 2021).

range of airline-level outcomes from the different free allowance allocation options and, although airline-level costs are lower in the case that there are more free allowances available, the extent to which this is the case is dependent on the airline and the extent to which they are eligible for free allowances. The difference in airline-level impacts between different policy options, however, is relatively small compared to the differences between average impacts by airline type.

CORSIA interaction option has minimal impact on UK regional airlines, as it affects international routes only. For other airlines, cost-related outcomes are similar between CORSIA options 4 and 6 (though there may be additional administrative costs for option 4 from CORSIA compliance)[136]. CORSIA option 2 imposes a small reduction in effective carbon prices on international routes once global CORSIA-eligible emissions rise above CORSIA baseline levels.

However, regional airline free allowance allocation outcomes are affected in particular by assumptions about how routes flown by airlines that have ceased operations are redistributed between other airlines, and so are particularly uncertain.

The central panels of Figure 24 show average airline-level carbon costs adjusted for cost pass-through in 2025. This roughly corresponds to the extent to which airline profits per passenger have changed. Because we assume that airlines set ticket prices based on marginal carbon costs, it is possible for this value to be negative where free allowances are provided (i.e., the ticket price increases resulting from the imposition of the UK ETS more than cover an airline’s incurred carbon costs, and airline profits increase). Under these assumptions, all UK ETS options are broadly cost-neutral for network airlines. Both UK regional and low-cost carriers are able to pass on much of their costs and, for options where significant amounts of free allowances are still available, some regional and low-cost carriers are able to pass on more than their incurred carbon costs. However, as discussed above, this effect reduces over time as airline operations grow.

These differences in costs and in cost pass-through also affect total demand by airline type. The right-hand panels of Figure 24 show the resulting impact on airline operations by airline type and policy option. In general, the largest impacts in terms of percentage decrease in demand are on smaller airlines, including regional airlines and smaller low-cost carriers. This follows both from the larger share of UK regional airline routes impacted by the UK ETS, and the larger assumed cost pass-through on the networks of these airlines.

The corresponding outcomes for the full range of policy options modelled are shown in ANNEX D. However, in general outcomes are similar to those shown here. For example, higher or lower carbon prices affect only the absolute level of impact, but do not affect which types of airlines are more or less affected by the different options.

---

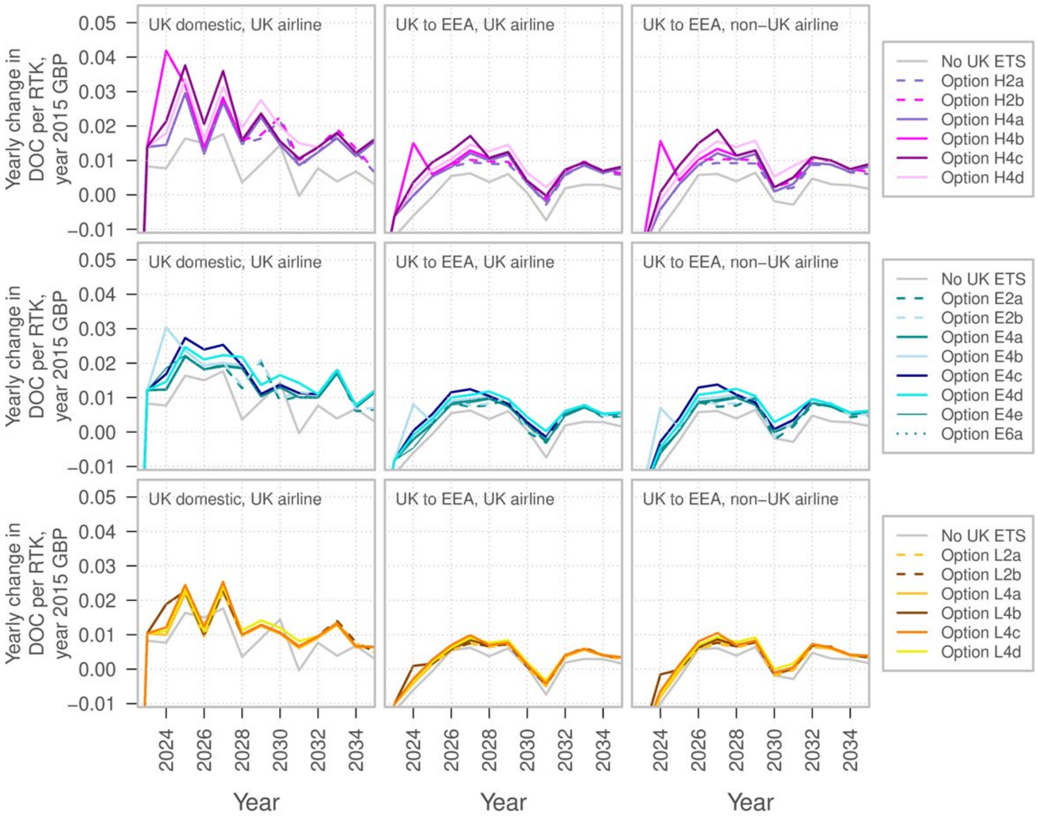
[136] For CORSIA and EU ETS administrative compliance cost estimates, see ICAO (2019) and Niklaß et al. (2019).

6.2.4 Effects of different phase-out speeds

The previous discussion of policy modelling outputs focussed on aggregate impacts, individual assessment years, and smooth changes over time. However, some impacts may be associated with step-changes or rapid transitions in airline costs or operations. This includes the process of transitioning from current UK ETS characteristics to those of a given policy option. It also includes the impact of changes in airline operations which might result from high carbon costs (e.g. airline changes of hub or service withdrawal on affected routes)[137]. Additional risks may apply in the case of rapid transitions which are not modelled; for example, airlines which are not able to adapt their operations at the same speed may be at risk of incurring significant losses and in extreme cases at risk of bankruptcy. These risks are greater in the case of faster transitions and transitions with shorter advance warning periods. This section discusses some of these transition-related effects and what impact they might have on carbon leakage and competitive disadvantage outcomes.

---

[137] The implicit impact of changes in airline location (e.g. airline changes of hub, bankruptcies, new airlines starting up outside the UK, etc.) is included in modelling via assumptions about flight frequency response to changes in demand. However, this modelling omits the step-change nature of many of these effects.



Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances; e = benchmark update to 2019.

**Note that costs are assigned to the year in which emissions occur, rather than the year that airlines submit allowances covering those emissions*.

Figure 25. Yearly change in direct operating cost per RTK for passenger airlines by route type and policy option.

Figure 25 shows the yearly change in passenger airline direct operating cost per RTK for the 20 policy options and ‘No UK ETS’ baseline case, under nominal scenario conditions. Because the pandemic period led to large variations in load factor and resulting operating cost per RTK, only the projected post-pandemic period is shown. For comparison, the change in aviation kerosene prices between late 2014 and early 2016 compared to current levels was equivalent to roughly a -0.04 to +0.05 change in DOC/RTK for UK-EEA type routes[138]. Where ‘most-likely’ values are used for uncertain scenario variables, as in Figure 25 above, the range in yearly variation of DOC/RTK is smaller than this (around +0.01 to +0.04). For the model sensitivity runs with higher EU ETS and UK ETS carbon price assumptions (see Section 6.4), the maximum yearly change in passenger aircraft DOC/RTK is around 0.06 (for policy options H4b and H2b on UK domestic routes, which have an immediate end to free allowances in 2024). The impact of a given

---

[138] EIA, 2021.

change in operating cost as part of a pre-announced policy measure is likely to be below that of the impact of an unanticipated change in fuel prices, however. This is because airlines have more time to plan ahead and can adjust ticket prices and operations in response[139].

Under the UK ETS, airlines need to submit allowances equivalent to their reportable emissions for a given year by 30th April in the following year[140]. Airlines can respond to anticipated changes in carbon costs by changing their capacity and/or ticket prices, or investing in technology to reduce emissions. Each of these strategies may be associated with time lags which may make it difficult for airlines to respond to more rapid policy changes. Important timeframes include:

- Timeframes associated with airline planning, scheduling and ticket sales. While airline corporate plans are normally made over multi-year periods, detailed schedule plans are made on a season-to-season basis with typical schedule planning beginning 6-9 months in advance of a season[141]. Airline tickets can be purchased on similar timescales, but a large proportion of tickets are purchased in the month before travel[142].
- The time delay between choosing to invest in a technology and achieving full benefits from that technology. Order-delivery times for new aircraft models were around 6-10 years in 2016[143]. However, order cancellations due to the COVID-19 pandemic have led to an oversupply of new aircraft[144], which means that airlines which have available capital to purchase new aircraft may be able to do so more rapidly than usual over the recovery period. For operational changes and retrofits to existing aircraft, timeframes may be shorter and depend on time lags associated with training and equipment installation (for example, some aircraft retrofits can only be installed at major maintenance checks).
- Timeframes associated with airline fuel costs. Many airlines hedge fuel costs, locking themselves into fuel prices up to 1-2 years in advance[145]. On average, airlines do not profit from hedging; instead, it is used to reduce uncertainty about future fuel prices. As such, this timeframe is relevant for unexpected changes in fuel price, but less relevant for changes in fuel-related costs which can be anticipated.
- The timeframe that SAF use can be ramped up. Currently, SAF use is limited[146], with demand driven by individual airport and airline initiatives. Some analyses suggest up to a decade time lag at present between project planning and achievement of nominal new plant capacity for dedicated SAF plants[147], though

---

[139] There is still likely to be some uncertainty associated with the impact of UK ETS changes, however, because the exact development of UK ETS carbon prices is uncertain. Airlines are also able to reduce the impact of fuel price uncertainty by hedging fuel costs (e.g. Morrell & Swan, 2005), although not all airlines do this.

[140] Environment Agency, 2021.

[141] Camilleri, 2018.

[142] E.g., Wen & Chen, 2017.

[143] Deloitte, 2016.

[144] McKinsey, 2021.

[145] Morrell & Swan, 2006.

[146] Sustainable Aviation, 2021. Globally, aviation SAF use within the next 3 years is projected to remain below 0.5% of total fuel demand, based on known fuel orders.

[147] Pavlenko, 2018.

shorter timeframes may be possible by adapting plants currently used for road vehicle biofuels. Over the longer term, demand may be driven by wider policy initiatives such the UK's proposed SAF mandate, which aims for a 10% SAF share in UK flight fuel by 2030[148], or RefuelEU[149], which aims for a 20% SAF share in EEA flight fuel by 2035.

Three levels of transition speed are covered by the different policy options: an immediate phase-out of free allowances in 2024 (option b), a phase-out of free allowances by 2027 (option c), and a phase-out of free allowances by 2031 (option d). These would allow airlines 2-3 years, 6-7 years and 9-10 years respectively to prepare for the full removal of free aviation allowances. This is enough time in all cases to adjust schedules and ticket prices, but the different phaseout lengths may differ in whether airlines are able to invest in new technologies before the policy fully takes effect. However, given the technologies that are likely to be available to airlines, technology adoption is likely to have only a small impact on operating costs[150], with the largest part of airline response likely to be in fleet and operations.

Historically, rapid changes in airline costs have occurred during periods of rapid change in oil price. Airlines responded to fuel price surges in the 2007-08 period with a range of strategies, including fuel surcharges, changes in ancillary revenue strategy, mergers, increased route-sharing, and capacity reduction[151]. Analysis of US airlines during the 2007-08 fuel price[152] surge found that eleven of 107 passenger airlines ceased operations during this time period, of which ten were regional or commuter airlines. Increased bankruptcy risks from fuel price surges were associated with smaller airlines and airlines with more diversity in fleet used[153].

The yearly change in operating cost per RTK in the policy scenarios assessed here is typically below the maximum yearly change in operating cost per RTK seen during the 2007-08 or 2014-16 fuel price fluctuations, with levels of variation approaching this amount seen only at the extreme end of the sensitivity cases run. For nominal-case model runs, the largest yearly changes in operating cost per RTK are associated with higher UK ETS carbon prices and more rapid phase-outs; in the case where UK ETS prices are high and aviation free allowance allocation stops in 2024, the maximum yearly level of variation in operating cost per RTK is about half that seen in the historical fuel price fluctuations discussed above. This suggests that there is the potential for risks to small airlines in this case if carbon prices are high. However outcomes are dependent on what other factors are affecting operations at the time that the policy comes into effect (for example, whether demand has recovered in the post-pandemic period), and airline strategies may differ in the case of announced policy measures compared to unanticipated fuel price changes, as more advance planning time is available. The

---

[148] DfT, 2021c; BEIS, 2021e.

[149] EC, 2021d.

[150] For example, replacing an older aircraft with a newer one could reduce fuel costs by 15% but may significantly increase capital costs; see discussion in Section 6.5.1.2. Similarly, SAF uptake can reduce carbon costs but, because projected SAF prices are higher than those of fossil aviation kerosene, the decrease is offset by increases in fuel costs.

[151] GAO, 2014; Cranfield University, 2011.

[152] Morrison et al., 2010.

[153] GAO, 2014; Berghöfer & Lucey, 2014.

rate of airlines' financial recovery from the pandemic will also be important for outcomes. UK and European airline finances have been significantly impacted by the pandemic, with year-2020 reductions in passenger revenue of around £70 billion in ICAO's 'Europe' region compared to 2019[154]. During the recovery period, airlines may be at greater risk of bankruptcy and/or have less available capital to invest in new technologies.

6.2.5 APD changes in the Autumn Budget 2021

In the October 2021 budget, changes to APD for domestic and ultra-long haul flights were announced[155]. From April 2023, a new domestic band for APD will be introduced. Economy rate APD for this band will be £6.50, half the previously-applicable value. It was not possible to include the impact of this change in the quantitative assessment as the report for this study was in the process of being finalised when this change was announced. However, approximate estimates of impact can still be made. Air passenger duty is levied upon airlines, and where this is passed through to passengers, directly affects the price that a passenger pays for a given itinerary. For a round-trip UK domestic journey, the change in average ticket price due to this change in APD is of a similar order of magnitude to projected differences in intra-UK ticket prices between the no UK ETS and the central-case policy options examined here. Under policy options E (UK ETS carbon price equal to EU ETS carbon price), the combination of APD changes and UK ETS would lead to year-2035 ticket prices similar to a scenario in which APD remains the same and the UK ETS does not apply. Under policy options L, the average change in UK domestic ticket prices due to the changes in APD is anticipated to be larger than that due to the UK ETS; under policy options H, the impact of the UK ETS and the impact of changes in APD are anticipated to be roughly equal in 2030, with UK ETS-induced changes in ticket price larger after this point.

The increase for ultra long-haul flights applies only to destinations whose capital cities are more than 5,500 miles from London (for example, trips to Japan, but not trips to China, India or the United States). For these journeys, APD will rise by £4, to £91. The change in ultra long-haul APD is unlikely to have a significant effect on UK ETS outcomes. This is because it applies to a relatively small number of passengers, most of whom are travelling on flights outside UK ETS scope, and because the level of change is relatively small compared to ultra long-haul ticket prices.

6.2.6 Inclusion of flights to Switzerland

Switzerland is not part of the EU ETS but has its own ETS, the Swiss ETS (FOEN, 2020). From 2020, the EU ETS and Swiss ETS have been linked. At the same time, aviation was added into the Swiss ETS. This section considers the potential implications on carbon leakage and competitive disadvantage of including or excluding flights from the UK to Switzerland in UK ETS scope.

---

[154] ICAO, 2020c.

[155] HM Treasury, 2021.

In 2019, excluding passengers to Basel-Mulhouse-Freiburg airport which is counted as a French airport for EU ETS purposes, 5.9 million passengers travelled between Switzerland and the UK (CAA, 2021—less than 4% of the total between the UK and EU countries. Most of these passengers travelled to or from Zurich or Geneva airports; around 55% travelled on scheduled flights to or from London Gatwick or Heathrow airports, with 21% travelling to or from other London airports and the remaining 24% travelling to or from a wide range of UK regional airports. Operations were carried out by a mix of network and low-cost carriers; for example, British Airways and Swiss International Air Lines both fly between Zurich and Geneva, and Heathrow and London City, while Easyjet flies from both Swiss airports to Gatwick and Luton airports. The direct CO2 associated with flights from the UK to Switzerland in 2015 is estimated to be around 0.25 Mt in 2015. This is of a similar order of magnitude to the total changes in UK ETS scope direct CO2 across the different policy scenarios modelled in this report, which implies that very large changes in UK-Switzerland CO2 would be required to make any significant impact on the overall leakage outcomes modelled here. If the impact of applying the UK ETS on UK-Swiss routes is similar to that on other routes, overall changes in direct CO2 of order 0.01 Mt are likely from applying the different UK ETS policy options, which would not materially change the leakage outcomes included in this report. Similarly, impacts on competitive disadvantage are likely to be relatively small because of the small geographic scope involved. More than half of the affected flights are to or from congested airports, suggesting fare and demand impacts will also be reduced by the typically lower cost passthrough at these airports. In the case that the UK ETS is not applied on routes to Switzerland, there is the potential for passengers travelling to airports relatively near Switzerland (e.g. Basel-Mulhouse-Freiburg, Lyon) to use Swiss airports instead, potentially providing some advantage to airlines based in Switzerland. However, UK demand to airports near Switzerland is typically much lower than UK demand to Swiss airports, limiting this effect (CAA, 2021).

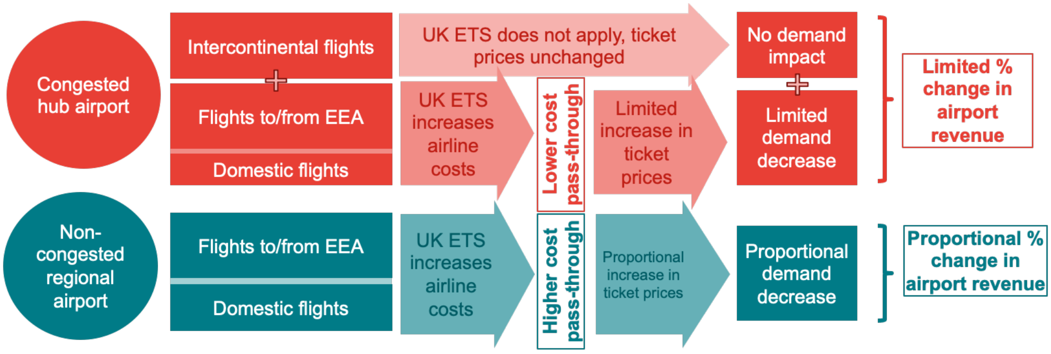
6.3 Impacts of UK ETS carbon price and CORSIA interaction option on airport competitive disadvantage

KEY FINDINGS

- The competition of UK hub airports with other hub airports is not expected to be substantially affected by the UK ETS. This is because UK hub airports have many intercontinental flights that are unaffected by the UK ETS, and because hub airports are often congested airports where airline cost pass-through is expected to be relatively low.
- Proportional impacts on UK airport passenger demand and profits compared to a no-UK ETS baseline are projected to be higher for airports outside London.

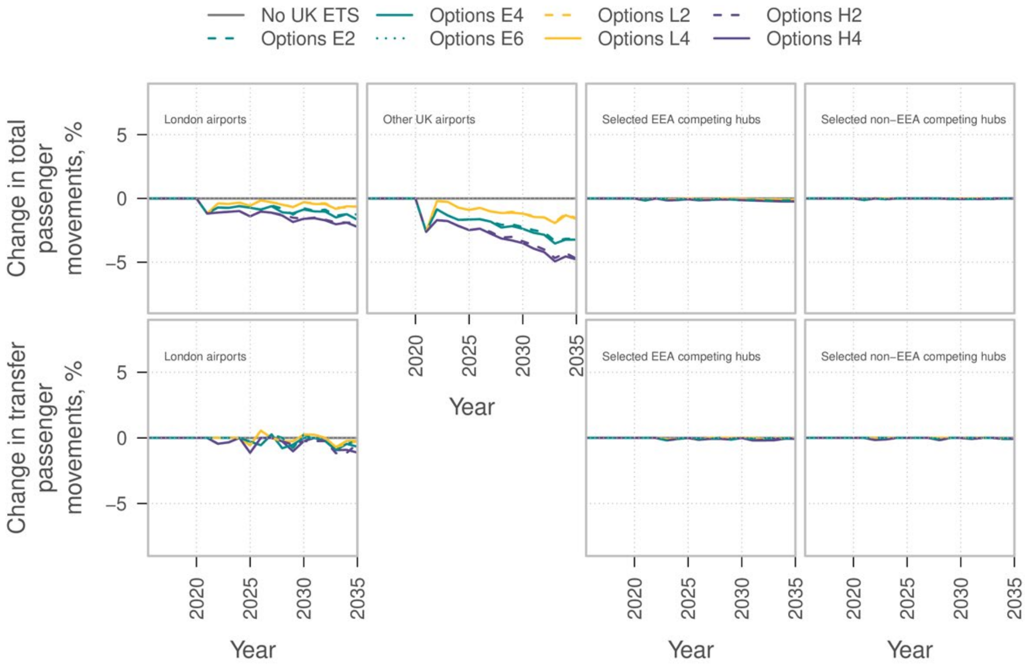
The changes discussed above in airline operations will also affect UK and non-UK airports. In particular, UK hub airports compete with non-UK hub airports for transfer passenger traffic. This applies both to EEA hub airports (e.g. Paris Charles de Gaulle, Frankfurt) and non-EEA hub airports for longer journeys (e.g. Istanbul, Dubai). This section assesses impacts on airports by type.

Figure 26. Schematic depiction of first-order UK ETS impacts on airport revenue, by type of airport.



Airports derive revenue from landing charges, and from income associated with passenger spending at airports, as was discussed in Section 2.1.2 and is further discussed in Annex B.5. The effect of different UK ETS options on airport-level passenger demand and number of flights will therefore feed through into changes in airport revenue. The level of impacts on different airports are affected by the route networks airports serve and any changes in demand and operations on those routes. Figure 26 illustrates the first-order impacts of the UK ETS that are likely at an airport level, considering only direct flights, for different types of airport. Congested hub airports serve a mixture of UK ETS and non-UK ETS routes. Additionally, cost pass-through is typically lower at congested airports. For regional airports, most routes are likely to be covered by the UK ETS and cost pass-through is likely to be higher. These factors on combination mean that regional UK airports are likely to experience larger percentage changes in demand and revenues than hub airports across all UK ETS options examined. Although model outcomes are complicated by transfer passenger impacts and second-order effects, these first-order effects still dominate.

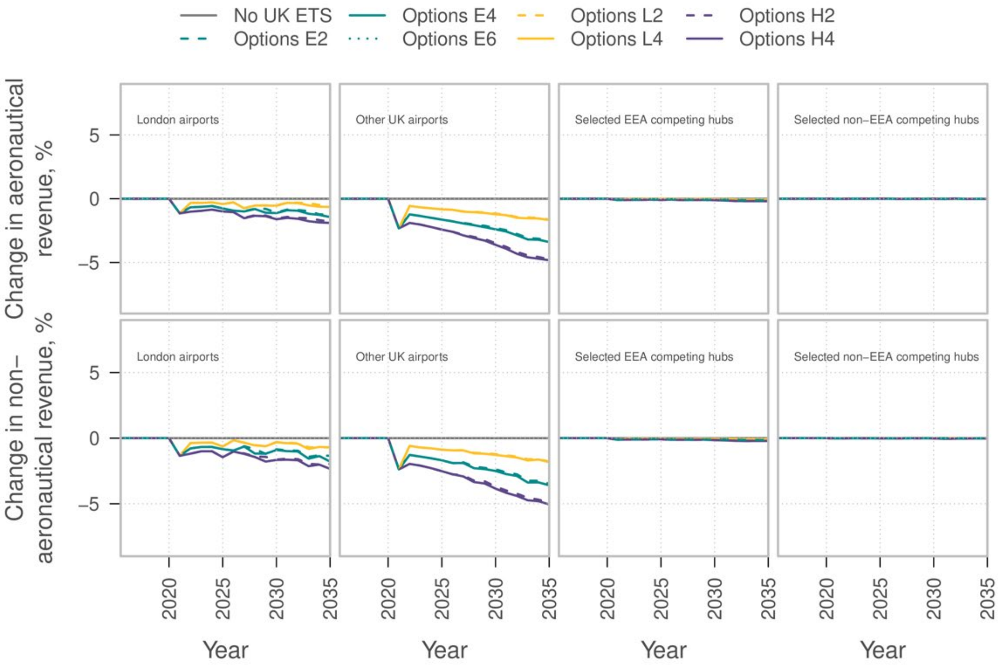
Figure 27. Changes in number of passengers by airport type and policy option, mppa.



Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6).

Figure 27 shows impacts on number of passengers per airport by airport type. We divide UK airports into London airports and airports outside London (omitting non-London airport transfer passengers due to small numbers). Typically, international-international transfer passengers travel through London, and London airports are more likely to be capacity-constrained. By 2030, decreases in London airport passenger numbers due to the different policy options are around 0.5-2% of total passenger demand. These impacts closely track effective carbon price, with higher carbon price options having higher demand impacts. Decreases in demand at non-London airports are higher (around 1.5-3.5% in 2030). These impacts are almost entirely driven by changes in direct passenger demand with origin or destination in the UK. As shown in the lower panels of Figure 27, impacts on transfer passengers are smaller and more variable. This follows directly from the discussion in Section 6.2.2 on the relative magnitude of impact different passenger itinerary types. Transfer passengers are much less-affected than UK origin and destination direct passengers both because their journeys usually include a much longer-haul flight leg which is not subject to the UK ETS, and because they are more likely to travel through congested airports where cost pass-through is lower. Similarly, demand is more affected at airports outside London as passengers at these airports are more likely to be travelling on a UK ETS flight leg, and because cost pass-through at these airports is assumed to be higher on average.

Figure 28. Changes in airport revenue by airport type and policy option.



Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6).

For airports outside the UK, two types of impact are possible:

- Reductions in demand from a decrease in direct passengers from and to the UK.
- Increases in transfer passengers who would have travelled via the UK, but have changed transfer airports in response to UK ETS costs.

As discussed in Section 6.2.2, the relative magnitude of these different impacts depends on the extent to which passengers on different itinerary types are affected by the UK ETS. Because there are many more direct passengers than transfer passengers, and because transfer passengers are typically little-affected by the UK ETS, the net impact is typically a small decrease in demand at competing hub airports. A similar conclusion was reached by the previous carbon leakage report commissioned by DfT[156].

Figure 28 shows corresponding changes in estimated airport aeronautical and non-aeronautical revenue. Both revenue sources are strongly affected by the number of passengers travelling through an airport: non-aeronautical directly (via passenger spending at the airport) and aeronautical revenue both directly via per-passenger components of landing charges and indirectly via per-aircraft components of landing charges. As such, changes in airport revenue behave similarly to changes in the number of passengers at a given group of airports, and are driven by the same factors. In 2030, revenue at London airports is projected to

---

[156] ATA & Clarity, 2018.

be around 0.7-1.6% below revenue in a no UK ETS case, with the extent of reduction strongly dependent on assumed carbon price. Revenue at non-London UK airports is projected to be around 1.5-3.3% below that in a no UK ETS case. Impacts on non-UK airports are projected to be small[157].

6.4 Sensitivity analysis

As discussed in Section 5.2.3, many of the input assumptions in this study are uncertain. Factors such as aviation demand growth, oil prices or future passenger behaviour can be difficult to predict, and may also have an impact on leakage and competitive disadvantage outcomes. To assess the impact of assumptions deviating from the nominal-case assumptions shown above, we carry out a sensitivity analysis of key uncertain variables, both individually and in combination. First, we show outcomes for carbon leakage and airline and airport competitive disadvantage for the range of values defined in Section B.7 for uncertain input variables, including for scenarios which combine values of uncertain input parameters which are particularly likely to cause extreme outcomes. Second, we examine the case of uncertainty cost passthrough assumptions more closely, as these assumptions can have an important impact on the analysis of operating cost impacts. As it is not possible to account for all factors in the quantitative modelling, the qualitative assessment findings should be read in parallel.

Table 15 shows outcomes for carbon leakage for the different policy options and sensitivity cases in 2030 on a fuel lifecycle emissions basis. All sensitivity case outcomes for leakage in 2030 are negative, i.e., CO_2 emissions decrease outside the policy area.

Leakage outcomes for sensitivity runs with low carbon prices (Policy Options L) are very variable and can be extremely high. As discussed in Section 6.1, leakage as a metric depends on the ratio between emissions changes outside and inside the policy area. Where emissions changes inside the policy area are small, calculating the leakage metric involves dividing by a small number, producing outputs which can be both large and sensitive to small changes. This is the case with Policy Options L – i.e., large leakage metrics reflect primarily that aviation emissions reductions within the policy area are small, rather than that emissions reductions outside the policy area are particularly large. For Policy Options E (UK ETS carbon price equal to EU ETS carbon price) and H (UK ETS price 50% above EU ETS carbon price), outcomes are more stable. For most combinations of uncertain input variables, carbon leakage in 2030 for Policy Options E varies between around -60% and -150%. Similarly, leakage for Policy Options H varies between around -50% and -160% in most cases.

---

[157] Because most of the flights affected by the UK ETS are international ones, the total demand decrease at UK airports will be roughly matched by a similar level of demand decrease at non-UK airports. However, this demand decrease is spread across many more airports, making individual airport-level impacts much smaller.

Table 15. Carbon leakage (percent, on a fuel lifecycle basis) for the different sensitivity model runs, 2030.

Option	Demand growth	Technology assumptions	Oil price	Alternative fuels	Price sensitivity	Cost pass-through	EU ETS and CORSIA assumptions	High/low emissions	High/low ticket price	High/low risk of emissions increases outside the policy area	High/low competitive disadvantage risk
Options E2	-140 – -130	-830 – -140	-550 – -29	-140 – -140	-69 – -140	-110 – -140	-140 – -90	-43 – -180	-140 – -92	-38 – -180	-45 – -140
Options E4	-130 – -110	-760 – -130	-500 – -29	-130 – -130	-69 – -130	-110 – -130	-140 – -100	-45 – -150	-130 – -91	-41 – -150	-59 – -130
Options E6	-120 – -94	-760 – -120	-490 – -1	-120 – -120	-65 – -120	-100 – -120	-56 – -120	-32 – -140	-120 – -77	-34 – -140	-43 – -120
Options L2	-100 – -110	-1500 – -100	-180 – -100	-100 – -100	-24 – -120	-65 – -100	-81 – -360	-31 – -120	-93 – -140	-25 – -120	-33 – -120
Options L4	-99 – -46	-1400 – -99	-790 – -99	-99 – -99	-30 – -120	-67 – -99	-97 – -310	-33 – -170	-95 – -120	-27 – -170	-37 – -120
Options H2	-50 – -61	-610 – -50	-420 – -37	-78 – -50	-50 – -47	-32 – -57	-200 – -50	-46 – -130	-120 – -50	-42 – -130	-50 – -130
Options H4	-53 – -68	-560 – -53	-390 – -37	-81 – -53	-53 – -48	-34 – -57	-190 – -53	-50 – -160	-120 – -53	-36 – -160	-53 – -120

Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6).

Two uncertain variables have the potential for a notably larger effect on leakage under the assumptions used here: technology assumptions and oil price. Both increase the potential for negative leakage. These outcomes both relate to similar effects. Where oil prices are low, airlines have more limited incentives to invest in new technologies which reduce their fuel costs. In this situation, the relative impact of applying a carbon price is greater and can have a larger impact both on uptake of aircraft technologies and SAF. Aircraft technologies are used on routes both inside and outside the policy area, leading to negative leakage. For SAF, the cost curve model used in AIM projects larger fuel supply if scale-up of SAF production begins earlier. This larger supply can be used in multiple world regions. Similarly, using more pessimistic assumptions about the benefits available from, and costs of, alternative technologies, means that airlines are more reluctant to invest in new technologies under baseline conditions. Under these circumstances, the additional emissions benefits of applying a carbon price can be larger[158]. However, as discussed in Section 6.1, almost all leakage due to different UK ETS policy options is onto routes covered by the EU ETS or CORSIA, and as such will mainly act towards reducing obligations under these schemes.

For 2030, all leakage outcomes involve emissions decreases outside the policy area. A small number of outcomes where emissions increase outside the policy area are seen in some sensitivity cases in 2035. However, this only occurs for Options E6 where CORSIA carbon prices are high and demand growth is high. Under CORSIA, airlines on eligible routes have offset requirements which are wholly or partly determined by the extent to which the whole scheme is above a whole-scheme baseline.[159] In this case, removing UK-EEA routes from CORSIA scope changes both the CORSIA baseline and the extent to which whole-scheme CORSIA CO_2 emissions are above that baseline. This affects airline CORSIA obligations globally. At high CORSIA carbon prices, the impact of this effect on global demand and CO_2 can be enough to lead to a small net increase on CO_2 outside the policy area, although global aviation CO_2 emissions still decrease in these outcomes because the reduction in CO_2 emissions inside the policy area is of greater magnitude.

To assess the sensitivity of airline competitive disadvantage by policy option to different assumptions for uncertain policy options, Table 16 shows the ratio of change in UK airline RTK to change in non-UK airline RTK. The purpose of using this metric is to provide a single-metric way of assessing whether UK and non-UK airlines are affected differently by different policy options. Typically, we would expect a greater amount of reduction in UK airline RTK than non-UK airline RTK because UK airlines dominate on UK domestic routes; the mix between UK and non-UK airlines on UK international routes is more even. Outcomes for this metric are generally very consistent between different sensitivity cases. For policy options E (UK ETS price equal to EU ETS price) and H (UK ETS price 50% above EU ETS price) the ratio of change in UK and non-UK airline RTK is consistently between 1.21 and 1.41. Outcomes for option L (UK ETS price 50% below EU ETS price) are more variable, particularly in the case where a low EU ETS price is assumed. In this case, the assumed year-2030 UK ETS carbon price is £20/tCO_2, a level of carbon price which does not have a strong impact on demand. As such, similarly to the leakage calculations above, the small magnitude of impacts on both airline types leads to metric values that are large and variable.

For options E and H, divergence between outcomes for UK and non-UK airlines is similarly largest in the cases that EU ETS prices are assumed to be low. As well as the sensitivity case looking specifically at EU ETS and CORSIA prices, this also includes some of the combined sensitivity cases (for example, ‘High emissions’ and ‘Low ticket price’). For other sensitivity cases, the range of outcomes is much

---

[158] Note that high leakage values which relate to bringing the time at which a technology is invested in forwards or backwards compared to the time it is adopted in the baseline case are typically transient.

[159] The extent over time by which CORSIA offset requirements are determined by aggregate emissions across the whole scheme or individual airline emissions is discussed in Annex B.1.2.

smaller, typically in the 1.2-1.3 range. The relative consistency of outcomes reflects that UK and non-UK airlines are not treated differently by any of the policy options.

Table 16. Ratio of change in UK airline RTK to change in non-UK airline RTK for the different sensitivity model runs by policy option, 2030.

Option	Demand growth	Technology assumptions	Oil price	Alternative fuels	Price sensitivity	Cost pass-through	EU ETS and CORSIA assumptions	High/low emissions	High/low ticket price	High/low risk of emissions decreases outside the policy area	High/low competitive disadvantage risk
Options E2	1.29 – 1.3	1.22 – 1.3	1.29 – 1.24	1.29 – 1.29	1.28 – 1.31	1.22 – 1.35	1.41 – 1.29	1.28 – 1.41	1.25 – 1.36	1.27 – 1.41	1.29 – 1.41
Options E4	1.29 – 1.32	1.2 – 1.29	1.29 – 1.24	1.29 – 1.29	1.26 – 1.29	1.21 – 1.33	1.38 – 1.24	1.22 – 1.33	1.22 – 1.3	1.21 – 1.33	1.29 – 1.32
Options E6	1.29 – 1.33	1.2 – 1.29	1.29 – 1.24	1.29 – 1.29	1.26 – 1.29	1.21 – 1.34	1.39 – 1.27	1.23 – 1.34	1.23 – 1.34	1.23 – 1.34	1.29 – 1.32
Options L2	1.3 – 1.37	1.12 – 1.32	1.3 – 1.22	1.3 – 1.3	1.27 – 1.3	1.24 – 1.42	-2.45 – 1.3	1.29 – 1.43	1.25 – 1.41	1.3 – 1.43	1.29 – 1.42
Options L4	1.26 – 1.32	1.17 – 1.31	1.2 – 1.26	1.26 – 1.26	1.25 – 1.26	1.22 – 1.4	7.96 – 1.21	1.23 – 1.33	1.23 – 1.28	1.24 – 1.33	1.26 – 1.33
Options H2	1.27 – 1.32	1.24 – 1.3	1.29 – 1.26	1.27 – 1.27	1.27 – 1.3	1.25 – 1.36	1.35 – 1.27	1.27 – 1.42	1.25 – 1.4	1.26 – 1.42	1.27 – 1.4
Options H4	1.26 – 1.3	1.21 – 1.29	1.25 – 1.26	1.26 – 1.26	1.26 – 1.29	1.24 – 1.35	1.32 – 1.26	1.22 – 1.32	1.23 – 1.32	1.21 – 1.32	1.26 – 1.31

Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6).

As such, differences in outcomes arise only from the different route networks that UK and non-UK airlines operate on. The main differences in route networks are:

- UK airlines dominate on UK domestic routes, so a combination of uncertain variables which has larger impacts on UK domestic routes will have a larger impact on UK airline RTK.
- UK and non-UK airlines operate a slightly different selection of routes to and from the UK. On average, non-UK airline UK-EEA routes are slightly longer-

distance than UK airline UK-EEA routes. This means that a combination of uncertain parameters which has higher impact on longer-haul routes will have a larger impact on non-UK airline RTK.

- UK airlines operate many routes to and from UK congested airports. Increases in cost pass-through at congested airports will therefore have a larger impact on UK airline RTK. Cost passthrough sensitivity outcomes are discussed in more detail in the next section.

Table 17. Net reduction in UK airport mppa, for the different sensitivity model runs by policy option, 2030

Option	Demand growth	Technology assumptions	Oil price	Alternative fuels	Price sensitivity	Cost pass-through	EU ETS and CORSIA assumptions	High/low emissions	High/low ticket price	High/low risk of emissions decreases outside the policy area	High/low competitive disadvantage risk
Options E2	-4.7 – -7.2	-4.7 – -4.6	-4.8 – -4.7	-4.8 – -4.7	-4.7 – -5.7	-3.3 – -6.5	-2.1 – -7.2	-4.5 – -5.2	-2.4 – -7	-3.9 – -5.2	-7.3 – -2.4
Options E4	-5.2 – -7.1	-5.6 – -5.2	-6.1 – -4.8	-5.2 – -5.2	-5.2 – -6.1	-3.6 – -6.7	-2.6 – -8.5	-5.2 – -6.2	-2.7 – -9	-4.6 – -6.2	-8.5 – -2.9
Options E6	-5.2 – -7.1	-5.6 – -5.2	-6.1 – -4.8	-5.2 – -5.2	-5.2 – -6.1	-3.6 – -6.7	-2.6 – -8.3	-5.2 – -6.2	-2.6 – -8.4	-4.5 – -6.2	-8.2 – -2.9
Options L2	-2.2 – -3.4	-2.1 – -2.5	-2.7 – -1.9	-2.3 – -2.2	-2.2 – -3.2	-1.8 – -3.5	-0.8 – -3.5	-2.2 – -2.6	-1.2 – -3.3	-2.1 – -2.6	-4.1 – -1.2
Options L4	-2.2 – -4.9	-3 – -2.2	-2.9 – -2	-2.3 – -2.2	-2.2 – -3.3	-2.1 – -3.7	-0.9 – -4.4	-2.2 – -3.2	-1.3 – -4.5	-2.2 – -3.2	-4.3 – -1.4
Options H2	-8.1 – -11.2	-8.2 – -7.9	-8.2 – -7	-7.6 – -8.2	-7.4 – -8.9	-6.2 – -9.7	-3.3 – -10	-6.6 – -8.2	-3.5 – -10	-5.6 – -8.2	-10.5 – -3.3
Options H4	-8.3 – -12.1	-8.8 – -8.3	-9.7 – -7.2	-8.4 – -8.3	-7.7 – -9.3	-6.5 – -10.7	-3.9 – -12.6	-7.8 – -9.9	-3.8 – -12.8	-6.9 – -9.9	-12.2 – -4.3

Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6).

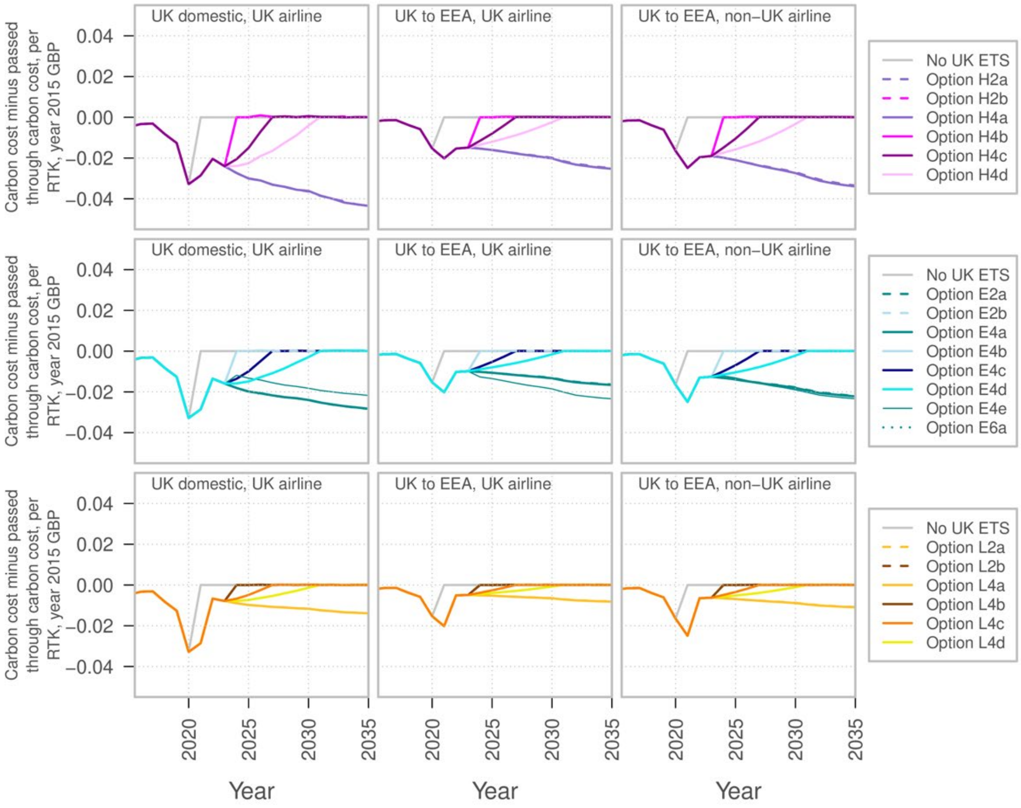
To assess the sensitivity of airport competitive disadvantage outcomes to uncertain input parameters, we carry out a similar analysis for airport passengers (mppa).

Because reducing the number of UK-EEA flights by one necessarily reduces passenger movements at both UK and EEA airports by the same amount, we compare only the net reduction in UK airport mppa in each case. Outcomes are shown in Table 17.

The same basic mechanisms which affect airport outcomes in the nominal case model runs also largely apply in the sensitivity case model runs. Because the UK ETS applies only to UK domestic and UK-EEA routes, airports which have more intercontinental flights are less-affected. UK international-international transfer passengers are typically little-affected by the UK ETS, limiting the impact of the policy on non-UK competing hub airports. None of these factors change significantly when different values are used for uncertain scenario variables.

Airport outcomes by sensitivity case largely track the carbon price and cost pass-through assumptions used in each case. Where EU ETS carbon prices are assumed to be higher (High EU ETS and CORSIA assumptions; Low Emissions; High Ticket price; etc.), reductions in demand at UK airports compared to a no UK ETS base case are larger. Similarly, where more costs are passed through onto ticket prices, reductions in demand are larger and differences between London and non-London airports smaller, as discussed in the next section. The largest reduction in demand at UK airports is in the ‘high ticket price’ case with UK ETS price higher than EU ETS price and CORSIA option 4. This case combines both high carbon prices and high cost passthrough. In this case, the total reduction in UK airport demand is 12.8 mppa, or around 3.6% of total projected passenger movements at UK airports in a ‘no UK ETS’ baseline for 2030.

Figure 29. Level of carbon cost passthrough for the different policy options by year, geographic scope and airline type, high cost passthrough sensitivity case.

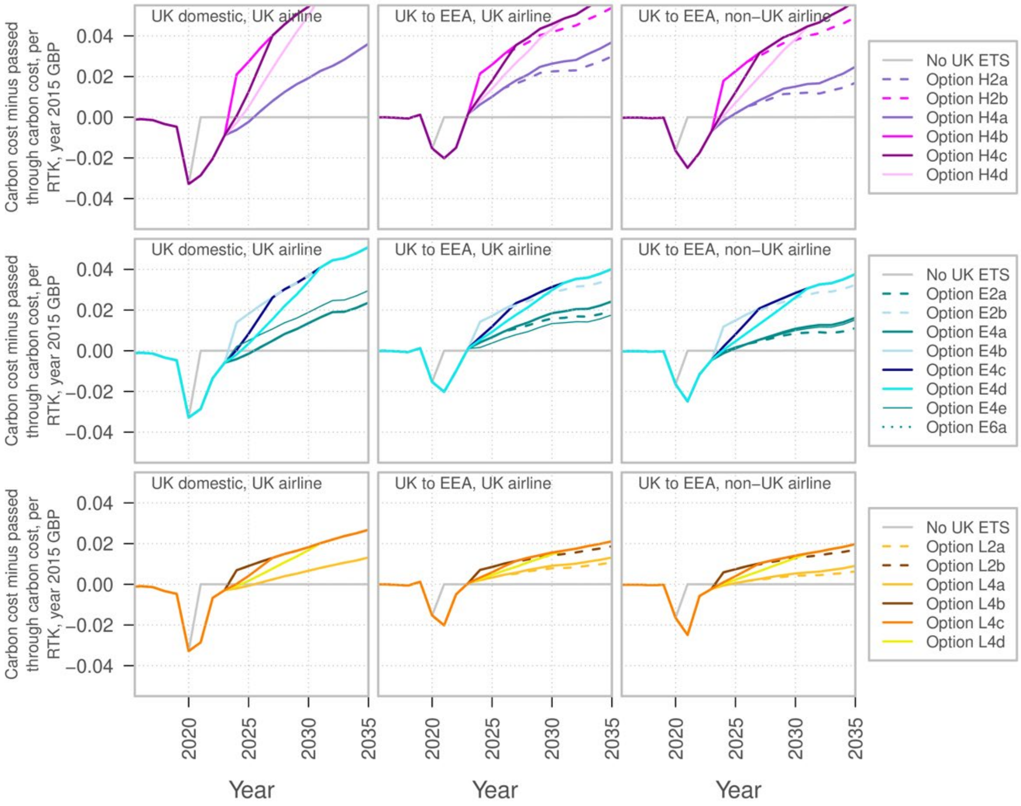


Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances; e = benchmark update to 2019.

6.4.1 Impact of cost pass-through assumptions

Cost pass-through is chosen as a special case for sensitivity analysis because the extent to which airlines on different routes are advantaged or disadvantaged by the UK ETS is dependent on pass-through. In particular, the assumption of 50% carbon cost pass-through at congested airports is uncertain.

Figure 30. Level of carbon cost passthrough for the different policy options by year, geographic scope and airline type, low cost passthrough sensitivity case.



Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances; e = benchmark update to 2019.

As discussed in Sections B.7.5 and 5.2.3, literature estimates of cost pass-through vary widely and the extent to which airline behaviour is fully consistent with theoretical assumptions is uncertain. Higher cost pass-through at congested airports could lead to larger impacts on transfer passengers and on UK-EEA demand in general for the same set of UK ETS policy characteristics. Lower cost pass-through at congested airports, conversely, would increase the regional differences observed in the 50% cost pass-through case, with regional airports much more strongly impacted than London-area airports. Figure 29 shows incurred carbon costs minus passed through carbon costs by policy option, geographic scope and airline type in the case that cost pass-through at congested airports is assumed to be high (100%). In this case, free allowances are always associated with increases in airline profit. In the case that free allowances are phased out, the increase in airline incurred costs is almost exactly the same as the increase in passed through costs. High passthrough may be more likely in the case that carbon prices are higher. As discussed in Section 4.1.1.5, at capacity-constrained airports, the profit-optimal fare is a function of capacity rather than operating costs and is typically higher than that at comparable non-constrained airports[160]. This implies both that airlines make higher profits (scarcity rents) operating from congested airports, and that they are less likely to pass on operating cost changes (as modelled here). However, if carbon costs increase operating cost to the point where the scarcity rent from operating at the airport is zero, then an increase in passthrough is likely.

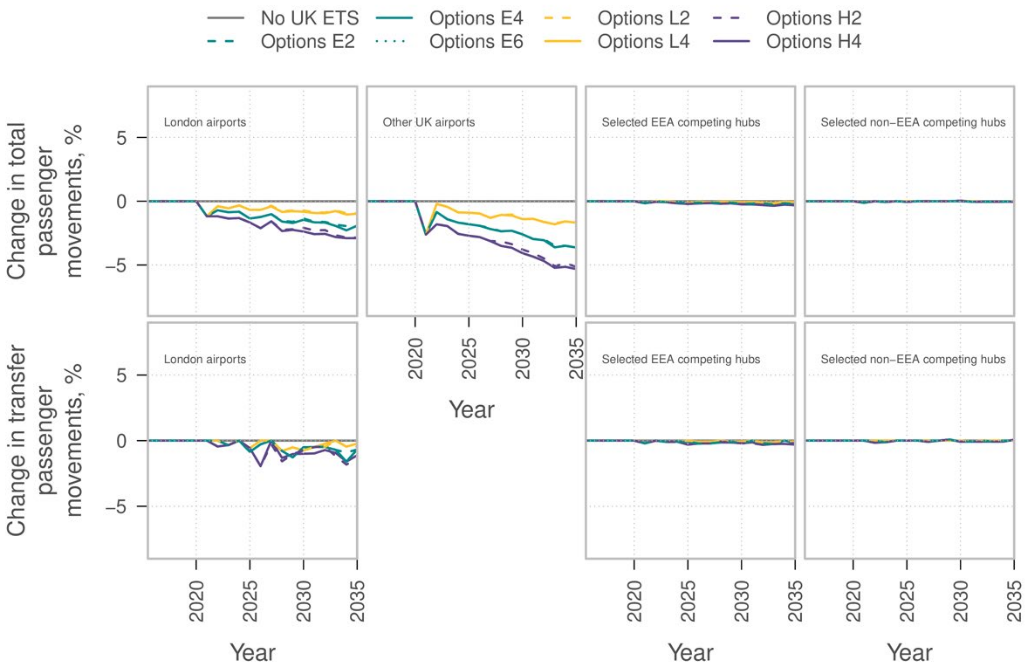
In the case where carbon cost pass-through is assumed to be 0% at congested airports, the current level of free allocation is not sufficient to cover increases in airline costs, and airline profits decrease in all cases. Lower levels of cost pass-through are more likely where capacity limits are more severe, absolute levels of cost change are lower, levels of competition are higher, or competing airlines experience unequal levels of cost increase[161]. This case is shown in Figure 30**.** The different impact of these different levels of cost pass-through can be illustrated by the extent to which London airport passenger demand and passenger demand at other airports change. Outcomes are shown for high cost passthrough at congested airports in Figure 31, and low cost passthrough at congested airports in Figure 32.

---

[160] E.g. Frontier, 2019; Dray et al., 2020.

[161] E.g. Dray et al., 2020.

Figure 31. Change in passengers by airport and itinerary type, for the high cost passthrough sensitivity case.

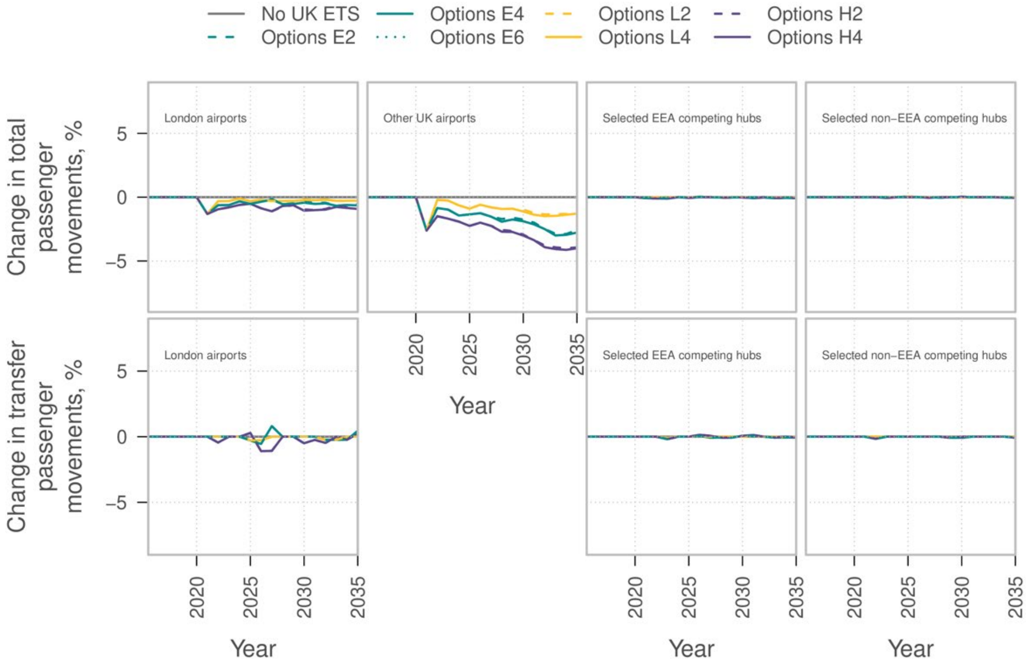


Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6).

Outcomes are not identical at non-London UK airports for both cases. This is because, although no non-London UK airports are assumed to be in the congested airport category, some of the destination airports flown to from these airports are. However, there is much greater variation at London airports in the different sensitivity cases. In the low cost passthrough case, impacts on transfer passengers from the different UK ETS options are minimal. Demand impacts at London airports are also very small compared to those at non-London airports, implying also greater differences between outcomes for network and regional airlines. Similarly, impacts at EEA competing hubs are smaller at low cost passthrough, reflecting that many of these airports face their own capacity constraints.

In the high cost pass-through case, percentage decreases in demand at London airports are still only around half of those at non-London airports. This is because London airports have a higher share of intercontinental flights which are not subject to the UK ETS. However, London and non-London airports experience more similar outcomes than in the cases with lower passthrough. As in the nominal case outcomes shown in Section 6.3, relative outcomes between the different policy options depend strongly on the effective UK ETS carbon price in each scenario. The only difference is that the absolute level of impact is higher.

Figure 32. Change in passengers by airport and itinerary type, for the low cost passthrough sensitivity case.



Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6).

In combination, these impacts suggest that changing the level of cost passthrough at congested airports does not eliminate differences between regional and other airlines, or between London-area and other airports. This is because these airports and airlines also differ significantly in terms of their proportion of non-UK ETS flights. For higher carbon cost cases, passthrough closer to 100% may be likely, as airlines are unable to absorb the full extent of any operating cost changes. As indicated above, this will act to reduce system-wide impacts on operating costs and increase system-wide impacts on demand, with greater changes for network airlines and London airports. However, larger percentage impacts on demand for non-London airports are predicted in all cases. Similarly, larger percentage impacts on UK regional airline demand compared to UK network airline demand are likely in all cases.

6.5 Assessment of other potential leakage channels not explicitly modelled in AIM

In the analysis in Sections 6.1 - 6.4, we consider the impacts of leakage and competitive disadvantage mechanisms related to changes in airline operations, passenger and freight demand, ticket prices, and airline technology choice. These mechanisms are straightforwardly modellable with AIM. However, several potential leakage channels are not included in that analysis. This includes non-modelled impacts related to changes in airline behaviour (freight network change, early retirement of older aircraft potentially with additional changes in price for high-emissions aircraft, changes in oil price resulting from changes in aviation fuel demand, reassignment of high-emissions aircraft away from UK ETS routes and changes in fuel tankering) and related to changes in passenger behaviour (changes in destination choice, changes in emissions from other sectors due to reassignment of spending from aviation to other activities). In this section, we consider these potential leakage channels in turn, and assess the potential for each to have significant impacts on leakage or competitive disadvantage under UK ETS conditions. These channels are summarised in Table 18.

Table 18. Summary of analysis of leakage channels not explicitly modelled in AIM

Channel	Impact on Leakage	Impact on Competitive Disadvantage	Circumstances in which this channel might materially affect outcomes
Freight network change and route substitution	Likely negative (for air-truck substitution), small.	Impact likely small	Low impact expected; will be largest where carbon prices are high.
Early retirement of older aircraft	Likely negative, small.	Impact likely small	Minimal impact expected; could be a factor during early COVID-19 recovery period (if new aircraft prices remain low)
Reduction in fossil kerosene use affects oil price	Likely positive, may be large, high uncertainty.	Impacts likely small but may affect actors across multiple sectors and world regions	Could be important if substitution elasticity of fossil fuel production is small.
Increase in SAF use affects SAF price or production	May be positive or negative. Likely small.	Impacts likely small. Might affect ability of airlines of different nationalities to comply with SAF mandates.	Impacts likely higher at higher carbon price.
Reassignment of high emissions aircraft towards/away from UK ETS routes	May be positive or negative depending on whether UK ETS price is above or below EU ETS price. Likely small.	May affect the operating costs of airlines which have more flights to the UK on non-UK routes	Applies only where EU ETS and UK ETS prices diverge significantly. Applies only to large airlines with suitable fleet and route networks.
Changes in fuel tankering	Negative[162], very small.	Impact likely small	None.

---

[162] Negative impact here relates to airlines choosing not to tanker because it increases their fuel and carbon costs. The UK ETS does not promote tankering under any scenario.

Changes in destination choice	May be positive or negative. Likely small.	May be benefit for UK holiday destinations.	High UK ETS carbon price.
Changes in spending on non-aviation activities	May be positive or negative. Small.	Impact likely small.	Unlikely to have a material impact.

6.5.1 Changes in airline behaviour

6.5.1.1 Freight network change and route substitution

Air freight may be carried in the holds of passenger aircraft or in dedicated freighters. The impact of changing hold freight capacity due to changes in passenger flights is already considered in the model runs. However, there may also be impacts from airlines who operate freighter aircraft choosing to adapt their networks in response to increased carbon costs (for example, switching from freight trans-shipment in the UK to trans-shipment in another location.) Because freight flows are much more directional than passenger flows, freighter network structures differ significantly from passenger ones[163]. Various studies have assessed freight airline airport choice,[164] network change,[165] trans-shipment airport location choice[166] and mode choice,[167] including under different carbon price conditions. In 2017, around 25% of departing UK air freight tonnes were domestic or to destinations in Europe, with the corresponding share of tonne-km much lower[168]. In general, UK ETS impacts on freighter networks are likely to be small, given that the vast majority of freight tonne-km to and from the UK is intercontinental and does not incur UK ETS-related costs.

UK airports with significant freight flows include Heathrow, East Midlands, Stansted and Manchester[169]. At Heathrow and Manchester freight is mainly carried in the holds of passenger aircraft, so networks are constrained by passenger aircraft operations. East Midlands and Stansted have more freighter aircraft operations. Steer (2018) report that there is non-negligible use of trucking from continental Europe with assigned flight numbers (‘truck flights’; i.e., the freight is carried on a truck but classified as air freight) both to be loaded onto North America-bound flights from Heathrow, and for freight from Asia with the UK as a final destination. Similarly, because Heathrow receives a large amount of long-haul belly freight, freight is sometimes trucked from Heathrow to another cargo airport (for example, East Midlands) and loaded onto a shorter-haul flight to its final destination. These types of operations are primarily a response to system restrictions, for example available airport capacity for freighter flights and curfews on night flights, but may also be influenced by costs.

---

[163] Budd & Ison, 2017.

[164] Gardiner et al., 2005.

[165] Derigs & Illing, 2013.

[166] Ohashi et al., 2005.

[167] Mitra & Leon, 2014.

[168] Steer, 2018.

[169] Steer, 2018.

Based on available literature and the characteristics of the different policy options, several broad conclusions about the impact of the UK ETS on UK freight networks can be drawn:

- There is likely to be minimal impact on UK long-haul belly freight capacity from the different UK ETS options chosen, as UK intercontinental flights are outside the scope of the UK ETS.
- Similarly, intercontinental freighter flights are likely to be affected only in the specific case that the freight is flown onwards to a UK or EEA destination afterwards.
- Where airlines have a choice between transporting incoming belly freight onwards to continental or UK destinations by freighter flight or truck, higher-cost UK ETS options may favour the truck option.
- Reductions in passenger flights to and from the EEA may reduce pressures on UK airport capacity, potentially allowing more direct freighter flights between the UK and non-EEA destinations.

Where switching to road transport is anticipated for trips that would otherwise be flights, this would likely lead to a reduction in overall UK outbound and inbound emissions (negative leakage)[170], though there is some overlap in the energy intensity of trucks and freighter aircraft depending on the size of truck and size of aircraft assumed[171]. If freighter airlines switch EEA-UK freighter flights to non-UK destinations and add a final truck leg, this may lead to net positive leakage.

These interactions will be complicated by different relative changes in belly freight and freighter aircraft capacity during the COVID-19 pandemic recovery period, and by administrative issues related to the UK's exit from the European Union. Different types of freight operations are also time-sensitive to different extents, with network changes which add additional journey time less likely for more time-sensitive freight. As such, overall outcomes are uncertain. However, UK departing freighter flights accounted for only around 1 $MtCO_2$ in 2015 (around 3% of UK departing flight CO_2)[172], the vast majority of which was on non UK ETS routes, limiting the magnitude of leakage via this effect.

6.5.1.2 Airlines selling older aircraft in combination with buying new ones and reductions in price of high emissions aircraft

Airlines replacing older aircraft with newer ones can either scrap the older aircraft or (if a suitable buyer exists) sell them. At present, there is an oversupply of new aircraft due to the COVID-19 pandemic[173], which may make it difficult to sell second-hand aircraft during the immediate recovery period. Therefore the viability of this route will depend on the extent of pandemic recovery at the point that policy measures are applied. Similarly, the pandemic has increased airline capital

---

[170] E.g. McKinnon, 2007.

[171] E.g. Gucwa & Schäfer, 2013.

[172] DfT, 2017.

[173] McKinsey, 2021.

constraints and associated airline bailouts may also impose constraints on airline behaviours[174].

If the older aircraft was used on international routes and is scrapped, the impact of this leakage channel is to reduce emissions both inside and outside the policy area because a higher-emissions aircraft operating on routes to and from the UK has been directly swapped for a lower-one (i.e., negative leakage). If the older aircraft is sold to an airline in another world region, leakage impacts depend on the aircraft's new use, but could involve emissions increases outside the policy area (positive leakage) if the aircraft is used for flights that would not otherwise have happened, or displaces a new aircraft purchase in that area. Impacts on airline competition in either case are likely to be relatively small as airlines which opt to retire and replace aircraft will have increased capital costs but reduced carbon and fuel costs.

Historically, average aircraft age at scrappage has remained remarkably constant at around 30 years[175]. While early scrappage of older aircraft in combination with purchase of newer aircraft can provide significant emissions benefits, the cost per kg CO_2 saved is typically above that of other mitigation measures[176], due to the high capital costs involved[177], making retiring and replacing older aircraft a lower-priority way of reducing carbon costs than other responses. Similar issues affect early sales of older aircraft. For this reason, this leakage channel was not found to be important for outcomes in the previous carbon leakage study commissioned by DfT, which considered carbon prices of up to £200/tCO_2. To confirm this outcome, we apply the aircraft purchase decision model which was used in the previous carbon leakage study[178], updating cost assumptions to those used in the current study. Even at the highest carbon prices used in this study, the estimated potential for early aircraft retirements using this model is limited, with under 15 early retirements/replacements of aircraft projected, and early retirements mainly occurring in the smallest aircraft size class where scope for leakage is more limited. At carbon prices equal to the central projections used here for 2035, only 2 early retirements/replacements due to carbon price are projected, both in the smallest aircraft size class. This suggests limited impact via this leakage channel.

Additionally, changes in aircraft purchase choices for airlines operating on routes to and from the UK may affect prices for higher-emissions aircraft. If these airlines consistently opt for lower-emissions aircraft (e.g., buying new aircraft instead of older second-hand ones, or getting rid of older aircraft and buying newer ones) then this in turn could lead to a decrease in the price of high-emissions aircraft, making them more attractive to buy for capital-constrained consumers from other world regions.

This effect is likely small for several reasons. First, the impact of the UK ETS on higher-emissions aircraft purchases is uncertain. Typically, a limited selection of aircraft models are available for purchase in any given size and range class, with

---

[174] Abate et al., 2020.

[175] Dray, 2013.

[176] Schäfer et al., 2016.

[177] Morrell & Dray, 2009. Retirement and replacement was identified in this study as being of limited cost-effectiveness in particular for narrowbody aircraft, which are the aircraft most typically used on UK ETS routes.

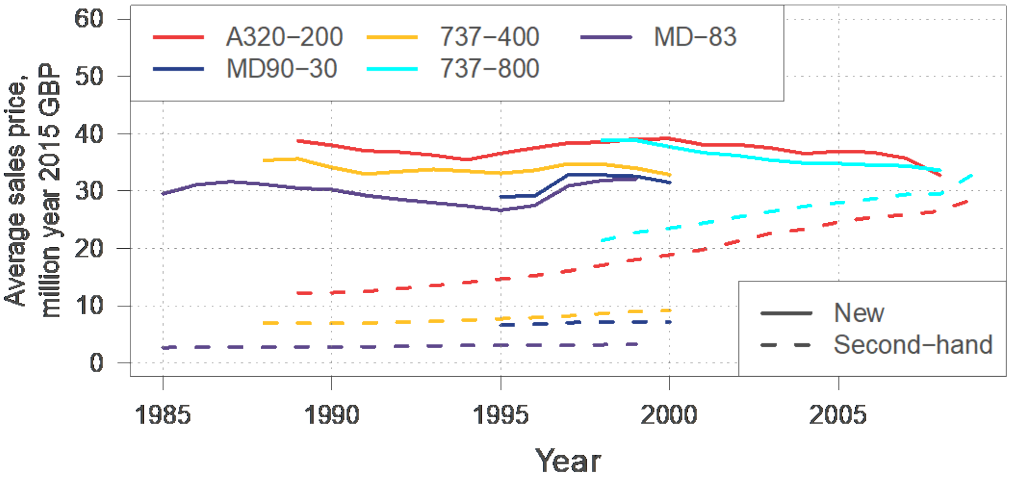
[178] Morrell & Dray, 2009; ATA & Clarity, 2018.

older and higher-emission designs phased out of production once new designs become available. Many airlines operate homogeneous fleets to reduce maintenance and training costs, which may further constrain their choices.

Second, this channel of leakage relies on reductions in aircraft cost leading to changes in emissions outside the policy area. The most likely way that this might happen is that airlines in other world regions buy lower-priced aircraft than they otherwise would have, this reduces their capital costs, and they pass that cost saving onto passengers, leading to a demand rebound effect. This effect relies on a combination of second-order impacts (the likely small change in aircraft price due to changes in aircraft choice on UK-related flights, its impact on airline costs, the extent to which this is passed on to ticket prices, and the extent to which passengers respond to that change) which, although uncertain, suggests that its magnitude is likely to be small.

Third, it is not clear how much aircraft prices would be affected, or how that impact would interact with constraints related to production line capacity. Figure 33 shows new and second-hand average sale price for mid-size narrowbody aircraft from 1985-2009, based on historical sales price data[179]. Over this time period, there was a transition away from older, less-efficient aircraft types (e.g., the MD-83) towards newer, more-efficient aircraft types (e.g., the Boeing 737-800). Fuel prices were initially low, but began to increase from around 2000. However, the main trend seen in the data is an increase in second-hand prices of all aircraft over time, including during the period of increasing fuel price. New aircraft prices tend to increase at points of more rapid demand growth (e.g., the 1998-2000 time period) and decrease where demand growth is lower (e.g., 1990-1992, 2007-2009). This suggests that, historically, aircraft supply constraints have been a more important factor affecting aircraft sales prices than fuel-related costs.

Figure 33. Average new and second-hand prices for selected mid-size narrowbody aircraft from 1985-2009.



---

[179] E.g. The Airliner Price Guide, 2018, https://www.airlinerpriceguide.com

6.5.1.3 Reduction in fossil kerosene use affects oil price

If the UK ETS causes UK aviation fuel use to decrease, this may result in a global decrease in prices for aviation fuel and/or for other oil-derived products. In turn, this may cause an increase in demand for these products.

The magnitude of this impact is likely to track the extent to which global aviation fuel use is affected by different policy options. Routes covered by the UK ETS are currently around 1% of global aviation fuel use (around 2% if non-covered return journeys are considered), and this fraction is not likely to increase over time. Because the likely impact of UK ETS policy on fuel use on these routes is itself only a few percent, the overall impact on global aviation fuel demand is likely very small. As discussed in the literature,[180] this channel of impact is also highly uncertain. Outcomes depend critically on the supply elasticity of fossil fuels; if fossil fuel supply is perfectly inelastic, adjustment is via price only and all decreases in use in policy-effected regions would be matched by increases in use elsewhere, i.e., 100% leakage, whereas a perfectly elastic supply of fossil fuels would imply 0% leakage. Literature estimates of this effect vary widely, but some sources have suggested that it could be a major source of leakage[181]. However, literature studies considering this leakage channel have been typically carried out on policies with much greater geographic scope, and hence both larger potential for reduction in demand for oil products and larger within-policy scope emissions change, making it uncertain whether they can be used to infer outcomes in this case. For example, Arroyo-Currás et al. (2015)[182] project leakage mainly via this channel of up to 16% for hypothetical unilateral carbon pricing policy at carbon prices of up to around £120/tCO_2 by the US, China and Europe respectively. This level of positive leakage is relatively small compared to the typical negative leakage outcomes of the UK ETS aviation options examined here, and would not significantly change the conclusions of this study. Similarly, Bauer et al. (2015)[183] examine the response of fossil energy markets to climate policy across multiple models and leakage implications, finding potential for both positive and negative leakage (between 46.5% and -3.2% by model used for EU policy scenarios) depending on trade and substitution patterns between coal, oil and gas[184].

6.5.1.4 Increase in SAF use affects SAF price or production

A related channel for leakage is the case where the UK ETS affects SAF demand and production. If the UK ETS stimulates increased SAF demand on UK routes, three types of impact are possible:

- Increased SAF demand stimulates earlier and/or more ambitious SAF production, which may act to increase supply and/or decrease SAF prices in later years, through learning and scale effects.

---

[180] E.g. Gerlagh & Kuik, 2007; Boeters & Bollen, 2012.

[181] Gerlagh & Kuik, 2007.

[182] Arroyo-Currás et al., 2015.

[183] Bauer et al., 2015.

[184] For example, a decrease in oil prices may result in lower emissions overall if it encourages a switch away from coal use.

- SAF use switches to UK routes from other routes (i.e., there is an increase in SAF price beyond what is cost-effective for those routes, or constrained supply available to those routes), leading to decreased use outside the policy area.
- Depending on the fuel production pathways and feedstock assumed, increased SAF demand could lead to reduced biomass use in other sectors. This has the potential to result in positive leakage if alternative, non-aviation uses of the biomass are located outside the UK.

Which effects dominate depends on assumptions about biomass supply and cost, the timeframe examined, global aviation SAF production capacity, how fast production capacity can be scaled up, SAF policy in other world regions, the extent and ambition of SAF mandates[185], and the extent of biomass demand from other sectors. Because the model runs use cost curves for SAF use which take account of route-level carbon costs, an estimate of the first two effects is already included in the modelling. Under the assumptions used here, SAF prices in other world regions increase by small amounts (under 1%) in response to different UK ETS options, even in the sensitivity modelling. This reflects three factors. First there is a balance of impacts on SAF prices in other world regions in different directions. Second, SAF use is typically dominated by EEA countries, reducing the size of impact of different UK policy options. Third, SAF use is typically very low outside Europe in these model runs, reflecting limited assumed policy incentives to adopt it[186]. This means that available SAF in these regions typically reflects the characteristics of the fuel production pathways and feedstocks at the bottom of the cost curve across all different UK ETS options. As a result, increasing SAF prices in these world regions has limited impact on SAF use because uptake is already low before the price increase.

6.5.1.5 Airlines reassign fleet to put low-emissions aircraft on UK routes

If an airline has both high-emissions and lower-emissions aircraft in its fleet, it might choose to operate its lower-emissions aircraft on routes with a higher carbon cost, leading to lower emissions on those routes and higher emissions elsewhere. This channel of leakage is highly uncertain, with some empirical evidence that airlines and airline groups may not assign fleet to different routes in response to environmental policy[187]. In the previous carbon leakage study commissioned for DfT, this channel of leakage was found to be less likely for carbon pricing-type policies.

Most CO_2 emissions on UK ETS routes are from narrowbody aircraft. The largest scope for fleet swapping is likely to be by UK- and EEA-based airline narrowbody aircraft between UK-EEA routes and intra-EEA routes. This is because UK-related CORSIA and/or non-covered routes are typically long-haul routes where larger aircraft are used, limiting the potential to swap aircraft. In general, an aircraft which is used on a UK-EEA route will take a corresponding EEA-UK (EU ETS-eligible)

---

[185] E.g. DfT, 2021c.

[186] Note that this applies even where a higher CORSIA price is assumed. This is because the effective carbon price that airlines pay under CORSIA is much less than the price per allowance, as they only pay for emissions above the CORSIA baseline.

[187] E.g. Nero & Black, 2000; Roy, 2007.

return journey. A typical substitute route for this aircraft would be covered by the EU ETS in both directions.

To assess the possible extent of leakage and/or competitive disadvantage via this route, we consider the case where a non-UK airline has the option of using a lower-emissions aircraft either on a route to and from the UK, or an alternative route of similar length within the EEA. In 2035, airline narrowbody fleets will likely be composed of a mix of current-generation aircraft (e.g. the Airbus A320neo) and next-generation aircraft, which are assumed to become available from the early 2030s. For a mid-size narrowbody aircraft at nominal technology characteristics, around a 15% reduction in fuel use for the next-generation aircraft compared to current-generation aircraft for the same flight is assumed. The extent to which cost savings can be made by fleet swapping on typical routes depends on the difference between the UK ETS and EU ETS marginal carbon price on both routes. Table 19 examines the cost incentives to do this for a single aircraft operating for the whole year on an example route (London-Rome), assuming swappage onto a route of comparable length which is EU ETS-eligible in both directions. Note that, because marginal costs are considered, outcomes are not affected by the free allowance allocation methodology.

Table 19. Incentives to swap fleet between routes by policy option, for the example of London-Rome

Policy Option	Yearly total difference in carbon costs, UK ETS and equivalent EU ETS route, year 2015 GBP per aircraft	Route-level change in carbon costs from switching an aircraft from a UK ETS to an EU ETS route, year 2015 GBP	Net change in UK departing flight CO_2 with fleet swap, tonnes (one aircraft)[a]	Approx. per-aircraft leakage impact from fleet swap, central case[b]
Options E2	-42000	-6300	1440	-0.013
Options E4	439	66	1440	0.012
Options E6	0	0	0	0
Options L2	-568000	-85100	1440	-0.033
Options L4	-545000	-81700	1440	-0.03
Options H2	450000	67500	1430	0.010
Options H4	514000	77000	1430	0.009

[a] This change will matched by a corresponding change in the opposite direction in non-UK departing flight CO_2.

[b] This is the approximate change in the nominal case leakage metrics for each policy option that would result from a single aircraft's operations being swapped in the direction which reduces carbon costs. Note that, because of the way leakage is defined, this value may be larger in the case that the underlying changes in UK departing CO_2 are smaller.

The main factor affecting costs savings that are possible from fleet swapping is the extent to which UK ETS, EU ETS and (for options which apply CORSIA on UK ETS routes) CORSIA carbon prices are different. Outcomes are also affected to a smaller extent by the UK ETS CORSIA interaction option. In the case that the UK ETS and EU ETS carbon prices are similar (which is currently the case) there is limited incentive to swap fleet because only small cost savings can be made. In the case that the UK ETS price is much lower than the EU ETS price, airlines may have an incentive to swap less-efficient aircraft onto UK ETS routes. Similarly, where the UK ETS price is higher than the EU ETS price, airlines may have an incentive to swap less-efficient aircraft from UK ETS routes onto EU ETS routes. For the scenarios modelled, airlines with eligible aircraft could save around £68,000-85,000 by swapping one aircraft for a year if UK ETS prices are half EU ETS prices or 1.5 times EU ETS prices. This is a similar order of magnitude to the costs of rebranding a narrowbody aircraft[188], suggesting that this option is not feasible where rebranding is required (i.e., between airlines with different branding in the same airline group). However, it may be an option where airlines within a group have similar branding (e.g., Easyjet and Easyjet Europe).

For fleet swap to occur, other conditions also have to be met:

- The airline must have a network containing routes of both types (UK-EEA and intra-EEA). This is more likely to apply to EEA airlines.
- The airline must have a mix of older and newer aircraft types with similar size and range.
- The airline must have systems which enable aircraft to be scheduled based on environmental costs.
- The alternative aircraft must be fully compatible with the route, including being compliant with any special requirements imposed by the origin and destination airports and countries, and route-specific requirements (e.g., safety requirements for flights over water).

Given these conditions, we assess impacts on outcomes from fleet swapping as unlikely unless there is significant divergence between EU ETS and UK ETS carbon prices; even in the case that this occurs, the scope to swap fleet for most airlines is likely to be small.

6.5.1.6 Fuel tankering

Tankering is the practice of taking on fuel at one airport sufficient for more than one flight leg to avoid having to refuel at an intermediate airport. Airlines might do this if the costs on the outbound leg of the increased fuel burn from carrying more fuel weight are greater than the additional costs associated with refuelling at the intermediate airport. As such, this mechanism is not important for the UK ETS, because the location where the fuel was taken on board is not a factor in UK ETS costs. Tankering still may take place in response to higher fuel prices at individual airports, and airlines may choose to do this type of tankering less often when carbon prices increase. Reduction in tankering is included in AIM as one of the

---

[188] SimpleFlying, 2021.

operational strategies[189] that airlines can adopt if cost-effective, but uptake of this measure is not substantially different across the different UK ETS options modelled here.

6.5.2 Changes in passenger behaviour

6.5.2.1 Destination choice

Faced with increasing ticket price to some destinations, passengers may choose alternative destinations instead. The impact of destination choice on carbon leakage is difficult to calculate, because it is different for different destinations. If UK travellers choose a nearer destination which has lower flight costs due to the shorter flight distance, or switch modes, this is likely to lead to negative leakage (emissions reductions both within and outside the policy area). If UK travellers choose a more distant destination which has lower UK ETS flight costs because it is outside the EEA, this will likely lead to positive leakage (lower emissions inside the policy area, higher emissions outside, potentially resulting in an overall increase in global aviation CO_2). For travellers originating from other countries, destination switching from a UK to a non-UK destination will always lead to positive leakage. Similarly, the effect on competitive disadvantage is different for different destinations but, because a switch away from UK inbound trips to other locations will tend to favour non-UK airlines, there is likely to be a net disadvantage effect for UK airlines and airports.

Destination choice is mainly a factor for tourism and depends critically on uncertain future factors such as marketing, loyalty and public perception.[190] As such, impacts on destination choice due to changes in carbon price may be difficult to distinguish from other effects. As well as choosing where to holiday, tourists also choose when to travel, how long to stay, what activities they would like to do, and how much they are willing to spend on accommodation, food and activities, and these choices also interact with the choice of where to go and the cost of getting there (portfolio decisions; e.g. Oppewal et al., 2015). For example, the existence of low-cost carrier flights to a destination has been shown to influence student holiday choice (Grigolon et al. 2012). Because of the hedonistic character of tourism choices, some studies have argued that increasing holiday price may act to increase demand under some circumstances[191].

For case of the UK ETS, UK tourists to EEA destinations, and EEA tourists to UK destinations are likely to be affected. In 2019, by far the most popular destination for UK-originating tourists was Spain, accounting for nearly 20% of UK-originating trips[192], and 71% of UK-originating international holiday trips were to EU countries. 60% of UK-arriving tourists in 2019 were from EU countries, with the US, France and Germany the most-represented countries. Because the Canary Islands, Azores and Madeira are EU outermost regions, holiday trips from the UK to and from these regions will be unaffected. However, for other holiday destinations the difference in costs between a UK ETS scenario and no UK ETS may be non-

---

[189] See e.g. Schäfer et al., 2016, pp. 412-417.

[190] E.g. Chi & Qu, 2008; Nicolau & Más, 2021.

[191] Nicolau & Más, 2021

[192] ONS, 2021.

negligible, and becomes greater with increasing trip distance. Table 20 shows the typical change in carbon costs per passenger for the example of flights between the UK and Greece, compared to typical year-2019 spending abroad of £680 for holidays to Greece by UK travellers (ONS, 2019). As one of the most distant EEA destinations for UK travellers, Greece is likely to be more affected than most other EEA destinations. Destinations themselves may respond to changes in demand from increased flight costs, for example by offering discounts on accommodation, which means that this is likely an upper limit on the change in holiday costs.

Table 20. Impact on holiday price of UK-Greece flights by policy option, 2030

Policy Option	Change in carbon costs per passenger, year 2015 GBP	As a fraction of current typical holiday spending, %
Options E2	11.7	1.7
Options E4	12.9	1.9
Options E6	12.9	1.9
Options L2	6.0	0.9
Options L4	6.6	1.0
Options H2	17.8	2.6
Options H4	19.4	2.9

Similarly, changing destination is only one way that tourists may respond to changes in flight costs. Outcomes from an EC survey[193] of European tourists are shown in Table 21. For EU27 tourists in general, reducing holiday length and cheaper accommodation were generally prioritised over changing destination. However, UK tourists were more willing to travel to a different destination.

Table 21. Passenger survey ranking of ways to reduce holiday cost, from EC (2009)

	Ranked most important EU27 (UK)	Ranked second most important EU27 (UK)
Reduce length of holiday	25% (17%)	15% (17%)
Cheaper accommodation	19% (19%)	10% (22%)
Change destination	16% (26%)	12% (12%)
Fewer holidays	13% (15%)	10% (12%)
Cheaper transport method	6% (7%)	11% (14%)
Holiday in off-peak season	9% (10%)	7% (10%)

---

[193] European Commission, 2009a.

Other	8%	6%

An indication of overall impacts on tourism from cost changes is given in research by UNWTO[194] on fuel price impacts. This found limited impact on tourism from oil price shocks, due to the small overall resulting change in total holiday cost (<5%) of oil price-linked changes in airfare. If similar behavioural impacts could be expected from the UK ETS, this would suggest limited differences between the different UK ETS scenarios modelled here. However, because fuel price changes apply to all origin-destination pairs (with some differences by airline due to different hedging strategies), but UK ETS carbon price changes apply to a smaller subset of UK origin-destination destination pairs, these outcomes are more applicable to the case of UK-originating tourists than tourists from other countries visiting the UK. Similarly, Tol (2007) apply a destination choice model for international travellers at global carbon prices of up to £170/tCO_2 at constant total passenger number, finding up to around a 1% reduction in UK international tourism arrivals. However, this includes reductions in long-distance tourism demand which would be unaffected in a UK ETS scenario and so again is a likely upper limit.

6.5.2.2 Substitute aviation for another activity outside the policy area which produces non-priced carbon emissions

Different UK ETS options have the potential to change how much UK residents, and residents of other countries, spend on air travel. In the case that people spend less of their income on air travel, they may choose to spend more on other activities and, if these activities are outside the policy area and/or not covered by carbon emissions policy, this may lead to leakage.

The UK ETS options investigated typically both increase the cost of an individual air ticket and reduce the number of tickets bought. This leads to both positive and negative impacts on per capita aviation spending which partially cancel out, leaving relatively small net changes. The most common outcome in the nominal case model runs is an overall increase in average UK per capita aviation spending. For the highest carbon price nominal case options (e.g. Options H2, H4) this increase can be up to around £0.90, or 0.16%. Under combinations of uncertain parameters likely to result in high ticket prices, as examined in the model sensitivity case runs, per capita average aviation spending can be up to £2.7 higher (0.42%).

The impact of changes in per capita aviation spending has previously been examined with AIM via the calculation of per-capita spending on aviation which was then used as input to a wider macroeconomic model[195]. That analysis suggested that levels of variation close to those seen in the nominal case model runs in this study had minimal impact on total CO_2 from non-aviation activities, and that the size of those impacts was much smaller than the level of uncertainty involved in projecting spending on different activities. The impact on emissions outside the scope of the UK ETS, EU ETS or other related carbon policy is likely to be even smaller. Similarly, for passengers originating outside the UK, average

---

[194] UNWTO, 2006.

[195] ICF et al., 2020.

changes in per capita aviation spending due to UK ETS changes are extremely small (under 0.05% even where combinations of uncertain parameters likely to result in high ticket prices are used).

7 CONCLUSIONS

The qualitative and quantitative analyses both examined free allocation policy. The analyses had a number of shared findings:

- Increasing the rate of free allocation phase-out reduces the protection against competitive disadvantage, decreasing airline profitability and increasing risk of market exit.
- The profitability of regional airlines is more sensitive to changes in UK ETS free allocation design compared to international airlines, as proportionally more of regional airlines' flights are captured by the policy.
- Updates to the activity data would likely reduce the level of shielding to regional airlines relative to international airlines.

We summarise results below, first for the qualitative assessment and then for the quantitative modelling.

7.1.1.1 Qualitative assessment of design options

The assessment highlighted the trade-off between abatement and competitiveness: ETS is an additional cost item designed to incentivise abatement where it is most cost-effective to do so. **If the cost to airlines of UK ETS compliance increases, all else equal, this will likely increase incentives to reduce emissions** both within and outside the policy scope, **and reduce the competitiveness of the UK as an aviation market**. The magnitude of the loss of competitiveness depends on the size of the costs imposed by the ETS, the cost of aviation decarbonisation investments, and the ability of airlines to withstand reduced profitability and remain in the UK aviation market.

Free allocation can be used in theory to offset the impacts of higher costs from the UK ETS and affects airlines' business models in a way that is distinct from the carbon price, but in practice these impacts are subject to caveats. Free allowances do not impact airlines' marginal costs and retain the marginal decarbonisation incentive arising from the UK ETS. Free allowances do increase total revenue. Where airlines participate in the market with low profitability, free allowances will increase the likelihood that those airlines can remain in the UK aviation market. In practice, there is a spectrum of financial difficulty that may lead airlines to adjust scale rather than fully exit the market. Under some circumstances, where airlines operate low profitability routes that may otherwise not be backfilled, free allocation may increase competition in the market by increasing the number of players in the market, leading to increased capacity.

The analysis finds that **there is minimal risk of a trade-off between strengthening abatement incentives and reducing carbon leakage**, under the current scope of the UK ETS due to the symmetric nature of aviation itineraries. This result draws on the findings of the quantitative modelling in this study: in general a reduction in emissions within the policy area is associated with a reduction in emissions outside the policy area. This finding is specific to aviation and the current UK ETS scope, as other sectors that do not have the same symmetries can face a trade-off between achieving decarbonisation within the policy area and mitigating carbon leakage.

Free allowances have the potential to create competitive distortions between airlines within the UK aviation market. For example, particular airlines may receive a proportionately larger or smaller share of free allowances relative to the scale of their current operations, as the UK ETS free allocation is currently predominantly based on 2010 activity data. However, these distortions can be reduced by combining design features such as reserve permits to support market competition (e.g. reserves for new entrants or fast growers) or by updating activity data baseline years to reflect current market conditions.

In updating free allocation to more closely reflect current market conditions, on a one-off or regular basis, there is a risk of greater loss of competitiveness among regional airlines given that they have seen lower growth relative to the market average in the last decade. Regional airlines are likely to be relatively sensitive to free allocation policy, as a large portion of their operations fall under UK ETS scope. If maintaining the profitability of regional airlines contributes to government objectives, then the risk to regional airlines' profitability could be mitigated by defining short-haul and medium-haul subsectors within the free allocation mechanism to reflect that short-haul routes are more emissions-intensive, as take-off and landing form a larger proportion of the flight.

7.1.1.2 Quantitative modelling of policy options

The qualitative modelling in the report identified key characteristics of the UK ETS which could affect carbon leakage and competitive disadvantage outcomes for UK airlines and airports. In parallel, the quantitative modelling assessed outcomes from a smaller number of combinations of these characteristics in more detail. Central-case and sensitivity model runs were carried out for a set of 20 policy scenarios combining different UK ETS design options. These were chosen on the basis of combinations of:

- UK ETS carbon price;
- The methodology used for interaction between the UK ETS and CORSIA; and
- UK ETS free allocation methodology.

Several key conclusions arose from this modelling. These relate both to general likely UK ETS outcomes across all policy options, and to the impact in outcomes that changing specific UK ETS design options may have.

With regard to general UK ETS outcomes, we conclude that:

Under nearly all combinations of policy options, CO_2 emissions are projected to decrease both inside and outside UK ETS scope compared to a no UK ETS case. This is because the most prominent impact of the UK ETS on aviation is to increase airline costs and ticket prices on flights from the UK to EEA countries. Most passengers on these routes are flying round-trip journeys with a return journey in the opposite direction, so demand and emissions decrease in both directions. This means that leakage is almost always negative[196]. However, the vast majority of emissions changes outside the UK ETS policy area are on EU ETS or CORSIA routes[197]. In practice, these changes will reduce airline obligations under the EU ETS and/or CORSIA. For example, emissions on EEA-UK flights are covered by the EU ETS and count towards total EU ETS emissions. For a given year, total EU ETS emissions are capped at a set value. Where the UK ETS causes reductions in emissions on these flights, this means that less emissions mitigation is required elsewhere in the EU ETS (by an amount equal to the reduction in flight emissions). As such, the net emissions impact outside the UK ETS policy area is likely close to zero across all policy options.

None of the different combinations of UK ETS design options assessed produces substantially different outcomes between UK and non-UK airlines that are in competition with each other. As such, **we would not expect UK airlines to be significantly disadvantaged compared to their non-UK competitors under any of the options assessed here**.

The absolute level of impacts differs by type of airline. UK regional airlines have a larger fraction of their route network covered by the UK ETS than low-cost carriers or network airlines. As such, they are likely to be more affected by changes to the UK ETS which increase airline costs or reduce airline revenues (e.g. increases in carbon price or reductions in free allowances). Network airlines have more flights on intercontinental routes where the UK ETS does not apply. **As such, the impact of the UK ETS on network airline costs is projected to be smaller than for other airline types, as a proportion of their total costs.** However, regional airlines may have a greater ability to pass through costs onto ticket prices. This is because they typically operate routes from smaller airports without capacity constraints, and estimates of cost pass-through are typically higher for these types of route.

Similarly, **we do not project a large impact on the number of passengers transferring through UK hub airports** from any of the UK ETS options examined here. This is because most of these passengers are travelling on intercontinental journeys for which the UK ETS has only a small (or no) impact on costs. Because we also assume that cost pass-through is lower at congested airports, we project relatively little airport-level demand or revenue impact in general for UK hub airports. **Impacts on airport passenger demand and profits are projected to be higher for airports outside London.** This is because airports outside London are less likely to be congested (higher cost passthrough, leading to larger changes in ticket price) and have fewer intercontinental flights (so a higher proportion of their flights are covered by the UK ETS).

For the relative impacts of the different UK ETS characteristics examined, we find:

UK ETS carbon price has the largest impact on outcomes of the different characteristics examined. **Higher carbon prices are associated with greater reductions in demand and greater and earlier adoption of alternative**

---

[196] Negative leakage means that a CO_2 emissions decrease inside the policy area is associated with a CO_2 emissions decrease outside the policy area.

[197] ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) scheme applies on international routes between CORSIA-participating countries (apart from routes covered by the EU ETS). This includes most UK arriving and departing intercontinental flights.

technologies and fuels and greater reductions in demand. For example, under mid-range input assumptions for uncertain future trends, the modelling suggests that passenger aircraft tonne-km on UK-EEA routes is 0.9-3.4% lower than in a no UK ETS scenario, depending mainly on carbon price. Higher carbon prices are also associated with larger decreases in aviation emissions both inside and outside the policy area. At low carbon prices, direct emissions decreases both inside and outside the policy area may be small (under 0.25 $MtCO_2$ at a global level under mid-range input assumptions for uncertain future trends). **The absolute level of UK ETS carbon price is more important in determining outcomes than the relative level of the UK ETS carbon price compared to the EU ETS carbon price.** This is because impacts which depend on relative carbon prices (for example, passengers choosing to transfer via hubs in EEA countries rather than in the UK) are relatively small compared to those which depend on absolute carbon prices (for example, reductions in UK-EEA passenger demand for direct flights).

The different CORSIA interaction options have a smaller impact on airline costs and operations. For example, the combination of UK ETS carbon prices equal to EU ETS carbon prices and a range of different CORSIA interaction options result in reductions in UK-EEA passenger flight tonne-km of between 1.8 and 2%. Six potential CORSIA interaction options were identified in DfT’s 2021 consultation on how the UK ETS and CORSIA could interact (Options 1-6). Recognising that there are a wide range of options for CORSIA and UK ETS interaction that might be taken forward, we selected three options (Options 2, 4 and 6) for modelling from among those included in DfT’s consultation. This was done simply as a proportionate and broadly representative means of illustrating the range of impacts that the wide variety of interaction options could have. Fully applying CORSIA and the UK ETS on UK-EEA routes (Option 4) would require airlines operating on these routes to both surrender UK ETS allowances and purchase CORSIA eligible units for a proportion of their emissions on these routes. This is the highest-cost option for airlines and has the largest impact on demand. Reducing airlines’ UK ETS obligations to account for their CORSIA obligations on UK-EEA routes (Option 2) reduces average airline carbon costs on these routes, though outcomes may be dependent on the exact design of Option 2. This is because CORSIA carbon prices are below UK ETS carbon prices and are forecast to remain so for the foreseeable future. If CORSIA is not applied at all on UK-EEA routes (Option 6), costs are likely to be similar to those in Option 4, again because CORSIA carbon prices are projected to be relatively small.

Free allowance allocation impacts primarily on the balance of airline operating costs and airline revenues. **Yearly cost changes in all phase-out cases are projected to remain below those airlines have experienced in recent years due to fluctuations in fuel price.** We assume that airlines set ticket prices based on marginal costs; potential deviations from this assumption are examined further in the qualitative assessment. This means that changes in free allocation do not have a significant impact on carbon leakage or on route-level competitive disadvantage in model outcomes. However, they do affect airline profitability. **If the free allowance allocation methodology remains as at present, we project that airline increases in carbon costs after adjustment for free allowances will typically be similar to the amount of carbon costs they are able to pass through onto ticket prices after the pandemic recovery period**, i.e., airline profitability would be similar to a case without the UK ETS in this specific case. If free allowances are phased out, under the assumptions used in this study it is likely that airline profitability (for both UK and non-UK airlines on UK ETS routes) will decrease. More rapid phase-outs increase the rate at which airline costs change per year, increasing the risks to participating airlines of exiting the market. Changing free allowance allocation to a more recent baseline mainly acts to shift free allowances from UK domestic to international routes, because international demand has grown more rapidly than domestic demand since the current baseline was established; however, the exact impact is uncertain due to uncertainties in how airline networks will develop.

8 LIST OF REFERENCES

Abate, M., Christidis, P. & Purwanto, A., 2020. Government support to airlines in the aftermath of the COVID-19 pandemic. Journal of Air Transport Management, 89, 101931.

Aberdeen International Airport Limited, 2020. Annual Report and Financial Statements for the year ended 31 December 2019.

Abrell, J., Ndoye Faye, A. and Zachmann, G., 2011. Assessing the impact of the EU ETS using firm level data (No. 2011/08). *Bruegel working paper.*

Acemoglu, D., Aghion, P., Bursztyn, L., & Hemous, D. (2012). "The environment and directed technical change." *American economic review*, 102(1): 131-66.

Acworth, W., Kardish, C. and Kellner, K., 2020. Carbon Leakage and Deep Decarbonization: Future-proofing Carbon Leakage Protection. *Berlin: ICAP. June*.

Åhman, M., Nilsson, L. J., & Johansson, B. (2017). "Global climate policy and deep decarbonization of energyintensive industries." *Climate Policy*, 17(5): 634-649.

Airbus, 2019. Global Market Forecast 2019-2038. https://www.airbus.com/aircraft/market/global-market-forecast.html

Airbus, 2021. ZEROe. https://www.airbus.com/innovation/zero-emission/hydrogen/zeroe.html.

Albalate, D., Bel, G., & Fageda, X., 2015. 'Competition and cooperation between high-speed rail and air transportation services in Europe'. *Journal of Transport Geography*, 42, 166-174.

Albers, S., Bühne, J.A. and Peters, H., 2009. Will the EU-ETS instigate airline network reconfigurations?. *Journal of Air Transport Management*, 15(1), pp.1-6.

Alderighi, M., Cento, A., Nijkamp, P., & Rietveld, P., (2012). 'Competition in the European aviation market: the entry of low-cost airlines'. *Journal of Transport Geography*, 24, 223-233.

Aldy, J.E. and Pizer, W.A., 2015. The competitiveness impacts of climate change mitigation policies. *Journal of the Association of Environmental and Resource Economists*, 2(4), pp.565-595.

Allaire, D., Noel, G., Willcox, K., & Cointin, R., 2014, 'Uncertainty quantification of an Aviation Environmental Toolsuite'. *Reliability Engineering and System Safety*, 126, 14-24.

Ambec, S., Cohen, M.A., Elgie, S. and Lanoie, P., 2013. The Porter hypothesis at 20: can environmental regulation enhance innovation and competitiveness?. *Review of environmental economics and policy*, 7(1), pp.2-22.

Anger, A., & Köhler, J., 2010. ‘Including aviation emissions in the EU ETS: Much ado about nothing? A review’. *Transport Policy*, 17(1), 38-46.

Arroyo-Currás, T., Bauer, N., Kriegler, E., Schwanitz, V., Luderer, G., Aboumahboub, T., Giannousakis, A. & Hilaire, J., 2015. Carbon leakage on a fragmented climate regime: the dynamic response of global energy markets. Technological Forecasting and Social Change, 90(A), 192-203.

ATA and Clarity, 2018. The carbon leakage and competitiveness impacts of carbon abatement policy in aviation. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/763260/carbon-leakage-report.pdf

ATA and Ellondee, 2018. Understanding the potential and costs for reducing UK aviation emissions. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/785685/ata-potential-and-costs-reducting-emissions.pdf

Bann, S., Malina, R., Staples, M., Suresh, P., Pearlson, M., Tyner, W., Hileman, J., & Barrett, S., 2017. ‘The cost of production of alternative jet fuel: a harmonized stochastic assessment’. *Bioresource Technology*, 227, 179-187.

Bauer, N., Bosetti, V., Hamdi-Cherif, M., Kitous, A., McCollum, D., Méjean, A., Rao, S., Turton, H., Paroussos, L., Ashina, S., Calvin, K., Wada, K. & van Vuuren, D., 2015. CO_2 emission mitigation and fossil fuel markets: Dynamic and international aspects of climate policies. Technological Forecasting and Social Change, 90(A), 243-256.

Behrens, C., & Pels, E. (2012). ‘Intermodal competition in the London–Paris passenger market: High-Speed Rail and air transport’. *Journal of Urban Economics*, 71(3), 278-288.

BEIS, 2019. Fossil Fuel Price Assumptions. https://www.gov.uk/government/publications/fossil-fuel-price-assumptions-2019

BEIS, 2020a. ‘UK Business Competitiveness and the Role of Carbon Pricing: An assessment of the determinants of business competitiveness and the role of carbon pricing policy in the UK’. BEIS Research Paper Number 2020/017. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/911247/UK_Business_Competitiveness_and_the_Role_of_Carbon_Pricing_report.pdf

BEIS, 2020b. The Future of UK Carbon Pricing Impact Assessment. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/889038/The_future_of_UK_carbon_pricing_impact_assessment.pdf

BEIS, 2020c. UK Business Competitiveness and the Role of Carbon Pricing. BEIS Research Paper Number 2020/017.

BEIS, 2021a. Guidance: Participating in the UK ETS. https://www.gov.uk/government/publications/participating-in-the-uk-ets/participating-in-the-uk-ets

BEIS, 2021b. UK ETS aviation allocation table. https://www.gov.uk/government/publications/uk-ets-aviation-allocation-table

BEIS, 2021c. Final UK greenhouse gas emissions national statistics. https://data.gov.uk/dataset/9568363e-57e5-4c33-9e00-31dc528fcc5a/final-uk-greenhouse-gas-emissions-national-statistics

BEIS, 2021d. Carbon prices and sensitivities 2010-2100 for appraisal. https://webarchive.nationalarchives.gov.uk/ukgwa/20210728004418/https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

BEIS, 2021e. Net Zero Strategy: Build Back Greener. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1028157/net-zero-strategy.pdf

Berghöfer, B. & Lucey, B., 2014. Fuel hedging, operational hedging and risk exposure - Evidence from the global airline industry. International Review of Financial Analysis, 34, 124-139.

Birmingham Airport Holdings Limited, 2020. Annual Report and Consolidated Financial Statements for the year ended 31 March 2020.

Boeing, 2017. World Air Cargo Forecast. https://www.boeing.com/commercial/market/cargoforecast/.

Boeing, 2020. Commercial Market Outlook 2020-2039. https://www.boeing.com/commercial/market/commercial-market-outlook/

Boeters, S., & Bollen, J., 2012. 'Fossil fuel supply, leakage and the effectiveness of border measures in climate policy'. CBP discussion paper 215. Netherlands Bureau for Economic Policy Analysis, Den Haag.

Borenstein, S. and Rose, N., 2014. 'How airline markets work… or do they? Regulatory reform in the airline industry', in Rose, N. (ed.), *Economic Regulation and Its Reform: What Have We Learned?*, University of Chicago Press, Chicago.

Branger, F. and Sato, M., 2017. Solving the clinker dilemma with hybrid output-based allocation. *Climatic change*, *140*(3-4), pp.483-501.

Brons, M., Pels, E., Nijkamp, P., & Rietveld, P., 2002. 'Price elasticities of demand for passenger air travel: a meta-analysis'. *Journal of Air Transport Management*, 2002, 165-175.

Brussels Airport Company NV, 2019. Annual Investor Call 2019.

Bruyn, S.M., Nelissen, D. and Koopman, M.J., 2013. Carbon leakage and the future of the EU ETS market: Impact of recent developments in the EU ETS on the list of sectors deemed to be exposed to carbon leakage. CE Delft.

Budd, L. & Ison, S., 2017. The role of dedicated freighter aircraft in the provision of global airfreight services. Journal of Air Transport Management, 61 34-40.

Burke, J., Byrnes, R. and Fankhauser, S., 2019. How to price carbon to reach net-zero emissions in the UK. Policy Report, London School of Economics, London.

Calel, R. and Dechezleprêtre, A., 2016. Environmental policy and directed technological change: evidence from the European carbon market. *Review of economics and statistics*, 98(1), pp.173-191.

Cames, M., Harthan, R., Füssler, J., Lazarus, M., Lee, C., Erickson, P., & Spalding-Fecher, 2016. How additional is the Clean Development Mechanism? https://ec.europa.eu/clima/sites/clima/files/ets/docs/clean_dev_mechanism_en.pdf

Camilleri, M., 2018. Airline Schedules Planning and Route Development. In *Travel Marketing, Tourism Economics and the Airline Product* (Chapter 11, pp. 179-190) Cham, Switzerland: Springer Nature.

CCC, 2019. Net Zero: The UK's Contribution to Stopping Global Warming. https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/

CCC, 2020. The Sixth Carbon Budget: Aviation. https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Aviation.pdf

Centre for Aviation, 2021. 'Aircraft lessor fleet falls disproportionately'. https://centreforaviation.com/analysis/reports/aircraft-lessor-fleet-falls-disproportionately-lease-rates-plummet-530864

Chao, C., & Hsu, C., 2014. Cost analysis of air cargo transport and effects of fluctuations in fuel price. *Journal of Air Transport Management*, 35, 51-56.

Chi, C., & Qu, H., 2008. 'Examining the structural relationships of destination image, tourist satisfaction and destination loyalty: an integrated approach'. *Tourism Management*, 29(4), 624-636.

Civil Aviation Authority (CAA), 2000-2019. UK Airport Data. https://www.caa.co.uk/data-and-analysis/uk-aviation-market/airports/datasets/uk-airport-data/

Civil Aviation Authority (CAA), 2011. The Airport Charges Regulations 2011. https://www.caa.co.uk/Commercial-industry/Airports/Economic-regulation/Competition-policy/Airport-charges-regulations/

Civil Aviation Authority (CAA), 2020. UK Airline Data. https://www.caa.co.uk/Data-and-analysis/UK-aviation-market/Airlines/Datasets/Airline-data/

Civil Aviation Authority (CAA), 2021a. Operating License Holders. https://www.caa.co.uk/Commercial-industry/Airlines/Licensing/Licence-types/Airline-licence-holders

Civil Aviation Authority (CAA), 2021b. Aircraft Type and Utilisation: Individual Airlines January 2021. https://www.caa.co.uk/uploadedFiles/CAA/Content/Standard_Content/Data_and_analysis/Datasets/Airline_data/2021/January/Table_08_2_Aircraft_Type_and_Utilisation_Individual_Airlines.pdf

Civil Aviation Authority (CAA), 2021c. Information about Airport charges regulations 2011. https://www.caa.co.uk/Commercial-industry/Airports/Economic-regulation/Competition-policy/Airport-charges-regulations/

CE Delft, 2005. 'Giving wings to emission trading Inclusion of aviation under the European emission trading system (ETS): design and impacts', Report for the European Commission.

Coase, R.H., 1960. The problem of social cost. *In Classic papers in natural resource economics* (pp. 87-137). Palgrave Macmillan, London.

CPLC, 2019. Report of the High-Level Commission on Carbon Pricing and Competitiveness. Washington D.C.: World Bank Group.

Cranfield University, 2011. Fuel and Air Transport: report for the European Commission. https://ec.europa.eu/transport/sites/default/files/modes/air/doc/fuel_report_final.pdf

Cui, J., Zhang, J. and Zheng, Y., 2018, May. Carbon pricing induces innovation: evidence from China's regional carbon market pilots. In *AEA Papers and Proceedings* (Vol. 108, pp. 453-57).

Davidson, L., Littleford, C., & Ryley, T., 2014. 'Air travel attitudes and behaviours: The development of environment-based sectors'. *Journal of Air Transport Management*, 36, 13-22.

Deloitte, 2016. Aircraft order backlog analysis, June 2016. https://www2.deloitte.com/content/dam/Deloitte/ie/Documents/ConsumerIndustrialProducts/ie-manufacturing-aircraft-order-backlog-analysis.pdf.

Derigs, U., & Illing, S., 2013. 'Does the EU ETS instigate Air Cargo network reconfiguration? A model-based analysis'. *European Journal of Operational Research,* 225(3), 518-527.

De Vivo, N. and Marin, G., 2018. How neutral is the choice of the allocation mechanism in cap-and-trade schemes? Evidence from the EU-ETS. *Argomenti*, (9), pp.21-44.

DfT, 2017. UK Aviation Forecasts 2017. https://www.gov.uk/government/publications/uk-aviation-forecasts-2017

DfT, 2021a. Implementing the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). https://www.gov.uk/government/consultations/implementing-the-carbon-offsetting-and-reduction-scheme-for-international-aviation/implementing-the-carbon-offsetting-and-reduction-scheme-for-international-aviation-corsia#policy-options-for-interaction-between-corsia-and-a-uk-emissions-trading-scheme

DfT, 2021b. Jet Zero Consultation: Evidence and Analysis. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1002163/jet-zero-consultation-evidence-and-analysis.pdf

DfT, 2021c. Sustainable aviation fuels mandate. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1005382/sustainable-aviation-fuels-mandate-consultation-on-reducing-the-greenhouse-gas-emissions-of-aviation-fuels-in-the-uk.pdf

Dray, L., 2013. ‘An analysis of the impact of aircraft lifecycles on aviation emissions mitigation policies’. *Journal of Air Transport Management, 28,* 62-69.

Dray, L., & Doyme, K., 2019. ‘Carbon leakage in aviation policy’. *Climate Policy*, 19(10),1284-1296.

Dray, L., Doyme, K., & Schäfer A.W., 2020. ‘Airline profit maximisation, cost passthrough, and scarcity rents in capacity-constrained aviation systems’, *Journal of Transport Economics and Policy*, 54(4), 244-266.

Dray, L., Evans, A., Reynolds, T., Schäfer, A., Vera-Morales, M., & Bosbach, W., 2014. ‘Airline fleet replacement funded by a carbon tax: an integrated assessment’. *Transport Policy*, 34, 75-84.

Dray, L., Krammer, P., Doyme, K., Wang, B., Al Zayat, K., O’Sullivan, A., & Schäfer A., 2019. ‘AIM2015: Validation and initial results from an open-source aviation systems model’. *Transport Policy,* 79, 93-102.

Dray, L. & Schäfer A., 2021. Initial long-term scenarios for Covid19's impact on aviation and implications for climate policy. Transportation Research Record, in press.

Dray, L., Schäfer, A., & Al Zayat, K., 2018. ‘The global potential for CO2 emissions reduction from jet engine passenger aircraft’. *Transportation Research Record*, 2672(23), 40-51;

Duddu, P. 2020. ‘Airbus vs Boeing: a tale of two rivals’. *Aerospace Technology.*

EASA, 2019. The EU Emissions Trading System. https://www.easa.europa.eu/eaer/topics/market-based-measures/the-eu-emissions-trading-system

Easyjet, 2021. Our Fleet. https://www.easyjet.com/en/help/boarding-and-flying/our-fleet

Edinburgh Airport Limited, 2020. Annual Report and Financial Statements for the year ended 31 December 2019.

Efthymiou, M. and Papatheodorou, A., 2019. EU Emissions Trading scheme in aviation: Policy analysis and suggestions. *Journal of Cleaner Production*, 237, p.117734.

EIA, 2021. US Gulf Coast Kerosene-type Jet Fuel Spot Price. https://www.eia.gov/dnav/pet/hist/eer_epjk_pf4_rgc_dpgD.htm.

Elliott, D., & Cuttle, C., 2019. ‘Estimating the Congestion Premium at Heathrow’, A report prepared for Heathrow.

Environment Agency, 2021. UK Emissions Trading Scheme for aviation: how to comply. https://www.gov.uk/guidance/uk-emissions-trading-scheme-for-aviation-how-to-comply

Ernst & Young and York Aviation, 2007. Analysis of the EC Proposal to Include Aviation Activities into the Emission Trading Scheme. https://www.verifavia.com/bases/ressource_pdf/120/AM-Ernst-Young-2007-Full.pdf

Ernst & Young and York Aviation, 2008. ‘Inclusion of aviation in the EU ETS: cases for carbon leakage’, Report for AEA. https://www.verifavia.com/bases/ressource_pdf/112/AN-EY-FULL-TEXT-OCT08.pdf

European Commission, 2009a. Europeans and Tourism – Autumn 2009 analytical report. https://ec.europa.eu/commfrontoffice/publicopinion/flash/fl_281_en.pdf

European Commission, 2009b. Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008 amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0101

European Commission, 2013a. ‘Impact Assessment’, amending Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowances trading within the Community, in view of the implementation by 2020 of an international agreement applying a single global market-based measure to international aviation emissions.

European Commission, 2013b. Trends to 2050: Reference Scenario 2013. https://ec.europa.eu/energy/sites/ener/files/documents/trends_to_2050_update_2013.pdf

European Commission, 2017. Handbook on the external costs of transport. https://ec.europa.eu/transport/sites/transport/files/studies/internalisation-handbook-isbn-978-92-79-96917-1.pdf

European Commission, 2019. Revision for Phase 4 (2021-2030). https://ec.europa.eu/clima/policies/ets/revision_en

European Commission, 2021a. EU ETS Data viewer. https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1

European Commission, 2021b. Allocation to Aviation. https://ec.europa.eu/clima/policies/ets/allowances/aviation_en

European Commission, 2021c. Reducing Emissions from Aviation. https://ec.europa.eu/clima/policies/transport/aviation_en

European Commission, 2021d. Proposal for a Regulation of the European Parliament and of the Council, establishing a carbon border adjustment mechanism. https://ec.europa.eu/info/sites/default/files/carbon_border_adjustment_mechanism_0.pdf

EC, 2021e. Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union, Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and Regulation (EU) 2015/757.

EC, 2021f. Proposal for a Regulation of the European Parliament and of the Council on ensuring a level playing field for sustainable air transport. https://ec.europa.eu/info/sites/default/files/refueleu_aviation_-_sustainable_aviation_fuels.pdf

EC, 2021g. Revision of the EU Emission Trading System for Aviation. https://ec.europa.eu/info/files/revision-eu-emission-trading-system-aviation_en

European Commission, 2021h. Questions and Answers - Emissions Trading – Putting a Price on carbon https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3542

European Court of Auditors, 2020. The EU's Emissions Trading System: free allocation of allowances needed better targeting. Luxembourg: Publications Office of the European Union.

European Parliament, 2020. Sustainable Aviation Fuel Briefing. https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/659361/EPRS_BRI(2020)659361_EN.pdf

Eurostat, 2020. Transport tables. https://ec.europa.eu/eurostat/data/database

Evans A., 2008. Rapid Modelling of Airport Delay, 12th Air Transport Research Society (ATRS) World Conference, Athens, Greece, July 6-10.

Evans, A., & Schäfer, A., 2011. 'The impact of airport capacity constraints on future growth in the US air transportation system'. *Journal of Air Transport Management,* 17, 288-295.

Fageda, X. and Teixido-Figueras, J., 2020. Pricing Carbon in the Aviation Sector: Supply Effects of the European Emissions Trading System. Available at SSRN 3600105.

Fearnehough, H., Day, T., Warnecke, C., & Schneider, L., 2018. Marginal costs of CER supply and implications of demand sources. https://www.dehst.de/SharedDocs/downloads/EN/project- mechanisms/Marginal-cost-of-CER-supply.pdf?__blob=publicationFile&v=1

Fell, H., 2015. Comparing policies to confront permit over-allocation. Journal of Environmental Economics and Management, 80, pp.53-68.

Feng, B., Yanzhi, L., & Zuo-Jun, M., 2015. 'Air cargo operations: Literature review and comparison with practices'. *Transportation Research Part C: Emerging Technologies*, 56, 263-280.

Fischer, C., & Fox, A. K. (2007). "Output-based allocation of emissions permits for mitigating tax and trade interactions." *Land economics*, 83(4). 575-599.

Fischer, C., Greaker, M., & Rosendahl, K. E. (2014). "Robust policies against emission leakage: the case for upstream subsidies." CESifo Working Paper, No. 4742. Munich: Center for Economic Studies and Ifo Institute (CESifo).

Flightglobal, 2016. Ascend Online Fleet Database. http://www.ascendworldwide.com/what-wedo/ascend-data/aircraft-airline-data/ascend-online-fleets.html

Flightglobal, 2021. What does Norwegian exit mean for long-haul, low-cost adventure? https://www.flightglobal.com/strategy/what-does-norwegian-exit-mean-for-long-haul-low-cost-adventure/141961.article

Flughafen Zurich AG, 2020. Annual Report 2019.

FOEN, 2019. CO2 statistics: emissions from thermal and motor fuels. https://www.bafu.admin.ch/bafu/en/home/topics/climate/state/data/co2-statistics.html

FOEN, 2020. Linking the Swiss and EU emissions trading systems. https://www.bafu.admin.ch/bafu/en/home/topics/climate/info-specialists/reduction-measures/ets/linking-swiss-eu.html

Francis, G., Dennis, N., Ison, S., & Humphreys, I., 2007. 'The transferability of the low-cost model to long-haul airline operations'. *Tourism Management*, 28(2), 391-398.

Frontier Economics, 2006. Economic consideration of extending the EU ETS to include aviation. A report for the European Low Fare Airline Association.

Gardiner, J., Ison, S., & Humpherys, I., 2005. 'Freight choice airlines' choice of airport: a three-stage process'. *Transport Reviews*, 25(1), 85-102.

GAO, 2014. Impact of Fuel Price Increases on the Aviation Industry. https://www.gao.gov/assets/gao-14-331.pdf.

Gerlagh, R., & Kuik, O., 2007. 'Carbon leakage with international technology spillovers'. FEEM Working Paper No. 33.2007. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=979915

Graham, A., Kremarik, F., & Kruse, W., 2020. 'Attitudes of ageing passengers to air travel since the coronavirus pandemic'. *Journal of Air Transport Management*, 202165.

Graver, B., Rutherford, D. and Zheng, S., 2020. CO2 emissions from commercial aviation: 2013, 2018, and 2019. Int Council Clean Transport, pp.1-36.

Grigolon, A., Kemperman, A. & Timmermans, H., 2012. The influence of low-fare airlines on vacation choices of students: Results of a stated portfolio choice experiment*. Tourism Management*, 33(5), 1174-1184.

Grimm, V. and Ilieva, L., 2013. An experiment on emissions trading: the effect of different allocation mechanisms. *Journal of Regulatory Economics*, 44(3), pp.308-338.

Groupe ADP, 2020. Universal Registration Document and Annual Financial Report 2019.

Gucwa, M. & Schäfer, A., 2013. The impact of scale on energy intensity on freight transportation. Transportation Research Part D, 23, 41-49.

Heathrow Airport Limited, 2020. Annual Report and Financial Statements 2019.

Hepburn, C., Quah, J., & Ritz, R. (2013). 'Emissions trading with profit-neutral permit allocations'. *Journal of Public Economics*, 98C, 85-99.

HM Revenue and Customs, 2019. Rates for Air Passenger Duty. https://www.gov.uk/guidance/rates-and-allowances-for-air-passenger-duty

HM Treasury, 2020. The Green Book: Central Government Guidance On Appraisal And Evaluation.

HM Treasury, 2021. Autumn Budget 2021. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1029973/Budget_AB2021_Print.pdf

IATA, 2007. Estimating Air Travel Demand Elasticities. https://www.iata.org/whatwedo/Documents/economics/Intervistas_Elasticity_Study_2007.pdf

IATA, 2019a. Strong Airline Profitability Continues in 2018. https://www.iata.org/en/pressroom/pr/2017-12-05-01/

IATA, 2019b. Carbon emissions per passenger decrease more than 50% since 1990. https://www.iata.org/en/pressroom/pr/2019-12-12-01/

IATA, 2020. Airline and Location Code Search. https://www.iata.org/en/publications/directories/code-search/

IATA, 2021. Covid19: Airline Industry Financial Outlook Update. https://www.iata.org/en/iata-repository/publications/economic-reports/airline-industry-economic-performance---april-2021---presentation/

IBA, 2021. What Does Aercap's Acquisition of GECAS Mean For Aircraft Leasing? https://www.iba.aero/insight/what-does-aercaps-acquisition-of-gecas-mean-for-aircraft-leasing/

ICAO, 2006. Convention on International Civil Aviation - Doc 7300. https://www.icao.int/publications/pages/doc7300.aspx

ICAO, 2015. What would be the impact of joining CORSIA? https://www.icao.int/environmental-protection/pages/a39_corsia_faq3.aspx

ICAO, 2016. Presentation of Year 2015 Statistical Results. https://www.icao.int/annual-report-2015/Documents/Appendix_1_en.pdf

ICAO, 2017a. Long-term Forecasts of Scheduled Passenger Traffic. https://www.icao.int/sustainability/Pages/GATO2030.aspx

ICAO, 2017b. Airline Operating Costs and Productivity. https://www.icao.int/mid/documents/2017/aviation%20data%20and%20analysis%20seminar/ppt3%20-%20airlines%20operating%20costs%20and%20productivity.pdf

ICAO, 2019a, CORSIA Emissions Unit Eligibility Criteria, https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO_Document_09.pdf

ICAO, 2019b. CORSIA Frequently Asked Questions. https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-FAQs.aspx

ICAO, 2019c. ICAO Environmental Report 2019. https://www.icao.int/environmental-protection/pages/envrep2019.aspx

ICAO, 2019d. Destination Green – The Next Chapter. https://www.icao.int/environmental-protection/pages/ENVrep2019.aspx

ICAO, 2019e. Analysis on the estimation of CO_2 emissions reductions and costs expected to result from CORSIA. https://www.icao.int/environmental-protection/CORSIA/Documents/CAEP_Analysis%20on%20the%20estimation%20of%20CO2%20emissions%20reductions%20and%20costs%20from%20CORSIA.pdf

ICAO, 2020a. ICAO Council agrees to the safeguard adjustment for CORSIA in light of COVID-19 pandemic. https://www.icao.int/Newsroom/Pages/ICAO-Council-agrees-to-the-safeguard-adjustment-for-CORSIA-in-light-of-COVID19-pandemic.aspx

ICAO, 2020b. Presentation of Year 2019 Statistical Results. https://www.icao.int/annual-report-2019/Documents/ARC_2019_Air%20Transport%20Statistics.pdf

ICAO, 2020c. Effects of Novel Coronavirus on Civil Aviation: Economic Impact Analysis. https://www.icao.int/sustainability/Documents/COVID-19/ICAO_Coronavirus_Econ_Impact.pdf

ICAO, 2021a. CORSIA States for Chapter 3 Pairs. https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_States_for_Chapter3_State_Pairs_Jul2020.pdf

ICAO, 2021b. April 2021 CORSIA Newsletter. https://www.icao.int/environmental-protection/CORSIA/Pages/corsia-newsletter-apr21.aspx

ICAP, 2021. Berlin: International Carbon Action Partnership. https://icapcarbonaction.com/en/

ICCT, 2018. 'CO_2 emissions from commercial aviation, 2018'. ICCT Working Paper 2019-16. https://theicct.org/sites/default/files/publications/ICCT_CO2-commercl-aviation-2018_20190918.pdf

ICCT, 2019a. The Cost of Supporting Alternative Jet Fuels in the European Union. https://theicct.org/sites/default/files/publications/Alternative_jet_fuels_cost_EU_2020_06_v3.pdf.

ICCT, 2019b. Long-term Aviation Fuel Decarbonization: Progress, Roadblocks, and Policy Opportunities. https://theicct.org/sites/default/files/publications/Alternative_fuel_aviation_briefing_20190109.pdf

ICCT, 2020. CO2 Emissions from Commercial Aviation: 2013, 2018 and 2019. https://theicct.org/publications/co2-emissions-commercial-aviation-2020

ICF, ATA, Cambridge Econometrics, HFW, NewClimate, & Starcx, S., 2020. 'Assessment of ICAO's global market-based measure (CORSIA) pursuant to Article 28b and for studying cost passthrough pursuant to Article 3d of the EU ETS Directive'. Report submitted to DG CLIMA.

IEA, 2018. World Energy Statistics, 2018. http://www.iea.org/statistics/

IEA, 2019. Tracking clean energy progress: assessing critical energy technologies for global clean energy transitions. IEA, Paris. https://www.iea.org/topics/tracking-clean-energy-progress

IEA, 2020a. Energy Technology Perspectives. OECD/IEA, Paris.

IEA, 2020b. World Energy Outlook 2020. https://www.oecd-ilibrary.org/energy/world-energy-outlook-2020_557a761b-en

IEA, 2021. Net Zero by 2050: A Roadmap for the Global Energy Sector. https://www.iea.org/reports/net-zero-by-2050

IETA, 2020. Carbon Market Business Brief: Switzerland. https://www.ieta.org/resources/Resources/CarbonMarketBusinessBrief/CarbonMarketBusinessBriefSwitzerland2020.pdf

IMF, 2021. World Economic Outlook: April 2021. https://www.imf.org/en/Publications/WEO/Issues/2021/03/23/world-economic-outlook-april-2021

INFRAS/IWW, 2000. External Costs of Transport: Accident, Environmental and Congestion Costs of Transport in Western Europe. Karlsruhe/Zurich/Paris.

InterVistas, 2007. Estimating Air Travel Demand Elasticities. https://www.iata.org/en/iata-repository/publications/economic-reports/estimating-air-travel-demand-elasticities---by-intervistas/

Ivy Holdco Limited, 2020. Annual Report and the Consolidated and Parent Company Financial Statements for the year ended 31 March 2019

Jaffe, A.B., Newell, R.G. and Stavins, R.N., 2003. Technological change and the environment. In *Handbook of environmental economics* (Vol. 1, pp. 461-516). Elsevier.

Kling, C. and Rubin, J., 1997. Bankable permits for the control of environmental pollution. *Journal of Public Economics*, *64*(1), pp.101-115.

Kopsch, F., 2012. Aviation and the EU Emissions Trading Scheme—Lessons learned from previous emissions trading schemes. Energy Policy, 49, pp.770-773.

Kupfer, F., Kessels, R., Goos, P., Van de Voorde, E., & Verhetsel, A., 2016. The origin–destination airport choice for all-cargo aircraft operations in Europe'. *Transportation Research Part E: Logistics and Transportation Review*, 87, 53-74.

Li, G. (2016). 'The nature of leisure travel demand'. In Aviation and Tourism (pp. 37-50). Routledge.

Lijesen, M. G., Nijkamp, P., & Rietveld, P. (2002). 'Measuring competition in civil aviation'. *Journal of Air Transport Management*, 8(3), 189-197.

Lo, W., Wan, Y., & Zhang, A., 2015. 'Empirical estimation of price and income elasticities of air cargo demand: the case of Hong Kong'. *Transportation Research Part A*, 78, 309-324.

London Luton Airport Operations Limited, 2020. Financial Statements for the year ended 31 December 2019.

Malina, R., McConnachie, D., Winchester, N., Wollersheim, C., Paltsev, S. and Waitz, I.A., 2012. The impact of the European Union emissions trading scheme on US aviation. Journal of Air Transport Management, 19, pp.36-41.

Manchester Airports Group, 2020. Financial Statements. https://www.magairports.com/investor-relations/offerings/financial-statements/.

Maertens, S. (2012). 'Estimating the market power of airports in their catchment areas–a Europe-wide approach'. *Journal of Transport Geography*, 22, 10-18.

Marcu, A., Egenhofer, C., Roth, S. and Stoefs, W., 2013. *Carbon leakage: an overview. CEPS Special Report No. 79, 6 December 2013*.

Marcantonini, C. and Verde, L., 2017. Free allowance allocation in the EU ETS. European University Institute, Florença.

Martin, R., Muûls, M., De Preux, L.B. and Wagner, U.J., 2014. On the empirical content of carbon leakage criteria in the EU Emissions Trading Scheme. Ecological Economics, 105, pp.78-88.

Mayer, R., 2018. 'Airline sustainability and corporate social responsibility'. The Routledge Companion to Air Transport Management, 277.

Mayer, R., & Suau-Sanchez, P., 2019. When the engines are switched off: the impact of European airline bankruptcies on market concentration. 23rd ATRS world conference, Amsterdam, July 2019.

Mayor, K., & Tol, R., 2007. ‘The impact of the UK aviation tax on carbon dioxide emissions and passenger numbers’. *Transport Policy*, 14(6), 507-513.

McKinnon, A., 2007. CO_2 emissions from freight transport: an analysis of UK data. https://www.researchgate.net/profile/Alan-Mckinnon/publication/228801629_CO2_Emissions_from_Freight_Transport_An_Analysis_of_UK_Data/links/57a8bdb508aef20758cd0635/CO2-Emissions-from-Freight-Transport-An-Analysis-of-UK-Data.pdf

McKinsey, 2021. Back to the future? Airline sector poised for change post-COVID19. https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/back-to-the-future-airline-sector-poised-for-change-post-covid-19

Meleo, L., Nava, C.R. and Pozzi, C., 2016. Aviation and the costs of the European Emission Trading Scheme: The case of Italy. *Energy Policy*, 88, pp.138-147.

Mitra, S., & Leon, S. 2014. ‘Discrete choice model for air-cargo mode selection’. *International Journal of Logistics Management*, 25(3), 656-672.

Morrell, P., & Dray, L., 2009. ‘Environmental aspects of fleet turnover, retirement and life cycle’. Final report for the Omega consortium. http://bullfinch.arct.cam.ac.uk/documents/FleetTurnover_CranfieldCambridge.pdf

Morrell, P., & Swan, B., 2006. ‘Airline jet fuel hedging: theory and practice’. *Transport Reviews*, 26, 713-739.

Morrison, J., Bonnefoy, P. & Hansman, R., 2010. Investigation of the Impacts of Effective Fuel Cost Increase on the US Air Transportation Network and Fleet. https://core.ac.uk/download/pdf/4427413.pdf.

Munich Airport, 2020. Integrated Report 2019.

Narassimhan, E., Gallagher, K.S., Koester, S. and Alejo, J.R., 2018. Carbon pricing in practice: A review of existing emissions trading systems. *Climate Policy*, 18(8), pp.967-991.

National Archives, 2020. The Greenhouse Gas Emissions Trading Scheme Order 2020. https://www.legislation.gov.uk/uksi/2020/1265/contents/made

Nava, C.R., Meleo, L., Cassetta, E. and Morelli, G., 2018. The impact of the EU-ETS on the aviation sector: Competitive effects of abatement efforts by airlines. *Transportation Research Part A: Policy and Practice*, 113, pp.20-34.

Nero, G., & Black, J. A., 2000. ‘A critical examination of an airport noise mitigation scheme and an aircraft noise charge: the case of capacity expansion and externalities at Sydney (Kingsford Smith) Airport’. *Transportation Research Part D*, 5(6), 433-461.

Neuhoff, K. et al. (2016). “Inclusion of Consumption of carbon intensive materials in emissions trading–An option for carbon pricing post-2020.” *Climate Strategies*.

http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2016/06/CS-Report.pdf

Nicolau, J. & Más, F., 2021. The influence of distance and prices on the choice of tourism destinations: The moderating role of motivations. *Tourism Management*, 27(5), 996.

Niklaß, M., Dahlmann, K., Grewe, V., Maertens, S., Plohr M. and Scheelhaase, J., 2019. Integration of non-CO_2 effects of aviation under the EU ETS and CORSIA. https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2020-07-28_climatechange_20-2020_integrationofnonco2effects_finalreport_.pdf

Niestadt, M., 2021. The future of regional airports: Challenges and opportunities. European Parliamentary Research Service.

Ohashi, H., Kim, T.-S., Oum, T., & Yu, C., 2005. 'Choice of air cargo transhipment airport: an application to air cargo traffic to/from Northeast Asia. *Journal of Air Transport Management*, 11(3), 149-159.

O'Neill, B. C., Kriegler, E., Riahi, K., Ebi, K., Hallegatte, S., Carter T. R. et al. 2013. 'A new scenario framework for climate change research: The concept of shared socio-economic pathways'. *Climatic Change*, 122(3), 387-400.

ONS, 2021. Travel trends estimates. https://www.ons.gov.uk/peoplepopulationandcommunity/leisureandtourism/datasets/ukresidentsvisitsabroad

OPIS, 2021. April 2021 Global Carbon Offsets Report. https://www.opisnet.com/wp-content/uploads/2021/04/OPISGlobalCarbonOffsetsReport-20210413.pdf

Oppewal, H., Huybers, T., & Crouch, G., 2015. Tourism destination and experience choice: A choice experimental analysis of decision sequence effects. *Tourism Management*, 48, 467-476.

Oum. T., Waters, W., & Yong, J., 1992. 'Concepts of price elasticities of transport demand and recent empirical estimates: an interpretative survey'. *Journal of Transport Economics and Policy*, 26(2), 139-154

Partnership for Market Readiness and International Carbon Action Partnership, 2021. *Emissions Trading in Practice: A Handbook on Design and Implementation*.

Pavlenko, N. Failure to launch: why advanced biorefineries are so slow to ramp up production. https://theicct.org/blog/staff/failure-to-launch-biorefineries-slow-ramp-up

Pizer, W.A. and Popp, D., 2008. Endogenizing technological change: Matching empirical evidence to modeling needs. *Energy Economics*, *30*(6), pp.2754-2770.

Polk, A., & Bilotkach, V. (2013). 'The assessment of market power of hub airports'. *Transport Policy*, 29, 29-37.

Porter, M.E., 1991. Towards a dynamic theory of strategy. *Strategic management journal*, *12*(S2), pp.95-117.

Raffaty, R., & Grubb, M., 2018. Policy brief: how can consumption-based carbon pricing address carbon leakage and competitiveness concerns? *Climate Strategies.* https://climatestrategies.org/wp-content/uploads/2018/05/27916-CPLC-ExecBrief-CarbonPricing-v7.pdf

Ramseur, J.L., 2017. Us carbon dioxide emissions trends and projections: Role of the clean power plan and other factors. *US Congressional Research Service*.

RDC, 2017. RDC Aviation airport and enroute charges databases. http://www.rdcaviation.com

Reguant, M. and Ellerman, A.D., 2008. Grandfathering and the endowment effect: An Assessment in the context of the Spanish National Allocation Plan. *Center for Energy and Environmental Policy Research, Cambridge, Massachusetts*.

Reuters, 2021. Britain's carbon market begins trading at higher prices than EU. https://www.reuters.com/business/sustainable-business/britains-carbon-market-begins-trading-higher-than-eu-prices-2021-05-19/

Reynolds T.G., 2009. Development of Flight Inefficiency Metrics for Environmental Performance Assessment of ATM", 8th USA.Europe Air Traffic Management Research and Development Seminar, Napa, CA, June 29 – July 2.

Reynolds T.G., 2014. 'Air traffic management performance assessment using flight inefficiency metrics'. *Transport Policy, 34,* 63-74.

Reynolds, T., Barrett, S., Dray, L., Evans, A., Köhler, M., Vera-Morales, M., Schäfer, A., Wadud, Z., Britter, R., Hallam, H., & Hunsley, R., 2007. ‚Modelling Environmental and Economic Impacts of Aviation: Introducing the Aviation Integrated Modelling Tool'. In: Proceedings of the 7th AIAA Aviation Technology, Integration and Operations Conference, Belfast, 18–20 September 2007, AIAA-2007-7751.

Richstein, J. C. (2017). "Project-Based Carbon Contracts: A Way to Finance Innovative Low-Carbon Investments." DIW Discussion Papers, No. 1714, DeutschesInstitut für Wirtschaftsforschung (DIW), Berlin.

RoutesOnline, 2018. Monarch one year on – how the market reacted. https://www.routesonline.com/news/29/breaking-news/280794/monarch-one-year-on-how-the-market-reacted/

Roy, R., 2007. 'A cost-effectiveness analysis of local air quality charges at Zurich and Stockholm airports'. In ICAO Environmental Report 2007, ICAO, Montreal, 2007.

Royal Schiphol Group, 2020. Annual Report 2019.

Sabre, 2017. Market Intelligence database. https://www.sabreairlinesolutions.com/images/uploads/AirVision-Market-Intelligence_GDD_Profile_Sabre.pdf

Saghir, J., & Hoekman, B., 2009. Air Freight: A Market Study with Implications for Landlocked Countries. World Bank.

Sartor, O., Pallière, C. and Lecourt, S., 2014. Benchmark-based allocations in EU ETS Phase 3: an early assessment. *Climate Policy*, *14*(4), pp.507-524.

Schäfer A., Barrett, S., Doyme, K., Dray, L., Gnadt, A., Self, R., O'Sullivan, A., Synodinos, A., & Torija, A., 2018. 'Technological, economic and environmental prospects of all-electric aircraft'. *Nature Energy*, 4, 160-166.

Schäfer, A., Evans, A. D., Reynolds, T., & Dray, L. M., 2016. 'Costs of mitigating co2 emissions from passenger aircraft'. *Nature Climate Change*, 6, 412-417.

Scheelhaase, J., Schaefer, M., Grimme, W. and Maertens, S., 2012. Cost impacts of the inclusion of air transport into the European emissions trading scheme in the time period 2012-2020. *European Journal of Transport and Infrastructure Research*, 12(4).

Schneider, L., & Graichen, J., 2020. Should CORSIA be changed due to the COVID-19 crisis? https://www.oeko.de/fileadmin/oekodoc/Should-CORSIA-be-changed-due-to-the-COVID-19-crisis.pdf

SEC, 2006. Impact assessment of the inclusion of aviation activities in the scheme for greenhouse gas emission allowance trading within the Community. https://ec.europa.eu/clima/sites/clima/files/transport/aviation/docs/sec_2006_1684_en.pdf

SimpleFlying, 2021. How much does it cost to paint an aircraft? https://simpleflying.com/aircraft-paint-cost/

Staples, M., Malina, R., Suresh, P, Hileman, J. & Barrett, S., 2018. 'Aviation CO_2 emissions reductions from the use of alternative jet fuels'. *Energy Policy*, 114, 342-354.

Starkie, D. N., 2020. Economic Rents at Heathrow Airport. Available at SSRN 3541027.

Stavins, R.N., 2007. *A US cap-and-trade system to address global climate change.*

Steer, 2018. Assessment of the value of air freight services to the UK Economy. Report for Airlines UK. https://airlinesuk.org/wp-content/uploads/2018/10/Assessment-of-the-value-of-air-freight-services-to-the-UK-economy-Final-Report-v22-Oct-2018-b-SENT.pdf

Sustainable Aviation, 2021. Sustainable Aviation Fuels Road-map. https://www.sustainableaviation.co.uk/wp-content/uploads/2020/02/SustainableAviation_FuelReport_20200231.pdf

Swarbrooke, J., & Horner, S., 2012. Business travel and tourism. Routledge.

Thelle, M. H., & la Cour Sonne, M. 2018. ‘Airport competition in Europe’. *Journal of Air Transport Management*, 67, 232-240.

Tietenberg, T., 2010. *Emissions trading: principles and practice*. Routledge.

Tol, R., 2007. The impact of a carbon tax on international tourism. *Transportation Research Part D*, 12(2), 129-142.

TS Prestwick Holdco Limited, 2020. Annual Report and Financial Statements for the year ended 31 March 2019.

UNWTO, 2006. The impact of rising oil prices on international tourism. https://www.e-unwto.org/doi/pdf/10.18111/9789284410521

US Department of State, 2017. Open Skies Agreements. https://2009-2017.state.gov/e/eb/tra/ata/index.htm

Van Asch, T. et al., 2019. ‘Air cargo and airport competitiveness’. *Journal of Air Transport Studies,* 10(2), 48-75.

Verde, S.F., Teixidó, J., Marcantonini, C. and Labandeira, X., 2019. Free allocation rules in the EU emissions trading system: what does the empirical literature show?. *Climate policy*, 19(4), pp.439-452.

Vivid Economics, 2007. ‘A Study to Estimate Ticket Price Changes for Aviation in the EU ETS’, A report for Defra and DfT, November.

Vivid Economics, 2015. ‘Carbon Leakage Theory, Evidence and Policy Design’. Washington D.C.

Vivid Economics, 2019. The future of carbon pricing in the UK.

Wadud, Z., 2015. ‘Imperfect reversibility of air transport demand: Effects of air fare, fuel prices and price transmission’, *Transportation Research Part A*, 72, 16-26.

Wang B., O’Sullivan A., Dray L., & Schäfer A.W., 2018. ‘Modelling airline cost passthrough within regional aviation markets’. *Transportation Research Record,* 2672(23), 146-157.

Wen, C.-H. & Chen, P.-H., 2017. Passenger booking timing for low-cost airlines: A continuous logit approach. Journal of Air Transport Management, 64(A), 91-99.

Wizz Air Holdings, 2021. Q3 F21 Results Press Release. https://wizzair.com/static/docs/default-source/downloadable-documents/corporate-website-transfer-documents/results-and-presentations/q3---earnings-transcript-vf_0c0cfdca.pdf

World Bank, 2015. Carbon Leakage: Theory, Evidence and Policy Design.

World Bank, 2020. World Bank Data: Air transport – Freight. https://data.worldbank.org/indicator/IS.AIR.GOOD.MT.K1?locations=GB

Yokomi, M., Wheat, P., & Mizutani, J., 2017. ‘The impact of low cost carriers on non-aeronautical revenues in airport: An empirical study of UK airports’. *Journal of Air Transport Management*, 64, 77-85.

Zaklan, A., 2016. Free allocation and the endowment effect in cap-and-trade systems: evidence from the European electricity sector.

Zetterberg, L. (2014). “Benchmarking in the European Union emissions trading system: abatement incentives.” Energy Economics, 43: 218-224.

Zuidberg, J. (2014). ‘Key drivers for differentiated airport passenger service charges’. *Journal of Transport Economics and Policy (JTEP)*, 48(2), 279-295.

ANNEX A ADDITIONAL QUALITATIVE ANALYSIS

This annex summarises main findings from the literature review that contributed to the qualitative assessment methodology and the assessment.

This review included:

1. The methodology of major ETS schemes, most principally the EU ETS[198].
2. Academic literature on ETS carbon leakage and competitive disadvantage, focussing on free allocation mechanisms
3. Grey literature on free allocation

DfT and BEIS stakeholders contributed to the source list of the review.

The annex is organised as follows. We summarise aspects of ETS policy design that affect leakage and competitive advantage (**Section A.1**), other carbon policy mechanisms that affect leakage and competitive disadvantage (**Section A.2**), provide a more detailed literature summary on free allocation (**Section A.3**), and conclude (**Section A.4**).

A.1 Overview of ETS policy design

In this section we provide a general overview of ETS policy design features that may impact carbon leakage and competitive disadvantage. This general review provided evidence that fed into our longlist of design options prior to identifying the shortlist of design options for assessment.

In stationary sectors, these policy design features typically seek to balance trade-offs between (1) incentivising abatement within the policy region and (2) mitigating carbon leakage and competitive disadvantage. These trade-offs will likely depend on whether the sector can substantially abate emissions through fuel-switching and efficiency improvements (lower carbon leakage risk) or whether emissions abatement is more likely to occur from demand response and production innovations (higher carbon leakage risk).[199]

In aviation, the principal trade-off is likely between (1) incentivising abatement within and outside the policy region and (2) mitigating competitive disadvantage. An additional aim is to balance these objectives during macroeconomic shocks to demand (e.g. pandemic decreases in passenger aviation) and to supply (e.g. energy price changes).

Below we outline key issues for the following areas:

- Allocation methods
- Carbon price
- Brief overview of other ETS design aspects

---

[198] We reviewed the design of the 10 largest ETS schemes by emissions covered: China, EU, Germany, South Korea, Mexico, USA (RGGI), USA (California), Kazakhstan, Canada (Quebec), New Zealand (ICAP).

[199] Acworth et al, 2020.

A.1.1 Allocation mechanisms

An ETS can distribute permits through auctioning or through free allowances. We discuss these in turn.

Auctioning has a variety of advantages and is considered the primary allocation methodology of mature ETSs. Auctioning is allocatively efficient (reflects firms' demand for allowances and provides firms equal opportunity to buy allowances), raises revenue to government which can be used on other decarbonisation measures, and facilitates carbon price discovery. Auctioning can avoid some of the distorting effects associated with free allocation which we discuss below. It can create risks of competitive disadvantage if there is a large carbon price difference between a given policy area and competing jurisdictions[200].

There are three common types of **free allocation** that are used to mitigate competitive disadvantage and carbon leakage risks[201]:

- Grandfathering: allocations are proportional to a firm's historical emissions with occasional periodic updating[202]. Examples include EU ETS Phases I and II, Korea (most sectors), Kazakhstan Phases I and II, some China schemes
- Fixed sector benchmark allocation: allocations are proportional to a firm's historical output and a sector-wide benchmark[203]. There are adjustments for changes in output only between phases. Examples include EU ETS Phase III and IV.
- Output-based allocation: allocations are proportional to firm's current output levels and a sector-wide benchmark. Examples include California, New Zealand, Australia.

Because free allocation reduces the cost of ETS compliance to firms, firms do not internalise the full cost of their ETS allowances. This can disadvantage lower-carbon alternatives because the emissions from carbon-intensive goods are not fully priced. This muted signal can propagate across the industrial value chain, disincentivizing efficiency gains in upstream and downstream activity and final consumption[204].

An ETS policy sets the overall level of auctioning versus free allocation. In practice, major ETS schemes include a wide range of free allocation levels as a fraction of the total cap. At one extreme, New Zealand and South Korea have 100% free allocation and indefinite exemptions for EITE-exposed industries. At the other extreme, RGGI, California and Quebec have full or majority auctioning of permits[205]. Increasing the proportion of allowances that are auctioned avoids the risk of oversupply of permits[206].

---

[200] World Bank, 2015.

[201] World Bank, 2015.

[202] Grandparenting should only be considered as a transitional approach while building the capacity for auctioning or a benchmarked approach to free allocation (World Bank, 2015)

[203] A key issue for free allocation compliance with WTO rules is whether differentiated benchmarks are applied to countries or airlines, and WTO compliance risks may be reduced by applying a single benchmark to the sector.

[204] Branger and Sato, 2017; Fisher and Fox, 2007; and Acworth et al., 2019.

[205] ICAP, 2021.

[206] Kopsch, 2012.

A.1.2 ETS carbon price

The carbon price achieved by the ETS results from the level of the cap and the marginal cost of abatement for those sectors covered by the ETS.

As aviation is a ‘hard-to-treat’ sector, carbon pricing can play an important role in abatement by driving a reduction or stabilisation of demand and increase in innovation. Such an abatement incentive requires a sufficiently high carbon price; in one estimate, a price of £160/tCO2 by 2050[207]. Stronger competition in a particular aviation market strengthens the abatement incentive created by a carbon price[208].

A high carbon price can introduce incentives to invest and innovate in low-carbon technology. There may be cases where firms have historically not made optimal use of resources, and well-designed environmental regulation can spur firms to become more productive (the Porter Hypothesis). A policy that can incentivise innovation will allow firms the flexibility to investigate and discover new technologies, incentivise continuous improvement, and provide regulatory certainty where possible[209].

However a high carbon price can create challenges for business competitiveness by increasing their operating costs, either through direct compliance costs or indirectly through higher input costs[210]. In theory, higher carbon prices would particularly impact airlines with inefficient short-haul routes, including feeder flights for network carriers and regional flights. We note that there is a relatively low risk of airlines changing traffic plans to have a stop-over just outside a policy region to save on emissions, as the increased travel time and reduced demand would likely outweigh benefits except under very high carbon prices[211].

Another challenge to airlines is carbon price uncertainty, including uncertainty about the duration of existing carbon pricing schemes[212]. Carbon price stability provides certainty to airlines not only about their short-run cost base but also contributes to the longer-run certainty needed to make significant decarbonisation investments. A variety of supply adjustment mechanisms have been introduced in ETS schemes, see Vivid Economics (2019) and Fell (2015) for overviews.

The empirical literature has found that carbon pricing has not significantly impacted competitiveness to date, and in some cases has found evidence that carbon pricing has led to increased low-carbon R&D[213], and that carbon pricing instruments have reduced industry emissions intensity[214].

Fagedo and Teixido (2020) found that although the EU ETS overall effect on aviation has been modest, it has had a significant impact on LCCs and much smaller impact on network carriers. They estimate that the EU ETS has led to low-cost airlines supplying 7% fewer seats. This is consistent with greater price-

---

[207] Burke et al, 2019.

[208] Nava et al, 2018.

[209] Ambec et al, 2013.

[210] World Bank, 2015.

[211] Scheelhaase et al, 2012.

[212] CPLC, 2019.

[213] Albers et al, 2009; Meleo et al, 2016; Aldy and Pizer 2015; BEIS, 2020.

[214] Vivid Economics, 2019.

sensitivity among LCC customers compared with network carrier customers, and with carbon costs on network feeder routes representing a smaller fraction of the total itinerary. For short-haul flights (routes on which intermodal competition may exist) the reduction in seats is ~20% greater than for medium-haul flights.

A majority of carbon prices in existing schemes remain significantly below the levels needed to meet the 2°C temperature goal set out in the Paris Agreement[215], and this limits the empirical evidence available on firm behaviour under future higher carbon prices.

A.1.3 Other ETS mechanisms

Below we provide a brief overview of other key ETS design features. A high-level assessment of the design of global ETS schemes is provided in Narassimhan et al (2018), covering a broad range of issues.

A central issue in ETS design is the **scope of routes** whose emissions are covered in the scheme. This is discussed in detail in the context of the EU ETS in Marcu et al (2013).

Banking and borrowing reserves introduces intertemporal flexibility that can reduce compliance costs for the ETS[216]. In theory, increased intertemporal flexibility should lead to the lowest-cost abatement, but in practice there are downsides to this flexibility. Borrowing of permits is risky from the perspective of the regulator, as they do not know which firms will stay in the scheme and if the permits will be paid back. Banking is risky if there is an oversupply of permits, because it will reduce the abatement impact of future cap reductions[217]. Most ETS schemes allow unlimited banking of permits, and restrict borrowing[218].

Inter-sector trading arrangements determine the ability of firms to trade permits between sectors. By enacting a closed system (which could be more or less restrictive, including different restrictions on inter-sector buying and selling, but at one extreme firms must only trade within the sector) reduces emissions in certain ‘hard-to-abate’ sectors but increases the average abatement cost[219].

In aviation, the **exchange rate** of permits is another issue that could be considered, so that it captures the full environmental impact of aviation emissions. Only around one-third of emissions from aviation are carbon emissions, and the rest are altitude dependent (e.g. NOx emissions that are more environmentally harmful at altitude than at ground level). As a result, aviation causes an estimated 2-4 times the environmental cost of what captured in a CO2 emissions metric[220]. In principle this could be incorporated into permit exchange rates, such that 1 permit in other sectors trades at less than 1 permit for aviation airlines. This could incentivise airlines to consider the trade-off between carbon emissions and NOx emissions,

---

[215] PMR & ICAP, 2021.

[216] Kling and Rubin, 1997; Tietenberg, 2010.

[217] Kopsch, 2012.

[218] Vivid, 2019.

[219] Kopsch, 2012.

[220] Scheelhases, 2020.

for example. **Geographic bubbles** can also be introduced in aviation in order that air quality is improved evenly[221].

Liability for an aviation ETS can be distributed between airlines and airports (or placed only with one or the other). A change in liability should not affect the policy outcomes, and so liability can be used to reduce transaction costs and increase the scope of the ETS. If small airlines are not included in a given scheme, placing liability with either fuel suppliers or airports would increase the scope of the scheme. However liability is arguably best placed with airlines as they have the greatest influence on fuel efficiency and consumption. One possible option is to place liability with airlines for cruise emissions (over which they have operational control), and take-off/landing/taxiing emissions with airports (as airports can impact the carbon efficiency of these stages)[222].

A.2 Overview of non-ETS policy design

Although the primary objective of an ETS is to reduce emissions, it is important that the overall suite of carbon measures provide incentives to invest in and achieve technological change in order to reduce the long-run cost of abatement[223]. This may in part be induced by an ETS scheme (the 'induced innovation hypothesis'),[224] and from a political perspective, induced innovation may improve the acceptability of ETS policies. Indeed, EU policy makers have articulated their vision that the EU ETS would be a driving force of low-carbon innovation and economic growth[225].

Policies that complement the ETS, such as funding for low-carbon technologies, infrastructure investment for SAF and R&D support are central to facilitating cost-effective emissions reductions[226]. Key points are discussed in Section 3.3.3, and the below provides supplementary material on evidence from other jurisdictions and sectors.

For example, **revenue from ETS auctioning** can be used to invest in other decarbonisation measures, which can be seen as a type of 'double dividend' in incentivising emissions reductions. The EU ETS, RGGI, California and Québec raise significant revenue through auctioning. RGGI devotes a larger percentage of its revenue to address social, environmental and economic needs such as supporting energy-intensive trade-exposed industries, energy efficiency programmes and low-income communities[227]. Québec earmarks all of its revenues to additional climate change mitigation[228].

Auction revenue can contribute to **government subsidies** for the development and adoption of low-carbon technologies have led to advances in areas such as

---

[221] An example of bubbles is the US Acid Rain ETS scheme. Kopsch, 2012.

[222] Kopsch, 2012.

[223] Jaffe, Newell, & Stavins, 2003; Stavins, 2007; Pizer & Popp, 2008.

[224] See Porter, 1991 and Acemoglu et al, 2012.

[225] For example see European Commission, 2021.

[226] BEIS, 2020.

[227] Ramseur, 2017.

[228] Narassimhan et al, 2018.

transport and energy[229] [230]. Subsidies targeted at upstream suppliers can generate positive spillovers and support domestic production markets[231], however need to be compliant with WTO rules. There is some evidence that optimal long-run policy may combine R&D subsidies with carbon pricing[232].

An important aspect of incentivising investment in low carbon technology, which may have uncertain returns and a long pay-back period, is **certainty about the future price of carbon** and longevity or policy stability of carbon pricing schemes. Project-based carbon contracts for difference (CCfDs) have been proposed as a mechanism to overcome this barrier, which pay out according to the carbon emissions reduction below a reference point based on current technology[233].

Consumption charges are another possible mechanism. In combination with free allocation, this has the potential to strengthen demand-side incentives that may be dampened by mechanisms to prevent carbon leakage[234].

Carbon border adjustments are a means of addressing leakage and competitive disadvantage concerns, but have not been implemented in the aviation sector, although a carbon border adjustment has been introduced in other sectors in the EU ETS Phase IV[235].

In addition, it will be important for national carbon policymakers to work with the ICAO in order to strengthen the **CORSIA** initiative and pursue a global carbon price for aviation[236].

A.3 Free allocation

In this section we provide more detailed findings from the literature on free allocation, as this was the specific focus of this study.

Whereas the material provided in the qualitative assessment was focussed on more granular design options, the below summarises general findings as they are typically presented in the literature. General overviews of free allocation mechanisms (grandfathering, fixed sector benchmarking, output-based allocation) can be found in Acworth et al (2020), Vivid (2019), and World Bank (2015).

Below we summarise:

- free allocation impacts on abatement incentives;
- free allocation impacts on competitive disadvantage; and
- distortion risks in free allocation.

Following the literature, the discussion focusses on the three main free allocation methods of grandfathering, fixed sector benchmarking, and output-based allocation.

---

[229] Åhman, Nilsson, & Johansson, 2017.

[230] IEA, 2019b.

[231] Fischer Greaker & Rosendahl, 2014.

[232] Acemoglu, Aghion, Bursztyn, & Hemous, 2012.

[233] Richstein, 2017.

[234] Raffaty & Grubb, 2018.

[235] European Commission, 2021.

[236] Burke et al, 2019.

A.3.1 Free allocation impacts on abatement incentives

As discussed previously, in aviation, abatement inside of an ETS policy region is likely associated with abatement outside of the policy region. The below summary of abatement incentives apply to emissions both inside and outside the policy region.

Comparison of free allocation methods

By basing free allocation on historical emissions, **grandfathering** does not distinguish between the emissions attributable to output volume and emissions attributable to the carbon intensity of that output. Grandfathering preserves the abatement incentive provided by the carbon price.

Fixed sector benchmarking and output-based allocation decouple the emissions attributable to output volume and emissions attributable to emissions intensity. In this way, they provide stronger incentives to reduce emissions intensity, and weaker incentives to reduce output volume, compared with grandfathering[237].

Fixed-sector benchmarking places some incentive on reducing emissions intensity and also some incentive on reducing output volume. In fixed sector benchmarking, there is greater incentive on reducing output volume the less frequent the updating year of the activity data.

Output-based allocation places all incentive on improving emissions intensity. By providing additional permits for additional production, it effectively subsidises production, reducing mitigation incentives compared with fixed sector benchmarking[238] [239].

Both fixed-sector benchmarking and output-based allocation reward early action to a greater degree than grandfathering.

Incentivising low carbon investment

A key factor in incentivising decarbonisation investment is how firms decide to use the cost-savings associated with the free allocation that they receive. It may be the case that free allocation contributes to the liquidity required to invest in new technologies. However whether firms make low-carbon investments with these profits depends on the relative viability of investment options available[240]. It also depends on whether the firm will credibly receive free allowances after making decarbonisation investments, for a sufficient period of time in order to recoup investment costs. This may be a challenging regulatory commitment if there is precedent within the jurisdiction that provides decreasing levels of free allocation to firms and sectors that have successfully invested in and implemented

---

[237] See Sartor et al (2015) for a discussion of efficiency improvements in the EU ETS from introducing benchmarking between Phase II and III.

[238] Fisher and Fox, 2007.

[239] There may be a conflict between apportioning output-based permits and setting (or decreasing) the total emissions cap. This may create uncertainty in the total emissions allowed under the policy. To address this, the scheme could cap the emissions allowed under output-based allocation; increases in free permits could be offset by a decrease in auctioned permits; or the emissions cap could adjust to accommodate changes in the number of free permits.

[240] Neuhoff et al, 2016.

decarbonisation technologies[241]. Empirical evidence from the EU ETS Phases I and II suggests that it had a moderate positive impact on low-carbon innovation and patenting in Europe[242]. Evidence on patent applications under China's regional pilot carbon pricing instruments suggests that carbon pricing effectively induced low carbon innovation[243].

A.3.2 Free allocation protection against competitive disadvantage

Grandfathering may offer weak protection against competitive disadvantage, as firms will internalise the full opportunity cost of their emissions pricing. In other words, they will be incentivised to decrease output as well as decrease emissions intensity. This may lead to a reduction in market share with respect to firms outside of the policy area. In decreasing output levels they may also face lower returns to scale, higher unit costs, and be able to offer less competitive pricing, which can potentially further decrease market shares[244].

With **fixed sector benchmarking** and **output-based allocation**, the firm's relative protection against competitive disadvantage compared with other firms in the market will depend on the cost impact of the deviation in their emissions intensity above or below the benchmark carbon intensity[245]. The level of the benchmark will determine the sector-level protection against competitive disadvantage[246]. Fixed sector benchmarking provides an intermediate level of protection between grandfathering and output-based allocation, with more frequent activity data updating corresponding to greater protection of competitiveness.

A.3.3 Key distortion risks from free allocation

In theory, free allocation can lead to a range of market distortions. These are discussed below.

Risk of windfall gains. Windfall gains are a particular concern if there is an oversupply of free permits, such that firms receive enough free allowances to cover their BAU operations. In this case, excess allowances above BAU requirements represent a wealth transfer to the firm. In aviation this can occur following large negative demand shocks (e.g. COVID-19)[247]. Risk of windfall gains is higher in sectors with high cost passthrough. However it is empirically difficult to determine cost passthrough ability[248] and also the downside risks of an ETS scheme are larger under low cost-passthrough scenarios[249]. In the EU ETS, providing free allocation to sectors not at genuine risk of carbon leakage has led to windfall

---

[241] Acworth et al, 2020.

[242] Calel and Dechezleprêtre, 2016.

[243] Cui, Zhang, & Zheng, 2018.

[244] Acworth et al, 2020.

[245] Acworth et al, 2020.

[246] World Bank, 2015.

[247] Kopsch, 2012.

[248] There is a large literature estimating cost passthrough rates, see Verde et al, 2019.

[249] BEIS, 2020.

profits[250]. In aviation, the European Court of Auditors (2020) found that EU ETS aviation free allocation did not reflect that airlines have the ability to pass on carbon costs to consumers.

Reducing free allowance levels reduces the risk of windfall profits[251].

Information asymmetries between the regulator and the market. In fixed sector benchmarking and output-based allocation, setting the benchmark requires assessing a stretching target. Establishing a benchmark may be complicated by information asymmetries between the regulator and market participants[252].

In theory, the particular level of the sector-wide benchmark should not significantly impact the opportunity cost of reducing emissions intensity, and therefore should not affect incentives to reduce emissions intensity. However, the level of the benchmark impacts firms' total carbon costs under the scheme, and there may be behavioural reasons why firms would respond differently to benchmarks set at different levels[253].

Potential to distort between and within sectors. The risk of intra-sector distortions (i.e. advantaging emissions-intensive activities over low-emissions activities) varies by free allocation methodology. The distortion risk is relatively high with grandparented free allocation relative to benchmarking approaches[254]. But with benchmarked free allocation, the distortion risk is higher if the sector produces relatively heterogenous output[255]. The risk of significant distortions is also higher as the carbon price increases[256].

Free allocation can also create distortions between sectors. For example, the European Court of Auditors (2020) found that EU ETS free allocation favoured air travel over rail travel, by comparing the effective cost of ETS compliance for airlines versus the passed-through electricity carbon costs for rail airlines.

Endowment effect. An endowment effect is a type of behavioural bias among firms, in which firms' free allocation 'endowment' impacts their production decisions. There is a literature investigating this issue using EU ETS data. Several studies[257] have found no significant evidence of an endowment effect. De Vivo and Marin (2018) and Abrell et al (2011) find that among sectors classified as at risk of carbon leakage, there is some association between free allocation and emissions reduction.

Inflating output to inflate free allocation. If firms can anticipate how their output and emissions incentives today affect their free allocation in the future, this can distort their production levels and/or investment in low-carbon technology[258]. This

---

[250] Vivid Eonomics, 2019; de Bruyn, 2013; Martin et al, 2014; Marcantonini and Verde, 2017. Further evidence of windfall profits is provided in Verde et al (2018), who showed that installation exits from the EU ETS (due to closure) were concentrated in the final years of Phases I and II, indicating windfall profits.

[251] Malina et al, 2012.

[252] See Efthymiou and Papatheodorou (2019) for a study of firm and airline allocation method preferences.

[253] World Bank, 2015.

[254] Acworth et al, 2020.

[255] Stenqvist and Ahman, 2016.

[256] Acworth et al, 2020; Nava et al, 2018.

[257] Grimm and Ilieva, 2013; Reguant and Ellerman, 2008; Zaklan, 2016.

[258] Zetterberg, 2014.

may be particularly the case for years that will determine the free allocation for many subsequent years, for example grandfathering[259].

New entrants. Free allocation can disadvantage new entrants if there are long ETS phases without activity data updating, and no special provision for new entrants[260]. Output-based allocation is the only free allocation method commonly used that avoids the risk of new entrant disadvantage by updating the activity data annually.

A.4 Conclusions

Historically, there have been limitations in ETSs' impacts on carbon abatement due to oversupply of allocations and (in stationary sectors) cheap abatement options, resulting in low allowance prices. However reductions in caps and adoptions of supply adjustment mechanisms to address oversupply of allowances will likely increase the contribution of ETSs to emissions reductions in the coming years. This will add to the evidence base on firm behaviour under high carbon prices, and on free allocation performance in practice.

---

[259] Kopsch, 2012; Malina et al, 2012.

[260] World Bank, 2015.

ANNEX B METHODOLOGY DETAILS

B.1 Key policies modelled in AIM

Currently, three separate carbon trading/offsetting schemes are modelled in AIM. The EU ETS and CORSIA were already represented in the model and the UK ETS has been added to the model for this study.

This section presents an overview of each scheme, along with APD, and sets out how they are modelled in AIM.

B.1.1 The EU ETS

The EU ETS has applied to intra-EEA flights since 2012, with the exception of flights to or from EU Outermost Regions (OMRs[261]). Aviation has a separate cap to the rest of the scheme, initially set at 95% of average year 2004-2006 CO_2 emissions[262]. For aviation, the effective cap in 2019 was around 36.2 $MtCO_2$ once changes in scope were accounted for[263]. For aviation emissions below this cap, EU aviation allowances (EUAAs) are issued: at present, 85% are freely allocated via benchmarking and/or the new entrants' reserve, and 15% are auctioned. Aviation emissions above the cap must be accounted for via the purchase of non-aviation allowances (EUAs) from other sectors. In 2019, around 48% of EU ETS-eligible route direct CO_2 emissions were above the cap. Sustainable alternative aviation fuel use (e.g. biofuel or power-to-liquids fuel) does not count towards the cap, provided that the fuel is eligible under Renewable Energy Directive (RED/REDII) criteria[264].

Several changes to the scheme apply from 2020. In 2020, the EU ETS was linked with the Swiss ETS, modestly increasing its scope. The Swiss ETS linkage is modelled in AIM by increasing the effective size of the EU ETS, rather than by separately modelling the interaction of the two schemes. The Swiss ETS aviation sector cap was 1.3 $MtCO_2$ in 2020[265], which covers Swiss domestic aviation and outbound flights to EEA countries. Additionally, flights from EEA countries to Switzerland have been added to the EU ETS scope. We therefore assess the combined aviation cap of both schemes in 2020 to be around 38.7 $MtCO_2$. The aggregate of the UK ETS, EU ETS and Swiss ETS from 2021 effectively maintains this scope, so for an initial estimate of UK routes removed from the EU ETS accounting for around 5.5 $MtCO_2$ of free and auctioned EUAAs, we would expect the effective combined EU ETS + Swiss ETS aviation cap to be around 33.2 $MtCO_2$.

---

[261] EU outermost regions (OMR) include the Canary Islands, French Guiana, Guadeloupe, Martinique, Layotte, Reunion, Saint-Martin, the Azores and Madeira. The Canary Islands in particular are popular UK holiday destinations, which means that OMR exemption impacts may be non-negligible for UK arriving and departing flights.

[262] This was initially set on a full scope basis (i.e. all flights to, from and within the EEA). In converting the scheme to the current reduced scope (intra-EEA flights only) a tonne-km rather than CO_2 methodology was used, so the present-day effective cap does not match exactly to the year 2004-2006 baseline.

[263] European Commission, 2021b.

[264] European Parliament, 2020.

[265] IETA, 2020; FOEN, 2019.

Initially, the 2021-2030 aviation cap (along with the cap for other EU ETS sectors) was planned to decrease by a linear reduction factor (LRF) of 2.2% per year[266]. However, the 2021 ‘Fit for 55’ package proposes updating this value to 4.2%[267]. From 2021, flights within and originating from the UK are removed from the EU ETS and become part of the UK ETS instead. This is discussed below.

In AIM, EU ETS eligibility is tracked at a flight segment and (where necessary) airline nationality level. CO_2 on eligible segments is summed and compared to the applicable cap in each model year. CO_2 emitted above this cap is assumed to be covered by allowances purchased from other sectors, with appropriate carbon costs for airlines calculated using an EUA price scenario. These allowances are assumed to result in a net reduction of one tCO_2 in another participating sector (e.g. power generation). CO_2 below the cap is divided into freely allocated and auctioned allowances. In the EU ETS, free allowances (82% of total EUAAs) are allocated based on a benchmarking process using year-2010 airline tonne-km data, supplemented by a reserve (3% of total EUAAs) for new entrants and fast-growing airlines[268]. At present, free allowances in AIM are modelled as a system-wide fraction of total allowances, effectively assuming that current operations are broadly representative of the tonne-km baseline once the new entrants’ reserve is factored in. However, this methodology can be adjusted to use estimated 2010 tonne-km, as discussed below.

Auctioned allowances are associated with an EUAA carbon cost. Typically, an airline would make operational and investment decisions based on the marginal cost of EUAAs. There is some debate in the literature about whether pricing decisions are affected by free allocation or not[269], and a wide range of assumptions have been used in other studies looking at this issue. These range from full pass-through of all costs including the opportunity costs of free allowances,[270] full pass-through of only incurred costs[271], and limited pass-through of all costs[272]. In this study, we treat the level of pass-through as an uncertain scenario variable and include it in the sensitivity analysis.

In practice, EUA and EUAA prices are very close and are modelled as a single EU ETS carbon price in AIM. EASA[273] estimates that allowance purchase costs were 0.3% of total intra-EEA airline operating costs in 2017, a level which is much smaller than typical airline operating cost fluctuations due to changes in fuel price, and therefore unlikely to have significant impacts on airline decisions. However, this estimate was made at a time when allowance prices were around €6. In early 2021, EUA prices were approximately €55 (£47) per tCO_2, implying a higher share of operating costs.

---

[266] European Commission, 2019.

[267] European Commission, 2021e.

[268] European Commission, 2021b.

[269] E.g. Anger & Köhler, 2010.

[270] E.g. SEC, 2006.

[271] European Commission, 2013a.

[272] Ernst & Young and York Aviation, 2008.

[273] EASA, 2019.

B.1.2 CORSIA

CORSIA is a global carbon offsetting scheme developed by the International Civil Aviation Organisation (ICAO). It covers international aviation emissions between participating countries from 2021. In 2019, around 70% of global scheduled aviation tonne-km were international and around 30% were domestic[274]. CORSIA is divided into three implementation phases: a pilot phase from 2021-2023, a first phase from 2024-2026 and a second phase from 2027-2035. Initially, it was intended that the scheme should use average 2019 and 2020 emissions as a baseline. However, following the dramatic impact of the COVID-19 pandemic on global aviation in 2020, this has been adjusted to a 2019-only baseline for the pilot phase[275]. Emissions above the 2019 baseline on routes between participating states must be offset using a scheme-accredited provider of international carbon credits. Initially, offsetting is applied on a sectoral basis: i.e. an effective carbon price is calculated based on the amount by which CORSIA-eligible routes are above the baseline and then this is applied to all participants (regardless of how much their own CO_2 emissions are above or below their CO_2 emissions in 2019). From 2030, this transitions to a part-sectoral, part-individual approach where part of an airline's CORSIA obligations is based partly on sector-wide emissions growth and partly on the individual airline's emissions growth[276]. This split is modelled in AIM. As with the EU ETS, CORSIA eligibility in AIM is tracked at a flight segment level. The summed CO_2 on eligible flight segments is used to track the extent to which the whole scheme is over the baseline, and individual segment CO_2 emissions from the baseline year are used to track the extent to which airlines are over their individual baselines. CORSIA eligible unit (CEU) appropriate carbon costs are applied to above-baseline emissions according to these fractions and to the split between individual and sectoral offsetting requirements in a given year. CORSIA is not a carbon trading scheme and airlines cannot sell on credits if they are under their individual baseline.

One key source of uncertainty in modelling CORSIA is capturing participation. As of January 2021, 88 states were participating in CORSIA[277]. Current participation status is shown in Figure 34. CORSIA-eligible airlines have already registered 577 $MtCO_2$ of year-2019 operations, over 60% of total year-2019 aviation CO_2 emissions.[278] Although participation is voluntary in the pilot (2021-2023) and first (2024-2026) phases, participation of states that are not exempt[279] is mandatory in the second phase (2027-2035). There are five states in the mandatory second phase group which have not currently indicated that they will participate (China, India, Brazil, Russia and Vietnam) and it remains unclear whether they will join before the second phase or not. The UK is one of the 88 states that have signed

---

[274] ICAO, 2020b. Domestic aviation refers to flights which start and finish in the same country. These flights are outside the scope of CORSIA.

[275] ICAO, 2020a.

[276] ICAO, 2019b.

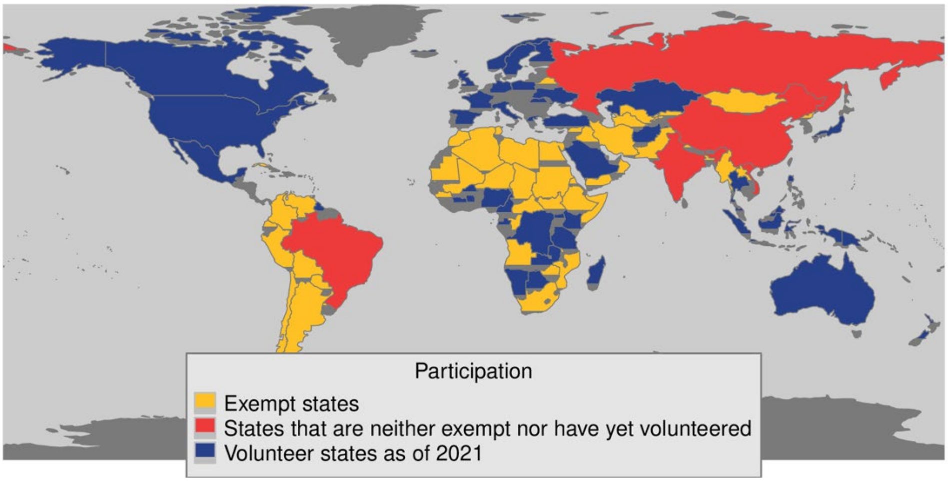
[277] ICAO, 2021a.

[278] ICAO, 2021b.

[279] Exemption conditions include Least Developed Countries (LDCs), landlocked developing countries (LLDCs), and small island developing states (SIDs); total revenue tonne-kilometres (RTK) activity in 2015 below 0.5% of global RTK; and states below a cumulative threshold of 90% of total year-2018 RTK when sorted from highest to lowest RTK. However, the list of current participants includes exempt states which are participating voluntarily (e.g. Singapore).

up from the beginning of the voluntary phase of CORSIA, which commenced in 2021. Because a flight is only eligible under CORSIA if both origin and destination countries are participants, the inclusion or absence of these countries may make a substantial difference to total CORSIA coverage. As such, it is an uncertain factor in CORSIA coverage and the amount of CORSIA offsets[280].

Figure 34 CORSIA participation status by country as of January 2021



Source: ATA

Current CEU prices are around £1.50/tCO_2[281], and are generally projected to remain low[282]. CORSIA carbon costs also apply only to CO_2 emitted above the year-2019 baseline level. In practice, this means that CORSIA-related costs are likely to remain very low unless there are changes to the design or stringency of the scheme. As such, although CORSIA participation will affect global levels of aviation offsetting and net global aviation CO_2, it is unlikely to have a large impact on competitive disadvantage either for the UK or other participating airlines (i.e. their costs with or without CORSIA are likely to be similar).

B.1.3 UK ETS

The UK ETS applies to flights within the UK, flights from the UK to an EEA airport, flights between the UK and Gibraltar, and flights from the UK to UK and EEA state offshore structures, from January 2021[283]. Initially, the broad characteristics of the wider UK ETS are similar to those for the EU ETS. The UK ETS cap is initially set 5% below the UK's notional share of the EU ETS cap for Phase IV of the EU ETS.

As announced in the UK Government's response to the Future of UK Carbon Pricing Consultation, now that the Climate Change Committee (CCC) has

---

[280] Note that higher CORSIA coverage does not necessarily correspond to more offsets. Because of the way the scheme is designed, adding in slow-growing routes and/or those most strongly affected by COVID-19 can act to increase the baseline and reduce the relative level of growth over the baseline, reducing offset totals.

[281] E.g. OPIS, 2021.

[282] Fearnehough et al., 2018.

[283] Environment Agency, 2021.

published its full advice on the Sixth Carbon Budget, the UK Government and Devolved Administrations will be consulting on a net-zero consistent trajectory for the cap. The UK ETS does not have a separate cap for aviation, as in the EU ETS. Instead, aviation and all other sectors participating are covered by a single cap, initially set at 155.7 $MtCO_2e$ for 2021[284], and reducing to 117.6 $MtCO_2e$ by 2030[285]. Of this, around 4.4 million allowances may be used for airlines' 2021 free allocation entitlements, around 3% of the total cap.

Modelling the UK ETS in AIM requires the following parameters: the number of allowances per year that will be freely allocated to airlines, the methodology for assigning free allowances to airlines and the price per tCO_2. The remainder of the allowances required by aviation are assumed to be purchased via auctioning or via the secondary market. An auction reserve price of £22 has been set for the UK ETS[286]. However, allowance prices at the start of UK ETS trading in May 2021 were around £45[287].

Initially, free allocation applications under the UK ETS are distributed under a similar methodology to those in the EU ETS, i.e. based on a year 2010 (or 2014) airline tonne-km benchmark. This could be subject to change in future as the government is reviewing the UK's approach to free allocation of UK ETS allowances. This review will consider potential carbon leakage and competitiveness impacts, including the outcome of this report, and the UK's domestic and international climate commitments, with any change likely to be implemented from the start of Phase I(b) at the latest. Free allocation is modelled in AIM using airline 2010/2014 benchmark tonne-km data in combination with airline flight schedule data to estimate route-level free allowance amounts, which are then used as an external input to the modelling. This effectively assumes that airline networks remain similar to the benchmark year. This benchmark can be updated to reflect operations in a more recent year, and the total amount of free allowances can be altered, simulating different options for free allowance allocation.

B.1.4 Air Passenger Duty

Air Passenger Duty (APD) is a UK departing per-passenger itinerary tax payable by airline which is applied in distance bands[288]. APD is paid on a passenger's whole itinerary; if the initial leg is on an exempt route, then the whole journey is exempt. The operating airline the first leg is responsible for paying APD appropriate to the whole journey. APD rates for 2015 and 2021 are summarised in Figure 35.

---

[284] National Archives, 2020.

[285] This corresponds to a linear reduction factor of 2.7% per year.

[286] BEIS, 2021a.

[287] Reuters, 2021.

[288] HM Revenue and Customs, 2019.

Figure 35 Air Passenger Duty rates by scope and ticket class

Origin-destination category	Reduced rate (e.g. economy class)	Standard rate (any other class)	Higher rate (aircraft of > 20 tonnes with <19 passengers)
Band A (0-2,000 miles)	£13	£26	£78
Band B (> 2,000 miles)	£71 (£82)	£142 (£180)	£426 (£541)
Direct flight departing from Northern Ireland or the Scottish Highlands and Islands region*	Exempt	Exempt	Exempt

Source: HM Revenue and Customs, 2019

Note: Values as of 2021 shown in brackets if different from 2015 value

**The Scottish Highlands and Islands region includes all Scottish airports in the airport set other than those associated with Glasgow, Edinburgh, Aberdeen and Dundee. Note that flights to airports in this region are still subject to APD; only departing flights are exempt.*

Because AIM's fare model is estimated from actual year-2015 fare data, the impact of APD on fares is already implicitly included in the model parameters. This study does not consider the impact of changes in APD from current values.

B.2 Modelling airline responses to policy

Airlines are affected by carbon trading policy mainly via the associated change in direct operating costs (DOCs). Most UK ETS costs incurred by airlines arise from the need to purchase allowances to cover their CO_2 emissions, although additional costs are associated with monitoring, reporting and verification (MRV) processes – i.e. the need to keep track of and report yearly eligible CO_2 emissions. In AIM, airlines can respond to changes in carbon costs in several ways. As a direct response to changes in costs, they may increase fares or choose to adopt different operational measures or technologies to reduce their emissions. As a second-order response based on their anticipation of passenger behaviour, they may also choose to reduce operations on routes that are more heavily affected, not add additional flights to and from affected regions, or add flights to routes that avoid the policy area. If costs are not fully passed on to fares, airlines are also in effect taking the decision to operate at a lower profit margin[289].

B.2.1 Changes in fare

Airline fare responses to changes in costs are governed by a fare model estimated from historical fare data[290]. For demand between cities *o* and *d*, passengers have the option of multiple alternative airport-airport itineraries *k*, from some airport *m* in

---

[289] Note that airline operating profit margins are usually small. Over the 2015-2018 period, global average airline operating margins were around 6-8%, but this is high compared to historical values (e.g. ICAO, 2020b; IATA, 2019). Net margins (i.e. airline profit margins after accounting for non-operating income and expenses) are quite often negative.

[290] Wang et al., 2018.

o to some airport *n* in *d*, and potentially via some number of hub airports. The fare f_{odk} between *o* and *d* on itinerary *k* is modelled as:

$$\ln f_{odk} = \alpha_0 + \alpha_1 \ln FC_{odk} + \alpha_2 \ln CP_{odk} + \alpha_3 \ln CF_{odk} + \alpha_4 \ln CR16_{mn} + \alpha_5 \ln AHHI_{mn} + \alpha_6 \ln LHHI_{odk} + \alpha_7 \ln Freq_{odk} + \alpha_8 \ln N_{odk} + \alpha_9 LF_{odk} + \alpha_{10} \ln RS_{odk} + \alpha_{11} Nlegs_{odk} + \alpha_{12} H_{odk} + \alpha_{13}(C_m) + \alpha_{14}(C_n),$$

where FC_{odk} is the sum of fuel cost per passenger over all segments on the itinerary, CP_{odk} and CF_{odk} are the sum of per-passenger and per-flight based non-fuel costs over all segments on the itinerary, $CR16_{mn}$ is the mean of the average 16-hour capacity ratio[291] for airports *m* and *n*, $AHHI_{mn}$ is the mean airport-level Herfindahl-Hirschmann Index (HHI)[292] over airports *m* and *n*, $LHHI_{odk}$ is the geometric mean of the city-pair HHI for all segments on itinerary *k*, $Freq_{odk}$ is the yearly frequency of the given itinerary, N_{odk} is the number of passengers using this itinerary, LF_{odk} is the geometric mean of passenger load factor over all segments, RS_{odk} is the share of the total origin-destination passengers on this city-pair using the itinerary, $Nlegs_{odk}$ is the number of flight legs in the itinerary, and H_{odk} is the number of major hub airports used on itinerary *k*. The parameters α are estimated[293]; α_{13} and α_{14} are origin and destination country fixed effects terms.

For this study, we treat carbon costs separately to other sources of cost and apply exogenous cost pass-through rates to determine the effect of carbon costs on fares. This allows the sensitivity of outcomes to different cost pass-through rates to be transparently assessed as part of the sensitivity analysis. There are also second-order impacts on fares from the UK ETS related to passenger response. For example, reductions in demand on a route may lead to fare increases as this implies a lower level of competition and/or reduced access to economies of scale.

B.2.2 Changes in technology choice

When carbon costs increase, adopting higher-cost emissions mitigation measures may become economical[294]. This includes operational measures such as single-engine taxiing or continuous descent approach; retrofitting existing aircraft (e.g. installing lighter seats or better winglets); changes in maintenance procedures (e.g. more frequent engine maintenance to reduce typical engine performance deterioration); adopting lower-carbon fuels; or investing in new, more efficient aircraft. Airlines typically use a given aircraft on multiple routes within their networks. For airlines whose route network covers flights both within and outside the policy area, this means that there is the potential for negative leakage (i.e. a decrease in CO_2 emissions outside the policy area which is caused by the policy) where airlines invest in a new technology due to carbon costs and then also use it on routes to which the policy does not apply.

Airline technology choices depend on the costs associated with the new technology, the costs associated with the technology the airline is currently using

---

[291] Capacity ratio refers to the average of the number of daily operations divided by the airport capacity (for slot-controlled airports, the number of available slots) across a 16-hour operating day.

[292] The HHI is the sum of the squares of the market shares (in passengers) of all airlines in the given market and is used to assess the amount of competition in that market.

[293] A full list of parameter values is given in the model documentation (http://www.atslab.org/data-tools/).

[294] E.g. Schäfer et al., 2016.

and the methodology used to make purchase decisions. New technology costs and capabilities are derived from ATA and Ellondee (2018)[295], with some additional mitigation measures from Schäfer et al. (2016). This includes costs and technologies associated with future generations of new aircraft as well as operational, maintenance, and air traffic management (ATM) related measures. It does not include radically different aircraft models (e.g. battery electric or hydrogen aircraft) whose development and use is more uncertain[296]. Aircraft are divided into nine types, as shown in Figure 36. Figure 36 also shows the size class from ATA and Ellondee (2018) used to assess alternative aircraft capabilities; where these estimates relate to a reference aircraft different to the one used in AIM, new technology capabilities relative to the reference aircraft are adjusted to reflect this.

Figure 36 Reference aircraft types used, and their relation to those used in ATA and Ellondee (2018)

Size category	Approx. seat range	Reference aircraft	Reference engine	Technology assumptions from ATA and Ellondee (2018)
Small regional jet	30-69	CRJ 700	GE CF34 8C5B1	Omitted (values from Dray et al. 2018 used)
Large regional jet	70-109	Embraer 190	GE CF34 10E6	Size class 2
Small narrowbody	110-129	Airbus A319	V.2522	Size class 2
Medium narrowbody	130-159	Airbus A320	CFM56-5B4	Size class 3
Large narrowbody	160-199	Boeing 737-800	CFM56-7B27	Size class 3
Small twin aisle	200-249	Boeing 787-800	GEnx-1B67	Size class 4
Medium twin aisle	259-299	Airbus A330-300	Trent 772B	Size class 4
Large twin aisle	300-399	Boeing 777-300ER	PW4090	Size class 4
Very large aircraft	400+	Airbus A380-800	EA GP7270	Omitted (size class end of production assumed instead)

Source: ATA

For new aircraft models, we assess the cost-effectiveness of an aircraft of technology *x* using net present value (NPV), i.e.:

$$NPV_x = \sum_{t=0}^{T_N} R_{t,x}/(1 + i^t) ,$$

where T_N is the time horizon over which the technology is evaluated, i is the discount rate, and $R_{t,x}$ is the cash flow associated with technology x in year t. The discount rate and time horizon are user input values in AIM. By default, they are set at 8% and seven years[297].

---

[295] ATA and Ellondee, 2018.

[296] The option to model these technologies exists in AIM but including them implies the existence of significant development and infrastructure investment.

[297] These defaults are originally based on analysis carried out for the Omega Project on aviation environmental impact on airline financial decisions (e.g. Morrell & Dray, 2009). Typical discount rates are derived from an analysis of airline financial reports.

For operational measures and retrofits, we use a simple payback period model. We assume a retrofit will be adopted if:

$$\sum_{t=0}^{T_P} R_{t,x} - R_{t,base} > 0,$$

i.e. the technology is adopted if over a period of T_P years overall cost savings relative to the base technology in use in that aircraft cohort can be made. The payback period is a user input but is three years by default[297].

For SAF uptake, we use AIM's default cost curve model. This model uses a cost curve to assess the amount of SAF via different pathways that is cost-competitive with fossil Jet A once carbon costs are factored in (if sold at production cost). This effectively sets the SAF supply available to aviation as well as the fuel lifecycle emissions associated with typical SAF blends over time. This model allows for assessment of interactions such as incentives for SAF use in one world region potentially reducing SAF use in other world regions.

In combination, these models assess how technology choice might be affected by carbon pricing.

B.2.3 Changes in flight frequency and aircraft size choice

Given some level of change in fare, passenger demand per route will be affected (through the mechanisms discussed in the section below on passenger response). Airlines are assumed to respond to changes in anticipated demand per route by reducing operations and potentially changing the aircraft they use on a given route. The proportion of aircraft, pr_{mns}, of each size class s on each segment between airports m and n is estimated as:

$$pr_{mns} = \frac{e^{U_{mns}}}{\sum_j e^{U_{mnj}}}, \text{ where}$$

$$U_{mns} = \theta_0 + \theta_1 d_{mn} + \theta_2 h_m + \theta_3 h_n + \theta_4 N_{mn} + \theta_5 LF_{mn} + \theta_6 R_m + \theta_7 R_n + \theta_8 NLCC_{mn} + \theta_9 HHI_{mn},$$

and d_{nm} is the distance between airports m and n, h_m and h_n are dummy variables indicating whether m and n are major hub airports, N_{mn} and LF_{mn} are the number of passengers and the passenger load factor on the segment, R_m and R_n are the lengths of the longest runways at m and n, $NLCC_{mn}$ is the number of LCCs operating in the segment, and HHI_{mn} is the segment HHI in terms of airline passenger share. Parameters θ_n are estimated from base year schedule data, as discussed in the AIM documentation. In practice, this means that aircraft size choice is largely set by static segment characteristics (e.g. distance, available runways, network structure) but can change in response to changes in segment-level demand. Combined with typical load factors for each segment and trends in load factor over time[298], this allows the overall and size-specific flight frequency to be estimated. If demand on a route is affected by increased ticket prices, the number of flights offered may decrease, and the average size of aircraft used on the route may also change.

---

[298] E.g. ICAO, 2020b.

AIM does not model the option for airlines to reallocate fleet between different routes (for example, using aircraft with higher per-passenger fuel use on routes with a lower carbon price); rather, it assumes that airlines use their fleet of a given aircraft size class uniformly over the routes on which they use that size class. The likelihood of airlines using this strategy is discussed in Section 6.5.1.

B.3 Modelling customer responses to policy

B.3.1 Passengers

Carbon trading impacts passengers mainly via changes in fare, although changes in airline decisions around technology may have secondary impacts on flight frequency, itineraries offered or journey time. When the fare or other characteristics of a given journey change, two potential passenger responses are assessed: they may decide not to fly at all; or they may change their itinerary.

The decision of whether or not to fly is modelled as the gravity-type model:

$$\ln N_{od} = \beta_0 + \beta_1 \ln(P_o P_d) + \beta_2 \ln(I_o I_d) + \beta_3 \ln(f_{od} + vot_R\, t_{od}) + \sum_i \beta_i D_{od}^i,$$

where N_{od} is the total passenger demand by any route between cities o and d, P_o and P_d are the populations of the greater metropolitan areas of o and d respectively, I_o and I_d are the per capita household incomes of o and d, f_{od} is the average fare for passengers travelling between these cities over all routes, vot_R is typical passenger value of time (VOT) for the world region in which the flight takes place, t_{od} is the average time (including delay) to travel between the two cities, D_{od} are dummy variables capturing other elements of the city-city connection (including whether it is a domestic route and whether a road or high-speed rail link exists between the cities), and the parameters ß are estimated. Elasticity parameters by world region-pair and distance (short-, medium- or long-haul) are taken from Dray et al. (2014)[299], including the use of income elasticities recommended by the International Air Transport Association (IATA)[300]. Values of time for air travel are taken from US estimated values and adjusted for different world regions by purchasing power parity (PPP) gross domestic product (GDP) per capita[301].

This model can either be used to assess the absolute level of demand over time or to assess changes from a given demand trend over time. In the latter case, model parameters (e.g. income elasticities over time) are adjusted to match an externally provided demand growth trend, either for a specific world region or globally. This allows policy assessments to be made that are consistent with other, separately modelled demand trends.

Over the COVID-19 pandemic and immediate recovery period, a couple of changes are made to the demand and operational modelling to reflect movement restrictions and pandemic-related operational changes. First, a set of damping factors[302] are applied to domestic and international demand by world region to simulate the impact of border closures and travel restrictions, based on observed

---

[299] Dray et al., 2014.

[300] IATA, 2007.

[301] INFRAS/IWW, 2000.

[302] For example, factors which reduce demand on a true origin-ultimate destination basis to levels consistent with observed movement restrictions and short-term recovery projections.

reductions in operations[303] and global IATA sector recovery projections[304]. Second, load factors are assumed to decrease by a factor derived from observed reductions in load factor at different levels of passenger demand reduction. These factors apply only in the immediate pandemic recovery period[305]. Other factors may have a longer-term impact. These include changes in attitudes to aviation and the long-term demographic and economic impacts of the pandemic. These can be reflected in model input GDP/capita, population and income elasticity decoupling projection assumptions, or in external demand projections if the model is used to match a given demand trend.

The decision of whether to change itinerary is modelled using a multinomial logit model. The number of passengers between cities *o* and *d* on itinerary *k* in year *y* is modelled as:

$$N_{odky} = \frac{N_{ody} e^{V_{odky}}}{\sum_j e^{V_{odjy}}} \, ,$$

where the deterministic part of the utility, V_{odky}, for an itinerary *k* between cities *o* and *d,* travelling between airport *m* in *o* and airport *n* in *d*, is:

$$V_{odky} = \gamma_0 + \gamma_1 f_{odky} + \gamma_2 t_{odky} + \gamma_3 \ln freq_{odky} + \gamma_4 Nlegs_{odky} + \gamma_5 P_{m,y-1} + \gamma_6 P_{n,y-q} \, ,$$

and f_{odky} is the itinerary fare, t_{odky} is the total itinerary travel time, $freq_{odky}$ is the itinerary frequency, $Nlegs_{odky}$ is the number of flight legs in the itinerary, $P_{m,y-1}$ and $P_{n,y-1}$ are the total number of passengers using airports *m* and *n* in the previous year, and the parameters γ are estimated using data from the Sabre passenger movement and fare database[306].

As discussed in the previous aviation carbon leakage report commissioned by DfT[307], passenger responses to increases in fare are often associated with negative leakage, i.e. with emissions decreases outside the policy area. This strongly depends on the definition of the policy area, as different definitions include or exclude different route groups. The reason that leakage is often negative is because many passengers whose origin or destination is in the policy area travel on multi-segment itineraries (including return flights). Typically, only part of these itineraries is within the policy area. However, where these passengers decide not to travel, demand reduces on all the flight segments in their itinerary, both those in the policy area and those outside.

B.3.2 Freight

The freight model in AIM is less detailed than the passenger model, due to the relatively small amount of data that are available about freighter operations.

---

[303] ICAO, 2020c.

[304] IATA, 2021.

[305] The assumed length of this period depends on the recovery scenario modelled. It is typically 2020 to 2022 but extends to 2025 in the case that an extended recovery period for aviation is assumed (e.g. recovery similar to the low end of the range of uncertainty in IATA projections).

[306] Sabre, 2017.

[307] ATA and Clarity, 2017.

Air freight accounted for around 24% of global RTK in 2018[308]. This includes freight carried in freighter aircraft and in the holds of passenger aircraft (roughly 50% of total freight RTK)[309]. To model freight in AIM, we start with 2015 estimated country-pair air freight flows, either directly from available databases[310] or estimated from country-level totals and hold freight flows[311]. For hold freight, the constraint on available capacity is typically volume rather than weight. As such, we assume that typical passenger-to-freight ratios in passenger aircraft per route group[312] represent what is practically achievable, and that additional freight per country-pair flow beyond what can be carried in passenger aircraft at these ratios is carried in freighter aircraft. Freighter fleets and utilisation are derived from fleet databases[313] and freight-specific operating costs are taken from literature estimates[314]. The technology composition of the freighter fleet is assumed to be similar to that for passenger aircraft of the same size and manufacture year. Freighter conversion from passenger aircraft is accounted for by conversion curves[315]. Changes in air freight demand due to changes in country-level GDP and country-pair level operating costs are accounted for via literature elasticity estimates[316]. Freighter flights are not assigned to individual airports but are aggregated to country-pair level, with flight distance assumed typical of the average flight between each country-pair. This model neglects trans-shipment-related and airport-specific effects and interactions with other transport modes. It does account for interactions between hold freight and freighter demand, as seen, for example, during the COVID-19 pandemic (i.e. reductions in the number of passenger flights reduce available hold capacity; if freight demand is unchanged this leads to an increase in freighter flights).

Changes in airline carbon costs affect air freight demand by changing average freight rates at a country-pair level; additionally, they may change the balance between hold freight and freight carried in freighter aircraft (necessitating more or fewer freighter flights). Changes in air freight routing are not currently modelled in AIM but are considered separately (Section 6.5.1).

B.4 Modelling impacts on UK airlines

AIM does not generally distinguish between individual airlines, although some metrics related to airline type (e.g. LCCs) are used to estimate route-level characteristics. However, where the impacts of a policy on a particular type of airline need to be assessed, operations by that type of airline can be separated out at a flight segment level. This procedure has previously been used to track impacts on EEA-registered airlines[317]. For this study, the division between UK airlines and non-UK airlines, and impacts on both, are of interest. One way of tracking UK-

---

[308] ICAO, 2020b.

[309] Boeing, 2017.

[310] E.g. Eurostat, 2020.

[311] ICCT, 2018; ICAO, 2020b.

[312] ICCT, 2018.

[313] E.g. Flightglobal, 2016.

[314] E.g. Chao & Hsu, 2014.

[315] Dray, 2013.

[316] Lo et al., 2015.

[317] ICF et al., 2020.

registered airlines is to assess the relative fraction of UK-registered airline operations in each segment in 2015 (the base year) and use this to assess airline-related impacts in subsequent years. However, over the 2015-2021 period significant changes have taken place in UK-registered airlines. These include the setting-up and transfer of operations to European subsidiary airlines in response to the UK's exit from the European Union (e.g. Easyjet Europe), the start of UK subsidiaries being set up by non-UK airlines (e.g. Norwegian Air UK), and the end of operations for a number of airlines both before and during the COVID-19 pandemic (e.g. Monarch, Thomas Cook, Flybe, Norwegian Air UK). As such, the policy-relevant UK airline presence in each flight segment needs to be adjusted to reflect the likely state of post-COVID-19 operations.

Figure 37 UK-registered airlines, by type of operations

Scheduled passenger flights	Cargo-only	Charter and other services	Ceased operations since 2015
Air Kilroe/Eastern Airways (T3/EZE)	CargoLogic Air (P3/CLU)	2Excel Aviation	Monarch Airlines (ZB/MON)
BA CityFlyer (CJ/CFE)	DHL Air (D0/DHK)	AirTanker Services(9L/TOW)	British Midland Regional (BM/BMR)
British Airways (BA/BAW)	West Atlantic UK (5O/NPT)	BAe Systems Corporate Air Travel (BAE)	Flybe (BE/BEE)
Easyjet UK (U2/EZY)*		Jota Aviation (ENZ)	Norwegian Air UK (DI/NRS)
Jet2 (LS/EXS)		RVL Aviation (REV)	Cello Aviation (CLJ)
LoganAir (LM/LOG)		TAG Aviation UK	Thomas Cook (MT/TCX)
Ryanair UK (RK/RUK)*		Titan Airways (ZT/AWC)	
TUI Airways (BY/TOM)			
Virgin Atlantic/ Virgin Atlantic International (VS/VIR/VGI)			
Wizz Air UK (W9/WUK)*			

** Airlines which began operations after 2015, including airlines which were operating in the UK in 2015 but re-registered as part of setting up UK and non-UK subsidiaries.*

The previous assessment of aviation policy carbon leakage and competitiveness impacts for DfT[318] discussed the definition of a UK airline. Relationships between airlines can be complex and reflect the international nature of aviation systems. At the most integrated level, airlines which are part of an airline group may act essentially as a combined entity, including fleet planning at a group level. Airlines also collaborate via alliances and/or codeshare agreements, may own or part own other airlines, or may wet-lease other airlines to perform operations for them. For this report we define a UK airline as one which currently holds a Type A operating licence in the UK, consistent with the previous analysis commissioned by DfT. These airlines (excluding helicopter-only airlines) are shown in Figure 37. Year-

---

[318] ATA and Clarity, 2018.

2021 IATA and ICAO codes are shown in brackets where assigned[319]. This represents a simplified description of airline links to the UK. In particular, UK airlines may be in airline groups with non-UK airlines (Easyjet UK/ Easyjet Europe; British Airways/Iberia) and this may affect whether they are in fact competing when they operate on the same routes, and how they deal with free allowances. In aggregate, these relationships should not affect the competitive disadvantage dynamics discussed in this report because airlines do not typically schedule competitive flights against other airlines they are in a group with.

A full assessment of the impact of the UK's exit from the European Union on the national registration of flights to and from the UK is complicated by the COVID-19 pandemic. An assessment of UK and non-UK subsidiary fleets of some key airlines is shown in Figure 38. Because fleet transitions may still be ongoing, these should only be taken as representing the situation as of June 2021 when this analysis took place. At present, Ryanair UK operates only one aircraft on international routes, and Norwegian Air UK ceased operations in January 2021. However, Easyjet has transferred a significant fraction of its fleet to Easyjet Europe. CAA airline data for 2019 include the impact of the removal of year-2019 Easyjet Europe operations[320]. Where an airline has divided into UK and non-UK subsidiaries since 2015, we split segment-level operations on international routes between UK and non-UK airline status by assuming that year-2019 operations are representative of post-pandemic ones, adjusted for UK/non-UK subsidiary fleet size where necessary. In practice, this results in a significant reduction in the fraction of UK airline flights in some UK ETS-eligible flight segments. As with other airline groups which include UK and non-UK airlines, for example IAG (which includes British Airways and Iberia, amongst others), there is the potential for co-operation or cross-subsidisation between the UK and non-UK parts of the group. In general, cross-subsidisation occurs more between different passengers on the same route, and/or different itineraries which use the same flight segment, than between different routes within the same airline or airline group. However, airlines may sometimes cross-subsidise a route to reduce fares if by doing so they can drive off a new airline from competing on that route[321]. In general, for this study, we do not assume cross-subsidisation between different airlines.

Figure 38 Fleets of UK and non-UK subsidiaries of low-cost carriers

Airline	UK subsidiary fleet	Total subsidiary fleets
Easyjet	192	318
Ryanair	1	450
Wizz	10	137
Norwegian Air UK	Norwegian Air UK recently ceased operations	

Sources: Easyjet, 2021; Civil Aviation Authority, 2021b; Wizz Air Holdings, 2021

In practice, when airlines cease operations, their routes are often taken up by other similar airlines (i.e. the main impact is a lowering of competition levels)[322]. For example, following the demise of Monarch, many of its routes were taken up by Jet2 (including increases in frequency on routes where Jet2 was already a

---

[319] E.g. IATA, 2020.

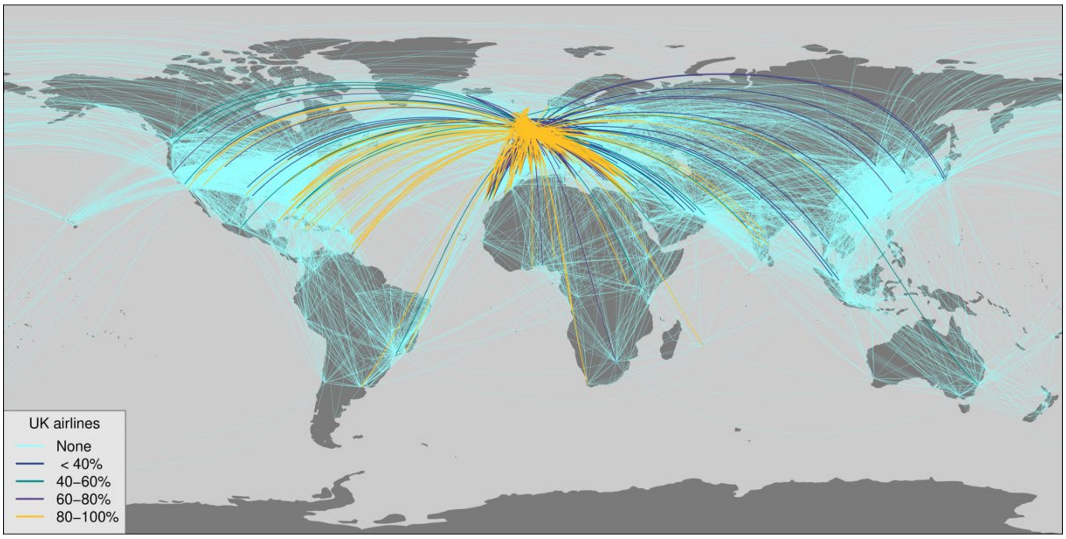
[320] Civil Aviation Authority, 2020.

[321] E.g. Francis et al., 2007.

[322] Mayer & Suau-Sanchez, 2019.

competitor), with British Airways, Thomas Cook and TUI also taking on routes[323]. Although COVID-19 complicates this picture, we assume that routes that were served by UK airlines that have ceased business will largely continue to be served by (different) UK airlines[324]. Figure 39 shows the UK airline activity by location of operations in 2015 under the definition of a UK airline used in this report.

Figure 39 UK airline activity, by location of operations in 2015



Source: AIM

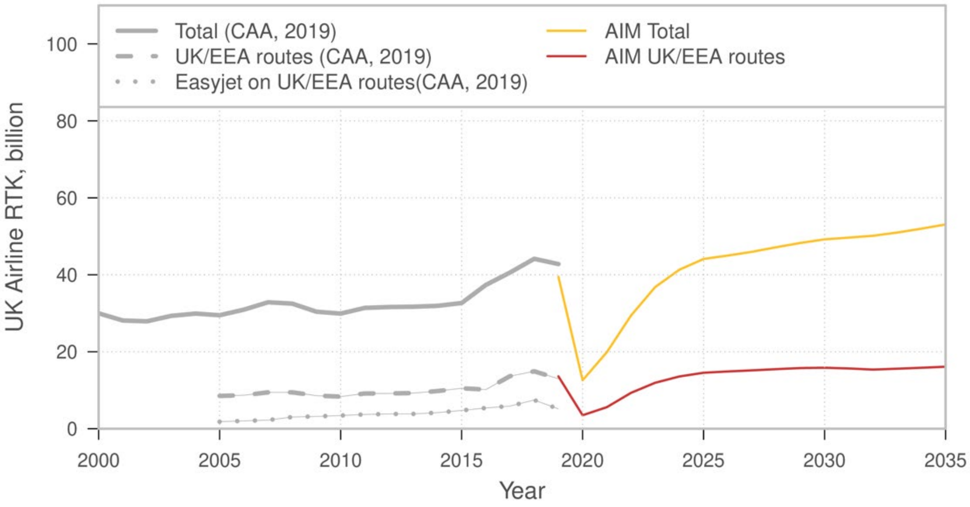
Modelled UK airline RTK, compared to CAA data, for a ‘No UK ETS’ baseline at nominal values for uncertain scenario variables, is shown in Figure 40. Historical data for Easyjet operations are shown separately. The decrease in UK airline RTK from 2018 to 2019 is due mainly to flights being transferred from Easyjet to Easyjet Europe, which leaves UK airline scope close to that modelled in this project.

---

[323] RoutesOnline, 2018.

[324] Excluding FlyBe’s routes in Finland, which have been taken up by FinnAir and are assumed to have no ongoing UK airline operations.

Figure 40 Baseline modelled UK airline RTK in comparison to CAA (2019) data



Source: AIM. UK/EEA routes includes all routes flown within the EEA and UK region by UK airlines

B.5 Modelling impacts on UK airports

Direct airport-level impacts of the UK ETS are likely to arise mainly from changes in the number, type and location of airline operations. Airport revenue is divided into two main sources: **aeronautical revenue** (e.g. from landing charges, passenger fees and aircraft parking fees) and **non-aeronautical revenue** (e.g. from in-airport shopping, car hire, car park charges or food sales)[325]. Aeronautical revenue is affected by the number and type of flights using the airport. For example, larger aircraft typically pay higher per-aircraft landing charges and carry more passengers, so are subject to higher total passenger-related landing charges; international flights often pay higher landing charges than domestic ones; and large and/or capacity constrained airports often have higher landing charges than small airports and those with spare capacity, though regulations apply to limit this effect[326]. We use typical per-aircraft and per-passenger landing costs from the RDC airport charges database, adjusted where necessary to reflect average levels of landing cost discounts, to assess aeronautical revenue per airport.

Non-aeronautical revenue is a function of the number and type of passengers going through the airport, as well as the available shopping facilities and typical access methods. Because this has not previously been included in AIM, a model was estimated for this study to assess non-aeronautical revenues for key UK airports and competing hub airports.

Data describing the non-aeronautical revenue were derived from airport financial reports. Figure 41 reports the assembled aeronautical and non-aeronautical revenues along with passenger and freight flows for seven UK airports, the

---

[325] E.g. Yokomi et al., 2017.

[326] RDC, 2017; Civil Aviation Authority, 2011.

Manchester Airport Group (MAG), and five European airports or airport management companies. Corresponding data from other UK airports were not accessible, mainly because these airports are privately held.

Figure 41 Operations and commercial revenues from seven UK airports, the Manchester Airport Group, and five European airports or airport management/holding companies, 2019

	Operations: PAX (m)	Operations: Freight, tonnes (m)	Operations: Retail & car parking	Commercial revenue, m£ (2019): Property & operational facilities	Commercial revenue, m£ (2019); Total non-aeronautical revenue	Commercial revenue, m£ (2019): Total aeronautical revenue
Aberdeen (ABZ)	2.9	0.006	13.9	4.2	18.1	38.4
Birmingham (BHX)	12.5	0.034	67.9	27.4	95.3	65.5
Edinburgh (EDI)	14.7	0.019	83.4	23.2	106.6	114.4
Glasgow Prestwick (PIK)	0.66	0.000	2.7	N/A	N/A	N/A
London Gatwick (LGW)	46.4	0.113	279.6	103.4	383.0	427.8
London Heathrow (LHR)	80.9	1.587	722.0	423.0	1145.0	1831.0
London Luton (LTN)	18.0	0.037	106.8	18.2	125.0	101.9
Manchester Airport Group (MAG)	61.9	0.675	419.5	115.4	534.9	354.5
Aeroports de Paris (ADP)	108.0	2.201	1005.0	560.6	1565.6	1020.8
Brussels (BRU)	25.6	0.544	91.9	71.3	163.2	353.4
Munich (MUC)	48.0	0.357	447.5	173.4	620.9	758.9
Royal Schiphol Group (RSG)	80.5	1.570	305.4	260.5	565.9	855.4
Zurich (ZRH)	31.5	0.452	202.2	135.5	337.7	529.2

Sources: Aberdeen International Airport Limited, 2020; Birmingham Airport Holdings Limited, 2020; Edinburgh Airport Limited, 2020; TS Prestwick Holdco Limited, 2020; Ivy Holdco Limited, 2020; Heathrow Airport Limited, 2020;. London Luton Airport Operations Limited, 2020; Manchester Airports Group, 2020; Groupe ADP, 2020; Brussels Airport Company NV, 2019; Munich Airport, 2020; Royal Schiphol Group, 2020; Flughafen Zurich AG, 2020.

Note: MAG includes East Midlands (EMA), Manchester (MAN) and Stansted (STN) airports. Aeroports de Paris includes Charles de Gaulle (CDG) and Orly (ORY) airports. Numbers of the Royal Schiphol Group include Amsterdam Schiphol (AMS), Rotterdam The Hague (RTM), and Eindhoven (EIN) airports. The BRU data relate to 2018. These data will be supplemented with Middle Eastern hub airport data where available.

Using the data in Figure 41, econometric models explaining the revenues from retail and car parking (RCP) and those from property and operational facilities (POF) were estimated. The explanatory variables include passenger flows (PAX), freight flows (FRT) and airport-related dummy variables.

Retail and car parking revenues. The key variable explaining RCP revenues is the airport passenger flow. The addition of a dummy variable for the Royal Schiphol Group to account for the inexplicably comparatively low retail revenue further improves the robustness of the estimates and the R^2 (t-statistics in parenthesis) in the case of all observations. The model is:

$$\ln(Rev_{RCP}) = \beta_0 + \beta_1 \ln Pax + \beta_2 I_{RSG} ,$$

where Rev_{RCP} is airport RCP revenue, *Pax* is the number of yearly passenger movements in million passengers per annum (mppa), I_{RSG} is a dummy variable indicating whether the airport is in the Royal Schiphol Group or not, and β_0 - $\beta_2$are parameters to be estimated. Parameter estimates are shown in Figure 42. The passenger elasticity of RCP revenues (β_1) is around 1.1, thus translating a 10% increase in airport passenger flows into an 11% increase in revenues.

Figure 42 Estimation results of the final model explaining the airport revenue of retail and car parking

Parameter	Value
N	13
Adj.R^2	0.981
β_0	1.339 (8.6)
β_1	1.153 (24.8)
β_2	-0.679 (-2.80)

Source: ATA analysis

Property and operational facilities-related revenues. Because POF-related revenue may also depend on air freight, POF revenues were estimated with passenger flows and freight flows. A dummy variable for Heathrow Airport was also tested, which is justified by the high concentration of office space within the airport perimeter; however, this parameter was only significant when estimating using just UK airports. The final model is:

$$\ln(Rev_{POF}) = \gamma_0 + \gamma_1 \ln Pax + \gamma_2 \ln Frt,$$

where Rev_{POF} is airport revenue from POF, *Pax* is the number of yearly passenger movements in million passengers per annum (mppa), *Frt* is the yearly amount of air freight handled at the airport in tonnes, and $\gamma_0 - \gamma_2$ are parameters to be estimated. Parameter estimates are given in Figure 43. As shown, the passenger elasticity of POF revenues is also around 1.1, thus translating a 10% increase in airport passenger flows into an 11% increase in revenues.

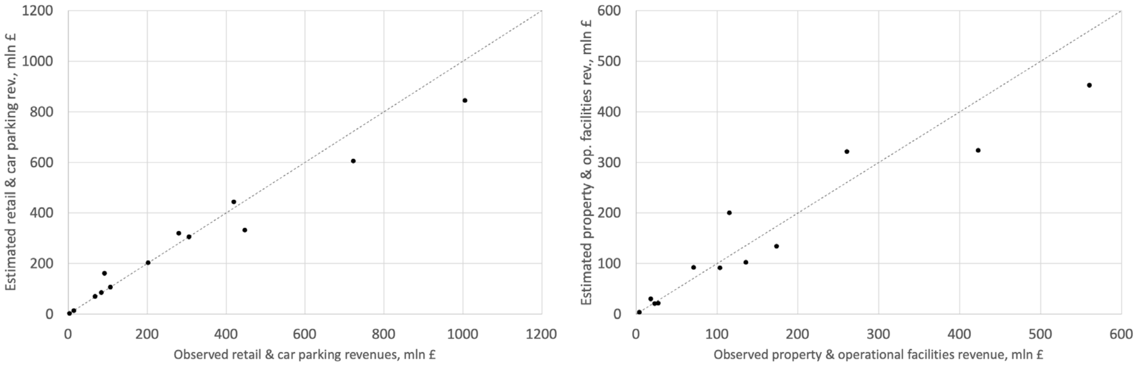
Figure 43 Estimation results of the final model explaining the airport revenue of property and operational facilities

Parameter	Value
N	12
Adj.R^2	0.945
γ_0	2.101 (1.98)
γ_1	0.805 (3.20)
γ_2	0.310 (2.35)

Source: ATA analysis

Figure 44 illustrates the precision of the estimates by plotting the estimated revenue over the observed revenue, transformed to the underlying multiplicative non-linear model with revenues expressed in million pounds. Ideally, all observations should be located on a 45 degrees straight line through the origin.

Figure 44 Estimated revenues versus observed revenues



Source: ATA analysis

Note: Retail and car parking (left), property and operational facilities (right)

For this study, we implement these models in AIM, using existing AIM outputs on airport-level passenger and freight flows as input. Revenues for all modelled UK airports are calculated and it is assumed that the relationships estimated above are representative for other UK airports for which data could not be gathered. In general, we do not assume that these relationships hold more generally for other global airports other than those used in the estimation process; however, because data on non-aeronautical revenue could not be obtained for non-EEA competing hub airports, we use the current model to provide first-order estimates for these airports[327]. For aeronautical revenues, we use data from the RDC airport charges database[328]. In practice, many airports offer discounts on advertised landing charges, and typical database landing charges may also not capture some of the more complex airport charge structures. Because of this, we apply reduction factors to database charges (on average around 30%) to reflect actual reported aeronautical revenue, as shown in Figure 41. These factors are based on the difference between the airport's own reported aeronautical revenue and the estimated value of aeronautical revenue based on number of flights and database values for per-flight/per-passenger landing costs. Outcomes for the 2015-2019 period for London airports, other UK airports and selected competing hub airports[329] are shown in Figure 45.

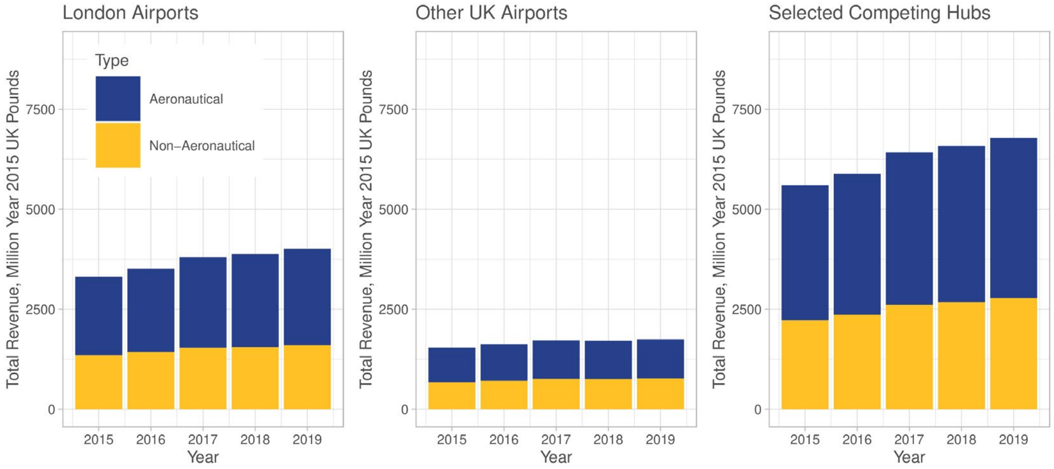
---

[327] Note that the primary conclusions of the report on impacts on non-EEA competing hub airports – i.e., that they are little-affected by the UK ETS – are unlikely to change even if this assumption is not accurate.

[328] RDC, 2017.

[329] The group 'Selected competing hubs' includes Paris Charles de Gaulle (GDG), Amsterdam Schiphol (AMS), Frankfurt (FRA), Munich (MUC) and Brussels (BRU).

Figure 45 Estimated airport revenues by revenue type and airport grouping



Source: AIM

B.6 Further information on uncertainty and sensitivity analysis in this study

AIM requires projections of key system drivers as model inputs. Where these variables are uncertain and are likely to affect outcomes, uncertainty in outputs can be assessed by running the model across a range of plausible values for these projections. Similarly, where model parameters (for example, demand elasticities) are uncertain, and this uncertainty is likely to affect outcomes, uncertainty can be assessed by running the model across a plausible range of parameter input values. To reduce the amount of computing time required, sensitivity analysis focuses primarily on variables and parameters which are both highly uncertain and to which model outcomes are likely to be sensitive, with other variables that are either less uncertain or less sensitive included only where they are of particular interest. This division is shown schematically in Figure 46.

Figure 46 Schematic representation of uncertainty analysis variable selection

	Low uncertainty	High uncertainty
Low impact on outcomes	For example: CORSIA state exemption criteria	For example: CORSIA carbon price
High impact on outcomes	For example: Population	Variables for Sensitivity Analysis (e.g. GDP/capita, oil price)

Source: ATA

Broadly, AIM input variables for this study can be divided into three classes. First, there are variables related to the 20 policy options chosen for evaluation **('policy variables'),** as discussed in Section 5.1. Examples of policy variables include variables related to the methodology used for UK ETS free allocation to airlines, or to the methodology used for UK ETS-CORSIA interaction.

Second, there are uncertain input variables which are not set by the specific details of each policy option, but to which policy outcomes may be sensitive (e.g. variables in the red and/or yellow regions of Figure 46). A selection of these variables **(‘uncertain scenario variables’)** are chosen for the uncertainty analysis based on their likely impacts on the outcomes assessed here.

Third, there are input variables that are either not very uncertain or have limited impact on model outcomes, or both (e.g. variables in the green and/or yellow regions of Figure 46). For these variables **(‘background variables’)**, an input assumption is needed, but there is no need to run additional sensitivity analysis. The assumptions already in use in AIM are maintained for these variables.

Based on an analysis of the literature and previous studies in this area, we identify seven groups of uncertain scenario variables which are likely to be important for model outcome sensitivity analysis. These variables are:

- Passenger and freight demand growth;
- Future technology characteristics;
- Oil price;
- Alternative fuel supply;
- Passenger price sensitivity;
- Cost pass-through; and
- Scenarios for non-UK policy (e.g. CORSIA and EU ETS characteristics).

The values used for these variables in the sensitivity analysis are discussed in the next section.

In some cases, uncertainty in future trends is the result of combined uncertainty in a large number of variables. For example, the future impact of technology developments encompasses uncertainty in the entry into service date of new aircraft models, the extent to which they are more fuel-efficient than their predecessors, and the costs associated with operating them, as well as uncertainty about operational strategies to reduce aircraft fuel use. For parameters of this type, we use a lens approach (e.g. Allaire et al., 2014)[330]. Combinations of the different uncertain parameters are grouped into a smaller number of model input ‘lenses’ reflecting particular high-level scenarios about their development. For example, for aircraft technologies, a ‘nominal’ lens might include all technology parameters set at central or most-likely values; a ‘pessimistic’ lens might include estimates on the low end of those available in the literature for fuel efficiency improvements, high-end estimates of technology cost and later estimates of entry into service dates.

---

[330] Allaire et al., 2014.

B.7 Further information on the selection of values for uncertain scenario variables

B.7.1 Demand growth

Long-term aviation demand growth at a global and regional level is uncertain, and has only become more so in the wake of the COVID-19 pandemic[331]. Demand growth rates can affect the extent to which aviation emissions are covered by free allowances and hence the average carbon costs incurred by airlines. They also affect the potential of technologies that are supply-limited to reduce within-sector emissions.

Demand projections in AIM can be generated from global projections of demand drivers, including country-level population and GDP per capita. Typically, we use trends for these variables derived from the IPCC SSP scenarios (e.g. O'Neill et al. 2013), adjusted for recent country-level economic growth trends and the impact of the COVID-19 pandemic using data and analysis from IMF (2021)[332]. Demand projections are also affected by assumptions about oil prices and other future developments. Aviation industry forecasts[333] of demand growth rates are typically higher than those used by policymakers[334]. For this study, we select scenarios for demand drivers which produce a range of outcomes similar to that seen between demand projections from these different sources:

- High growth: uses inputs based on the IPCC SSP2 scenario. Typically, these produce estimates of aviation growth rates that are comparable to industry forecasts[335]. UK aviation demand growth is higher than that projected by DfT (2017). This is used as a sensitivity case for outcomes in the case that demand growth exceeds expected levels.
- Low growth: uses inputs based on the IPCC SSP3 scenario. These inputs simulate a scenario where global aviation emissions do not rise substantially from present-day levels and are close to DfT (2017) projections for the UK. This scenario is used as the nominal case for examining outcomes.

Global and UK demand trends for these scenarios in a 'no UK ETS' baseline where all other uncertain scenario variables are set to nominal values are shown in Figure 47 and Figure 48. Both projections are adjusted for the socioeconomic and movement restriction impacts of the COVID-19 pandemic[336], and a moderate level of long-term demand decoupling from economic growth is used as aviation systems mature, derived from market maturity assumptions used in DfT (2017)[337].

---

[331] Dray et al., 2019 ; Dray & Schäfer, 2021.

[332] Further discussion about COVID-19 recovery assumptions is given in 0.

[333] E.g. Airbus, 2019; Boeing, 2020.

[334] E.g. DfT, 2017.

[335] E.g. Airbus, 2019; Boeing, 2020.

[336] ICAO, 2020c; IMF, 2021.

[337] Because income elasticities are specified on different market segments and geographic scopes in the DfT aviation model and AIM, it is not possible to directly use the same elasticity values, so the relative change over time is used instead to align market maturity assumptions. In DfT (2017) initial income elasticities in the range 0.5-1.2 are assumed to decline linearly to no more than 0.6 (unless initially below this value) by the

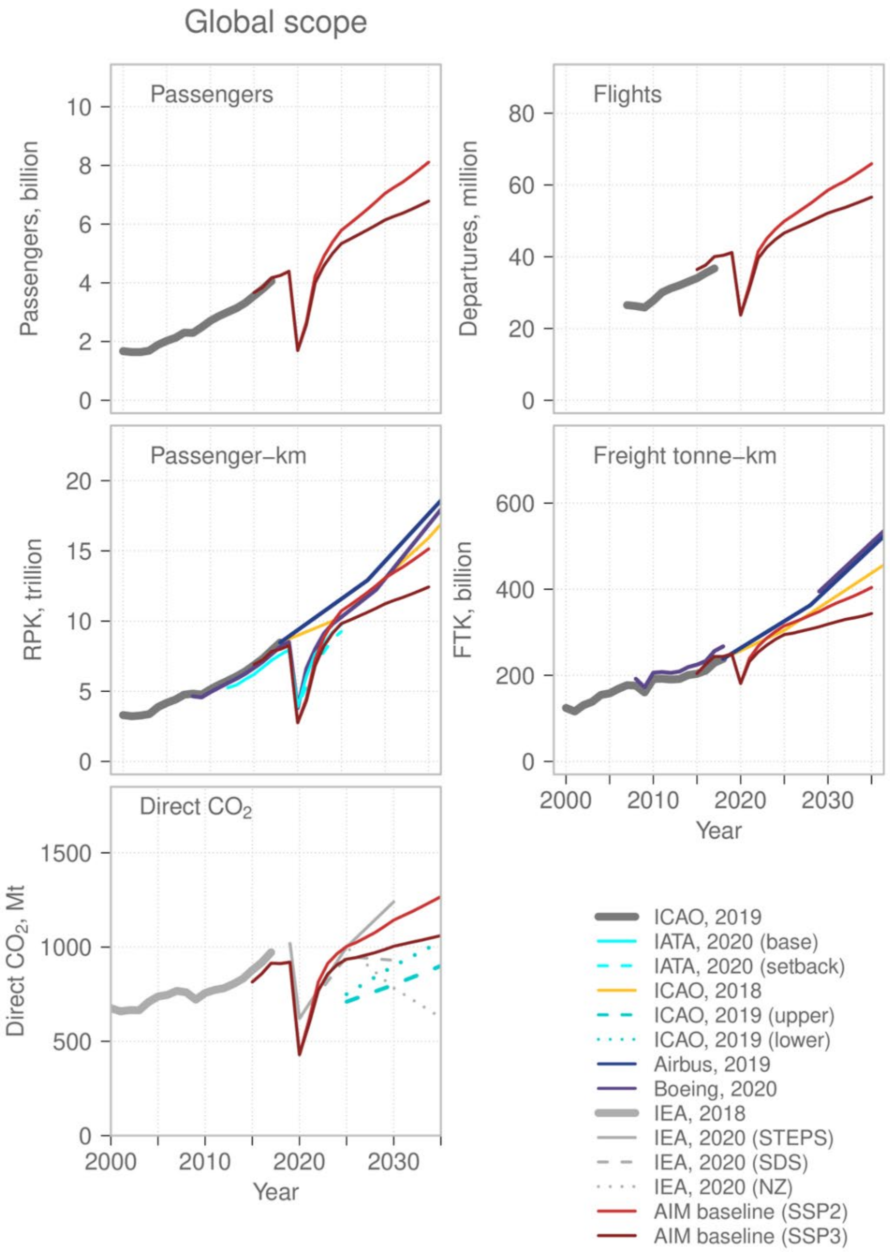


Figure 47. AIM nominal (SSP3) and high (SSP2) COVID19-adjusted global demand baselines to 2035, in comparison to historical data and alternative projections.

Because demand decoupling is assumed, longer-term growth even in the high growth case is slightly below industry projections. The exact value of modelled demand in any given year is a function of multiple uncertain factors, including input socioeconomic and demand decoupling trends and assumptions for other variables; as such, these scenarios are intended to illustrate two plausible cases for how demand might develop, rather than provide definitive projections.

To use AIM to model UK policy, we need to be sure that the model's baseline assessment of recent global and UK-related demand and emissions matches with

---

end of a 70-year period. This is used to derive a typical yearly rate of decline for income elasticities which is then applied in AIM.

actual values[338]. Figure 47 also shows ICAO passenger, flight, RPK and FTK data[339]; alternative projections of growth and COVID-19 impacts from Airbus, Boeing, IATA and ICAO[340]; and IEA aviation CO_2 data and projections[341]. Note that IEA CO_2 data and projections are above AIM (and IATA) totals because they include CO_2 from military flights and general aviation; IEA CO_2 projections differ widely due to differences in policy assumptions and include fuel lifecycle CO_2 reductions from SAF use. The ICAO CO_2 projections shown are pre-COVID-19 and include only international flights, i.e. they account for around 70% of total global aviation CO_2. Because alternative future projections concentrate on passenger- and freight- tonne-km, the total number of passengers and flights are shown for comparison with historical data only. Passengers are counted once per flight.

Figure 48 shows modelled UK domestic and international (including flights to and from the UK) aviation metrics for the nominal and high demand scenarios when all other uncertain scenario variables are set to nominal values. Also shown are historical UK passenger and flight data[342], RPK[343], freight tonne-km[344] and CO_2 emissions[345]. Pre-COVID-19 projections from DfT (2017) are also shown where applicable on a similar scope; note that DfT (2017) RPK and CO_2 totals shown include flights to and from oil rigs, which are not modelled in AIM.

---

[338] See also ANNEX C on QA tests.

[339] ICAO, 2020.

[340] Airbus, 2019; Boeing, 2020 ; IATA, 2020; ICAO, 2018.

[341] IEA, 2020b.

[342] Civil Aviation Authority, 2000-2019.

[343] DfT, 2017.

[344] World Bank, 2020. Note that the AIM data shown include mail as well.

[345] BEIS, 2021b.

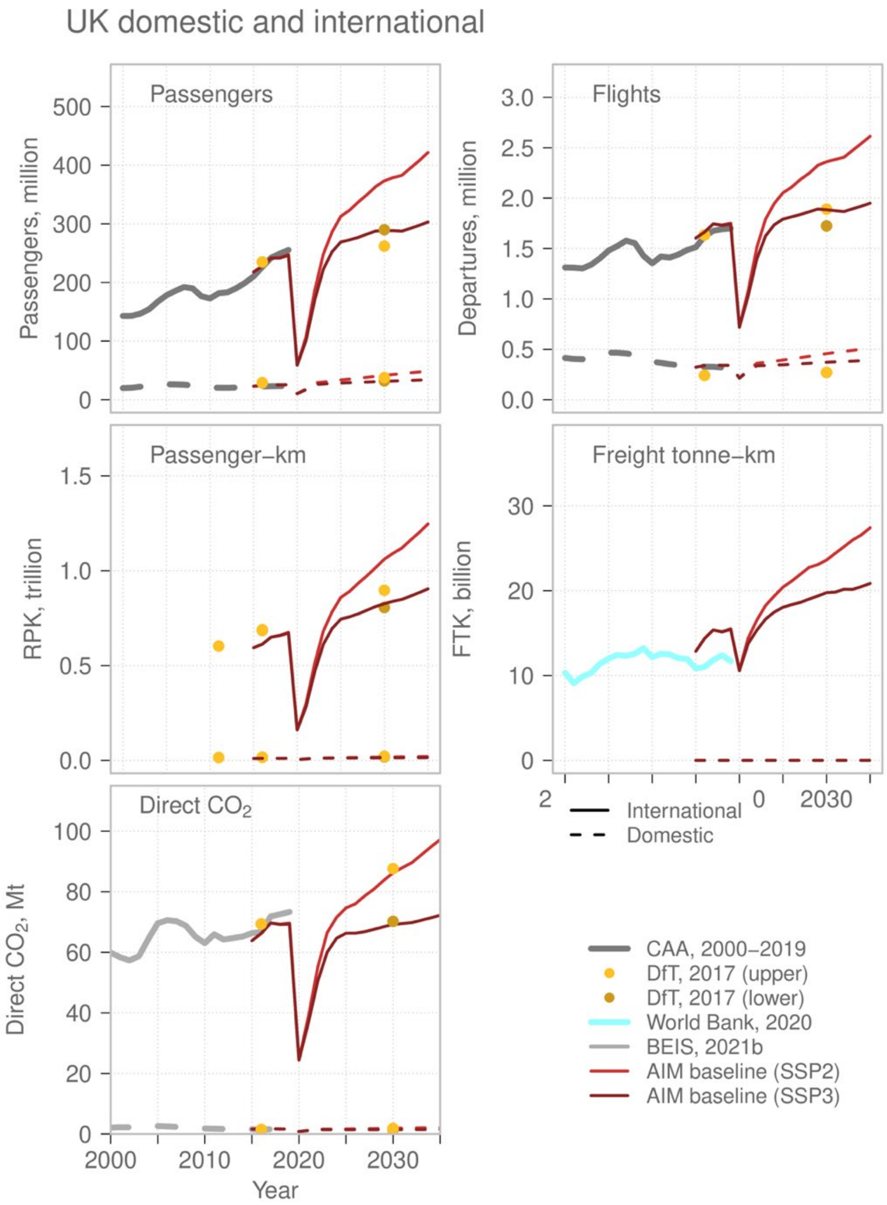


Figure 48. AIM nominal (SSP3) and high (SSP2) COVID-19-adjusted demand baselines to 2035, in comparison to historical data and alternative projections.

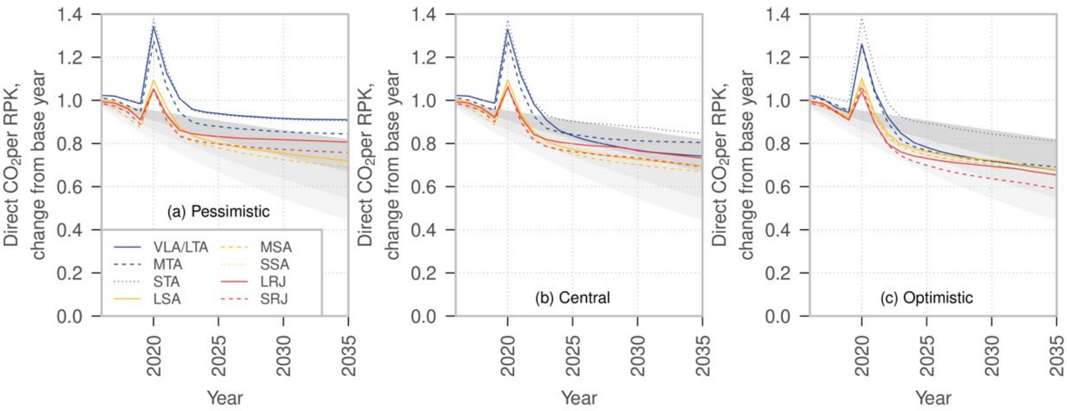
B.7.2 Future technology characteristics

The potential of different technologies to reduce airline CO_2 emissions affects the extent to which airlines can mitigate CO_2 within-sector rather than purchasing additional allowances. Airline technology choices depend on the costs associated with new technologies, the costs associated with the technology the airline is currently using, and the methodology used to make purchase decisions. Similar factors apply to airline decisions on whether to change operational strategies or retrofit existing aircraft to make them more fuel-efficient. Currently, new technology costs and capabilities in AIM are derived from ATA and Ellondee (2018)[346], with

---

[346] ATA and Ellondee, 2018. The upper and lower trends used here are taken from the Likely-Best and Likely-Worst scenarios where multiple dimensions of uncertainty are given for a given technology characteristic.

additional data from other literature sources[347] where required. Combinations of the different uncertain parameters are grouped into a smaller number of model input 'lenses'[348] reflecting particular high-level scenarios about their development as discussed in the previous section. Example trends in CO_2/RPK by aircraft size using these lenses by aircraft size class are given in Figure 49[349]. For comparison, the boundaries of the grey bands shown in the background of **Figure** 49 indicate 1%/year, 2%/year and 3%/year changes in CO_2 per RPK. Note that CO_2 per RPK increases significantly during the pandemic period due to reductions in average aircraft load factor.



Note: VLA: Very Large Aircraft; LTA: Large Twin Aisle; MTA: Medium Twin Aisle; STA: Small Twin Aisle; LSA: Large Single Aisle; MSA: Medium Single Aisle; SSA: Small Single Aisle; LRJ: Large Regional Jet; SRJ: Small Regional Jet.

Figure 49. Example trends in CO_2/RPK by aircraft size class for different technology lenses used in AIM.

For the sensitivity modelling, we use these lenses as input for the three future technology scenarios.

B.7.3 Oil price assumptions

Airline costs are strongly affected by oil price and its impact on jet fuel prices. Fuel is often the largest component of airline operating costs and can be 20-30% of total direct operating cost. Fuel prices are also highly uncertain and dependent on oil price fluctuations, though airlines often hedge fuel costs to reduce uncertainty in future operating cost.[350] In turn, fuel prices affect ticket prices (either directly or via fuel cost surcharges), and this impacts demand. Airline operating cost impacts from fluctuations in fuel price have historically been much larger than those from carbon pricing, although this could change in future depending on levels of carbon price. High fuel prices have a similar type of impact to high carbon prices, i.e. they may reduce demand and stimulate the adoption of technologies which reduce fuel

---

[347] E.g. Schäfer et al. (2016); Dray et al. (2018)

[348] Allaire et al., 2014.

[349] Note that these are illustrative values only as exact values of CO_2/RPK depend on multiple factors, including demand growth (as higher demand growth leads to a fleet which is younger on average) and oil prices (as more mitigation measures become cost-effective at higher fuel price). The peak in CO_2/RPK around 2020 is due to reduced load factors during the COVID-19 pandemic. The background grey bands shown indicate average 1%, 2%, 3% and 4%/year reductions in CO_2/RPK.

[350] Morrell & Swan, 2006.

use. As such, different scenarios for oil price are necessary to separate out factors that arise from fuel price from those that arise from carbon pricing.

For this project, oil price projections are based on BEIS Central (nominal), High and Low projections of oil prices[351]. Projections are shown in Table 22 and Figure 50, below.

Table 22. Oil price assumptions used in AIM for this project

	2015	**2020**	**2025**	**2030**	**2035**	**Derived from**
Low	48.7	38.4	40.1	45.7	51.3	BEIS, 2019
Central (nominal)	48.7	38.4	63.4	73.7	83.9	BEIS, 2019
High	48.7	38.4	98.8	110.0	121.3	BEIS, 2019

Note: Oil price, year 2015 USD/bbl

Central (nominal) values are used in the main set of model runs. High and low oil price scenarios are used in the sensitivity analysis to explore the sensitivity of outcomes to changes in oil price.

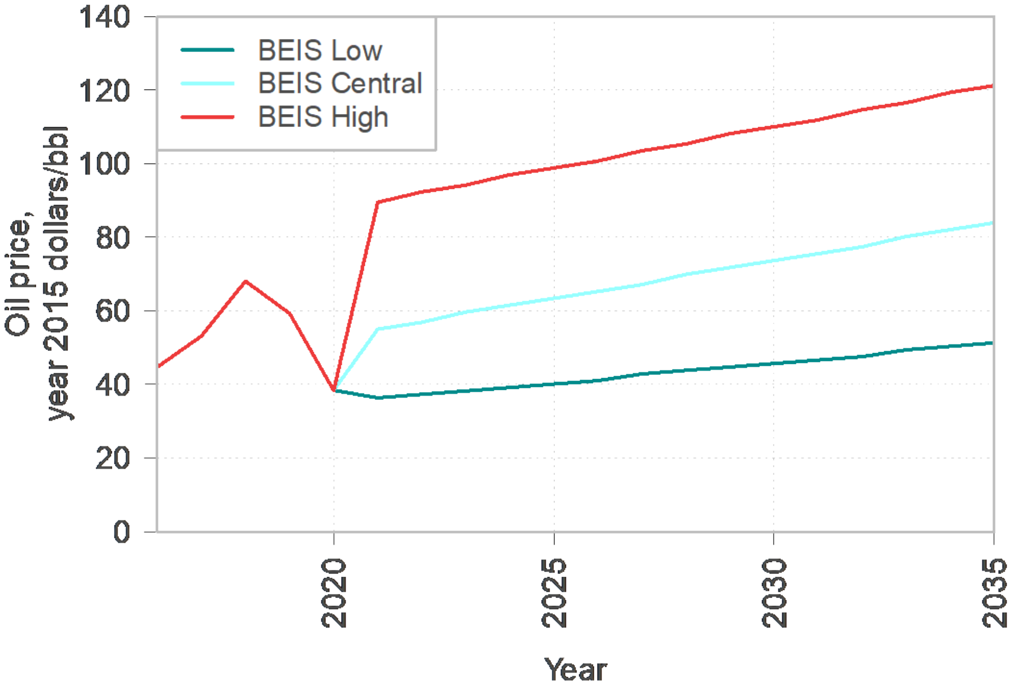


Figure 50. Oil price scenarios used in AIM for this project.

B.7.4 Assumptions about alternative fuels

SAF uptake in AIM is projected using a cost curve model based on supply and production cost estimates for a range of feedstock/production pathway combinations. This model simulates both global fuel supply limits and the impact

---

[351] BEIS, 2019.

on other regions of increased SAF demand stimulated by a carbon price increase on a given set of routes, allowing direct consideration of how route-level changes in carbon price may affect SAF use on other routes. At present, alternative aviation fuel production cost estimates are typically twice or more the current level of fossil Jet A price[352]. For a typical airline, this implies a roughly 20% increase in direct operating cost for hypothetical 100% alternative fuel use.

Different future projections differ in their assumptions about the amount and type of alternative fuels that will be used in aviation. For example, CCC (2019) assume SAF use of only 5-10% in 2050, due to priority use of biomass in other sectors. The recent UK Net Zero Strategy targets 10% SAF in 2030[353], and the UK Jet Zero Consultation[354] and UK SAF Mandate Consultation[355] explore scenarios with between 5 and 75% SAF in 2050. In contrast, the IEA Net Zero scenario[356] assumes 50% use of low-emissions aviation fuel by 2040. There is also the potential for an EU alternative fuel mandate policy via the RefuelEU initiative[357]. The RefuelEU preferred option specifies a 2% SAF blend for fuel supplied to EU airports from 2025, 5% SAF from 2030 and 20% SAF from 2035. Between then, these scenarios imply a large range of levels of SAF use are possible in 2035. To capture this, we use three scenarios:

- Low: SAF use remains at current levels to 2035
- Central: we use AIM's internal cost curve model, but SAF use is capped at a maximum of 10% of total aviation fuel use to 2035
- High: we use AIM's internal cost curve model, with SAF use capped at 40% of total aviation fuel use to 2035.

Typically, projections of SAF production capacity ramp-up are not linear, but involve an initial period of slow growth followed by more rapid growth afterwards[358].

Hydrogen and electric aircraft have also been proposed as more radical solutions to reduce aviation emissions. While the potential of these aircraft types over the longer term (e.g. to 2050) may be high, their potential to 2035 is likely to be limited. This is because time lags are associated with designing and certifying alternative aircraft technologies, and with the fleet turnover necessary for them to have a significant emissions impact[359]. For example, Airbus's ZEROe programme targets 2035 for initial availability of large commercial hydrogen aircraft[360], suggesting significant impacts are unlikely until well after 2035. For battery electric aircraft, advances in battery energy density are also required[361]. As such, it is likely that only small aircraft designs using these technologies will be available for use before 2035, and we do not consider them in this analysis.

---

[352] ICCT, 2019a.

[353] BEIS, 2021e.

[354] DfT, 2021b.

[355] DfT, 2021c.

[356] IEA, 2021

[357] EC, 2021

[358] E.g. ICCT, 2019b.

[359] E.g. Dray, 2013.

[360] Airbus, 2021.

[361] E.g. Schäfer et al., 2018.

B.7.5 Cost Pass-through

Multiple different assumptions have been used in the literature for the percentage of increased airline costs that is added on to ticket prices due to carbon trading, ranging from zero to more than 100%[362]. In practice, the level of cost pass-through depends on factors such as the extent to which origin and destination airports are subject to capacity constraints,[363] the level of competition[364], logistical constraints[365], the extent to which cost changes affect airlines equally, whether costs are increasing or decreasing[366], and the types of airlines operating on each route[367]. Calculating typical levels of cost pass-through is also complicated by airline revenue management strategies in ticket pricing, which may lead to effective pass-through that differs by when tickets were purchased, and by different yield and competition levels for transfer passengers when compared to direct passengers.

ATA and Clarity (2018) carried out an extensive review of the available literature on cost pass-through in aviation systems. Based on that analysis, they proposed the following scenarios:

- Low: 0% cost pass-through at congested airports, 100% cost pass-through elsewhere.
- Central (nominal): 50% cost pass-through at congested airports, 100% cost pass-through elsewhere.
- High: 100% cost pass-through everywhere.

These scenarios are also in line with results from more recent research in this area[368] and so are also used in this analysis. In this study, airlines are assumed to set ticket prices based on marginal carbon costs. As such, cost pass-through is assumed here to include the opportunity costs of free allowances. A discussion of the reasoning behind this assumption, and the limits associated with it, is given in Sections 2.3.1 and 3.3.2.

Airports in AIM can be divided into congested and non-congested based on the number of yearly flight operations compared to the airport's declared capacity for operations. This threshold is set at a level which includes London Heathrow and Gatwick airports in 2015, but excludes other UK airports[369].

---

[362] Anger & Köhler, 2010; Ernst & Young and York Aviation, 2007; European Commission, 2013a.

[363] Dray et al., 2020.

[364] E.g. ICF et al. 2020.

[365] E.g. Borenstein & Rose, 2014.

[366] Wadud, 2015.

[367] E.g. Vivid Economics, 2007.

[368] ICF et al. 2020; Dray et al. 2020.

[369] Note that, as discussed in Annex B.9, AIM uses a simplified model of airport capacity growth; in practice, this approximates a system in which there is an increase in operations at congested airports both because of incremental capacity increases and because operations increase at secondary airports which in tun become more congested.

B.7.6 Passenger demand elasticities

In the previous carbon leakage report commissioned by DfT[370], one of the largest identified areas of uncertainty in leakage was the extent of passenger sensitivity to changes in fare. There are a wide range of estimates of passenger price sensitivity in the literature[371]. Typically, business passengers are less price-sensitive than leisure passengers, and price-sensitivity may also vary by world region, length of flight, and the availability of suitable alternatives to flying. If the price-sensitivity of passengers is smaller, reductions in demand due to fare increases will be smaller, both inside and outside the policy area. Additionally, total passenger demand, and passenger price sensitivity, may change over time as aviation systems mature, attitudes to aviation change, or due to shifts in behaviour following the COVID-19 pandemic. However, at present there is limited data on the level and type of behavioural change that might occur[372].

ATA and Clarity (2018) used a central estimate of passenger fare elasticity of -0.5, with upper and lower estimates of -0.2 to -0.8. AIM uses generalized cost elasticities, which assess passenger response to changes in journey time and/or cost in a single term via the use of passenger values of time and are typically larger (more negative) than fare elasticities. Different elasticities are used by world region-pair and distance band[373]. To assess outcomes at different levels of passenger price sensitivity, we run AIM with these values adjusted upwards or downwards by a set amount. Based on an initial assessment of AIM's generalized cost elasticities per region in comparison to fare elasticities per region, and the corresponding values used in DfT (2017), we use the following scenarios:

- High: adjust all generalized cost elasticities upwards by 0.115
- Central: use current AIM baseline values
- Low: adjust all generalized cost elasticities downwards by 0.115

Note that, because cost elasticities apply to all cost changes, not just those caused by changes in carbon price, baseline demand trends also differ in the different elasticity cases.

B.7.7 Assumptions about the EU ETS and CORSIA

Multiple projections exist for future EU ETS carbon prices but this is subject to significant uncertainty. For this study, recognising this uncertainty, we instead used the latest published BEIS - central (nominal), lower and upper traded carbon value scenarios for appraisal[374] that were available at the time this analysis commenced (July 2021), which provide a wide range of potential carbon price trends. These values are used to explore outcomes across a wide range of carbon price futures, rather than to specify any individual projection as a 'most likely' case. Other

---

[370] ATA and Clarity, 2018.

[371] E.g. Brons et al., 2002; Oum et al., 1992; InterVistas, 2007.

[372] E.g. Graham et al. 2020; Davidson et al. 2014.

[373] There is no direct split between trip purpose for elasticities in AIM as this information is not available globally; however, some distinction between trip purposes is captured by the distance banding and regional specification as different distance/region-pair groups have different balances of trip purpose.

[374] BEIS, 2021.

available projections at the time that scenarios were constructed[375] fall within this range.

Future baseline CORSIA carbon price assumptions are based on analysis by Fearnehough et al. (2018). ICAO (2015) also provide CORSIA carbon price assumptions which are above the upper scenario in Fearnehough et al. (2018). We use these assumptions as our upper case. These assumptions are shown in Table 23. and Figure 51. For the different UK ETS policy options, we consider cases where the UK ETS carbon price is 50% above (H), 50% below (L) or equal to the EU ETS carbon price. Figure 45 also shows these price trends where they differ from the EU ETS price assumptions shown, including the values used in the sensitivity analysis.

Table 23. Future carbon price scenarios

	2015	2020	2025	2030	2035	Source
EU ETS lower scenario	5.5	18.1	19.8	39.6	58.8	BEIS, 2021d
EU ETS central scenario (nominal)	5.5	18.1	46.4	79.2	117.5	BEIS, 2021d
EU ETS upper scenario	5.5	18.1	73.0	118.8	176.2	BEIS, 2021d
CORSIA baseline	0.0	0.0	1.22	1.22	1.22	Fearnehough et al. (2018)
CORSIA upper scenario	0.0	0.0	11.4	21.6	26.2	ICAO (2015)

Note: Carbon value applicable to aviation, year 2015 GBP/tCO$_2$

There are currently a number of proposals for how the EU ETS for aviation may change in future[376]. For the EU ETS, we assume (as baseline):

- The LRF changes to 4.2%, in line with the Fit for 55 proposals;
- No further change in geographical scope after 2021;
- Free allocation decreases to zero by 2027, in line with the Fit for 55 proposals[377];
- Only the EU ETS applies to intra-EEA routes. CORSIA applies to other routes to and from the EEA where the non-EEA origin or destination is a CORSIA participant. Routes from EEA countries to the UK are covered by the EU ETS and not CORSIA.
- We do not explicitly assume increased fuel taxation and SAF mandates for EEA airports (in line with the Fit for 55 proposals), but outcomes consistent

---

[375] e.g. EC 2013; 2021.

[376] EC, 2021.

[377] EC, 2021.

with these proposals in terms of effective fuel price and SAF uptake are included in the sensitivity analysis.

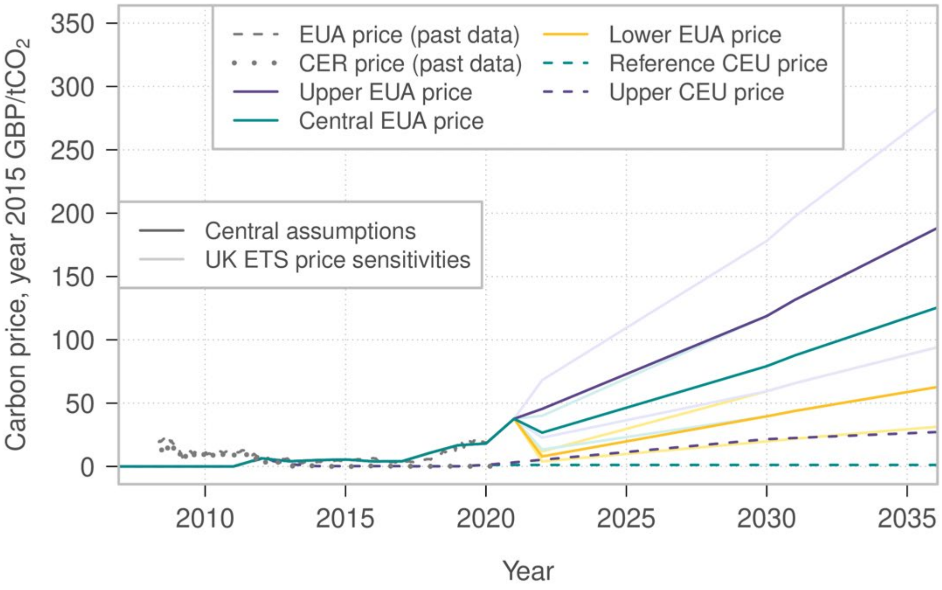


Figure 51. Scenarios for EU ETS and CORSIA carbon values

For CORSIA, we assume in the nominal case:

- Countries which are not currently participants but whose participation is mandatory in the Second Phase join at the start of the Second Phase, and
- The baseline remains 2019-only[378].

For the sensitivity analysis, we explore changes in some of these characteristics. We look at a high, nominal and low case for level of impact that the EU ETS and CORSIA are likely to have on operations and airline costs.

- High case: High EU ETS and CORSIA prices; CORSIA baseline reverts to 2019/2020 after the pilot phase.
- Nominal case: central case assumptions for all variables.
- Low case: low EU ETS price.

B.8 Modelling impacts of the COVID-19 pandemic

Because the UK ETS began in 2021, its initial years will be strongly impacted by recovery from the COVID-19 pandemic. For example, the initial impact of different CORSIA interaction options will be small, because airline offset obligations under CORSIA do not begin until CO_2 emissions on CORSIA-eligible routes increase above the CORSIA baseline level. In this section, we discuss the assumptions that

---

[378] The baseline is currently defined as an average of 2019 and 2020 emissions, however due to the COVID-19 pandemic, the ICAO Council agreed in June 2020 to change this to 2019 emissions only for the Pilot Phase. The CORSIA periodic review in 2022 will consider whether to extend the baseline change to the subsequent phases.

are used to model the impact of COVID-19 on aviation systems worldwide, and aviation system recovery.

The approach used in AIM to modelling impacts from COVID-19 is discussed in detail in Dray & Schäfer (2021)[379]. We directly model the immediate impact of movement restrictions on demand and load factors, changes in GDP/capita, and the impact of the pandemic on airline fleets. These are discussed in turn, below. Additionally, input oil and carbon price trends use the most recent data available at the time of modelling, incorporating the initial pandemic impacts on these variables[380].

The largest short-term impact of the pandemic on aviation arises from travel restrictions. International aviation RPK was 98% below year-2019 levels in May 2020[381], driven by border closures, quarantine regulations and distancing requirements. It is likely some movement restrictions will extend into late 2021 and potentially beyond, depending how the pandemic progresses. The extent and duration of these effects is highly uncertain. To generate scenarios for these impacts, we introduce demand damping factors for the immediate recovery period, applied separately for domestic and international passenger and freight demand. For 2020, these factors are estimated directly from available data on yearly average demand reductions (e.g. IATA, 2021). After 2020, we follow a scenario-based approach. For this study, the scenario for COVID19-related movement restrictions is derived from IATA's central recovery projection[382]. Movement restrictions are assumed to end before 2024, when the different free allowance allocation and CORSIA interaction options evaluated in this report begin. At this point, the residual impacts of COVID-19 are assumed to be primarily via offsets in GDP/capita from pre-pandemic projections, and in terms of available fleet.

Passenger damping factors apply to numbers of true origin-ultimate destination passengers per city-pair. In practice, flights are reduced by a smaller amount, with many operating at low load factors[383]. To account for this, passenger load factors are also adjusted when the damping factor is applied, with the amount of adjustment taken from IATA and ICAO data on typical load factors for routes with strongly reduced demand[384]. Because airlines lose money operating at low load factors, this is not sustainable over the long term and we assume that, when the damping factor is removed, load factors will return to pre-pandemic trends.

Storage of aircraft during demand downturns (and either retirement from storage if demand remains low, or stored aircraft returning to operations in the case of demand recovery) is already modelled in AIM. However, the COVID-19 pandemic has likely accelerated existing trends away from Very Large Aircraft (VLA). The Airbus A380 and Boeing 747 are due to end production before 2023, with no scheduled replacement. To simulate this, we restrict airline purchases and modelled technology development in the VLA size class from 2021 onwards; as

---

[379] Dray & Schäfer, 2021.

[380] Note that, due to airline fuel cost hedging, the impact of initially low oil prices during the COVID-19 pandemic has a partial time lag of 1-2 years.

[381] IATA, 2021.

[382] IATA, 2021.

[383] ICAO, 2020c.

[384] ICAO, 2020c; IATA, 2021.

the fleet declines through retirements, demand that would have been served by VLAs is typically served by twin-aisle aircraft at higher frequency but lower per-flight CO_2. However, the overall impact of this change over a case where VLA sales and development continue is small - around a 0.3% decrease in global direct aviation CO_2 by 2035.

Over the longer term, the main impact of the pandemic is likely to be through offsets in GDP/capita growth from pre-pandemic assumptions. The IMF provide country-level projections for 2020 and 2021, and global scenarios for how developments to 2025 may deviate from a no-pandemic baseline[385]. We use these projections to adjust the SSP GDP/capita scenarios used in AIM[386]. These impacts are therefore already included in the demand projections shown in in Section B.7.1.

B.9 Potential limitations of the methodology and mitigation strategies

The methodology we use has a number of limitations. These limitations, along with the mitigation strategies used to deal with them, are discussed below.

Omission of some leakage sources

As an aviation system model, AIM cannot model some potential multi-sector sources of leakage. These include where passengers who decide not to fly instead spend their money on some other activity which produces CO_2 outside the policy area and which is not itself subject to emissions trading, and where reductions in aviation fuel demand feed-through into lower oil prices, stimulating demand for aviation and other modes of transport. For these areas of leakage, more qualitative assessments based on available literature can be made. These assessments are discussed in Section 6.5.1.

Capacity constraints

Because long-term forecasts of runway capacity are not available in many world regions, AIM assumes that airport capacity at a regional level can be expanded as required to maintain typical airport delay at base year values. While this assumption is necessary to facilitate modelling world regions with rapid growth, for the UK it means that demand growth at Heathrow, in particular, may be overestimated and that additional growth that the model assigns to Heathrow may occur at other London-area airports, depending on the status of Heathrow Airport's planned expansion. This in turn may also increase the level of capacity constraint at those airports. Impacts on overall growth can be mitigated by matching overall demand to that from external projections which do include detailed capacity constraints[387]. This allows the demand-reduction impact of capacity constraints to be included. Because of this constraint, we also aggregate airport-level model outputs to a regional level (e.g. London airports, other UK airports, selected non-UK competing hubs).

---

[385] IMF, 2021.

[386] AIM uses the IPCC SSP scenarios (O'Neill et al. 2013) to provide baseline GDP/capita and population projections for internally self-consistent scenarios.

[387] DfT, 2017.

Implicit representation of passenger type

Passenger behaviour in AIM is specified using estimated relationships from detailed global databases of passenger movements and fares[388]. In general, these data sources do not include information about a passenger's reason for travel. As such, the different responses of leisure, business and VFR passengers are implicit in the estimated parameters (e.g. a group of routes within a given distance band in a given global region-pair may have lower price sensitivity if it has a higher fraction of business travellers) rather than being modelled separately. However, if routes change in trip purpose composition significantly over time, then we would expect price sensitivity on those routes to also change. To mitigate against the risk that this effect is not captured, we include passenger price sensitivity as an uncertain scenario variable and look at the impact of changing it in the sensitivity analysis.

---

[388] E.g. Sabre, 2017.

ANNEX C QUALITY ASSURANCE

As discussed in the project Quality Management Plan, model validation includes a specific list of tests against external data. In this annex we describe the project QA processes and the register of validation tests. Where outcomes have not already been presented earlier in the report, we also report the outcome of validation tests.

C.1 Methodology validation

As detailed in the project Quality Management Plan, all quality assurance work sits under Frontier's best-practice Quality Management System. This section details two separate validation processes to ensure that methods and outcomes are robust, cover all important interactions and areas of effect, and provide all information necessary to communicate results.

- First, all modelling is subject to ATA internal validation processes.
- Second, two stages of impartial external review will be undertaken by aviation experts (ICF) who are not directly involved in the modelling work.

These methods are described in the following sections.

C.1.1 ATA internal model validation

The AIM model was developed using a three-step validation process. As discussed in Section 5.2.1, AIM is composed of a series of modules and sub-modules. Each module simulates interactions within specific areas of the global aviation system (e.g. fares, demand, technology choice). These modules are first developed and validated separately, and then the final model with all modules in place is validated.

The first validation step is that individual modules and sub-modules are assessed via peer review in the academic literature. Each of the modules used in this study is the subject of peer-reviewed papers detailing the methodology used, estimation processes and results[389].

Second, the integrated outputs of the model with all modules included are checked against external data and alternative projections, and a backcasting validation process is carried out in which the model is run from a 2005 base year and outcomes are compared to actual aviation system developments over the 2005-2017 period. The process of validating the integrated model is further described in Dray et al., 2019.

Third, the model itself, documentation and a simplified version of input databases which omits commercially sensitive data is open source and is freely available for interested parties to review and test[390].

Additionally, all AIM model changes are subject to an internal model validation process against external data sources. This process has been carried out for this project. A register of validation tests and interim outcomes are given in Section

---

[389] For example: Demand and Fare Module: Dray et al., 2014; Wang et al., 2018; Dray & Doyme, 2019. Airport and Airline Activity Module:.Evans, 2008; Evans & Schäfer, 2011. Aircraft Movement Module: Reynolds, 2009, 2014: Aircraft Technology and Cost Module; Dray, 2014; Dray et al., 2018.

[390] http://www.atslab.org/data-tools/. Note that the current version of the model available (v9) is the version prior to the one used in this project (v10).

C.1.3, below. Depending on the scope and nature of the changes, internal validation can involve comparison of baseline totals against global and regional databases; comparison of growth rates and system trends against those from other projections; examining the sensitivity of model outcomes to changes in new model inputs; or backcasting from historical base years to test against observed trends and growth rates[391]. For this study, baseline validation involves checking global and UK-level domestic and international flight metrics (for example passengers, flights, RPK, freight tonne-km (FTK), fares, total CO_2, and CO_2 under the scope of different policies) against corresponding global and UK data.

This process of review is ongoing throughout the modelling phase whenever new assumptions or model inputs are introduced.

C.1.2 External review

To provide an additional level of independent validation, ICF has been contracted to provide an arms-length, independent quality assurance of the analytical inputs, methods and findings. ICF was not involved in developing or implementing any of the analysis to ensure that it could provide independent challenge. Two stages of review were undertaken..

At the first review stage, ICF reviewed the proposed methodology, concluding '*…the methodology you provided seems reasonable. We don't believe there are any major considerations which have been missed or are incorrect, and this framework is suitable to undertake the assessment'.* Additional clarification was requested in three areas, and was provided:

- Clarification was requested on the individual components making up total fare to ensure that fares modelled are consistent with ICF's internal data on airline revenues. After further investigation, modelled fares were found to be consistent with these data once taxes and charges are accounted for.
- Clarification was requested on assumptions regarding sustainable aviation fuels (SAF). We have clarified that assumptions on SAF uptake will be treated as uncertain and will be part of the scenario analysis.
- Clarification was requested on discounting of aeronautical charges, and data was added to the report discussing this.

At the second review stage, ICF reviewed the model outputs and draft final report concluding 'that the findings were both reasonable and consistent across the 20 scenarios and time horizon considered (2020-2035). Impacts by airline type, passenger type and market segment were reviewed and found to meet our expectations. Further clarification around input assumptions, scenarios and outputs was sought and provided, notably:

    - Clarification was provided on assumptions underpinning the nominal scenario, including further detail on the demand including overall levels of growth and nature of growth, primarily differences between different airport types.

---

[391] A description of this validation process for global projections is given in Dray et al., 2019.

- Further detail on the impact of various assumptions was sought reflecting the different stages of modelling including efficiency benefits, carbon prices and cost pass through.
- Suggestions were made relating to presentational topics such as absolute vs. relative impacts and metrics discussed in the report.
- Suggestions for some supporting diagrams of the modelling process as well as minor updates to second order impacts and industry examples including the impact of SAF on an airline's cost base were made.'

C.1.3 Register of validation tests

Figure 52 Register of validation tests

Test	Description	Data source(s)	Outcomes shown in:
1	Test 2015-2019 AIM projections of UK domestic passenger numbers and RPK match external data	CAA, 2015-2019; DfT, 2017	Section B.7.1, Section C.1.4
2	Test 2015-2019 AIM projections of UK international passenger numbers and RPK match external data	CAA, 2015-2019; DfT, 2017	Section B.7.1, Section C.1.4
3	Test 2015-2019 AIM projections of UK domestic flights match external data	CAA, 2015-2019	Section B.7.1, Section C.1.4
4	Test 2015-2019 AIM projections of UK international flights match external data	CAA, 2015-2019	Section B.7.1, Section C.1.4
5	Test 2015-2019 AIM projections of UK-related air freight tonne-km match external data	World Bank, 2020	Section B.7.1, Section C.1.4
6	Test 2015-2019 AIM projections of UK domestic aviation CO_2 match external data	BEIS, 2021b	Section B.7.1, Section C.1.4
7	Test 2015-2019 AIM projections of UK international aviation CO_2 match external data	BEIS, 2021b	Section B.7.1, Section C.1.4
8	Test 2015-2019 AIM projections of global passenger numbers and RPK match external data	ICAO, 2020	Section B.7.1, Section C.1.4
9	Test 2015-2019 AIM projections of global flights match external data	ICAO, 2020	Section B.7.1, Section C.1.4
10	Test 2015-2019 AIM projections of global air freight tonne-km match external data	ICAO, 2020	Section B.7.1, Section C.1.4
11	Test 2015-2019 AIM projections of global aviation CO_2 match external data	IEA, 2020; ICAO, 2019; ICCT, 2020	Section B.7.1, Section C.1.4
12	Test 2020-2035+ projections of UK passengers, RPK, FTK and CO_2 are consistent with other projections (and/or that differences with other projections are explainable)	DfT, 2017	Section B.7.1
13	Test 2020-2035+ projections of global passengers, RPK, FTK and CO_2 are consistent with other projections (and/or that differences with other projections are explainable)	Airbus, 2019; Boeing, 2020; ICAO, 2017a, 2019; IATA, 2021	Section B.7.1
14	Test 2015-2019 AIM projections of number of EU ETS free and auctioned EUAAs, and EUAs purchased by airlines from other sectors	EC, 2021	Section C.1.4
15	Test year-2019 AIM projections of UK airline RPK against external data	CAA, 2015-2019	Section B.4
16	Test year-2015 average fares for UK domestic flights match external data	Sabre, 2017	Section C.1.4
17	Test year-2015 average fares for UK-EEA flights match external data	Sabre, 2017	Section C.1.4
18	Test year-2015 average fares for UK-non-EEA international flights match external data	Sabre, 2017	Section C.1.4
19	Test year-2015 UK-related passenger flows by itinerary type match external data	Sabre, 2017	Section C.1.4
20	Test 2015-2019 UK and competing hub airport revenues match external data	Airport financial reports	Section B.5

Source: ATA

C.1.4 Additional model validation outcomes

As noted in the previous section, some model validation outcomes are given in the main body of the report or in ANNEX B. Additional validation tests which are not included elsewhere are given in this section.

Plots comparing key system metrics (passengers, flights, RPK, FTK and CO_2) on different UK and global scopes are given in Section B.7.1. Table 24 additionally shows a comparison of AIM year-2015 baseline outcomes with external data. Note that many external data sources use slightly different definitions or scopes when reporting data (e.g., whether mail is included in freight totals; whether military aviation is included or not); these differences are annotated in the table.

Table 24. Comparison of AIM baseline metrics with external data sources.

Variable	**AIM 2015 baseline:** Global	**AIM 2015 baseline:** UK to/from	**AIM 2015 baseline:** UK domestic	**External data:** Global	**External data:** UK to/from	**External data:** UK domestic	**External data source**
Passengers, million[392]	3,670	217	23	3,556	210	22	ICAO, 2020; CAA, 2016
Flights, million[393]	36.4	1.59	0.32	34.0	1.51	0.33	ICAO, 2020; CAA, 2016
RPK, billion[394]	6,900	594	10.0	6,860	548[395]	8.7[396]	ICAO, 2020; ICAO, 2016
FTK, billion[397]	204	12.8	0.006	204	10.9	-	ICAO, 2020; World Bank, 2020
Direct CO_2, Mt[398]	815	64	1.6	877[399]	66	1.6	IEA, 2018; BEIS, 2021b

Source: AIM

Figure 53 shows CO_2 covered by different types of allowances (free EUAAs, auctioned EUAAs and EUAs purchased from other sectors) in the EU ETS, in comparison to data from the EU ETS database[400]. The right-hand panel shows model CO_2 on a UK ETS scope over the same time period (i.e. UK domestic flights and UK departing flights to EEA countries). Note that this is not the same scope as EU ETS allowances required by UK airlines because, during this time period, more than half of flights on this scope were performed by UK airlines. For 2019, modelled

---

[392] On a flight segment basis, i.e. counting a passenger once each time they board an aircraft. Includes passengers on unscheduled flights.

[393] AIM numbers are for aircraft over 30 seats, including freighter and unscheduled flights.

[394] AIM estimates include unscheduled flights.

[395] Note this is an estimate based on scaling up the international RPK of UK airlines. Scheduled flights only.

[396] UK airlines only (i.e. excluding Ryanair).

[397] AIM numbers include mail.

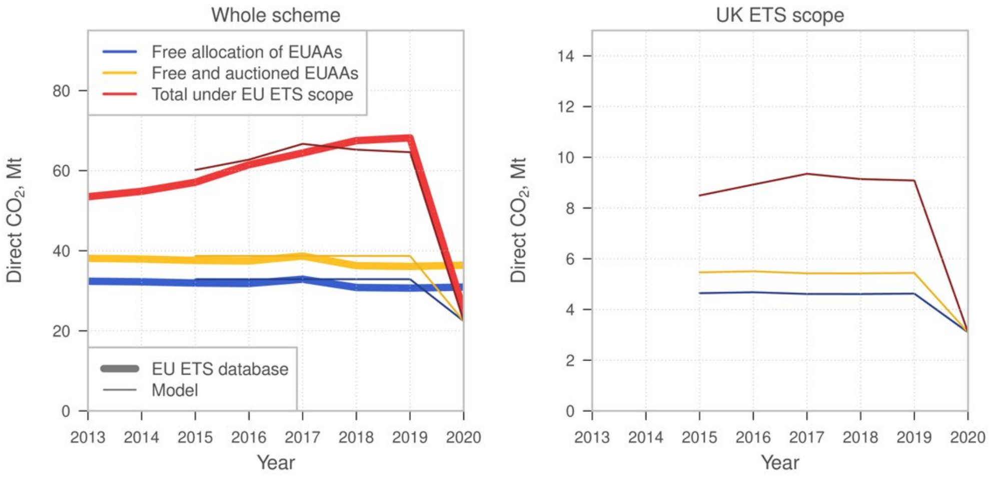
[398] AIM numbers include scheduled and unscheduled passenger and freighter flights and exclude military flights and general aviation.

[399] Note that this number includes military fuel use.

[400] European Commission, 2021b.

UK ETS scope free allowances in the EU ETS were 4.63 $MtCO_2$, close to the initial estimate that 3% of the UK ETS cap of 155.7$MtCO_2e$[401] will be allocated as free aviation allowances to ensure continuity with EU ETS conditions. For the EU ETS, divergences between modelled and database values in 2020 for free and auctioned allowances reflect that AIM tracks allowances required rather than allowances issued and that EU ETS aviation CO_2 was below the aviation cap in 2020.

Figure 53 EU ETS CO_2 on a whole-scheme and UK ETS scope, 2013-2020, in comparison to EU ETS database data



Source: AIM

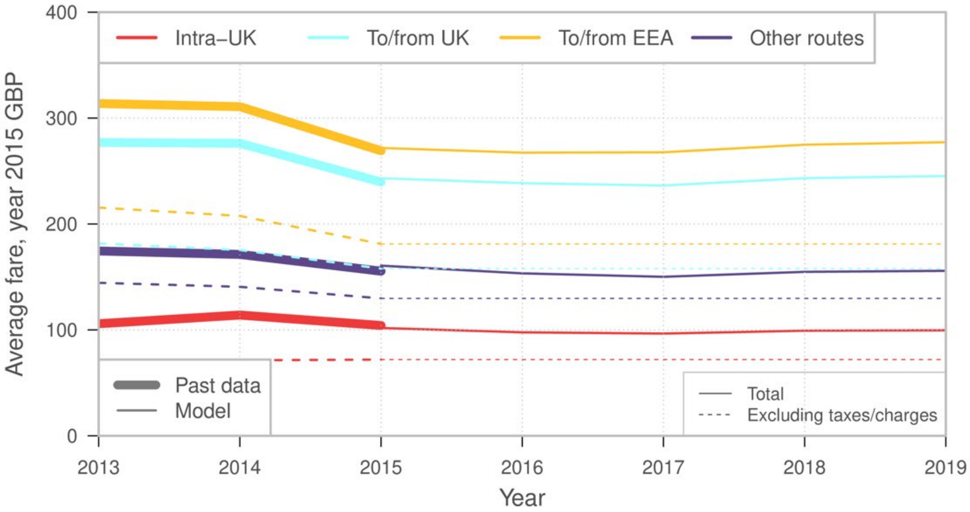
Figure 54 shows a similar comparison for average fares on some key route groups in comparison to historical data from the Sabre database of passenger fares[402]. Dashed lines indicate totals without taxes and charges (for example, Air Passenger Duty), which are more indicative of airline fare revenue on a given route group.

---

[401] National Archives, 2020.

[402] Sabre, 2017. Market Intelligence Database. https://www.sabreairlinesolutions.com/images/uploads/AirVision-Market-Intelligence_GDD_Profile_Sabre.pdf

Figure 54 Average fares on some key route groups, in comparison to historical data



Source: AIM

Finally, similarly to the previous carbon leakage study commissioned by DfT, we adjust AIM to output UK-associated CO_2 by itinerary type. This comparison, which is shown in Table 25, allows the impact of passenger choices on carbon leakage to be more closely assessed.

Note that totals are larger (by roughly 10%) than those calculated in the previous carbon leakage study as these tables include adjustments for non-scheduled flights. Totals do not include CO_2 from freighter aircraft but do include CO_2 due to the carriage of freight in passenger aircraft holds.

Table 25. Year-2015 passengers and CO_2 by type of itinerary and within/outside UK departing flight scope

	Itinerary passengers, mppa	CO_2 in UK departing flight scope, Mt	CO_2 outside UK departing flight scope, Mt
UK domestic-only itineraries	19.97	1.4	0
UK international departing direct itineraries to EEA	62.97	7.13	0
UK international departing direct itineraries to non-EEA	14.73	9.72	0
UK international arriving direct itineraries from EEA	62.86	0	7.14
UK international arriving direct itineraries from non-EEA	14.54	0	9.74
UK departing via UK hub	1.43	0.97	0.07
UK arriving via UK hub	1.47	0.09	0.98
UK departing via non-UK hub	12.27	5.86	5.48
UK arriving via non-UK hub	13.04	0	12
International-international transfer via UK	9.00	5.12	5.16
International-international transfer via non-UK, where a UK transfer airport is available as a reasonable alternative[403]	36.89	0	39.93
All other itineraries	2909.36	0	615.12

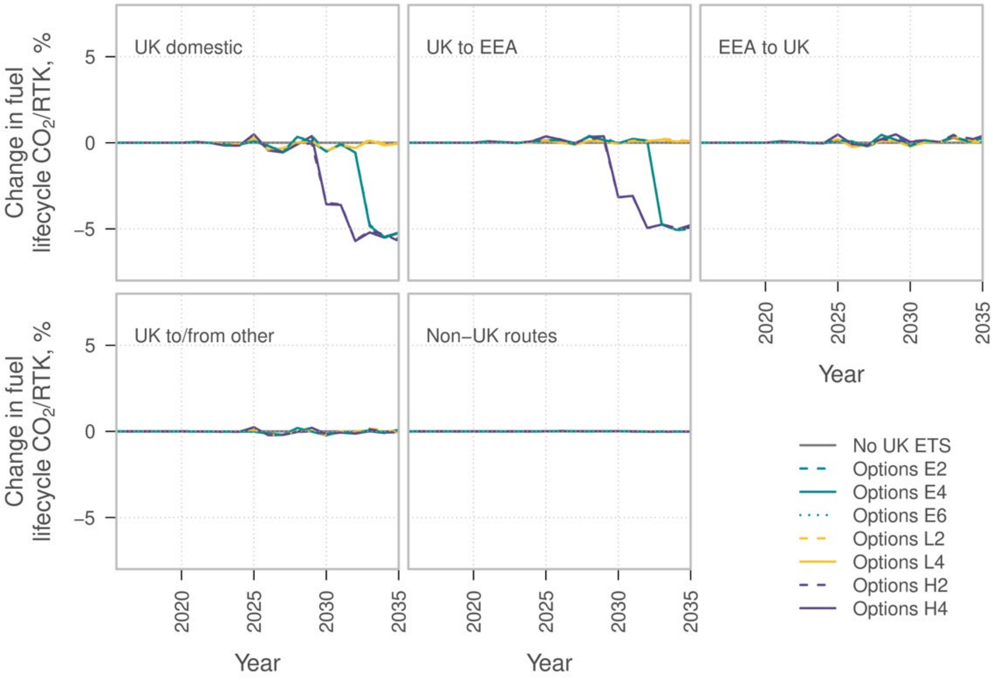
Source: AIM

---

[403] In AIM, passengers have a choice of up to 9 itineraries for a given city-pair journey. These itineraries are derived from the top 9 actual city-pair itineraries flown in 2015 (Sabre, 2017), including only itineraries which carry more than 5% of the total city-pair passenger traffic. We count a UK-hubbing itinerary as a reasonable alternative if it is available as a choice for passengers to take, but is not chosen.

ANNEX D ADDITIONAL OUTPUT METRICS

This Annex contains additional figures and tables to support the analysis shown in the main body of the report. This includes changes in CO_2 per RTK and load factor, which are relevant for carbon leakage outcomes; changes in number of passengers and total freight RTK, which are relevant for airline competitive disadvantage outcomes; and airline-level analysis for policy options which UK ETS price higher and lower than EU ETS price.



Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6).

Figure 55. Change in fuel lifecycle CO_2/RTK (%) from a no UK ETS baseline by policy option and geographic scope.

D.1 Additional metrics related to carbon leakage

CO_2 emissions on different routes are affected by the typical carbon intensity of flights (i.e. CO_2/RTK) and how full those flights are. This section shows metrics for typical carbon intensity by route type and passenger load factor (i.e. number of passengers divided by number of seats). Carbon intensity depends on aircraft choice of technologies and fuels. In the case of fuel lifecycle CO_2, there can be impacts from increases in SAF use in the case that UK ETS carbon prices are high enough that increased SAF use becomes cost-effective. A change in carbon intensity of 5% reflects roughly two years of technological progess at recent rates of improvement[404]. Changes in load factor largely reflect impacts on different route

---

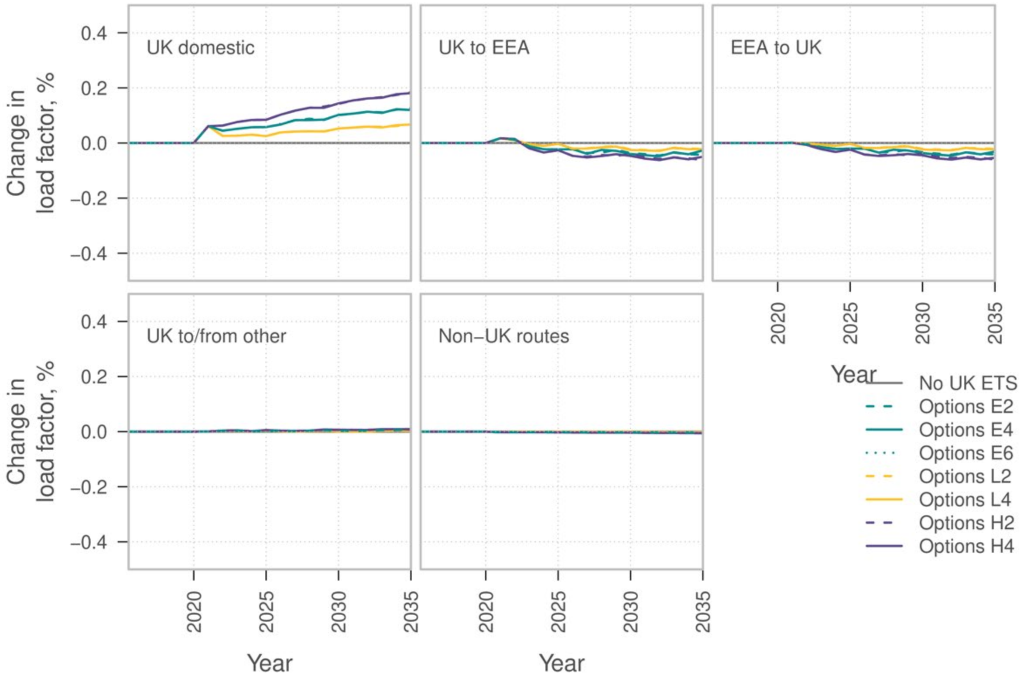
[404] IATA, 2019b.

types (i.e., routes operated at lower load factor experience higher per-passenger carbon costs and larger decreases in demand)

Table 26. Fuel lifecycle CO_2/RTK (%) from a no UK ETS baseline by policy option and geographic scope, 2030.

Option	UK domestic	UK to EEA	EEA to UK	Exempt EEA routes	UK to/from other	Other routes
Baseline fuel lifecycle CO_2/RTK	1.259	0.747	0.752	0.722	0.799	0.809
Difference from baseline, percent						
Options E2	-0.52	-0.08	-0.18	0.13	-0.23	0.01
Options E4	-0.5	-0.03	-0.18	0.16	-0.23	0.01
Options E6	-0.5	-0.03	-0.18	0.16	-0.23	0.01
Options L2	-0.48	-0.07	-0.23	0.09	-0.2	0.01
Options L4	-0.49	-0.05	-0.22	0.1	-0.21	0.01
Options H2	-3.49	-3.16	0.08	-0.08	-0.14	0.02
Options H4	-3.57	-3.16	0.05	-0.08	-0.15	0.01

Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6).



Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6).

Figure 56. Change in passenger load factor (%) by UK ETS policy option and geographic scope.

D.2 Additional metrics related to airline competitive disadvantage

This section contains additional metrics related to airline competitive disadvantage. Shown below are numbers of passengers by route and airline type, and total freight RTK by airline type, for the different policy options. These metrics display similar behaviour to the passenger and freighter aircraft RTK discussed in the main body of the report, or largely duplicate data that is already plotted in the main body of the report.

Table 27. Passenger aircraft direct operating cost (DOC) per RTK, compared to a no UK ETS scenario, by geographic scope, airline type and policy option, 2030.

Option	UK domestic, UK airline	UK to EEA, UK airline	UK to EEA, non-UK airline	EEA to UK, UK airline	EEA to UK, non-UK airline	Other UK routes, UK airline	Other UK routes, non-UK airline
Baseline DOC/RTK, Year 2015 GBP	1.868	0.651	0.727	0.803	0.82	0.341	0.348
Difference from baseline, %							
Option E2a	2.9	5.1	4.4	0	0.1	-0.3	0
Option E2b	4.2	7.1	6.9	0	0.1	-0.3	0
Option E4a	2.9	5.7	5.1	0	0.1	-0.3	0
Option E4b	4.1	7.7	7.4	0	0.1	-0.3	0
Option E4c	4.1	7.7	7.4	0	0.1	-0.3	0
Option E4d	4.0	7.4	7.2	0	0.1	-0.3	0
Option E4e	3.2	4.9	5.0	0	0.1	-0.3	0
Option E6a	2.9	5.7	5.0	0	0.1	-0.3	0
Option L2a	1.3	2.5	2.2	-0.1	0	-0.3	0
Option L2b	1.9	3.4	3.4	-0.1	0	-0.3	0
Option L4a	1.3	2.8	2.5	-0.1	0	-0.3	0
Option L4b	1.9	3.8	3.7	-0.1	0	-0.3	0
Option L4c	1.9	3.8	3.7	-0.1	0	-0.3	0
Option L4d	1.8	3.7	3.6	-0.1	0	-0.3	0
Option H2a	4.7	6.7	6.7	0.2	0.4	-0.3	0
Option H2b	6.6	10.8	10.5	0.2	0.4	-0.3	0
Option H4a	4.6	8.6	7.7	0.2	0.4	-0.3	0
Option H4b	6.5	11.7	11.4	0.2	0.4	-0.3	0
Option H4c	6.5	11.7	11.4	0.2	0.4	-0.3	0
Option H4d	6.3	11.4	10.9	0.2	0.4	-0.3	0

Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances; e = benchmark update to 2019.

Table 28. Number of passengers by airline nationality, geographic scope and policy option, 2030.

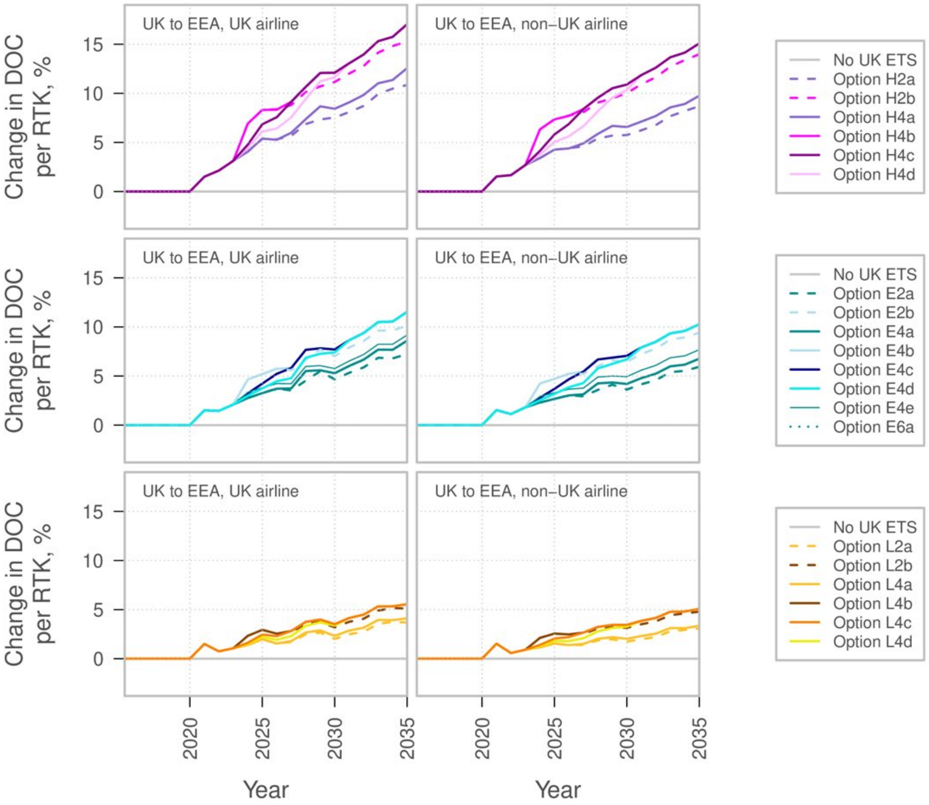
Option	UK domestic, UK airline	UK to EEA, UK airline	UK to EEA, non-UK airline	EEA to UK, UK airline	EEA to UK, non-UK airline	Other UK routes, UK airline	Other UK routes, non-UK airline
Baseline passengers, million	31.237	51.922	49.189	49.434	51.946	37.507	47.99
Difference from baseline, million							
Options E2	-0.946	-0.8	-0.777	-0.802	-0.747	0.062	0.036
Options E4	-0.941	-0.872	-0.847	-0.875	-0.813	0.067	0.042
Options E6	-0.941	-0.871	-0.846	-0.874	-0.812	0.067	0.042
Options L2	-0.462	-0.367	-0.371	-0.369	-0.355	0.081	0.059
Options L4	-0.46	-0.403	-0.409	-0.405	-0.391	0.084	0.062
Options H2	-1.547	-1.321	-1.268	-1.322	-1.227	0.012	-0.016
Options H4	-1.53	-1.405	-1.352	-1.406	-1.306	0.036	0.004

Table 29. Freight RTK (hold + freighter) by geographic scope and policy option, 2030.

Option	UK to EEA	EEA to UK	UK to/from other	Other routes
Baseline FTK, billion	0.205	0.266	19.297	299.085
Difference from baseline, billion FTK				
Options E2	-0.012	0	0.005	-0.005
Options E4	-0.013	0	0.007	0.002
Options E6	-0.013	0	0.008	0.007
Options L2	-0.006	0	0.009	0.001
Options L4	-0.007	0	0.01	0.001
Options H2	-0.018	-0.001	-0.024	0.022
Options H4	-0.019	-0.001	-0.007	0.016

Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6).

Operating costs for freighter aircraft, with and without adjustment for cost pass-through, and typical rates of cost pass-through for freighter aircraft by route and policy option, are shown below. These figures show similar outcomes to those reported for passengers in the main body of the report, with the exception that carbon costs are a higher percentage of operating cost for freighter aircraft than for passenger aircraft.



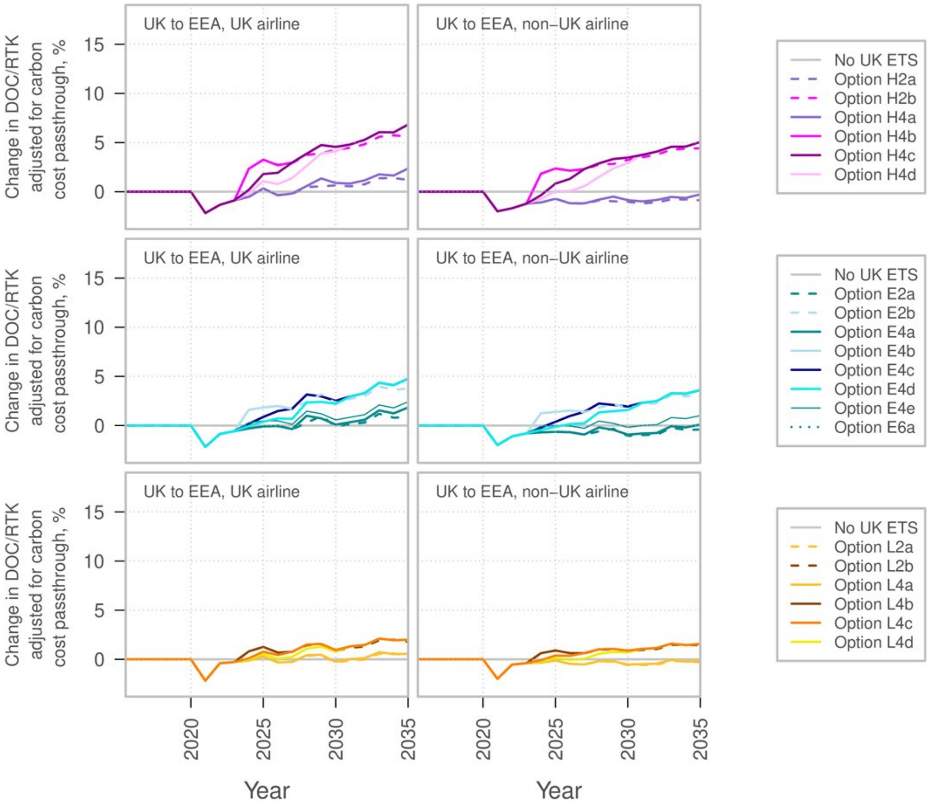
Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances; e = benchmark update to 2019.

Figure 57. Change in freighter aircraft operating costs per year, by geographic scope and policy option.

Table 30. Freighter aircraft operating costs per RTK by geographic scope and policy option, 2030.

Option	UK to EEA, UK airline	UK to EEA, non-UK airline	EEA to UK, UK airline	EEA to UK, non-UK airline	Other UK routes, UK airline	Other UK routes, non-UK airline
Baseline DOC/RTK, Year 2015 GBP	1.031	0.979	1.087	1.007	0.288	0.304
Difference from baseline, %						
Option E2a	4.7	3.6	-0.4	-0.2	-0.3	-0.3
Option E2b	7.1	6.4	-0.4	-0.2	-0.3	-0.3
Option E4a	5.3	4.2	-0.4	-0.2	-0.3	-0.3
Option E4b	7.8	7.0	-0.4	-0.2	-0.3	-0.3
Option E4c	7.8	7.0	-0.4	-0.2	-0.3	-0.3
Option E4d	7.4	6.6	-0.4	-0.2	-0.3	-0.3
Option E4e	5.8	4.9	-0.4	-0.2	-0.3	-0.3
Option E6a	5.3	4.2	-0.4	-0.2	-0.3	-0.3
Option L2a	2.0	1.7	-0.4	-0.2	-0.3	-0.3
Option L2b	3.2	3.1	-0.4	-0.2	-0.3	-0.3
Option L4a	2.3	1.9	-0.5	-0.2	-0.3	-0.3
Option L4b	3.5	3.4	-0.5	-0.2	-0.3	-0.3
Option L4c	3.5	3.4	-0.5	-0.2	-0.3	-0.3
Option L4d	3.4	3.2	-0.5	-0.2	-0.3	-0.3
Option H2a	7.6	5.7	-0.2	-0.1	-0.3	-0.3
Option H2b	11.2	10.0	-0.2	-0.1	-0.3	-0.3
Option H4a	8.4	6.5	-0.2	-0.1	-0.3	-0.3
Option H4b	12.1	10.8	-0.2	-0.1	-0.3	-0.3
Option H4c	12.1	10.8	-0.2	-0.1	-0.3	-0.3
Option H4d	11.6	10.3	-0.2	-0.1	-0.3	-0.3

Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances; e = benchmark update to 2019.



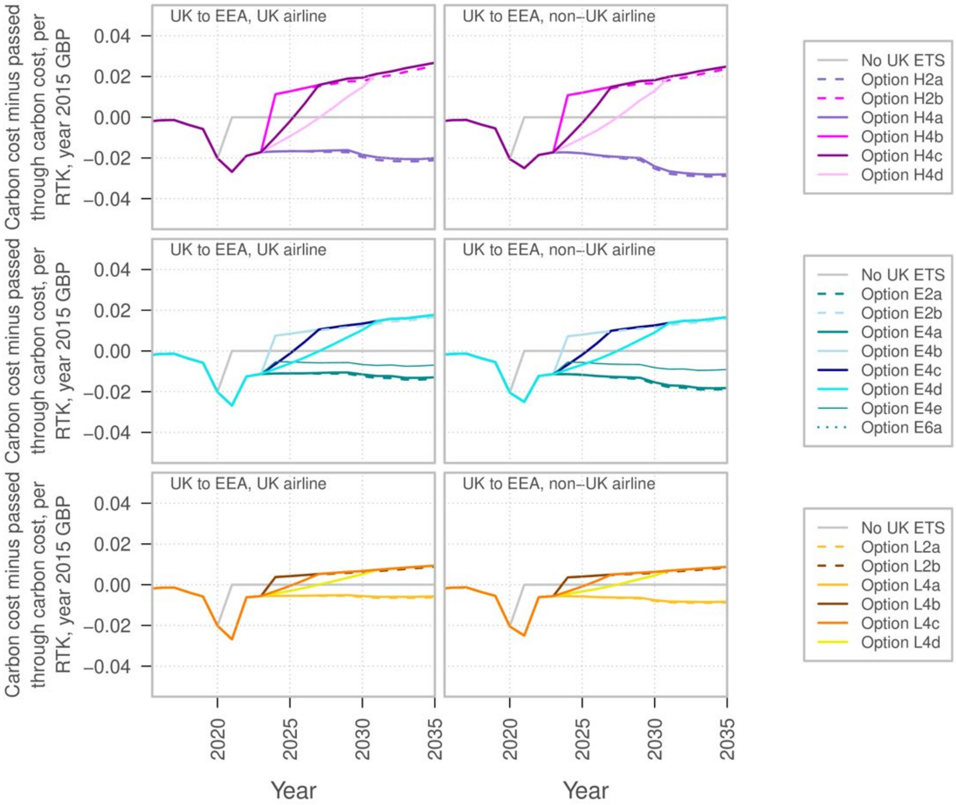
Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances; e = benchmark update to 2019.

Figure 58. Change in freighter aircraft operating costs per year adjusted for pass-through of carbon costs, by geographic scope and policy option.

Table 31. Ratio of passed through carbon costs to auctioned carbon costs by geographic scope and policy option, 2030

Option	UK to EEA, UK airline	UK to EEA, non-UK airline	EEA to UK, UK airline	EEA to UK, non-UK airline	Other UK routes, UK airline	Other UK routes, non-UK airline
Baseline passed through carbon cost/auctioned carbon cost	0.8	0.8	0.8	0.8	0.8	0.8
Passed through carbon cost/auctioned carbon cost by policy option						
Option E2a	1.339	1.547	0.8	0.8	0.8	0.8
Option E2b	0.8	0.8	0.8	0.8	0.8	0.8
Option E4a	1.274	1.443	0.8	0.8	0.8	0.8
Option E4b	0.8	0.8	0.8	0.8	0.8	0.8
Option E4c	0.8	0.8	0.8	0.8	0.8	0.8
Option E4d	0.839	0.847	0.8	0.8	0.8	0.8
Option E4e	1.141	1.195	0.8	0.8	0.8	0.8
Option E6a	1.275	1.444	0.8	0.8	0.8	0.8
Option L2a	1.329	1.533	0.8	0.8	0.8	0.8
Option L2b	0.8	0.8	0.8	0.8	0.8	0.8
Option L4a	1.265	1.431	0.8	0.8	0.8	0.8
Option L4b	0.8	0.8	0.8	0.8	0.8	0.8
Option L4c	0.8	0.8	0.8	0.8	0.8	0.8
Option L4d	0.839	0.847	0.8	0.8	0.8	0.8
Option H2a	1.379	1.611	0.8	0.8	0.8	0.8
Option H2b	0.8	0.8	0.8	0.8	0.8	0.8
Option H4a	1.309	1.497	0.8	0.8	0.8	0.8
Option H4b	0.8	0.8	0.8	0.8	0.8	0.8
Option H4c	0.8	0.8	0.8	0.8	0.8	0.8
Option H4d	0.841	0.85	0.8	0.8	0.8	0.8

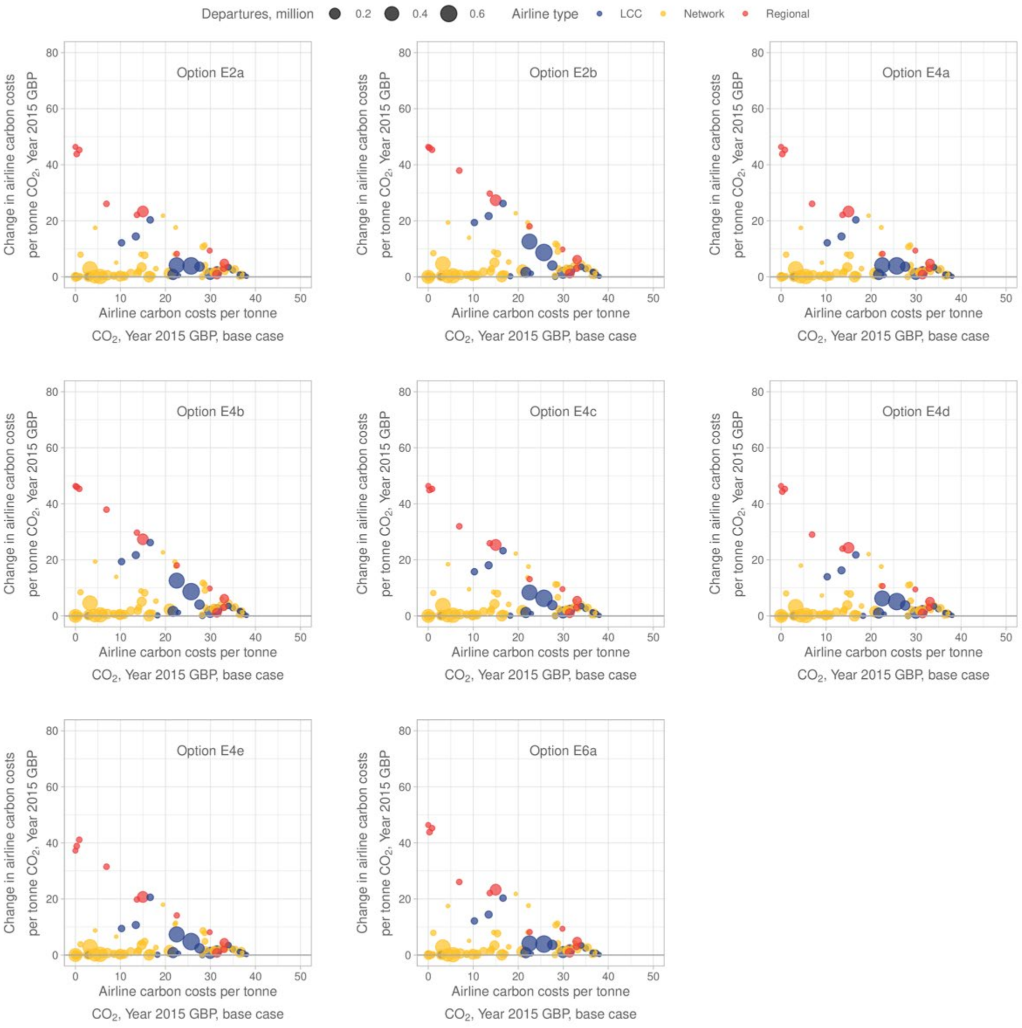
Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances; e = benchmark update to 2019.



Note on option names: Options H = UK ETS carbon price 50% higher than EU ETS carbon price; E = UK ETS carbon price equal to EU ETS carbon price; L = UK ETS price 50% lower than EU ETS carbon price. Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances; e = benchmark update to 2019.

Figure 59. Freighter aircraft incurred carbon costs minus passed through carbon costs by airline type, year and policy option.

We also include detailed airline-level metrics for all policy options E (UK ETS carbon price equal to EU ETS carbon price), H (UK ETS price 50% above EU ETS price) and L (UK ETS price 50% below EU ETS price) below, in addition to the analysis shown in the main body of the report for policy options E4a and E4b. These plots demonstrate that the absolute level of impacts on airline-level demand and carbon costs track the assumed UK ETS carbon price. However, the ways that different airlines are affected does not change from that shown in the analysis of policy options in the main report.



Note on option names: Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances; e = benchmark update to 2019.

Figure 60. Average carbon costs by airline type for the policy options E (UK ETS carbon price equal to EU ETS carbon price) in comparison to a no UK ETS case, 2025.

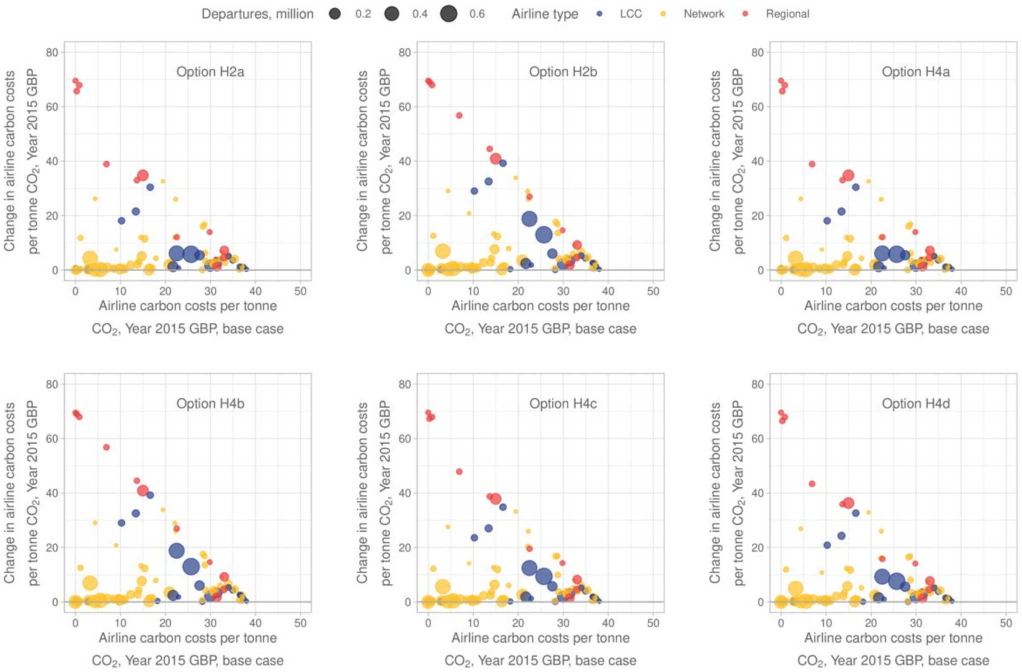


Figure 61. Average carbon costs by airline type for the policy options H (UK ETS carbon price 50% above EU ETS carbon price) in comparison to a no UK ETS case, 2025.

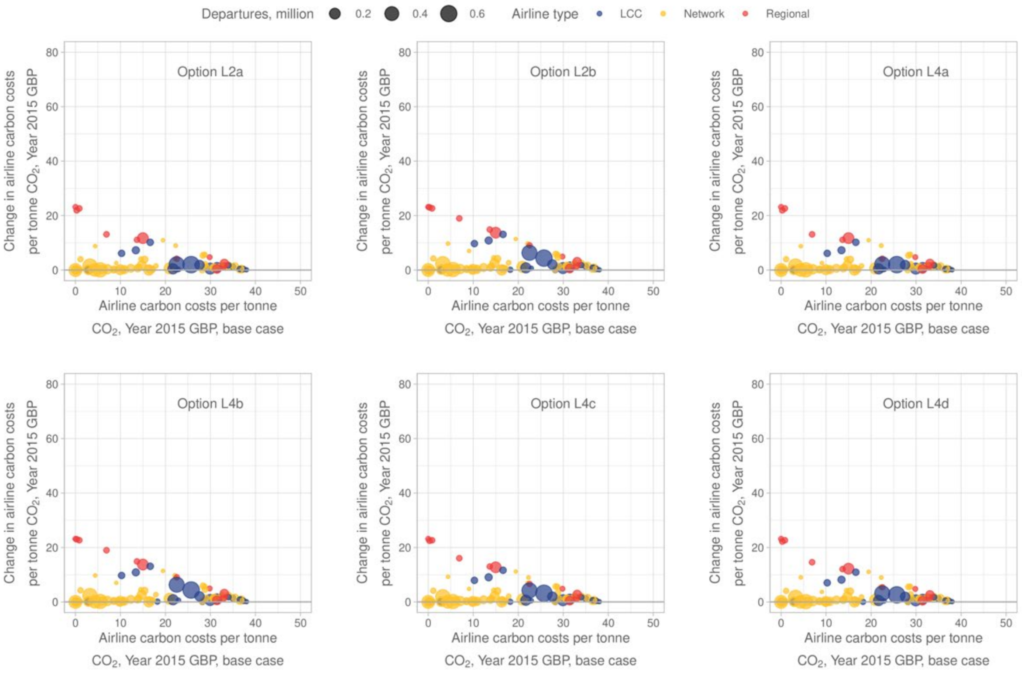
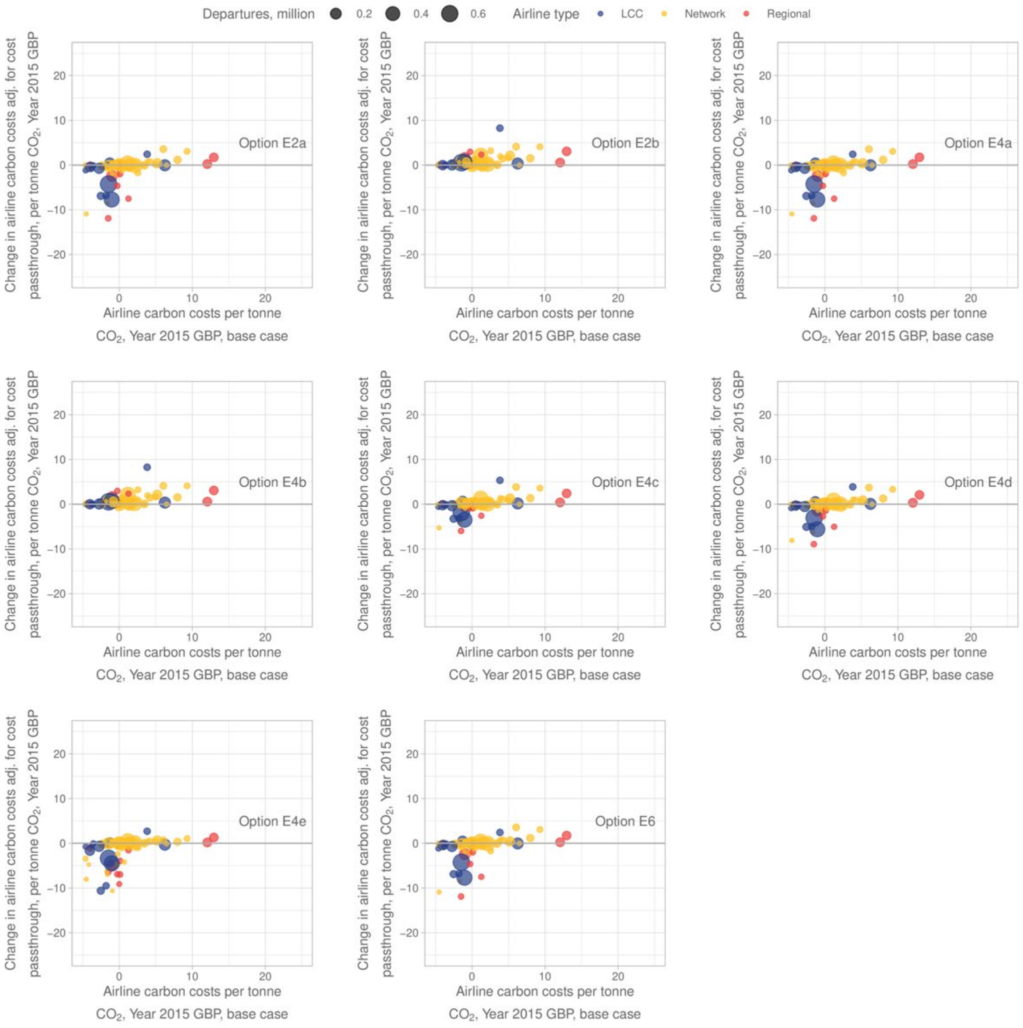


Figure 62. Average carbon costs by airline type for the policy options L (UK ETS carbon price 50% below EU ETS carbon price) in comparison to a no UK ETS case, 2025.

Note on option names: Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances.



Note on option names: Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances; e = benchmark update to 2019.

Figure 63. Average carbon costs adjusted for carbon cost pass-through by airline type for the policy options E (UK ETS carbon price equal to EU ETS carbon price) in comparison to a no UK ETS case, 2025.

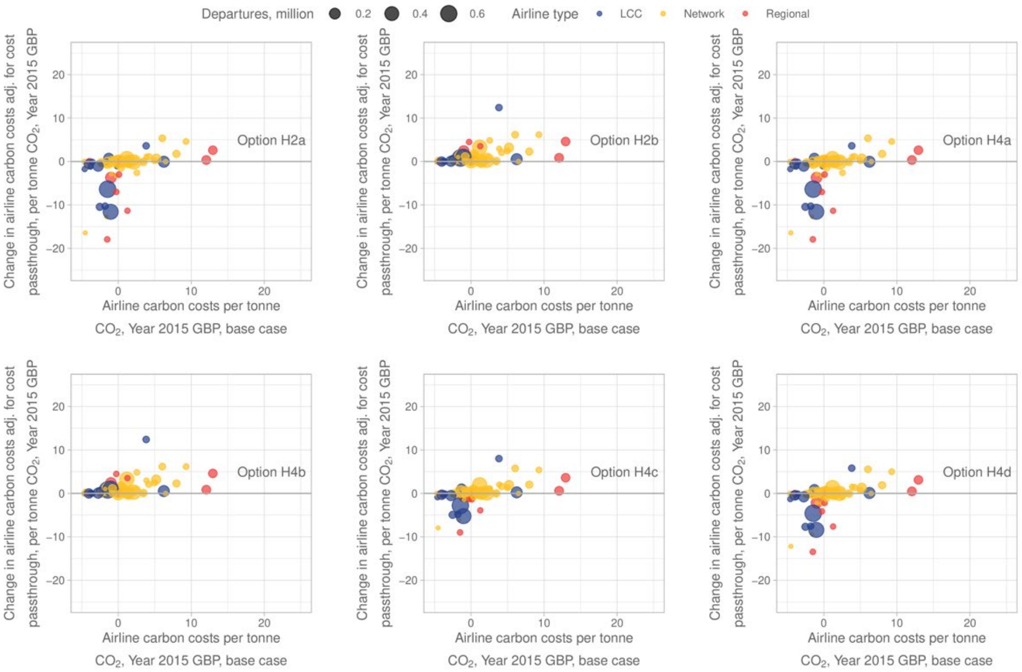


Figure 64. Average carbon costs accounting for carbon cost pass-through by airline type for the policy options H (UK ETS carbon price 50% above EU ETS carbon price) in comparison to a no UK ETS case, 2025.

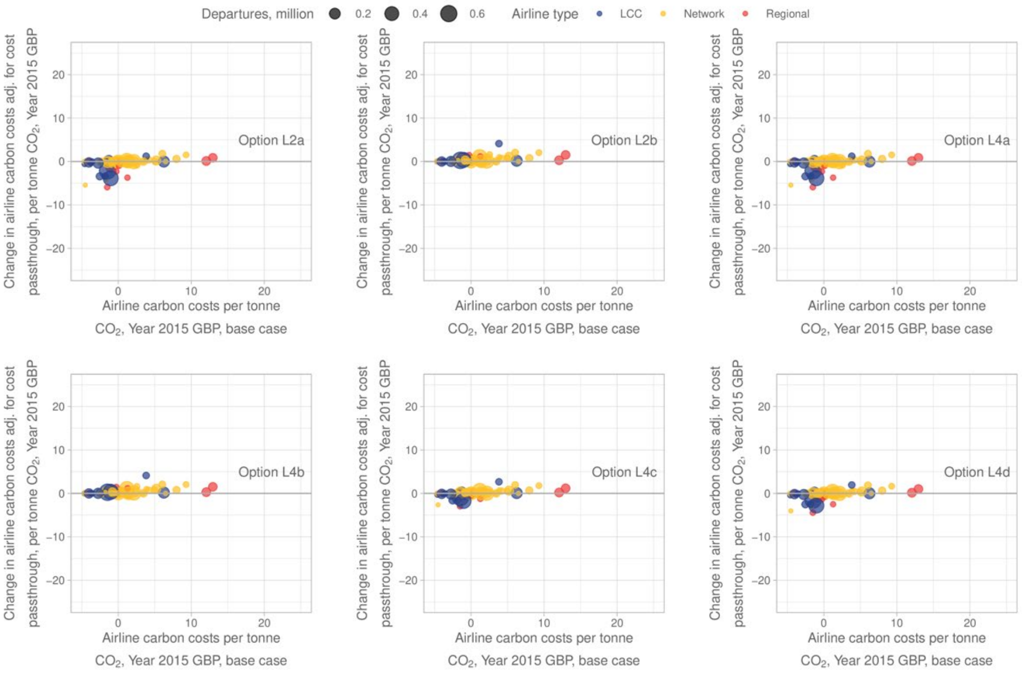
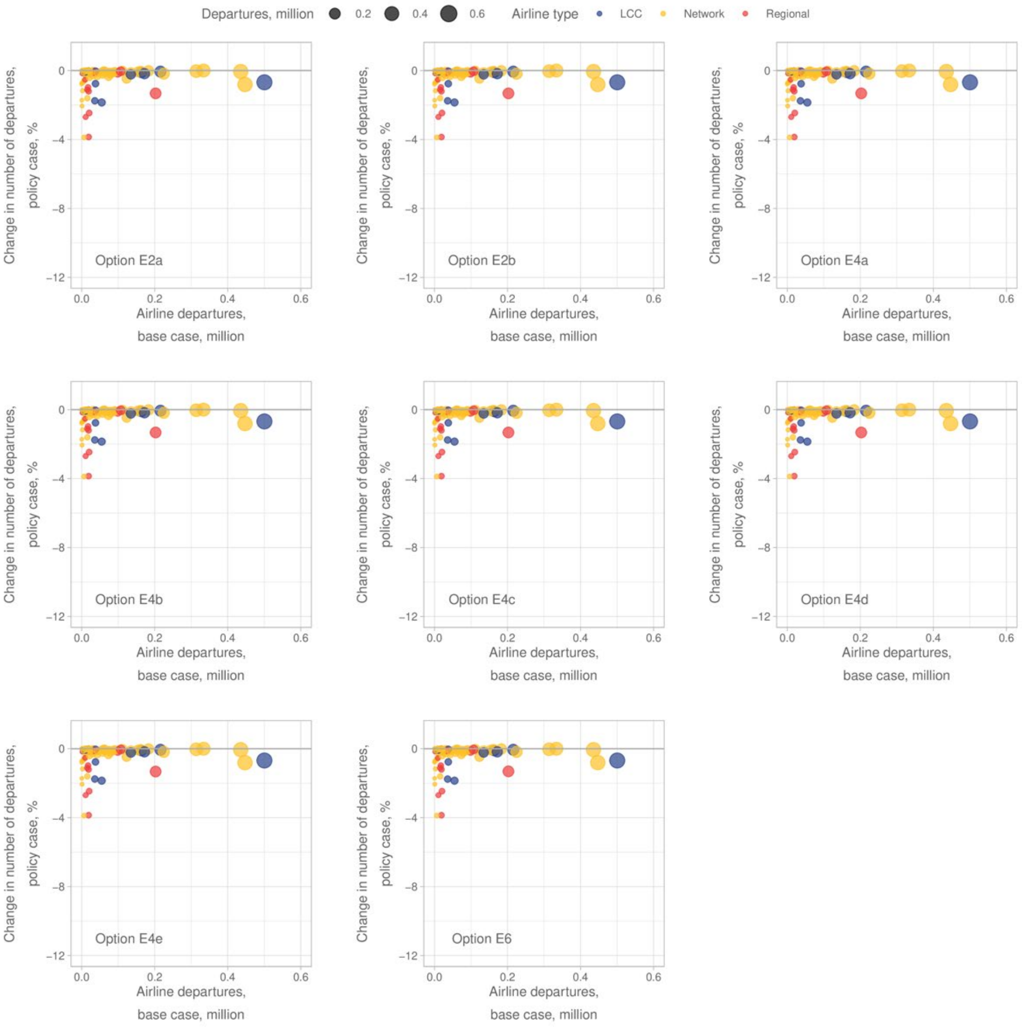


Figure 65. Average carbon costs by airline type accounting for carbon cost pass-through for the policy options L (UK ETS carbon price 50% below EU ETS carbon price) in comparison to a no UK ETS case, 2025.

Note on option names: Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances.



Note on option names: Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances; e = benchmark update to 2019.

Figure 66. Demand impact by airline type for the policy options E (UK ETS carbon price equal to EU ETS carbon price) in comparison to a no UK ETS case, 2025.

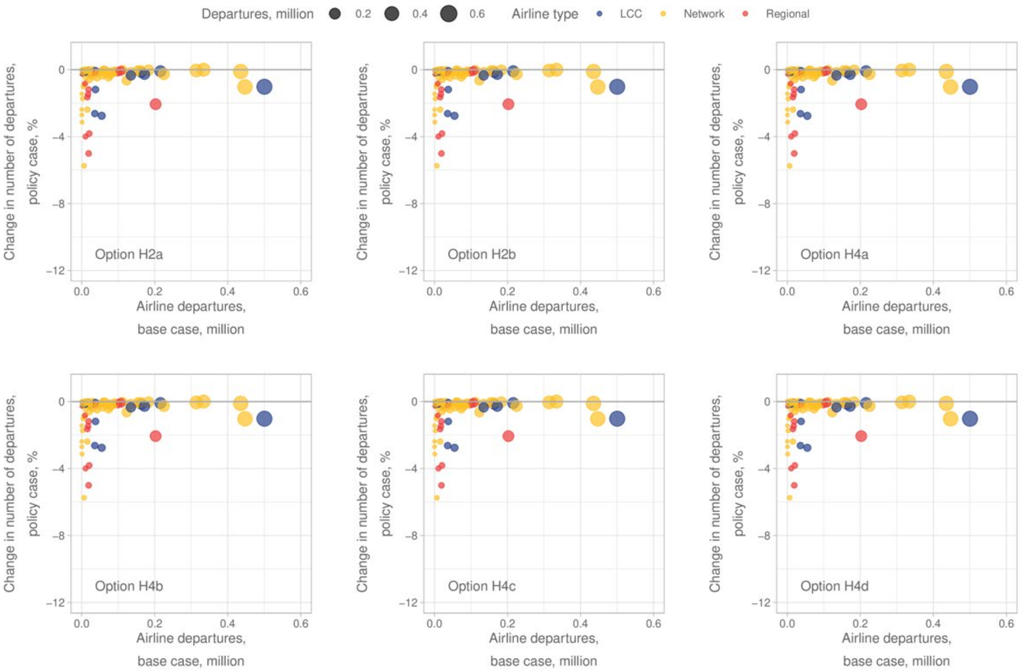


Figure 67. Demand impact by airline type for the policy options H (UK ETS carbon price 50% above EU ETS carbon price) in comparison to a no UK ETS case, 2025.

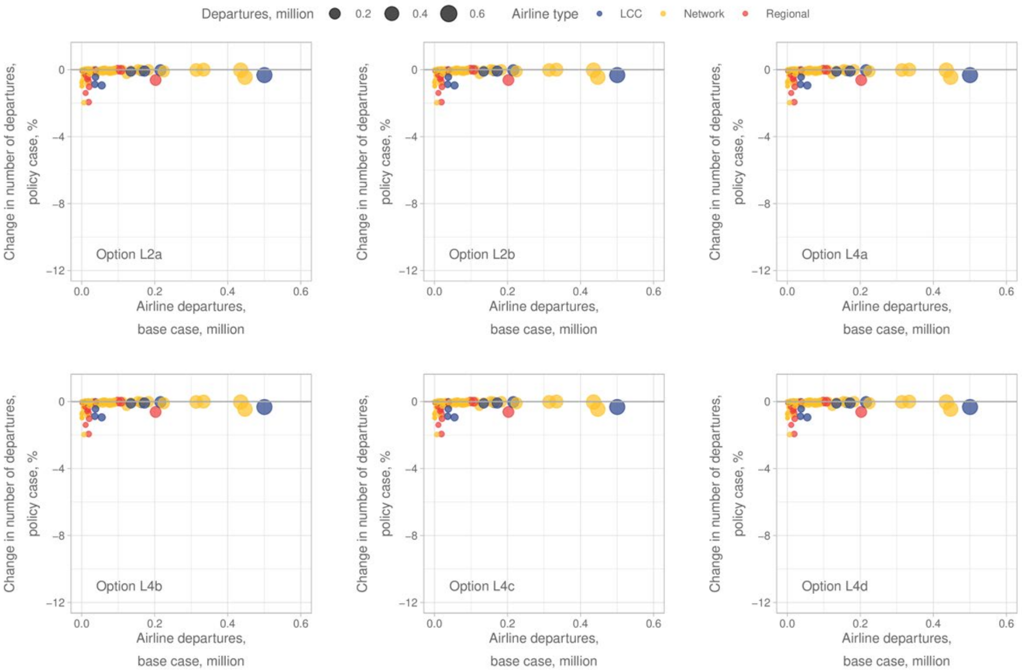


Figure 68. Demand impact by airline type for the policy options L (UK ETS carbon price 50% below EU ETS carbon price) in comparison to a no UK ETS case, 2025.

Note on option names: Numbering refers to CORSIA interaction option (2, 4, 6). Free allowance allocation options: a = current approach; b = immediate end to free allowances in 2024; c = 2024-2027 phase-out of free allowances; d = 2024-2030 phase-out of free allowances.

www.frontier-economics.com