European Commission

Assessment of ICAO's global market-based measure (CORSIA) pursuant to Article 28b and for studying cost pass-through pursuant to Article 3d of the EU ETS Directive

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Abstract

The regulatory coverage of aviation emissions under the EU ETS and CORSIA overlap, at least in part. The European Commission (EC) must report to the European Parliament and the Council with an assessment of specific elements of CORSIA, as well "consider ways" to implement CORSIA through the EU ETS Directive, as per Article 28b of the EU ETS Directive. Whilst the requirements for monitoring, reporting, and verifying emissions under CORSIA have been implemented through the EU ETS Directive, other decisions on CORSIA's relation to the EU ETS in terms of the interaction between their respective coverage are still pending. These decisions could have a large impact on the setup and stringency of regulation of aviation emissions both within the EU/EFTA and between the EU/EFTA and third countries. This report aims to inform these decisions through an assessment of the economic, social, and environmental impacts of different policy options for EU ETS and CORSIA implementation, as well as a review of the ability for aircraft operators to pass-through their carbon costs, pursuant to Article 3d of the EU ETS Directive. The results of the study support the European Commission's review of the regulation of aviation under the ETS Directive.

Executive summary

The objective of this study is to support the European Commission with its assessment of:

- The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) pursuant to Article 28b of the EU ETS Directive (2003/87/EC); in particular, the following aspects: ambition of the CORSIA goal; environmental integrity; level of participation in the scheme; enforceability and transparency; quality of offset credits; monitoring, reporting and verification provisions; registries; and rules for fuels.
- The economic, social, and environmental impacts of EU policy options for EU ETS and CORSIA.
- The ability for aircraft operators to pass-through their carbon costs, pursuant to Article 3d of the EU ETS Directive.

The results of the study support the European Commission's review of the regulation of aviation under the EU ETS Directive.

I. Introduction

The regulation of aviation within the EU ETS entered into effect from the beginning of 2012 (Directive 2008/101/EC). However, in order to allow for further work to continue in ICAO to develop a global approach to mitigate international aviation emissions, the EU 'stopped the clock' in April 2013, thereby temporarily limiting the EU ETS coverage to flights both taking-off and landing within the EEA. This suspension has subsequently been extended twice and is now running to the end of 2023.

In 2016, the 39th Session of the triennial ICAO Assembly adopted Resolution A39-3 'Consolidated statement of continuing ICAO policies and practices related to environmental protection – Global Market-based Measure (MBM) Scheme'. This Resolution established the basic features of the 'Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)'. The scheme has three phases: a voluntary pilot phase is scheduled to run from 2021-2023, followed by phase 1 (2024-2026) where States can also volunteer to participate, followed by a phase 2 (2027-2035), which covers all States that had a share above 0.5% of total Revenue Tonnes Kilometres (RTKs) in 2018 or whose cumulative share in the list of States from the highest to the lowest amount of RTKs reaches 90% of total RTKs. EU Member States, in accordance with Council Decision (EU) 2020/954, have notified ICAO of their voluntary participation in CORSIA from 1 January 2021, subject to differences filed under Article 38 of the Chicago Convention, and ICAO have included all EEA countries in its document entitled 'CORSIA States for Chapter 3 State Pairs' without reference to notifications sent.

The regulatory coverage of aviation emissions under the EU ETS and CORSIA overlap. The European Commission (EC) must report to the European Parliament and the Council with an assessment of specific elements of CORSIA, as well as "consider ways" to implement CORSIA through the EU ETS Directive, as per Article 28b of the EU ETS Directive. Whilst the requirements for monitoring, reporting, and verifying (MRV) emissions under CORSIA have been implemented through the EU ETS Directive, other decisions on CORSIA's relation to the EU ETS in terms of the interaction between their respective coverage are still pending. These decisions could have a large impact on the setup and stringency of regulation of aviation emissions both within the EEA and between the EEA and third countries. This report aims to inform these decisions.

During the course of the study several key decisions on the implementation of the CORSIA were taken and, other elements such as the intended participation of states continued to evolve. But the most unforeseen development was the COVID-19 pandemic. Whilst

references are made to the pandemic and its potential short- and long-term impacts to the extent feasible, it was not possible to fully take into account its effects.

II. Ambition of CORSIA relative to Paris Agreement goals and EU targets

In order to analyse CORSIA's ambition in relation to the Paris Agreement we base our assessment on the following criteria:

- Type and stringency of the target;
- Coverage of sources of climate impact;
- Policy timeframe;
- Ambition raising mechanisms; and
- Enforcement mechanisms.

We find that there are a number of features of CORSIA which imply its level of ambition for the international aviation sector is misaligned with, and weaker than the global level of ambition required to keep within the temperature goals of the Paris Agreement. That said, the collective pledges of all countries that are parties to the Paris Agreement is also well short of the level of required ambition. In several respects, such as type and stringency of the target, coverage of sources of climate impact, policy timeframe, and enforcement mechanism, CORSIA is less ambitious than the regulation of aviation within the EU ETS.

The EU aims to be a global leader on climate and environmental issues and promote and implement ambitious climate policies both domestically and across the world.[1] Participating in CORSIA – and leaving all international aviation (as defined by ICAO, including between EEA countries) outside the scope of the EU ETS – would risk undermining these objectives and weakening current EU climate policies. Following the publication of the European Green Deal, the European Council endorsed the objective of achieving a climate-neutral EU by 2050, in line with the objectives of the Paris Agreement. The European Parliament also backed the Green Deal. The European Green Communication clearly states that a 90% reduction target relative to 1990 levels for transport emissions is needed to achieve climate neutrality, recognising that aviation will need to contribute to this goal. If EU participation in CORSIA replaces part, or all, of its existing regulation for aviation it is unlikely that aviation would sufficiently contribute to the 90% reduction in transport emissions and risks undermining the ability to reach net-zero emissions by mid-century.

III. Environmental integrity

We assess the environmental integrity of CORSIA is assessed through 'the level of participation, its enforceability, transparency, the penalties for non-compliance, the process for public input, the quality of offset credits, monitoring, reporting and verification of emissions, registries, accountability, as well as rules on the use of biofuels.'

State participation in CORSIA

The chart on the left hand side of Figure 1 shows a breakdown of the 193 ICAO Member States according to their intended participation from the start of 2021, based on information published on ICAO's website in July 2019. Of the 81 volunteering States, 52 States are currently exempt from participation in the mandatory phase starting in 2027, due to one or both of the socioeconomic and activity-based exemption criteria. Of the

[1] European Commission, "Communication from the Commission to the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions: The European Green Deal (COM(2019) 640 Final)." Page 20

remaining 112 States that had not indicated they would participate from 2021, five are currently not exempt from participation, as foreseen under CORSIA: China, Russia, India, Brazil, and Vietnam. The chart on the right-hand side of Figure 1 depicts the same breakdown reflecting the grouping of States' relative share of total Revenue Tonnes Kilometres (RTKs) in 2018. The 81 States that indicated by July 2019 that they would participate from the start of CORSIA account for approximately 77% of the share of RTKs; and the five States that have not indicated they will participate, but which are not exempt, account for approximately 18% of the share of RTKs.

For States that are not exempt under CORSIA's second phase, the extent to which CORSIA would be binding on them is uncertain. The legal instruments used for establishing and implementing CORSIA are secondary law deriving from the Chicago Convention. These mainly include Resolutions of the Assembly as well as the SARPs.[2] However, ICAO member States are able to file "reservations" to Resolutions and notify "differences" to ICAO SARPs in accordance with Article 38 of the Chicago Convention. While the EU differences are public[3], ICAO has neither published other differences nor circulated them to other States[4].

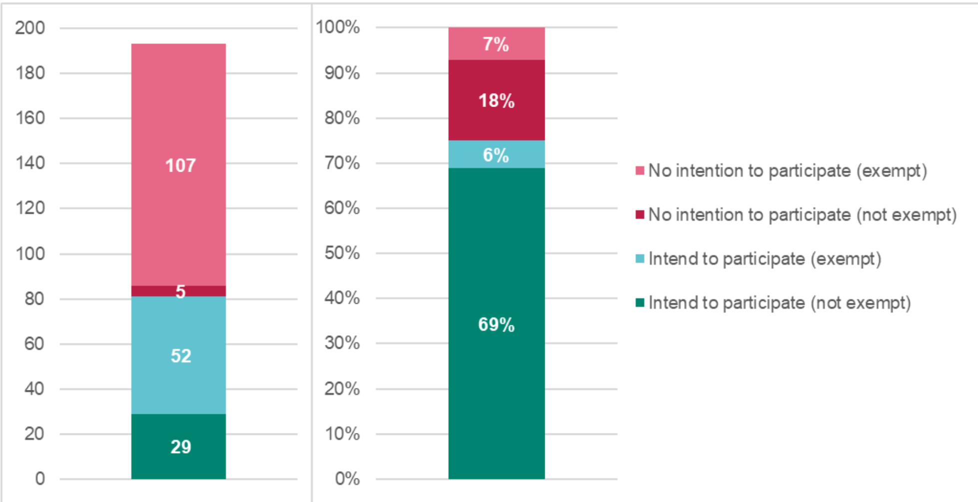

Figure 1. Initial assumed participation from 2021 (as of July 2019) by count (left) and share of total RTKs (right)

Figure 2 shows estimated projections of CORSIA's coverage of total carbon dioxide emissions from international aviation in 2025, 2030 and 2035 for three scenarios: the **initial assumed participation** scenario reflects the ICAO Secretariat's understanding of the countries that have expressed a willingness to participate in CORSIA by July 2019,

[2] Resolution OACI – A36-13 – Consolidated statement of continuing ICAO policies and associated practices related specifically to air navigation.

[3] Council Decision (EU) 2018/2027 of 29 November 2018 on the position to be taken on behalf of the European Union within the International Civil Aviation Organization in respect of the First Edition of the International Standards and Recommended Practices on Environmental Protection — Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32018D2027

[4] Chinese Reservation to Resolutions A40 –18 and A40 – 19 https://www.icao.int/Meetings/a40/Documents/Resolutions/china_EN.pdf.

including the USA[5]; the **high participation** scenario is the same as the *initial assumed participation* for CORSIA's pilot and first phases and adds China, Russia, India, Brazil and Vietnam for the second phase; and the **low participation** scenario reflects the same assumptions as the 'initial assumed participation' scenario, except that the USA does not participate.

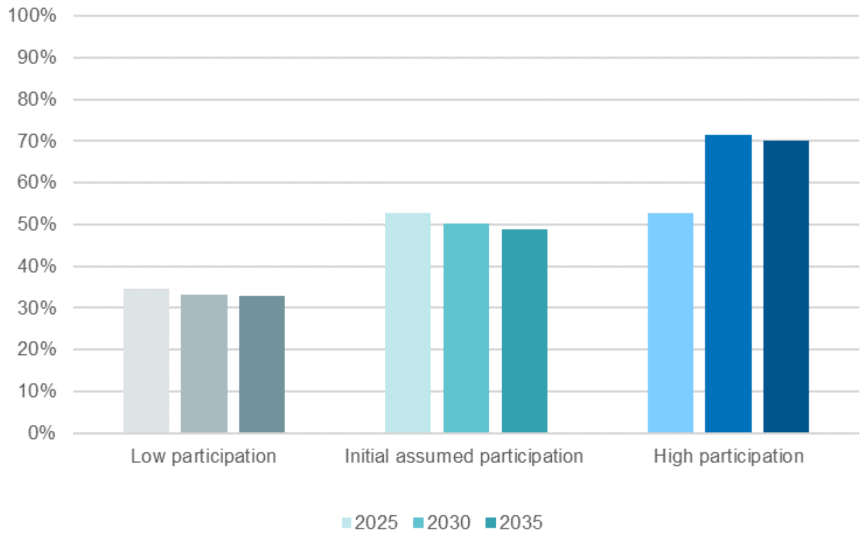

Figure 2. Estimated projections of CORSIA's coverage of global carbon dioxide emissions from international aviation under different scenarios for participation

As a comparison, we estimate that the full scope EU ETS would cover 33% of global international aviation emissions in 2025, and 28% in 2035; in both cases slightly below, but of the same order of magnitude as under the low participation scenario.

Transparency

EU principles for transparency and public participation are set out in the European Commission's principles for Better Regulation, including a number of initiatives in order to ensure that decision making is open and transparent; that citizens and stakeholders can contribute throughout the policy and law-making process; that EU actions are based on evidence and understanding of the impacts; and that regulatory burdens on business, citizens or public administrations are kept to a minimum. The European Union and all EU Member States ratified the United Nations Economic Commission for Europe Convention on Access to Information, Public Participation in Decision-Making, and Access to Justice in Environmental Matters (Aarhus Convention).

In comparison, the 1944 Chicago Convention that established ICAO does not mention transparency or public consultation in the regulatory function of the organisation. ICAO does not have a specific freedom of information policy, but decides on publication on an ad hoc basis and has no mechanism for members of the public to request unpublished documents. The transparency of CORSIA compliance reporting is affected by the confidentiality of the information that is reported as well as the aggregation of data. The SARPs recommend – but do not require – that States publish total final offsetting

[5] Public positions of the USA and its conditions for support are available here: https://www.faa.gov/about/office_org/headquarters_offices/apl/research/environmental_policy/media/corsia_mrv_program_statement.pdf and https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12494-Revision-of-the-EU-Emission-Trading-System-Directive-concerning-aviation-/F544637

requirements for each aeroplane operator attributed to the State and the total quantity of emissions units cancelled over a compliance period by each aeroplane operator. This may lead to questions of competition and fairness as important stakeholders may not know if a level playing field is established where all CORSIA participating States are enforcing CORSIA robustly.

Enforceability

Several legal instruments were available to ICAO for the establishment and implementation of CORSIA, including the amendment of the Chicago Convention, the adoption of a new treaty, the adoption of a resolution and the adoption of Standards and Recommended Practices (SARPs). From a legal perspective, an amendment of the Chicago Convention, together with adoption of Standards or the adoption of a new treaty to which technical annexes are attached, would have offered two options ensuring legal certainty and enforceability of CORSIA. However, Treaty changes would be subject to a potentially lengthy ratification process and uncertainty as to its outcome.

The legal instrument that has been chosen by ICAO is a mix between the Resolution, the SARPs and technical provisions, which will not have a (strong) binding effect. Besides the clear wish of ICAO to urge member States to observe and implement CORSIA, the enforcement of the Resolutions is limited by the concrete enforcement powers in the hands of the Assembly, which remains political towards the Member States. The SARPs are not part of the Chicago Convention itself but included in annexes to the Convention, so that they do not have the same nature as treaty provisions. The SARPs only receive binding force through their implementation in national/EU law, in the absence of which they can be considered as 'soft law'.

Quality of offset credits

The obligations placed on aeroplane operators under CORSIA are likely to be met largely through the purchase and cancellation of carbon offset credits because they offer a lower cost option compared to the use of CORSIA eligible fuels. Assessing the quality of the credits that might be used for compliance under CORSIA is therefore critically important to evaluating the overall climate impact of the scheme. ICAO established "CORSIA Emissions Unit Eligibility Criteria", or EUC (applied at the emissions unit programme level) to provide high-level guidance related to the carbon offset credits that should be eligible for use under CORSIA and "Carbon Offset Credit Integrity Assessment Criteria", which provide guidance on the interpretation of each criterion. ICAO requires eligible programmes to provide guidance regarding the provisions that they have in place in order to ensure that their projects meet these criteria. In order to assess each programme's ability to fulfil these criteria, ICAO created a "Technical Advisory Body" (TAB) to provide the ICAO Council with recommendations. Based on the January 2020 TAB report entitled "Recommendations on CORSIA Eligible Emission Units", related to the first wave of eligible units, approved by the ICAO Council at its 219th session in March 2020, while most criteria have been applied, and are respected by the eligible programmes, we find that some criteria have not been uniformly and consistently applied with regard to an assessment of the programme applications.

The TAB recommendations, and the subsequent decision of the ICAO Council on eligible units, include a cut-off date applicable to the Pilot Phase. Prior to the beginning of the First Phase in 2024, the ICAO Council will take a new decision on the programmes, project and unit types which will be eligible for that period. The Pilot Phase eligibility decision includes some restrictions which do not allow for some types of offsets based on environmental quality. No offsets generated by projects with a first crediting period starting before 2016 are eligible, setting a minimum vintage date for the units. This eliminates a significant amount of Clean Development Mechanism (CDM) credits on the market, while affecting other programmes to a lesser extent. Also, no offsets which represent emission reductions occurring after the end of 2020 are eligible for the Pilot Phase. We find that the application of the Emission Unit Criteria (EUC) is heterogeneous with no programme meeting all the criteria. Most approved programmes meet most of the criteria, however the assessment found notable variance with how programmes approach critical elements including safeguards, sustainable development, additionality, baselines, MRV, permanence, leakage, and no net harm. Only in some cases were specific subsets of programmes' projects excluded from eligibility. None of the programmes have comprehensive provisions to avoid double counting with pre-2020 commitments, which raises concerns with regards to the environmental integrity of relying on these credits to effectively offset, or neutralise, aviation sector emissions during the Pilot Phase. The TAB is proceeding to the assessment of the second wave of programmes, to be approved by the ICAO Council before the end of 2020.

MRV of emissions

Common rules regarding the monitoring, reporting and verification of emissions (MRV) under the EU ETS and CORSIA are crucial to ensure accuracy of emission reports and consistency.

The MRV processes and standards of the EU ETS and CORSIA are to a great extent comparable. Both schemes require as part of the, annual reporting and annual (accredited) verification of CO_2 emissions based upon a (Member) State's approved monitoring plan, in line with the minimum contents of such plan stipulated in both MRV requirements.

The Implementing Regulations and the Delegated Act have addressed some of the differences in alignment across both schemes, specifically relating to density, emission factor for jet kerosene, tier requirements for fuel consumption, uncertainty levels for fuel consumption, the definition of data gap threshold, small emitters, and the reporting template

The remaining MRV differences between the EU ETS and CORSIA concern scope and applicability, internal reviews and data validation requirements, Accreditation and Verification (AVR) bodies and competence requirements.

Registries

The CORSIA Central Registry (CCR) is one of the key implementation elements underpinning the CORSIA system. States will need to transmit an annual emission report to the CCR, containing details such as total annual CO_2 emissions per State pair aggregated for aeroplane operators and per each operator per State, emissions unit cancellation, and CORSIA eligible fuels use. A robust system will depend on the implementation of MRV rules across States to ensure correct reporting of emissions data. To prevent potential data gaps due to the lack of implementation of MRV rules, Article 2.5 of Annex 16, Volume IV provides a set of provisions to enable ICAO to estimate relevant items where data has not been reported.

Rules for fuels

ICAO developed a framework to reduce offsetting requirements under CORSIA through the use of eligible aviation fuels subject to compliance with sustainability criteria. Based on the sustainability criteria, CORSIA Eligible Fuels (CEF) include Sustainable Aviation Fuels (SAF, a renewable or waste-derived aviation fuel) and in principle but not yet, Lower Carbon Aviation Fuels (LCAF, a fossil-based aviation fuel). As of August 2020, no LCAF and only SAF's have been identified as eligible fuels.

For the pilot phase, ICAO established three sustainability criteria (achieve net greenhouse gas emissions reductions of at least 10% compared to the baseline, limitations and additional quantification requirements for feedstocks grown on land converted after 1 January 2008) for CEF applicable during the pilot phase of CORSIA (2021-2023). Additional sustainability criteria (e.g. water, soil, air, conservation, waste and chemicals, human and labour rights) have now undergone State consultation and are expected to be formally adopted by the ICAO Council at its 221st session for application from 1 January 2024 . Currently, these criteria are hard to implement without specific guidance, but they would ensure to cover a broad range of impacts.

The updated Renewable Energy Directive (RED II) requires raising the overall EU renewable energy consumption to 32% by 2030. Similar to CORSIA, RED II includes two sustainability criteria for biofuels: one for a GHG emission reduction threshold and the other for biofuel feedstocks. RED II categorizes the biofuels in two groups including "high ILUC-risk" and "Low ILUC-risk" based on the condition in which the feedstock is grown. RED II defines "high ILUC-risk" biofuels as those produced from feedstocks for which a significant expansion onto high carbon stock land is observed. On the other hand, "Low ILUC-risk" biofuels are those biofuels produced from feedstocks that avoid displacement of food and feed crops through improved agricultural practices or through cultivation of areas not previously used for crop production. Under RED II the consumption of high ILUC risk biofuels will be phased out. While the purpose of RED II is to increase the volume of biofuel consumption, CORSIA's approach is to generate credits based on the difference between the carbon intensity of eligible fuels and that of fossil fuels. Also, unlike RED II, LCAF are included under CORSIA.

Demand and supply of carbon offset credits

In our modelling analysis we estimate total carbon offset credit demand under nominal scenario assumptions of between 1.2-2.2 million in CORSIA's pilot phase, 25-29 million in the first phase, and 360-899 million in the second phase.[6] The range of estimates reflects different participation scenarios (see *State participation in CORSIA* above). We find that there is strong evidence to suggest a significant excess supply of carbon offset credits during CORSIA's pilot phase. Due to the timing of this analysis, it is based on pre-COVID-19 data and prior to the ICAO Council decision on the change of the baseline in the pilot phase. The effects of COVID-19 on aviation traffic in 2020 and beyond remain highly uncertain. However, the finding of excess supply of credits during CORSIA's pilot phase is likely to be reinforced by the reduction in aviation traffic as a result of COVID-19 as well as the adjustment to the baseline.

If ICAO were to allow carbon credits from projects considered eligible to supply units for CORSIA's pilot phase, extending eligibility to emission reductions delivered up to 2035 for use in the scheme's first and second phases, existing registered projects could supply approximately 1.5 billion credits. This is considerably higher than the demand of 493 million credits we estimated over the duration of CORSIA based on the initial assumed participation scenario and under nominal scenario assumptions. And it is similar to the level of demand of 1.6 billion credits estimated under high growth assumptions. A key risk

[6] The analysis does not fully capture the potential effects of COVID-19 and associated adjustments to the CORSIA emissions baseline, although we do not anticipate these to have a particularly material impact on the carbon credit demand estimates included here. The short-term reduction in aviation activity as a result of COVID-19, coupled with the revision of the CORSIA baseline to reflect only 2019 emissions for the pilot phase, increases the likelihood that the carbon credit demand in CORSIA's pilot phase is zero.

under the scenario that credits from existing projects are accepted for compliance use in CORSIA's first and second phase is that the emission reduction outcomes are also used towards achievement of the project host country's NDC targets, thereby double-counted. Indeed, a large share of existing projects are delivering emission reductions in sectors that are covered by their respective country's current NDC targets[7] and this share would rise as countries increase the scope of their NDCs over time, in line with the requirements of the Paris Agreement. It remains unclear if, and to what extent, future eligibility restrictions will be able to adequately avoid the risk of double-counting.

Potential climate impacts of CORSIA

The headline climate objective, to which CORSIA is intended to contribute as one of the four measures in the ICAO 'Basket of Measures', is 'carbon neutral growth' of international aviation from 2020. This target is unlikely be achieved because participation in CORSIA is likely to be partial, rather than complete, and the ability of ICAO to enforce compliance with the scheme is limited. Furthermore, it cannot be guaranteed that all carbon credits used to offset the actual growth in international aviation emissions reflect accurately measured real and permanent emission reductions that would not otherwise have occurred, i.e. that they are of high environmental integrity.

CORSIA is unlikely to materially alter the direct climate impact associated with air travel as the price signal that airlines will face under the scheme is, on its own, not expected to provide sufficient financial incentives for them to reduce emissions materially. CORSIA is designed to drive GHG emission reductions in other sectors through its requirement for aeroplane operators to purchase carbon credits.

Under all scenarios we consider in our analysis emissions from the international aviation sector rise over the duration of CORSIA to levels on the order of 1 billion tCO_2 by 2035. The sector's net contribution to atmospheric CO_2 levels is reduced the most when State participation in CORSIA is highest and the carbon credits used for compliance are of high quality. In this case CORSIA may reduce the sector's net contribution to atmospheric CO_2 levels in 2035 by approximately 20-30% but net emissions would still be considerably higher than the CO_2 impact of the sector in 2020. We find there is a risk the scheme may only provide a limited climate benefit compared to the case in which international aviation emissions remain unregulated.

IV. The economic, social and environmental impacts of policy options

Numerous different options exist for how the EU ETS and CORSIA could interact, ranging from abandonment of the EU ETS for aviation and full adoption of CORSIA, to a return of the EU ETS full scope including flights to and from the EU/EFTA[8] countries. To assess the economic, social and environmental impacts of different ways of combining the two instruments, aviation modelling was carried out using the aviation systems model AIM and wider economic modelling using the E3ME model to assess system metrics to 2035 for six different main policy options detailed in the Inception Impact Assessment on the Revision of the EU Emission Trading System Directive 2003/87/EC concerning aviation[9]. Aviation modelling was carried out both for a set of 'most likely' (pre-COVID-19) trajectories in

[7] Fearnehough, Warnecke, Schneider, Broekhoff, La Hoz Theuer, Offset credit supply potential for CORSIA, October 2019.

[8] Although technically the Swiss ETS is only linked with the EU ETS rather than fully integrated, for the purposes of modelling we include Swiss CO_2 with other intra-EU/EFTA CO_2 in one effective EU ETS cap.

[9] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12494-Revision-of-the-EU-Emission-Trading-System-Directive-concerning-aviation-

uncertain input scenario variables (oil price, carbon price, demand growth, CORSIA participation and changes in technology) and across a grid of variant scenarios for these input variables. Outputs are then reported for nominal scenario conditions (i.e., using the 'most likely' trajectories for all uncertain scenario variables; the E3ME modelling is also carried out on this basis) along with a given range in each output metric across all other combinations of uncertain scenario variables. It should be noted that, due to the absence of reliable data and the time constraints of this study, it was not possible to fully take into account the effects of the COVID-19 crisis in the modelling of impacts.

Aviation sector results

The following summarises the policy options and outcomes.

- Option 1 – EU ETS full legal scope – restores the EU ETS for aviation to full scope (i.e. all flights to, from and within the EU/EFTA, including to and from outermost regions) from 2024. This option is associated with the largest decrease in intra-EU/EFTA and global net aviation CO_2 - assuming that CORSIA would still be adhered to by third countries, which is a far from certain assumption - the largest increase in airline costs, the largest decrease in demand. Demand and cost impacts are still projected to be relatively small; for example, intra-EU/EFTA RTK differs from the lowest airline carbon cost option (option 3) by under 1.5% under nominal scenario conditions. Intra- and extra-EU/EFTA net aviation CO_2 closely follow the EU ETS aviation cap, with a small amount of residual uncertainty arising mainly from biofuel exemptions. Global net aviation CO_2 is projected to continue to rise on average over the time period to 2035 under nominal scenario conditions for option 1 due to growth on non-EU/EFTA, non-CORSIA routes. Legally, this option is covered by the differences notified by EU Member States in 2018 to ICAO regarding the CORSIA SARPs. However, this option would amount to the EU's non-participation in CORSIA, which runs contrary to the established formal EU position and the Council Decision adopted on 23 June 2021 related to the participation in CORSIA, subject to the differences filed.
- Option 2 – intra-EU/EFTA only – keeps the EU ETS for aviation at its current reduced scope (all flights within the EU/EFTA region, excluding those to and from outermost regions). CORSIA is not applied on routes within to and from the EU/EFTA region. This option is associated with slightly lower increases in intra-EU/EFTA airline costs than option 1, and slightly lower decreases in intra-EU/EFTA demand and emissions. Intra-EUEFTA net aviation emissions CO_2 decrease to 2035 but are projected to remain at a higher level than in Option 1 (around 4 Mt/18% under nominal scenario conditions by 2035) due mainly to outermost region exemptions. Global net aviation CO_2 is projected to be substantially higher (by 125 Mt/12% in 2035 under nominal scenario conditions) than in option 1, due to the lack of coverage of extra-EU/EFTA flights. The legal context is the same as Option 1. However, this option would amount to the EU's non-participation in CORSIA, which runs contrary to the established formal EU position and the Council Decision adopted on 23 June 2021 related to the participation in CORSIA, subject to the differences filed.
- **Option 3 – CORSIA only – removes aviation completely from the EU ETS. Instead, CORSIA applies to international flights to, from and within the EU/EFTA region**. **Domestic flights within the EU/EFTA would not be addressed anymore.**This option is associated with the biggest global net aviation CO_2 emissions increase, and the smallest impact on demand and airline costs. Under nominal scenario conditions, intra-EU/EFTA year-2035 net aviation CO_2 is projected to be higher than year-2015 values under option 3. Global net aviation CO_2 is projected to be 1.5 times year-2015 values in 2035 under nominal scenario

conditions if CORSIA offsets are assumed to be of high quality (as defined in Section 2.4). There is also a risk of even higher net aviation CO_2 in the case that CORSIA offsets are not fully additional. By removing EU ETS application, this option would avoid overlap regarding flights between EU/EFTA Member States, being covered by CORSIA.

- **Option 4 - ETS-CORSIA clean cut – keeps the EU ETS for aviation at its current reduced scope and applies CORSIA on flights to and from the EU/EFTA region**. Outcomes within the aviation sector are broadly similar to option 2, but net global aviation CO_2 is projected to be around 17 Mt/1.5% lower than option 2 in 2035 under nominal scenario conditions if CORSIA offsets are assumed to be of high quality, due to CORSIA coverage of extra-EU/EFTA flights. All flights would be covered by one of the two mechanisms and the option would also be legally grounded in the differences filed in 2018 to ICAO by the EU Member States.
- **Option 5 - ETS-CORSIA mix – is similar to Option 4, but the EU ETS and CORSIA both apply to routes within the EU/EFTA region**. The EU ETS counts only emissions below the CORSIA baseline. Under nominal scenario conditions, outcomes in terms of airline costs, demand and net CO_2 are similar to option 4. Net CO_2 may increase over option 4 values in the case that intra-EU/EFTA demand growth is higher than nominal scenario projections and CORSIA offsets are not of high quality..
- **Option 6 – ETS-CORSIA mix according to licence of aircraft operators – is similar to Option 4, but domestic flights and intra-EU/EFTA flights by non-EU/EFTA registered carriers are removed from EU ETS scope**. Under nominal scenario conditions, this option is projected to have broadly similar outcomes to options 4 and 5 because there are relatively few intra-EU flights operated by non-EU carriers. However, net aviation CO_2 is slightly higher than in Options 4 and 5 (by around 3 Mt) due to the exemption of domestic flights. From a legal perspective, this option would be illegal under EU law given the discriminatory treatment it would entail between flights operated by European and non-European airlines on the same route within the EU/EFTA area.

Socioeconomic impacts of the scenarios

The overall macroeconomic impacts of the different policy options considered, when evaluated through impacts on the aviation sector, fuel supply sectors, and through linked supply chains and associated multiplier effects, are small: less than 0.05% in terms of both value added and employment in all cases at the EU27 level. However, it is important to note that this presents only a partial analysis of the expected effects. As the aviation modelling shows, there are changes in flight frequency and capacity as a result of different policies, and these will affect the connectivity between regions and countries. It is reasonable to expect that such impacts may be more substantial, in macroeconomic terms, than the changes felt through the aviation sector and associated supply changes.

The E3ME modelling suggests that, of the policy options explored, when taking into account the effect of ETS revenue recycling to increase government expenditure or reduce taxes, extending the EU ETS to cover all flights (Option 1) would have the greatest positive impact on EU27 employment and GVA. The full-scope CORSIA scheme (Option 3) is associated with the weakest macroeconomic outcomes, while the other options with a mix of CORSIA and ETS scopes are expected to have broadly similar intermediate outcomes. However, the variation in expected macroeconomic effects between policy options is small.

Without the recycling of government revenues, there are weaker macroeconomic outcomes than in the case of revenue recycling for all options. The full-scope CORSIA scheme (Option 3) is still expected to deliver the weakest outcome for GVA, which reflects the impact on the aviation sector and associated impacts on its supply chain. However, the variation between policy options for employment is negligible and subject to a statistical margin of error so no meaningful conclusion can be drawn about relativity.

V. Cost pass-through for airlines

Cost pass-through, i.e., the percentage of an input cost change that is passed on to customers, typically depends on company-specific and industry-wide factors. Key factors affecting the carbon cost pass-through can be summarised as follows:

- The degree of competition – companies operating in highly competitive environments usually generate lower profits, forcing them to pass through increases in input costs to avoid losses and ultimately insolvency.
- The level of airport congestion – at congested airports, airlines price tickets to limit demand to the available capacity, known as the demand clearance point. In these conditions, increases to input costs are typically not passed-though, as this would raise the price above the demand clearance point. Cost pass-through is expected to be higher at uncongested airports.
- Demand elasticity, i.e., the degree to which supply or demand of a product responds to a change in price – highly elastic markets are expected to pass through less costs than inelastic markets.
- Exposure to international trade/competition – markets subject to high degree of international trade/competition are expected to pass through to a lower extent cost increases to avoid losing market share to unaffected firms in other locations.
- Carbon cost distribution – when carbon costs are not equally distributed (e.g., applied unilaterally only in one region), the worst-affected airlines are able to pass through to a lower extent cost increases compared with the least affected airlines.

Quantitative assessment of the carbon cost pass-through of airlines

To quantitatively assess the carbon cost pass-through of airlines, all flight routes within the European Economic Area were categorised into 27 route categories. The factors used in this analysis were competition intensity, airport congestion and route distance (which encapsulated substitution and demand elasticity).

The obtained cost pass-through figures range from 15% on long intracontinental routes connecting two congested airports with low competition, to 100% on short routes connecting two uncongested airports with high competition. Many airlines will pass the majority of the additional carbon cost on to the passengers, manifesting in higher ticket fares. However, the increase will be small compared to the total expenditure of a holiday or a business trip and is likely to have a small impact on aggregate demand. In aggregate, the pass-through estimations resulting from our modelling are:

- Initial average pass-through rates of around 74% for intra-EEA flights.
- Initial average pass-through rates of around 75-82% for extra-EEA flights, depending on the type of carbon cost applied.
- Initial average pass-through rates of around 77% for other routes.
- Initial average pass-through rates on routes to and from EU outermost regions of 74-77%, depending on the type of carbon cost applied.

Impact on airline behaviour and new entrants

The costs imposed by the EU ETS and CORSIA can influence airline network development in three ways – higher costs will increase the revenue cost for route viability, uneven allocation of costs can result in competitive advantages/disadvantages, or uneven geographical participation can result in reorientation of networks towards lower cost destinations. However, the carbon cost will likely be a relatively small factor in route profitability studies.

CORSIA exempts new entrants from the offsetting obligations for the first three years of operation, or when its emissions exceed a certain threshold. Furthermore, until 2027, the growth factor is calculated exclusively on sectoral, rather than individual, growth basis. These two factors together will give new entrants a slight cost advantage over incumbents. However, as the offsetting cost is likely to be small compared with the total operating costs, the impact of these effects will be minimal, and are likely to be outweighed by differences in other cost drivers.

The EU ETS Directive provides for year 2010 CO_2 tonne kilometre data to set the benchmark upon which free allocation is calculated. The Article 3f of the EU ETS Directive allows new operators who commence flight activity after 2010 or operators who experience a growth in tonne-kilometre activity in excess of 93.8% between 2010 and 2014 to apply for free allowances from the Special Reserve[10]. Beyond this date the legislation does not foresee further possibility for free allocation. The aviation ETS review in 2017 extended the current regime through to 2023 (in the context of considerations to implement CORSIA through the EU ETS). The corresponding FAQ explained that "*the allocation from the special reserve is a one off allocation based on 2014 activity. No new allocation will take place before the next review of the legislation*"[11]. Therefore, airlines which entered the market after 2014 are not entitled to any free allowances and would have to buy allowances to cover 100% of their emissions. The current method of free allocation seems detrimental to new entrants and fast growers operators. On average operators entitled to Special Reserve allowances seems to obtain a smaller share of free allowances (37%) than the other operators (55%) in 2015 and that gap tends to increase with the time.

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[10] Article 3f of the EU ETS Directive

[11] https://ec.europa.eu/clima/ets/ohaDetails.do?accountID=116541&action=all&languageCode=en

1 Introduction

This final report provides an *Assessment of the International Civil Aviation Organization (ICAO)'s global market-based measure (CORSIA) pursuant to Article 28b and for studying cost pass-through pursuant to Article 3d of the EU ETS Directive*[12]. The project was launched by DG CLIMA on 27 November 2019 and has been undertaken by ICF in association with NewClimate Institute, Air Transportation Analytics, Cambridge Econometrics, HFW, and Sven Starckx.

1.1 Study objectives

The objective of this study is to support the European Commission (DG CLIMA) with its assessment of:

- The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) pursuant to Article 28b of the EU ETS Directive; in particular, the following aspects: ambition of the CORSIA goal; environmental integrity; level of participation in the scheme; enforceability and transparency; quality of offset credits; monitoring, reporting and verification provisions; registries; and rules for fuels.
- The economic, social, and environmental impacts of EU policy options for the EU ETS and CORSIA.
- The ability for aircraft operators to pass-through their carbon costs, pursuant to Article 3d of the EU ETS Directive.

The results of the study support the European Commission's review of the regulation of aviation under the EU ETS Directive.

1.2 Structure of the Report

The contents and structure of this report are as follows:

- Section 2 presents an assessment of CORSIA pursuant to Art. 28b of the ETS Directive
- Section 3 presents an assessment of the economic, social, and environmental impacts of the different policy options; and
- Section 4 presents an assessment of the ability of the aviation sector to pass on the cost of CO_2 to its customers, in relation to the EU ETS and to the global market-based measure developed by ICAO

1.3 Latest developments and unforeseen circumstances

During the course of this study several key decisions on the implementation of CORSIA were taken by the ICAO Council and other elements, such as the participation in the scheme, continued to evolve. The most unforeseen development, however, was the COVID-19 pandemic. Due to the timing of this study, the latest developments could not always be fully integrated. This regards in particular the establishment of the assumptions underlying the modelling exercise. Whilst references are made to COVID-19 to the largest extent feasible, it was not possible to fully take into account the pandemic’s effects. In particular the adjustment of the CORSIA baseline to 2019 levels only for the pilot phase could not be fully reflected in the analysis and discussion.

[12] Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a system for greenhouse gas emission allowance trading within the Union and amending Council Directive 96/61/EC

2 Assessment of CORSIA pursuant to Art. 28b of the ETS Directive

2.1 Background to regulating emissions from aviation

The aviation sector accounted for 2.4% of total global anthropogenic carbon dioxide (CO_2) emissions in 2018[13] and accounted for 3.9% of the European Economic Area's (EEA) greenhouse gas (GHG) emissions in the same year.[14] As the level of sector activity as well as its associated emissions has expanded in recent years, while other sectors are decarbonising, aviation's contribution to CO_2 emissions has grown, and is expected to continue to grow.[15]

The COVID-19 pandemic has caused a material decrease in aviation activity and associated emissions in 2020. Exactly how much and for how long COVID-19 will continue to supress aviation activity is highly uncertain. However, medium-to-long term projections of significant aviation emissions growth are unlikely to be particularly materially affected by the short-term dip in activity as a result of the pandemic.[16]

In addition, aviation activities cause further non-CO_2 related climate impacts that drive radiative forcing through the release of nitrogen oxides (NO_x), water vapour, aerosols, contrail and contrail-cirrus effects.[17] Most emissions from aviation are released at altitudes of 8-12 km, where they have an increased warming effect.[18] Most non-CO_2 emissions are short-lived climate forcers, whereas CO_2 emissions can remain in the atmosphere for thousands of years. Due to both this temporal distinction as well as challenges in measurement, the global warming impacts of non-CO_2 emissions are subject to greater uncertainty than GHG emissions. According to previous research, non-CO_2 emissions could have a significant climate impact. For example, Owen, Lee and Lim (2010)[19] estimated that aviation contributed possibly as much as 4.9% to global radiative forcing in 2004 and the Intergovernmental Panel on Climate Change (IPCC) reported in 2007 that warming effects from NO_X emissions and contrails are two to four times greater than those of CO_2 – even

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[13] Brandon Graver, Kevin Zhang, and Dan Rutherford, "CO2 Emissions from Commercial Aviation, 2018," 2019.

[14] European Environment Agency, "EEA Greenhouse Gas - Data Viewer," 2019, https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer. Note that for aviation only CO_2 emissions are included in the statistics. Other GHGs from aviation, such as NO_x are not included.

[15] S El Takriti, N Pavlenko, and S Searle, "Mitigating International Aviation Emissions" (Washington D.C: ICCT, 2017), http://theicct.org/sites/default/files/publications/Aviation-Alt-Jet-Fuels_ICCT_White-Paper_22032017_vF.pdf.

[16] Climate Action Tracker, "International Aviation," 2020, https://climateactiontracker.org/sectors/aviation/ (accessed 2 July 2020); Lambert Schneider and Jakob Graichen, "Should CORSIA be changed due to the COVID-19 crisis?" Öko Institut, 2020.

[17] Volker Grewe, Sigrun Matthes, and Katrin Dahlmann, "The Contribution of Aviation NOx Emissions to Climate Change: Are We Ignoring Methodological Flaws?," *Environmental Research Letters* (2019), https://doi.org/https://doi.org/10.1088/1748-9326/ab5dd7.

[18] David S. Lee et al., "Aviation and Global Climate Change in the 21st Century," *Atmospheric Environment* 43 (2009): 3520–37, https://doi.org/10.1016/j.atmosenv.2009.04.024.

[19] Bethan Owen, David S. Lee, and Ling Lim, "Flying into the Future: Aviation Emissions Scenarios to 2050," *Environmental Science and Technology* 44, no. 7 (2010): 2255–60, https://doi.org/10.1021/es902530z.

without considering the potential impact of cirrus cloud enhancement.[20] This underlines that initiatives to address the climate impact of aviation need to focus on the full range of emissions from aircraft, not just CO_2 emissions but also that more knowledge is needed in this area. Article 30(4) of the European Union Emissions Trading System (EU ETS) Directive requires the European Commission to present an updated analysis of the non-CO_2 effects of aviation which, if relevant, should be accompanied by a proposal on how to best address those effects.[21] This separate study was ongoing at the time of finalising this report.

The International Civil Aviation Organization (ICAO) - a United Nations specialised agency – projected – prior to the COVID-19 crisis - that demand for international air transport would more than triple between 2015 and 2050, leading to an increase of 240-380% in fuel consumption and a similar increase in CO_2 emissions.[22] To project future fuel consumption and GHG emissions, ICAO developed five scenarios, where the scenario leading to the largest increase in fuel consumption and emissions assumes a 0.57% annual fuel burn improvement for new aircraft until 2050 and the most optimistic scenario assumes a 1.5% improvement to 2050.

Other research indicates that ICAO's projections may substantially underestimate the extent of future growth. A study by the International Council on Clean Transportation (ICCT), using data from the International Air Transport Association (IATA), found that emissions from both domestic and international commercial flights increased by 32% between 2013-2018. The 5.7% annual compound growth rate of emissions implied by these data is 70% higher than those used to develop ICAO projections.[23] The period of analysis for the ICCT study is characterised by relatively strong growth in aviation traffic, with levels higher than in the years leading up to 2013 and since 2018, which may exaggerate to some extent the differences compared to the ICAO projections.

Whereas aviation emissions are projected to increase significantly, the IPCC found that global net anthropogenic CO_2 emissions must reach net zero around 2050 to have a 66% probability of limiting global temperature increase to 1.5˚C.[24] A study prepared for the European Parliament's Committee on Environment, Public Health and Food Safety in 2015 found that CO_2 emissions from aviation must decrease by 41-96% from 2005 levels by 2050 to stay within a global temperature increase of 2˚C.[25] A 1.5˚C temperature limit requires even steeper reductions.

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[20] IPCC, *Climate Change 2007. Mitigation of Climate Change.*, ed. B. Metz et al. (Geneva; Switzerland: Cambridge University Press, 2007).

[21] The European Parliament and the Council of the European Union, "Directive (EU) 2018/410 of the European Parliament and of the Council of 14 March 2018 Amending Directive 2003/87/EC to Enhance Cost-Effective Emission Reductions and Low-Carbon Investments, and Decision (EU) 2015/1814," *Official Journal of the European Union*, 2018, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0410&from=DE.

[22] ICAO, "Destination Green: The Next Chapter - 2019 Environmental Report," 2019.

[23] Graver, Zhang, and Rutherford, "CO2 Emissions from Commercial Aviation, 2018."

[24] IPCC, "Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change," (Intergovernmental Panel on Climate Change, 2018), https://www.ipcc.ch/sr15/download/#full.

[25] Martin Cames et al., "Emission Reduction Targets for International Aviation and Shipping," 2015, http://www.europarl.europa.eu/RegData/etudes/STUD/2015/569964/IPOL_STU(2015)569964_EN.pdf.

2.1.1 Global regulation under UN bodies

Regulating the climate impacts from the aviation sector faces an important challenge with respect to jurisdictional accountability, particularly as many flights cross national and regional borders. Throughout this report we refer to 'international' aviation as the operation of an aircraft that takes-off from the aerodrome of one State and lands in the aerodrome of a different State. This is distinct from 'domestic' aviation which refers to the operation of an aircraft taking-off and landing within the same State. Whilst flights between different EU Member States are sometimes referred to as domestic aviation – e.g. domestic to the bloc – we include these under the definition of international aviation, providing further clarification where helpful.

Due to the lack of consensus in how to assign emissions from international bunker fuels to individual countries, responsibility for regulating those emissions has historically been left to ICAO, for aviation, and the International Maritime Organization, for maritime emissions. Whilst the 1992 United Nations Framework Convention on Climate Change (UNFCCC) does not mention bunker fuels, the 1997 Kyoto Protocol called for countries to work through ICAO to address emissions from international aviation.[26]

The 2015 Paris Agreement aims to limit global temperature increase to 'well below 2˚C above pre-industrial levels', pursuing efforts to limit the increase to 1.5˚C.[27] Although the Agreement does not explicitly mention international bunkers, these are covered by the Agreement's targets: Article 4.1 states "Parties aim to reach global peaking of greenhouse gas emissions as soon as possible […] and to undertake rapid reductions thereafter […], so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century". The Paris Agreement mentions economy-wide absolute emission reduction targets[28] thereby arguably also covering international bunker fuels as these still play an important role in many countries' economies. Indeed, in addition to the EU - which already regulates international aviation emissions under the EU ETS[29] (see following sub-section) – a few countries have started to include international transport emissions in discussions on decarbonisation strategies.[30]

2.1.2 Regulation of aviation within the EU ETS

In 2008, the EU took the initiative to extend the scope of the EU emissions trading system (ETS) to cover all CO_2 emissions from flights within, to and from airports in the EEA. This was prompted, in part, by a lack of progress within ICAO on how to regulate global international GHG emissions in the years since the 1997 Kyoto Protocol as well as indications that ICAO may seek to pursue a market-based approach. The regulation of aviation within the EU ETS entered into effect from the beginning of 2012 (Directive 2008/101/EC). The EU ETS is a legally binding cap-and-trade scheme, which limits

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[26] Kyoto Protocol (1997), Article 2.2

[27] Paris Agreement, Article 2

[28] Paris Agreement (2015) Article 4.4

[29] European Parliament, "Directive 2003/87/EC of the European Parliament and of the Council Establishing a Scheme for Greenhouse Gas Emission Allowance Trading within the Community and Amending Council Directive 96/61/EC: 2003/87/EC," *Official Journal of the European Union*, vol. 275, 2003, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:275:0032:0046:EN:PDF.

[30] For example, see the recommendations of the UK Committee on Climate Change, "Net Zero The UK's Contribution to Stopping Global Warming"; or the Scottish Climate Change Act 2019: Climate Change (Emissions Reduction Targets) (Scotland) Act 2019, 2019.

emissions from regulated entities by requiring them to surrender permits - European Union Allowances, or EUAs - corresponding to their actual emissions. Aircraft operators must therefore surrender allowances for all CO_2 emissions from flights covered by the scheme. Aircraft operators may use European Aviation Allowances (EUAAs), which are allowances issued specifically for the aviation sector, or EUAs. During phase 3 of the EU ETS (2013-2020) aircraft operators receive 82% of available allowances free of charge, 15% are auctioned and 3% are set aside in a special reserve to cover free allocation to new entrants and fast growers.[31] Aircraft operators may purchase allowances from other sectors under the ETS. As of 2021, the quantity of allowances will be reduced by 2.2% annually for all sectors covered by the EU ETS – including aviation (see also Section 2.2.4).

Under the full scope of its coverage, the EU ETS was expected to regulate approximately 35% of global CO_2 emissions from domestic and international flights and 50% of all international flights.[32] However, in order to allow for further work to continue in ICAO to develop a global approach to mitigate international aviation emissions, the EU 'stopped the clock' in April 2013, thereby temporarily limiting the EU ETS coverage to flights taking-off and landing within the EEA.[33] This suspension has subsequently been extended twice and is now running to the end of 2023.[34]

2.1.3 CORSIA

In 2016, the 39th Session of the triennial ICAO Assembly adopted Resolution A39-3 'Consolidated statement of continuing ICAO policies and practices related to environmental protection – Global Market-based Measure (MBM) Scheme'. This Resolution established the basic features of the 'Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)'.[35] The overarching objective of CORSIA is to help achieve – alongside three other measures making up a 'Basket of Measures'[36] – "carbon neutral growth" in the international aviation sector from the beginning of 2021, relative to a baseline of the annual

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[31] European Commission, "Impact Assessment Accompanying the Document Proposal for a Regulation of the European Parliament and of the Council - Amending Directive 2003/87/EC Establishing a Scheme for Greenhouse Gas Emission Allowance Trading within the Community in View of the Implementation of a single global market-based measure to international aviation emisions."

[32] European Commission, "Impact Assessment Accompanying the Document Proposal for a Regulation of the European Parliament and of the Council - Amending Directive 2003/87/EC Establishing a Scheme for Greenhouse Gas Emission Allowance Trading within the Community in View of the Implementation of a single global market-based measure to international aviation emisions."

[33] European Parliament and Council, "Decision No 377/2013/EU of the European Parliament and of the Council of 24 April 2013 Derogating Temporarily from Directive 2003/87/EC Establishing a Scheme for Greenhouse Gas Emission Allowance Trading within the Community," *Official Journal of the European Union*, vol. L, 2013. Preamble para 6, Article 1

[34] European Parliament and Council, "Regulation (EU) 2017/2392 of the European Parliament and of the Council of 13 December 2017 Amending Directive 2003/87/EC to Continue Current Limitations of Scope for Aviation Activities and to Prepare to Implement a Global Market-Based Measure from 2021," L Official Journal of the European Union § (2017), https://doi.org/10.1016/j.jclepro.2010.02.014.

[35] ICAO Assembly, "Resolution A39-3: Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection – Global Market-Based Measure (MBM) Scheme" (2016). https://www.icao.int/environmental-protection/Documents/Resolution_A39_3.pdf.

[36] https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2019/ENVReport2019_pg111-115.pdf

average CO_2 levels emitted in 2019 and 2020.[37] CORSIA does not regulate emissions from the domestic aviation sector, nor any international aviation emissions below the baseline level.

In June 2020, the ICAO Council decided to amend the baseline for CORSIA's pilot phase to use 2019 emissions instead of the average of 2019-2020 as a response to the reduction in aviation traffic during 2020 due to the COVID-19 pandemic.[38] This decision also concerns two other CORSIA features: the reference year for calculating offsetting requirements for the pilot phase and the new entrant threshold. The Council also highlighted that the first periodic review, which will take place in 2022, "will offer an opportunity to examine the impact of COVID-19 on CORSIA on various issues, including the impact on the baseline beyond the pilot phase"[39]. In the course of this study, it was not possible to fully take into consideration the effects of COVID-19 and adjustment to the CORSIA baseline in the analysis and discussion.

CORSIA complements a broader package of measures to achieve this goal of "carbon neutral growth" and addresses any annual increase in gross CO_2 emissions through the use of CORSIA eligible fuels and/or the purchase and retirement of carbon offset credits, which represent emission reductions or removals including in other sectors.[40] As technological solutions, operational improvements and alternative fuels have limited potential to reduce aviation emissions in the short term,[41] aviation is expected to continue to be predominantly dependent on fossil fuels in during the intended lifetime of CORSIA, i.e. until 2035.[42] ICAO therefore has expected CORSIA to be an important tool to achieve its objective of "carbon neutral growth".[43]

The scheme is designed to have three phases (see Figure 3). A voluntary pilot phase is scheduled to run from 2021-2023, followed by phase 1 (2024-2026) where States can also volunteer to participate, followed by a phase 2 (2027-2035), which is foreseen to cover all States that had a share above 0.5% of total Revenue Tonnes Kilometres (RTKs) in 2018 or whose cumulative share in the list of States from the highest to the lowest amount of RTKs reaches 90% of total RTK[44]. All States with aeroplane operators that undertake international flights are required to implement CORSIA's Monitoring, Reporting and

[37] ICAO Assembly. Paragraph 11.

[38] CORSIA and COVID-19 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-and-Covid-19.aspx

[39] Idem

[40] ICAO Assembly. Paragraph 4

[41] Benoît Chèze, Julien Chevallier, and Pascal Gastineau, "Will Technological Progress Be Sufficient to Stablize CO2 Emissions from Air Transport in the Mid-Term?," *Transportation Research Part D: Transport and Environment* 18 (2012): 91–96, https://www.sciencedirect.com/science/article/pii/S1361920912000946.

[42] Chris Lyle, "Beyond the ICAO's CORSIA: Towards a More Climatically Effective Strategy for Mitigation of Civil-Aviation Emissions," *Climate Law* 8 (2018): 104–27, https://doi.org/10.1163/18786561-00801004; Paul Peeters et al., "Are Technology Myths Stalling Aviation Climate Policy?," *Transportation Research Part D: Transport and Environment* 44 (2016): 30–42, https://doi.org/10.1016/j.trd.2016.02.004.

[43] ICAO, "Destination Green: The Next Chapter - 2019 Environmental Report."

[44] ICAO Assembly, Resolution A39-3: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Global Market-based Measure (MBM) scheme. Paragraph 9

Verification (MRV) rules and collect data on international aviation emissions.[45] No decision has been taken in ICAO on regulating through a market-based mechanism international aviation emissions after CORSIA's second phase, which runs to the end of 2035. ICAO will conduct a review of CORSIA by the end of 2032 to consider termination of the scheme, its extension or any other improvements of the scheme beyond 2035.[46]

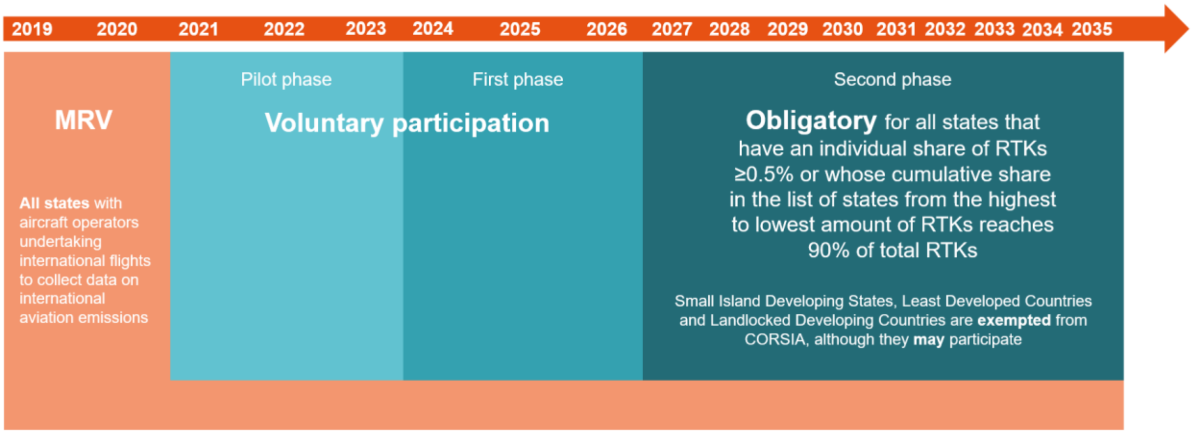

Figure 3. Overview of the different phases in CORSIA

Resolution A39-3 further called for the ICAO Council, with the technical contribution of the Council's Committee on Aviation Environmental Protection (CAEP), to develop a number of technical aspects of CORSIA, including:[47]

- Standards and Recommended Practices (SARPs) and guidance for MRV;
- Guidance for Emissions Units Criteria (EUC);
- To establish a standing Technical Advisory Body (TAB) to make recommendations to the Council regarding eligible emission units for use by CORSIA;
- Policies and related guidance material to support the establishment of registries under the scheme and a consolidated central registry; and
- Provisions for sustainable alternative fuels.

From this mandate, CAEP, working through the special Global Market Based Measure Task Force (GMTF) and the Alternative Fuel Task Force (AFTF), made recommendations on the design of the overall CORSIA, including the SARPs, the Environmental Technical Manual, and registry design. The Council adopted the recommendations, and ICAO published the first edition of the SARPs along with supporting documents into a 'CORSIA Package' in June 2018.[48]

[45] ICAO Assembly. Paragraph 20b

[46] ICAO Assembly, Resolution A39-3: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Global Market-based Measure (MBM) scheme. Paragraph 18(c).

[47] ICAO Assembly, Resolution A39-3: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Global Market-based Measure (MBM) scheme. Paragraph 20,

[48] ICAO, "Annex 16 to the Convention on International Civil Aviation. Environmental Protection. Volume IV, Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)," 2018.

The EU and its Member States endorsed the adoption, while filing differences on the SARPs to ICAO.[49,50] These ensured not to prejudge the outcome of the EU's eventual process for CORSIA implementation. The ICAO secretariat has not published any filed differences which makes it difficult to conduct a complete assessment.

2.1.4 Interaction between CORSIA and the EU ETS

The regulatory coverage of aviation emissions under the EU ETS and CORSIA overlap, at least in part. The European Commission (EC) must report to the European Parliament and the Council with an assessment of specific elements of CORSIA, as well "consider ways" to implement CORSIA through the EU ETS Directive, as per Article 28b of the EU ETS Directive. Whilst the requirements for monitoring, reporting and verifying emissions under CORSIA have been implemented through the EU ETS Directive, other decisions on CORSIA's relation to the EU ETS in terms of the interaction between their respective coverage are still pending. These decisions could have a large impact on the setup and stringency of regulation of aviation emissions both within the EEA and between the EEA and third countries. This report aims to inform these decisions.

The remainder of the Chapter is structured as follows. In Section 2.2 we assess the ambition of CORSIA in terms of climate mitigation, relative to the Paris Agreement and relevant EU climate policy. In Section 2.3, we then evaluate the environmental integrity of CORSIA, focusing on a selection of key elements, including: participation in the scheme, transparency of policy design and ongoing oversight, enforcement of compliance, the potential quality of carbon offset credits used for compliance, MRV considerations, requirements for registries to track carbon offset credit obligations and the cancellation of units, and rules on the use of CORSIA eligible fuels. In Section 2.4 we examine possible compliance costs under CORSIA and set out two price scenarios for carbon offset credits. Finally, in Section 2.5 we draw on the key points made throughout the chapter to identify potential economic, social and environmental implications of implementing CORSIA.

2.2 Ambition

Article 28b of the EU ETS Directive stipulates that the European Commission shall report to the European Parliament and the Council on the ambition and environmental integrity of the global market-based mechanism, 'including its general ambition in relation to the Paris Agreement'.[51] In this Section we describe CORSIA's ambition and compare it to the Paris Agreement – both its overall temperature goal and its Nationally Determined Contributions (NDCs) – as well as relevant EU climate targets and policies, such as the EU ETS.

We understand the term ambition – in this context - to reflect both the degree to which an institution or agreement aims to reduce anthropogenic GHG emissions and the extent to

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[49] European Commission DG for Mobility and Transport, "Letter to the Secretary General of the International Civil Aviation Organization Regarding the State Letter AN1/17.14" (Brussels, Belgium, 2019), https://ec.europa.eu/transport/sites/transport/files/2018-03-01-eu-reply-to-corsia-state-letter.pdf.

[50] Council Decision (EU) 2018/2027 of 29 November 2018 on the position to be taken on behalf of the European Union within the International Civil Aviation Organization in respect of the First Edition of the International Standards and Recommended Practices on Environmental Protection — Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32018D2027

[51] European Parliament and Council, Regulation (EU) 2017/2392 of the European Parliament and of the Council of 13 December 2017 amending Directive 2003/87/EC to continue current limitations of scope for aviation activities and to prepare to implement a global market-based measure from 2021.

which enduring policy measures are put in place to target challenging climate change mitigation options. Comparing ambition across different policies, pledges or targets is challenging, particularly where their scope is not aligned in terms of economic sectors, timeframe, coverage of types of GHG emissions or the type of target, amongst other metrics. For example, CORSIA focuses exclusively on the growth of carbon dioxide emissions from international aviation. The remit of the Paris Agreement is considerably wider. It sets out a global temperature limit and calls on all countries to work towards decarbonising their economies to stay within this limit. However, there is no prescribed overall pathway, nor are there top down quantified efforts for individual countries or sectors to achieve the objectives of the Paris Agreement.

In order to help inform an assessment of CORSIA's ambition in relation to the Paris Agreement we set out a number of criteria which we consider determinants of ambition. We discuss the following criteria, in turn, in the sections that follow:

- Type and stringency of the target;
- Coverage of sources of climate impact;
- Policy timeframe;
- Ambition raising mechanisms; and
- Enforcement mechanisms.

Estimates of the potential climate impact of CORSIA are included later in the report in section 2.5.2, with more detailed comparisons of climate impacts across policy options, including configurations of both CORSIA and the EU ETS explored in Section 3, and in particular reported in section 3.2.10.

2.2.1 Type and stringency of the target

Paris Agreement

The Paris Agreement aims to limit global warming to 'well below 2˚C above pre-industrial levels' and to pursue 'efforts to limit the temperature increase to 1.5˚C above pre-industrial levels'.[52] The importance of limiting global warming to 1.5˚C was reiterated in the IPCC Special Report on 1.5˚C, which found that an average global temperature increase of 1.5˚C results in significantly lower climate-related risks for natural and human systems than higher temperature levels.[53] Furthermore, according to the IPCC, staying within the 1.5˚C temperature limit requires fast and steep emission cuts leading to net-zero emissions around 2050. Carbon dioxide removals - for instance afforestation and bioenergy with carbon capture and storage (BECCS) - are likely necessary to compensate for residual emissions[54] but their potential is limited.[55]

To stay within the 1.5˚C limit, the Paris Agreement requires all Parties to undertake 'ambitious efforts' that represent 'a progression over time'[56], and to prepare and achieve

[52] Paris Agreement, Article 2

[53] IPCC, "Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change" (Geneva, Switzerland: Intergovernmental Panel on Climate Change, 2018), https://www.ipcc.ch/sr15/.

[54] Ibid.

[55] Sabine Fuss et al., "Negative Emissions—Part 2: Costs, Potentials and Side Effects," *Environmental Research Letters* 13, no. 6 (June 1, 2018): 063002, https://doi.org/10.1088/1748-9326/aabf9f.

[56] Paris Agreement, Article 3

emission reduction targets that are set out in NDCs.[57] Developed countries are to undertake economy-wide absolute actions and developing countries are encouraged to move to such targets over time.[58] The Paris Agreement does not specify the type of policy measures that countries should take, nor does it prescribe the relative effort of each country, or indeed sector, required to stay within the overall temperature limit. It does, however, state that each country's NDC should "reflect its highest possible ambition".[59]

The first round of NDCs falls well short of the ambition needed to reach the 2˚C temperature limit, let alone the 1.5˚C goal.[60] However, many NDCs were drawn up before the Paris Agreement text was adopted. Countries may increase their level of ambition in the next round of new, or updated, NDCs, due to be submitted in 2020, now that it is clear what the Paris Agreement calls for. The extent to which these collectively reflect a ratchet in ambitious climate action remains to be seen. By April 2020, only six countries had submitted an updated NDC – Norway[61], the Marshall Islands[62], Moldova[63] and Suriname[64], Singapore[65] and Chile[66]. One other country – Mongolia – proposed a new target. After submitting its Intended NDC in 2016, Japan submitted its first NDC in March 2020.[67] The United States of America – which is planning to withdraw from the Paris Agreement - and Australia indicated they will not submit an updated NDC.[68] There is therefore likely to remain a sizeable gap between the overall ambition of the Paris Agreement and the collective ambition of all countries, as signalled through their NDCs.

CORSIA

ICAO aims - via CORSIA - to achieve net zero growth in CO_2 emissions from the international aviation sector over the period 2021-2035, compared to a baseline of average levels across 2019-2020. Due to the COVID-19 crisis, the ICAO Council decided to use

[57] Paris Agreement, Article 4

[58] Paris Agreement, Article 4(4)

[59] Paris Agreement, Article 4(3)

[60] UNEP, "Emissions Gap Report 2019" (Nairobi, Kenya: United Nations Environment Programme, 2019), https://wedocs.unep.org/bitstream/handle/20.500.11822/30797/EGR2019.pdf?sequence=1&isAllowed=y.

[61] Norway, "Update of Norway's Nationally Determined Contribution," 2020, https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Norway First/Norway_updatedNDC_2020 (Updated submission).pdf.

[62] The Republic of the Marshall Islands, "Nationally Determined Contribution," 2018.

[63] Government of the Republic of Moldova, "Updated Nationally Determined Contribution of the Republic of Moldova," 2020, https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Republic of Moldova Second/MD_Updated_NDC_final_version_EN.pdf.

[64] The Republic of Suriname, "Nationally Determined Contribution 2020," 2020, https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Suriname Second/Suriname Second NDC.pdf.

[65] Singapore, "Singapore's Update of Its First Nationally Determined Contribution (NDC) and Accompanying Information," 2020.

[66] Government of Chile, "Chile's Nationally Determined Contribution - Update 2020," 2020, http://blog.sciencenet.cn/home.php?mod=space&uid=448901&do=blog&id=1227033.

[67] Japan, "Submission of Japan's Nationally Determined Contribution (NDC)," 2020.

[68] Climate Action Tracker, "CAT Climate Target Update Tracker," 2020, https://climateactiontracker.org/climate-target-update-tracker/.

2019 levels only for the pilot phase [69] Annual emissions below the baseline level are left unaddressed altogether. This means that, even if the target ambition of CORSIA is achieved, the scheme does not encourage net emissions from the international aviation sector to decrease over time.

Aeroplane operators are required to offset any increase in sectoral emissions above the baseline level on routes between participating States by purchasing eligible carbon credits, which deliver emission reductions or removals in other sectors. Whilst CORSIA may provide a degree of financial incentive to aeroplane operators to limit emissions, the design of the scheme allows emissions from international aviation to continue to increase without limits. In fact, ICAO has expected – prior to the COVID-19 crisis - that sector emissions will grow rapidly over the coming decades.

Participation in CORSIA is voluntary until 2027. From 2027, many States are exempt from participating based on a socioeconomic and/or activity-based criteria (see Section 2.3.1.1). Participation in CORSIA is therefore highly unlikely to include all States. Because its route-based approach means that it only covers flights where both the departure and arrival State participate, without full participation of all States the scheme will not deliver its stated ambition of complete offset of carbon emissions above the baseline.

The method of calculating offsetting requirements under CORSIA for each aeroplane operator limits to a certain extent the direct financial incentive for operators to reduce their own emissions. At the end of the first CORSIA compliance period the aggregate sector growth factor of emissions across all covered routes, relative to the baseline level, determines how many carbon credits each aeroplane operator needs to surrender for every tonne of its own emissions from flights on CORSIA covered routes. For example, if sector emissions are 10% higher than the baseline level in 2025, then each aeroplane operator is required to surrender 0.09 carbon credits per tonne of CO2 emitted on CORSIA covered routes in that year, regardless of whether its individual emissions rose or fell.[70] By definition, the price per tonne of an aeroplane operator's actual CO_2 emissions under CORSIA will always be less than the price of one carbon credit. For the duration of CORSIA the price signal is likely to remain a relatively small fraction of the price of a carbon credit. For example, even if total sector emissions were to rise by 300%, relative to the baseline, the effective price per unit of emissions would still only be three-quarters of the cost of purchasing a carbon credit.[71] An aeroplane operators' individual growth factor is only planned to play a role in determining their offset requirement after 2030 (at least 20% for

[69] At the time of conducting the study the COVID-19 pandemic was ongoing and had already significantly cut aviation activity in the first months of 2020. The effect of COVID-19 on the baseline is highly uncertain, with the possibility that the existing rules for determining the baseline may be adjusted. If the baseline of average emissions in 2019 and 2020 is retained, this implies that - depending on future growth - aeroplane operators will have to offset more emissions than previously anticipated.

[70] The offset requirement is initially calculated as the sectoral growth in emissions, relative to the baseline, divided by the total emissions in the year. If the sector baseline emissions were 100 tCO_2 and total emissions in 2025 were 110 tCO_2, then each aeroplane operator needs to surrender (110-100)/110 = 0.09 carbon credits for each tonne of its own CO_2 emissions covered by CORSIA's offsetting requirements.

[71] Again, taking the same baseline emissions level of 100 tCO_2, emissions in this example would be 400 tCO_2 and the offset requirement for each aeroplane operator would be (400-100)/400 = 0.75 carbon credits for each tonne of its own CO_2 emissions covered by CORSIA's offsetting requirements.

the period 2030-2032 and at least 70% for the period 2033-2035).[72] This provision was a necessary concession to fast growing developing countries such as China and India.

Furthermore, aeroplane operators will not actually know the offsetting requirements and associated cost they face per unit of their emissions until well after the activity takes place, as, until 2030, this depends on sectoral growth rather than on individual operators' growth. States inform them about their offsetting requirement for any given year only in November of the following year.[73] This again limits the extent to which the price signal derived from CORSIA compliance costs can feasibly enter into aeroplane operator's investment and operational decision-making processes and thereby incentivise emission reductions.

EU policy

The EU's current NDC, which was submitted in 2015, sets the target of reducing economy wide GHG emissions by at least 40% by 2030 compared to 1990 levels. The NDC explicitly states that it would not use international carbon credits towards this target.[74] The EU ETS and the Effort Sharing legislation are the primary regulatory instruments to deliver these reductions, in addition to national policies and other related climate policy measures.[75]

Although the EU's NDC does not explicitly include international aviation within the target, all CO_2 emissions from both the international and domestic aviation sector are covered by the EU's main regulatory instrument to tackle climate change, the EU ETS, albeit with a reduced scope until 31 December 2023, unless otherwise revised.[76] In its most recent biennial report to the UNFCCC, the EU stated as regards its international commitment under the Paris Agreement that aviation is included in the scope of the EU ETS and in practice total outgoing flight emissions are considered.[77]

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72 ICAO, "Annex 16 to the Convention on International Civil Aviation. Environmental Protection. Volume IV, Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)." Chapter 3.

73 ICAO. Appendix 1.

74 Latvia, "Submission by Latvia and the European Commission on Behalf of the European Union and Its Member States," 2015, https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/European Union First/LV-03-06-EU INDC.pdf.

75 The European Parliament and the Council of the European Union, "Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on Binding Annual Greenhouse Gas Emission Reductions by Member States from 2021 to 2030 Contributing to Climate Action to Meet Commitments under the Paris Agreement And ," *Official Journal of the European Union*, 2018, https://eur-lex.europa.eu/eli/reg/2018/842/oj; European Parliament and the Council of the European Union, "Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the Effort of Member States to Reduce Their Greenhouse Gas Emissions to Meet the Community's Greenhouse Gas Emission Reduction Commitments up to 2020," *Official Journal of the European Union* L 140 (2009): 136–148, https://doi.org/10.3000/17252555.L_2009.140.eng.

76 European Parliament and Council, Regulation (EU) 2017/2392 of the European Parliament and of the Council of 13 December 2017 amending Directive 2003/87/EC to continue current limitations of scope for aviation activities and to prepare to implement a global market-based measure from 2021. Preamble paragraph 8.

77 Fourth Biennial Report from the European Union under the United Nations Framework Convention on Climate Change December 2019 https://www4.unfccc.int/sites/SubmissionsStaging/NationalReports/Documents/045612387_European%20Union-BR4-1-European%20Union-BR4_C_2019_8832_and_SWD_2019_432.pdf

The European Green Deal, presented in December 2019, sets the objective to reach net-zero GHG emissions by 2050.[78] The Commission also states it will present an impact assessed plan to increase the EU's greenhouse gas emission reductions target for 2030 to at least 50% and towards 55% compared with 1990 levels "in a responsible way". The European Parliament backed the Green Deal in January 2020.[79] The Commission has considered that to reach net-zero economy-wide emissions by 2050, transport emissions need to decrease by 90% compared to 1990[80] and aviation should contribute to that reduction. Also, the Commission will propose to reduce the share of EU ETS allowances allocated for free to airlines.[81] Although the Green Deal provides a broad outline of the Commission's plans until 2050, it does not specify to what extent aviation should contribute to a 90% reduction in transport emissions or how to neutralise the remaining 10% in order to reach net-zero emissions overall.[82] The Commission's long-term low greenhouse gas emission development strategy for the EU and its Member States, submitted to the UNFCCC in March 2020, aligns with the ambition of the European Green Deal and sets the objective to achieve net-zero GHG emissions in 2050.[83] Following the European Green Deal, the European Council endorsed the objective of achieving a climate-neutral EU by 2050, in line with the objectives of the Paris Agreement.[84]

The EU ETS applies a declining cap to emissions from fixed installations within its scope by reducing the quantity of EUAs issued by 1.74% each year until 2020 and by 2.2% from 2021[85]. The aviation cap is set until 2020 at 95% of the 2004-2006 average level of aviation emissions. To date, the annual issuance of allowances to the aviation sector (EUAAs) has remained fixed at around 38 million allowances [86]. However, as noted above in section 2.1.2, the revised linear reduction factor of 2.2% will also apply to aviation from 2021. As under CORSIA, the design of the EU ETS does not prevent emissions from the aviation sector from growing. However, it does cap the aggregated emissions from all sectors covered by the scheme and ensure that they fall over time. Historically, limited use of carbon credits was permitted under the EU ETS as an alternative to surrendering EUAs or

[78] European Commission, "Communication from the Commission to the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions: The European Green Deal (COM(2019) 640 Final)" (Brussels, Belgium, 2019), https://doi.org/10.1017/CBO9781107415324.004.

[79] European Parliament, "European Parliament Resolution of 15 January 2020 on the European Green Deal (2019/2956(RSP))" (Brussels, Belgium, 2020).

[80] Note the text of the Green Deal is not explicit what year's emissions the reduction target relates to. However, other EU climate objectives for 2050 are expressed relative to 1990 levels.

[81] European Commission, "Communication from the Commission to the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions: The European Green Deal (COM(2019) 640 Final)." Pages 10-11.

[82] Aviation accounted for 13.9% of all transport sector CO_2 emissions in the EU in 2017. The transport sector accounted for 27% of total EU emissions. Statistical Pocketbook 2019 : EU transport in figures, https://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2019_en.

[83] Croatia and the European Commission, "Submission by Croatia and the European Commission on Behalf of the European Union and Its Member States. Long-Term Low Greenhouse Gas Emission Development Strategy of the European Union and Its Member States," 2020.

[84] European Council, "European Council Meeting (12 December 2019) - Conclusions" (Brussels, Belgium, 2019), https://www.consilium.europa.eu/media/41768/12-euco-final-conclusions-en.pdf.

[85] https://ec.europa.eu/clima/policies/ets/cap_en

[86] https://ec.europa.eu/clima/policies/ets/cap_en

EUAAs, subject to quantitative as well as qualitative restrictions. The EU does not envisage continuing the use of carbon credits for compliance under the EU ETS after 2020.[87]

Aircraft operators need to surrender an allowance for each tonne of CO_2 they emit on flights within the EEA. The financial incentive to reduce their emissions – which should enter aircraft operators' investment and operational decision-making process even if they are among those operators that receive a majority of their allowances for free[88] – corresponds directly to the prevailing market value of an EUA or EUAA. The price of allowances is likely to rise over time as the cap on emissions is reduced.

2.2.2 Coverage of sources of climate impact

Paris Agreement

The Paris Agreement sets a global temperature goal and explicitly states that all countries should reach a peak in GHG emissions as soon as possible and undertake rapid reductions thereafter to achieve a 'balance between anthropogenic GHG emissions by sources and removals by sinks of greenhouse gases in the second half of this century'.[89]

In addition to CO_2 emissions, non-CO_2 emissions and related impacts also drive climate change and therefore impact the ability to reach the Paris Agreement temperature goal. Non-CO_2 emissions are particularly relevant in the context of aviation.

CORSIA

CORSIA only addresses the growth in CO_2 emissions from international aviation on participating routes and does not cover emissions under the baseline level. It also does not regulate emissions from domestic aviation, which is responsible for approximately 40% of CO_2 emissions from all passenger aviation.[90] Informed by the modelling set out in Section 3 – we estimate CORSIA will mitigate just 1.4% of international aviation emissions in 2025 through biofuels and offsetting under a participation scenario that is based on the list of July 2019 with 81 countries joining the scheme from its inception and assuming all carbon credits have high quality, i.e. they actually reflect a tonne of CO_2 emission reductions that would not otherwise have happened (see Section 2.3.1.2). This share would increase to 5.8% in 2030 and 9.8% in 2035. The share of total aviation (i.e. domestic and international) emissions that CORSIA would mitigate ranges between 0.9% in 2025 and 6.6% in 2035.[91]

In addition, CORSIA leaves non-CO_2 emissions and related impacts unregulated. So, while the ambition of CORSIA is to enable "carbon-neutral growth" for the sector, this does not imply an ambition to enable what could be called "climate-neutral growth". If international aviation traffic continues to grow over time, the sector's contribution to climate change

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[87] https://ec.europa.eu/clima/policies/ets/credits_en

[88] In 2019, aircraft operators under the EU ETS on average received free allowances covering 46% of their emissions (https://ec.europa.eu/clima/news/emissions-trading-greenhouse-gas-emissions-reduced-87-2019_en)

[89] Paris Agreement, Article 4(1)

[90] Graver, Zhang, and Rutherford, "CO2 Emissions from Commercial Aviation, 2018."

[91] Note that these shares reflect the emissions that would actually be *mitigated* by CORSIA – assuming the use of high-quality carbon credits. The share of emissions *covered* by the scheme is considerably higher (on the order of 50% of international aviation emissions and 35% of total aviation emissions – see section 2.3.1.5) but a large share of the covered emissions are not addressed, because CORSIA only regulates the growth of emissions above the baseline on participating routes.

would also likely increase, irrespective of whether the growth in CO_2 emissions released by aircraft is actually offset, via emission reductions or removals in other sectors.

EU policy

The European Union's climate target, as well as the European Green Deal, cover all GHGs within the region that are not controlled by the Montreal Protocol. It does not foresee to specifically address non-CO_2 emissions from aviation.[92] Although EU policy is mainly focused on EU Member States, the European Green Deal does set out plans to implement a carbon border adjustment mechanism in certain sectors, which would effectively incentivise emission reductions in third countries seeking to export products in those sectors to the EU.

With specific regards to aviation emissions, the EU ETS covers all domestic aviation as well as international aviation between countries within the EEA. Under its full scope, the EU ETS would also cover emissions from all flights to, and from, non-EEA countries. Based on the modelling set out in Section 3, we expect the full scope EU ETS to cover 23.5% of all global aviation emissions – i.e. domestic and international – in 2025 and 20.2% in 2035. The current reduced scope EU ETS would cover 4.5% of all global aviation emissions in 2025 and 3.7% in 2035.

Like CORSIA, the EU ETS only covers CO_2 emissions from aviation. It does not regulate non-CO_2 emissions and related impacts from the sector.[93]

2.2.3 Policy timeframe

Paris Agreement

The Paris Agreement comes into effect from 2021. It has no end date and will continue to apply until Parties adopt a new treaty or withdraw from the Agreement.

CORSIA

CORSIA's pilot phase starts at the beginning of 2021. In contrast to the Paris Agreement, CORSIA's second phase is scheduled to end in 2035 and ICAO currently has no plan for addressing through a market-based instrument the climate impact from international aviation for the period after that. Following the 40th Session of the ICAO Assembly, work on developing options for a long-term goal for international aviation is ongoing in ICAO – including in the recently established CAEP task group for this purpose. As noted above, by 2032, ICAO will conduct a special review of CORSIA for the period after 2035.

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92 Latvia, "Submission by Latvia and the European Commission on Behalf of the European Union and Its Member States."

93 European Parliament and the Council of the European Union, "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," L Official Journal of the European Union § (2009), https://doi.org/ISSN 1725-2555.

EU policy

The European Union has set overall emission reduction targets for 2030[94] and 2050[95]. Within the EU, domestic and intra EEA aviation has been regulated under the EU ETS since the start of 2012[96] and there are no plans to end the scheme. Formally flights to and from the EEA are also included although suspended until 2023.

2.2.4 Ambition raising mechanisms

Paris Agreement

The Paris Agreement stipulates that the Conference of the Parties shall undertake a 'Global Stocktake' every five years, starting in 2023.[97] Based on the outcome of the Global Stocktake, parties will be encouraged to update and enhance their NDCs.[98] This provides a mechanism for regular review and updating of country-level pledges to move towards achieving the overall ambition of the Paris Agreement.

CORSIA

Under CORSIA, Assembly Resolution A40-19 states that, as of 2022 the ICAO Council will review the implementation of the scheme every three years, including its impact on the growth of international aviation.[99] This review serves as an important basis for the ICAO Council to consider whether adjustments to the next phase or compliance cycle are necessary.

As part of this review cycle, the Council's assessment will include progress towards achieving ICAO's aspirational goal; the impact of the scheme on the market and costs of both states and aeroplane operators, as well as its impact on international aviation; and the functioning of the scheme's design elements.[100] Importantly, as part of this review cycle, the ICAO Council is to consider improvements to CORSIA that 'would support the purpose of the Paris Agreement, in particular its long-term temperature goals'; as well as adjusting elements of CORSIA to improve implementation, increase effectiveness, and minimise market distortion.[101]

Furthermore, the Council will assess at the end of 2032 whether CORSIA will be terminated, extended or improved.[102] The review cycle could thus lead to raising the ambition of

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[94] Latvia, "Submission by Latvia and the European Commission on Behalf of the European Union and Its Member States."

[95] European Commission, "Communication from the Commission to the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions: The European Green Deal (COM(2019) 640 Final)."

[96] European Parliament and the Council of the European Union, 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.

[97] Paris Agreement, Article 14(2)

[98] Paris Agreement, Article 14(3)

[99] ICAO, "Resolution A40-19: Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection - Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)." Paragraph 9(g)

[100] ICAO. Paragraph 17(a)

[101] ICAO. Paragraph 17(b)

[102] ICAO. Paragraph 17(c)

CORSIA, but this is not its principle aim and it may well focus on more technical implementation elements associated with delivering the existing level of ambition.

Following the ICAO Council decision to change the baseline, it was also decided that the 2022 review will offer an opportunity to examine the impact of COVID-19 on CORSIA on various issues, including the impact on the baseline beyond the pilot phase, the different phase of CORSIA implementation and on the growth factors.

EU policy

Since 2005, the EU ETS has been implemented in phases and it has undergone a number of reforms since its inception to increase its scope and effectiveness, taking into account lessons learned, and market and political developments. For example, free allocation of allowances has been progressively reduced for fixed installations, aviation was included in the EU ETS starting in 2012, and a market stability reserve was introduced in 2019. As the Effort Sharing Regulation (Article 15), the EU ETS Directive includes a general clause on its review in the light of the implementation of the Paris agreement (Article 30).

Regarding the regulation of aviation emissions, in the absence of a change to the legislation, the EU ETS would revert to its full scope from 2024 onwards, thereby raising its coverage relative to the third phase. This scenario may however face EU-internal misgivings and political resistance/reactions from non-EEA countries as was the case when aviation was first included in the EU ETS. Other options to increase the ambition of the EU ETS include adjusting the linear reduction factor (LRF), which determines the quantity of allowances issued every year. For the period up to 2020 the quantity of allowances for the aviation sector did not change (except due to bankruptcies), whereas the number of allowances allocated each year to other sectors in the EU ETS was reduced by 1.74%. This LRF will increase to 2.2% a year - for all sectors, including aviation - as of 2021, tightening the overall cap on regulated emissions at a faster pace.[103]

2.2.5 Mechanisms to enforce compliance

Paris Agreement

Article 15 of the Paris Agreement establishes a mechanism to 'facilitate implementation of and promote compliance with the [Agreement's] provisions'. This mechanism consists of a committee of experts that is 'facilitative in nature', transparent, non-adversarial and non-punitive. Furthermore, the Global Stocktake, established through Article 14 of the Paris Agreement, should be carried out every five years to inform Parties in updating and enhancing their NDCs. While the committee and the Global Stocktake can be used to call-out countries that do not meet their pledges, the Paris Agreement lacks a sanction mechanism for enforcement.

CORSIA

The CORSIA SARPs include an MRV framework and reporting cycle.[104] The SARPs receive binding force through their transposition into national, or regional (for example, in the case

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[103] European Parliament, "Directive 2003/87/EC of the European Parliament and of the Council Establishing a Scheme for Greenhouse Gas Emission Allowance Trading within the Community and Amending Council Directive 96/61/EC: 2003/87/EC." Article 9

[104] ICAO, "International Standards and Recommended Practices, Environmental Protection - Carbon Offsetting and Reduction Scheme Fo International Aviation (CORSIA) (Annex 16, Volume IV to the Convention on International Civil Aviation)" (Montreal: ICAO, 2018).

of the EU), law and ICAO can carry out audits to check whether States comply with the SARPs.[105]

States may file differences between the elements of the SARPs and national regulations, thereby removing any legal obligation for those States to comply with the applicable parts of the SARPs (see also Section 2.3.1.3).[106] Whilst the filing of differences and ICAO audits can serve to highlight non-compliance with the CORSIA SARPs, ICAO has no instruments at its disposal to enforce compliance[107] (see also Section 2.3.3 for a more detailed discussion of enforcement).

EU policy

The EU’s overall climate objectives are facilitated through a mix of different policy instruments for different sectors. The EU ETS covers large emitting installations and aviation, whilst most other sectors such as non-aviation transport, buildings, agriculture and waste are covered by EU Effort Sharing legislation. EU Member States are legally bound to comply with the Effort Sharing Regulation[108], which sets national reduction targets for sectors that are not covered by the EU ETS for the period 2021-2030. Article 9 of the Effort Sharing Regulation provides that compliance checks will take place in 2027 and 2032.

Compliance with the rules of the EU ETS is legally binding on regulated entities. The responsible administrating Member States[109] must ensure that each aircraft operator submits a monitoring plan, which outlines measures to monitor and report emissions and tonne-kilometre data.[110] All Member States submit annual reports on the application of Directive 2003/87/EC to the Commission.[111] Article 16 of the EU ETS Directive requires that aircraft operators who fail to surrender sufficient allowances by 30 April of each year to cover their emissions in the previous year, must pay a penalty of EUR 100 for each surplus tonne of CO_2. In addition, any shortfall in compliance is added to their obligation for the following year. Article 16 also requires Member States to publish the names of regulated entities – including aircraft operators - who do not surrender sufficient allowances.[112] In case aircraft operators fail to comply with the requirements laid down in

[105] Pablo Mendes de Leon et al., “Possible Legal Arrangements to Implement a Global Market Based Measure for International Aviation Emissions,” 2015, https://ec.europa.eu/clima/sites/clima/files/transport/aviation/docs/gmbm_legal_study_en.pdf.

[106] Mendes de Leon et al.

[107] Michael Milde, *International Air Law and ICAO*, ed. Marriette Benkö (Utrecht, Netherlands: Eleven International Publishing, 2008).

[108] The European Parliament and the Council of the European Union, “Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on Binding Annual Greenhouse Gas Emission Reductions by Member States from 2021 to 2030 Contributing to Climate Action to Meet Commitments under the Paris Agreement And .”

[109] As provided for by Directive 2003/87/EC, Article 18a, the responsible administrative Member State is the Member State that granted the operating licence to the aircraft operator or otherwise the Member State with the greatest attributed aviation emissions from flight performed by that aircraft operator in the base year - are to ensure that aircraft operates.

[110] European Parliament, “Directive 2003/87/EC of the European Parliament and of the Council Establishing a Scheme for Greenhouse Gas Emission Allowance Trading within the Community and Amending Council Directive 96/61/EC: 2003/87/EC.” Article 3g

[111] European Parliament. Article 21

[112] European Parliament and the Council of the European Union, “Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 Establishing a System for Greenhouse

the EU ETS Directive, and where other enforcement measures do not lead to compliance, Member States can ask the Commission to impose an operating ban.[113] France, Germany and the United Kingdom, for instance, have recently imposed fines on aircraft operators that did not submit sufficient allowances for their carbon emissions.[114]

Further, EU Member States may be pursued by the European Commission if they fail to transpose or (properly) implement the Effort Sharing Regulation and EU ETS Directive and subsidiary legislation.[115]

2.2.6 Summary of CORSIA's ambition in relation to the Paris Agreement as well as related EU policy

Based on our assessment of the criteria set out in the sections above, there are a number of features of CORSIA which imply its level of ambition for the international aviation sector is mis-aligned with, and weaker than, the global level of ambition required to keep within the temperature goals of the Paris Agreement. That said, the collective pledges of all countries that are parties to the Paris Agreement is also well short of the level of required ambition.

In several respects, CORSIA is also weaker than the regulation of aviation within the EU ETS. Replacing part, or all, of the coverage of aviation from the scope of the EU ETS with CORSIA therefore risks weakening EU climate targets or may require the implementation of deeper emission cuts and removals in other sectors.

First, while according to the IPCC, the Paris Agreement temperature goal would require a 100% reduction of net global emissions across all sectors by 2050, CORSIA aims to offset emissions growth from 2020 levels onwards through the use of carbon credits, but does not address the continuation of emissions below that threshold. In practice this means that emissions from the international aviation sector are allowed to continue to grow – with the growth offset through emission reductions or removals implemented in other sectors. As the Paris Agreement calls for all countries to expand and ratchet their climate mitigation efforts over time, the scope for delivering high quality credited emission reductions will decline. Moreover, because CORSIA only covers flights between participating States, and a number of States are either exempt from participating or are unlikely to elect to participate in all years, an important share of emissions growth above the baseline will not be offset.

Gas Emission Allowance Trading within the Union and Amending Council Directive 96/61/EC" (2018). Article 16

113 European Parliament, "Directive 2003/87/EC of the European Parliament and of the Council Establishing a Scheme for Greenhouse Gas Emission Allowance Trading within the Community and Amending Council Directive 96/61/EC: 2003/87/EC." Article 16(5)

114 Ministère de la Transition écologique et solidaire, "Understand and Implement the EU Emissions Trading Scheme," 2017, https://www.ecologique-solidaire.gouv.fr/en/understand-and-implement-eu-emissions-trading-scheme; Deutsche Emissionshandelsstelle (DEHSt), "Sanktionierung," 2018, https://www.dehst.de/DE/Emissionshandel-verstehen/Sanktionierung/sanktionierung_node.html; United Kingdom Environment Agency, "Climate Change Civil Penalties," 2019, https://data.gov.uk/dataset/13c0893a-049a-4608-9f9b-7f268a71f15a/climate-change-civil-penalties.

115 Following Article 258 of the Treaty on the Functioning of the European Union, which provides that: "If the Commission considers that a Member State has failed to fulfil an obligation under the Treaties, it shall deliver a reasoned opinion on the matter after giving the State concerned the opportunity to submit its observations. If the State concerned does not comply with the opinion within the period laid down by the Commission, the latter may bring the matter before the Court of Justice of the European Union."

The EU has committed to reduce its emissions by at least 40% by 2030 compared to 1990 levels and to net-zero by 2050 in-line with the Paris Agreement temperature goals and does not plan to use carbon credits towards this goal. The EU's main climate policy instrument – the EU ETS – targets all CO_2 emissions from the aviation sector. Its declining cap helps deliver aggregate emission reductions across all regulated entities over time. However, under the EU ETS emissions from the aviation sector could still continue to grow, subject to the availability of allowances, if emissions reductions in other sectors covered by the scheme are more cost-effective and therefore emissions in those sectors decline at a faster rate than the cap.

Second, whereas the Paris Agreement covers all anthropogenic sources of climate change, CORSIA addresses just CO_2 emissions from aircraft, leaving non-CO_2 impacts unregulated. This limitation currently also applies to the regulation of aviation under the EU ETS, although as per Article 30(4) of the ETS Directive, an ongoing study is considering updated analysis of the non-CO_2 effects of aviation and options for addressing them.

It is particularly problematic in the context of the Paris Agreement temperature limit that neither CORSIA nor the EU ETS currently cover non-CO_2 emissions from aviation. Whilst their climate impact tends to be short-lived and is more uncertain than CO_2 impacts, these can be at least as detrimental to the climate as the CO_2 released into the atmosphere by aircraft.[116] In terms of coverage, CORSIA's reach is global – at least on participating routes - but only extends to international aviation, with the regulation of domestic aviation left to national governments. The EU ETS covers both domestic and international aviation on routes within the EEA. At its full scope, it would also extend to covering flights to and from EEA countries, regardless of the departure or arrival country.

Third, to stay within the Paris Agreement temperature limit requires ambitious and enduring policy to facilitate reaching global net-zero emissions by 2050, and likely net-negative emissions beyond mid-century. CORSIA's second phase will end in 2035. Beyond 2035 ICAO has no agreed regulation for the international aviation sector. It is clear that to be consistent with the Paris Agreement objectives, ambitious and effective policies for international aviation are needed well beyond 2035.

The relative ambition of CORSIA with respect to the Paris Agreement on other criteria we have considered is more aligned. Both the Paris Agreement and CORSIA have established regular review cycles to consider progress towards their respective targets. The Paris Agreement's Global Stocktake is explicitly focused on measuring progress and updating ambition, whereas CORSIA's review cycle covers a broader range of implementation issues. It should, however, explicitly consider improvements to CORSIA that 'would support the purpose of the Paris Agreement'. And both UN coordinated processes rely on the willingness of national governments and regulated private actors to comply with their respective rules and procedures. CORSIA is not explicitly legally binding and relies to a large extent on measures to identify and highlight non-compliance. The EU ETS, on the other hand, is legally binding and has a number of penalty mechanisms to enforce compliance. These measures can assist in ensuring the achievement of the target ambition of the scheme.

The EU aims to be a global leader on climate and environmental issues and promote and implement ambitious climate policies both domestically and across the world.[117] Participating in CORSIA – and leaving all international aviation (as defined by ICAO, including that between EEA countries) outside the scope of the EU ETS – would risk

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[116] Owen, Lee, and Lim, "Flying into the Future: Aviation Emissions Scenarios to 2050."

[117] European Commission, "Communication from the Commission to the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions: The European Green Deal (COM(2019) 640 Final)." Page 20

undermining these objectives and weakening current EU climate policies. Following the European Green Deal, the European Council endorsed the objective of achieving a climate-neutral EU by 2050, in line with the objectives of the Paris Agreement. The European Parliament also backed the Green Deal. The European Green Communication clearly states that a 90% reduction target for transport emissions is needed to achieve climate neutrality, recognising that aviation will need to contribute to this goal. . If the EU is to participate in CORSIA, and simultaneously replace part, or all, of its existing regulation for aviation, it is unlikely that aviation will substantially contribute to the 90% reduction in transport emissions and risks undermining the ability to reach net-zero emissions by mid-century.

2.3 Environmental integrity

Following Article 28b of the EU ETS Directive, the European Commission shall report to the European Parliament and the Council on CORSIA's ambition and overall environmental integrity, including 'the level of participation, its enforceability, transparency, the penalties for non-compliance, the process for public input, the quality of offset credits, monitoring, reporting and verification of emissions, registries, accountability, as well as rules on the use of biofuels'.[118]

In the context of climate change policy, the concept of environmental integrity relates to preserving the state of the environment and, in particular, avoiding further (anthropogenic) warming to the climate. In this section we assess a number of the key features of CORSIA focusing on the likelihood that they enable the avoidance or reduction of climate impacts both from within the international aviation sector as well as other affected sectors, such as those in which CORSIA eligible carbon offset crediting projects are based. Similarly, we identify and discuss a number of features of CORSIA that may introduce risks to the preservation of the climate and therefore the overall environmental integrity of the scheme. The assessment is based on the aspects outlined by Article 28b of the EU ETS Directive.

2.3.1 State participation in CORSIA

For CORSIA to deliver on its stated objective of "carbon neutral growth" for the international aviation sector from 2020, all countries would need to participate in the scheme from the beginning of 2021. The way the scheme is designed, if there is not full participation, then neither the emissions from aircraft flying routes to, nor from, non-participating countries will be regulated. Those countries that do participate in CORSIA will not be obliged to make up for any resulting shortfall in the total volume of carbon credits required to offset the sector's global CO_2 emission levels above 2020 levels. Incomplete participation in CORSIA therefore poses a material risk to the environmental integrity of the scheme and its ability to achieve its stated objective. In the following paragraphs we examine a range of sources to provide an evidence-based assessment of likely participation in CORSIA over time.

2.3.1.1 Requirements for participation

As we note in Section 2.1.3 above, CORSIA is planned across three phases, starting at the beginning of 2021 and running until the end of 2035. Participation of States in the pilot

[118] European Parliament and Council, Regulation (EU) 2017/2392 of the European Parliament and of the Council of 13 December 2017 amending Directive 2003/87/EC to continue current limitations of scope for aviation activities and to prepare to implement a global market-based measure from 2021. Article 28b (2)

phase (2021-23) and first phase (2024-27) is voluntary, whereas the second phase (2027-2035) is meant to be mandatory for all ICAO Member States that are not exempt.[119]

There are two categories of exemptions for participation in the second phase. A socioeconomic criterion exempts all States that are classed as either Small Island Developing States (SIDS), Least Developed Countries (LDCs) or Landlocked Developing Countries (LLDCs) (or more than one, where applicable). An activity-based criterion exempts all states whose share of Revenue Tonne Kilometres (RTKs) were less than 0.5% of the total for all ICAO Member States in 2018, and who are not included in the top 90% of the cumulative share of activity when States are ranked from the highest share to the lowest. A State's annual RTK value is an activity metric of all aeroplane operators registered to the State, reflecting the weight and distance of both passengers and cargo that are transported in the year.

There are 193 ICAO Member (or "Contracting") States, broadly matching membership of the United Nations.[120] The socioeconomic criterion currently exempts a total of 92 of these States from participating in the second phase and the activity-related criterion currently exempts 157 of these States. As a number of States fall under both categories, there are a total of 159 States currently exempt from participation. These States can, however, elect to participate on a voluntary basis.

For the remaining 34 States that are not exempt under CORSIA's second phase, the extent to which CORSIA would be binding on them is uncertain. The legal instruments used for establishing and implementing CORSIA are secondary law deriving from the Chicago Convention. These mainly include Resolutions of the Assembly as well as the SARPs.[121] ICAO member States are able to file "reservations" to Resolutions and notify "differences" to ICAO SARPs in accordance with Article 38 of the Chicago Convention. As ICAO has not published the differences notified, only the differences filed by EU Member States are publicly accessible[122].

The uncertainty regarding the binding nature of ICAO's legal instruments was discussed at the time of assessing the preliminary ruling before the European Court of Justice in the context of the claim introduced by the Air Transport Association of America against the EU ETS in 2011. The Advocate General Kokott recalled the absence of legally binding effect of ICAO's Resolution and in particular to the Resolution adopted at the 37th Assembly of the ICAO in respect of the envisaged global market based measure to be applied in the aviation sector.[123] Except under special circumstances, Assembly Resolutions therefore have no

[119] ICAO Assembly, Resolution A39-3: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Global Market-based Measure (MBM) scheme. Paragraph 9

[120] See: https://www.icao.int/about-icao/Pages/member-states.aspx (accessed on 13 January 2020)

[121] Resolution OACI – A36-13 – Consolidated statement of continuing ICAO policies and associated practices related specifically to air navigation.

[122] Council Decision (EU) 2018/2027 of 29 November 2018 on the position to be taken on behalf of the European Union within the International Civil Aviation Organization in respect of the First Edition of the International Standards and Recommended Practices on Environmental Protection — Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32018D2027

[123] Opinion of Advocate General Kokott, 6 October 2011 in Case C-366/10, Air Transport Association of America and Others.

legal binding force and can at most merely be considered as 'soft law'[124] – depending on factors such as formal acceptance, repetition and the language used in the resolution.[125]

2.3.1.2 Participation by States

The international aviation sector is dominated by traffic in and out of a relatively small number of States. Figure 4 shows the top 25 States in 2018 in terms of both estimated CO_2 emissions for passenger operations on international routes assigned to the State from which the aircraft departed and RTKs (which are assigned to where the aeroplane operator is registered). In both instances the top 25 States account for approximately 80% of the global total. Across both metrics China (CHN), the USA, the UK (GBR), the United Arab Emirates (ARE) and Germany (DEU) are the States accounting for the largest share of aviation activity. Aggregating across all of the States covered by the EU ETS in 2020, they account for 29% of global carbon dioxide emissions for passenger operations and 27% of RTK in 2018 (not shown in Figure 4).[126]

[124] U. M. Erling, "How to Reconcile the European Union Emissions Trading System (EU ETS) for Aviation with the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), Air & Space Law, 43, No. 4&5 (2018), p. 381.

[125] Mendes de Leon et al. (2015)

[126] These figures include the UK, which may end its participation in the EU ETS at the end of 2020. Excluding the UK reduces the shares to 23% and 21%, respectively.

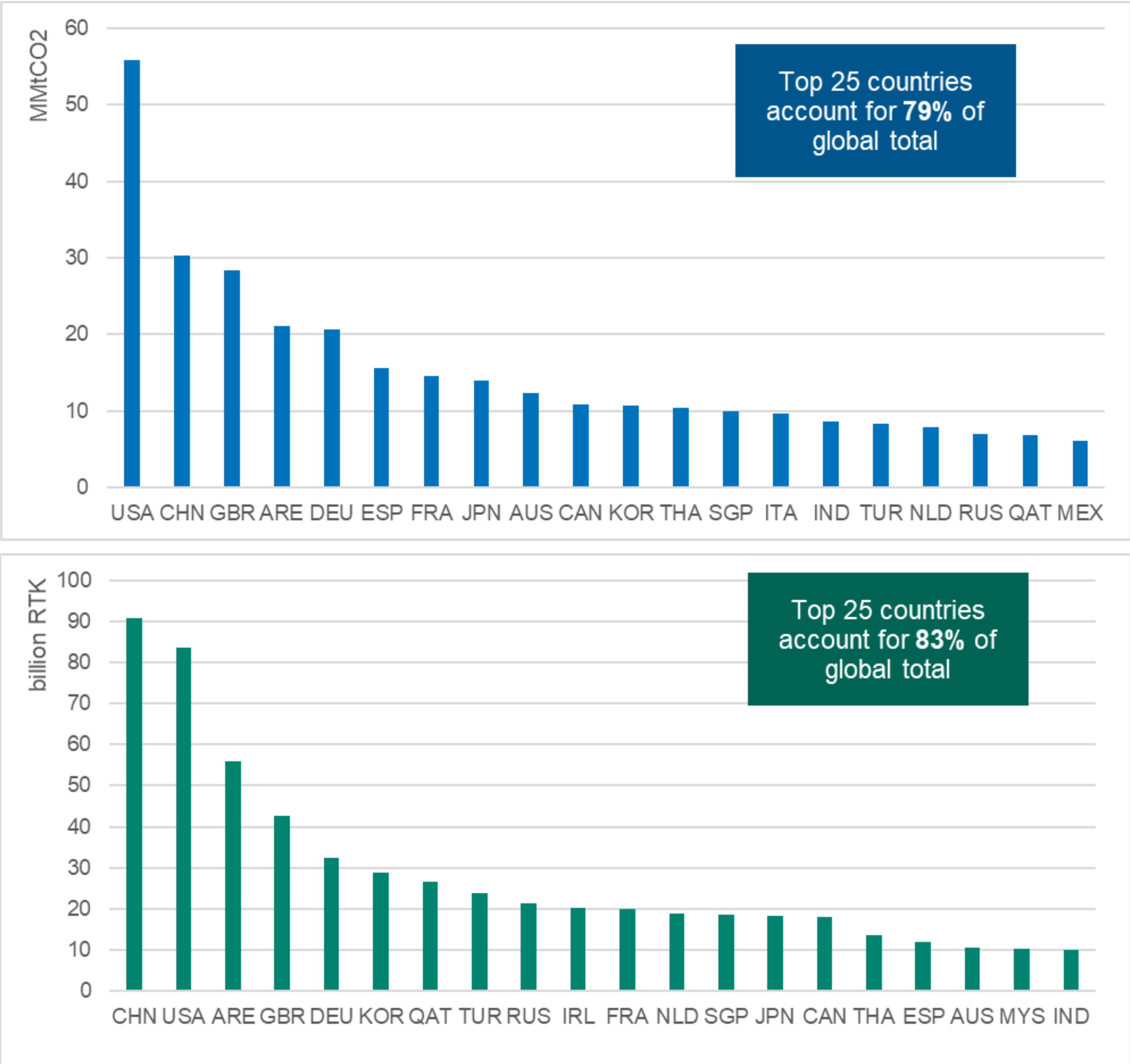

Figure 4. Top 25 countries ranked according to share of global carbon dioxide emissions from outgoing international passenger flights (top chart) and share of global RTK for all international flights of registered aeroplane operators (bottom chart), both for 2018.

The ICAO website maintains a record of States that have indicated their intention to participate in CORSIA's pilot and first phase.[127] However formally, States electing to voluntarily participate in CORSIA may participate from the beginning of any given year and should notify ICAO of their decision by the end of June of the preceding year. ICAO has not requested a second round of State Letters confirming participation based on the final SARPs, but until 30 June 2020, States had to notify ICAO of their decision to participate in CORSIA as of the 2021 calendar year.

[127] CORSIA Participation, https://www.icao.int/environmental-protection/CORSIA/Lists/CORSIAParticipation/AllItems.aspx (accessed August 2020).

ICAO published. the list of States that will participate in CORSIA from 1 January 2021.[128] This document, "CORSIA States for Chapter 3 State Pairs"[129] includes 88 States, including all Member States of the European Union and other Member States of the European Civil Aviation Conference (ECAC);[130] all G7 countries, including the United States of America; Gulf States; and South-East Asian States among others. However, States may also subsequently withdraw their participation in CORSIA so there remains uncertainty regarding which States will actually participate in CORSIA from 2022 and thereafter.

In "CORSIA States for Chapter 3 State Pairs", ICAO does not refer to the notification received. Ahead of the 30 June deadline, the EU adopted a decision on the notification of voluntary participation recalling that "This notification is without prejudice to differences, under Article 38 of the Chicago Convention, with the provisions of Annex 16, Volume IV to the Chicago Convention"[131].

The ICAO website list[132] refers to commitments by these States made in a range of different documents in support of their intention to participate. Most States are included based on countries' statements at the 2016 triennial ICAO Assembly and other summits before the 2016 Assembly. Eighteen States - including the USA, the United Kingdom, Germany and Japan - have submitted a formal response to the State Letter that was sent to all ICAO Member States in September 2016 asking them to inform ICAO of their intention to participate (see Annex 1 for a full overview of States that responded to the State Letter). The responses of these 18 States were based on Assembly resolution A39-3 and submitted before the SARPs and associated Environmental Technical Manual[133] were final and published

The chart on the left hand side of Figure 5 shows a breakdown of the 193 ICAO Member States according to their intended participation from the start of 2021, based on the information published on ICAO's website as of July 2019.[134] Of the 81 listed States, 29 States are currently not exempt from the second phase and 52 States are currently exempt

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[128] ICAO, "CORSIA States for Chapter 3 State Pairs - Updated Information on the States That Intend to Voluntarily Participate in CORSIA from Its Outset," 2019, https://www.icao.int/environmental-protection/CORSIA/Pages/state-pairs.aspx.(accessed August 2020).

[129] CORSIA States for Chapter 3 State Pairs, July 2020. https://www.icao.int/environmental-protection/CORSIA/Pages/state-pairs.aspx

[130] Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Georgia, Iceland, Republic of Moldova, Monaco, Montenegro, Republic of North Macedonia, Norway, San Marino, Serbia, Switzerland, Turkey and Ukraine.

[131] Council Decision (EU) 2020/954 of 25 June 2020 on the position to be taken on behalf of the European Union within the International Civil Aviation Organization as regards the notification of voluntary participation in the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) from 1 January 2021 and the option selected for calculating aeroplane operators' offsetting requirements during the 2021-2023 period. https://eur-lex.europa.eu/eli/dec/2020/954/oj

[132] https://www.icao.int/environmental-protection/CORSIA/Lists/CORSIAParticipation/AllItems.aspx

[133] ICAO, "Doc 9501. Environmental Technical Manual. Volume IV - Procedures for Demonstrating Compliance with the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)" (Montreal, 2018), https://www.unitingaviation.com/publications/9501-Vol-04-Edition1-EN/#page=1.

[134] Over the course of this research project, seven additional states indicated they will participate in CORSIA in 2021: Afghanistan, Benin, Côte d'Ivoire, Honduras, Kazakhstan, Madagascar and Rwanda. We were not able to include these States in our modelling. Considering that the seven States combined accounted for approximately 0.03% of global RTKs in 2018, their inclusion would not materially alter our findings.

from participation, due to one or both of the exemption criteria mentioned above. Of the remaining 112 States that have not indicated they will participate from 2021, 107 are currently exempt from participation in phase 2 and five are currently not exempt, as foreseen under CORSIA. These five States are China, Russia, India, Brazil and Vietnam. The chart on the right-hand side of Figure 5 depicts the same breakdown reflecting the grouping of States' relative share of total RTKs in 2018. The 81 States that indicated by July 2019 that they will participate from the start of CORSIA account for approximately 77% of the share of RTKs; the five States that have not indicated they will participate, but which are not exempt account for approximately 18% of the share of RTKs; and the remaining 107 exempt States, which have not indicated they will participate account for 7%.

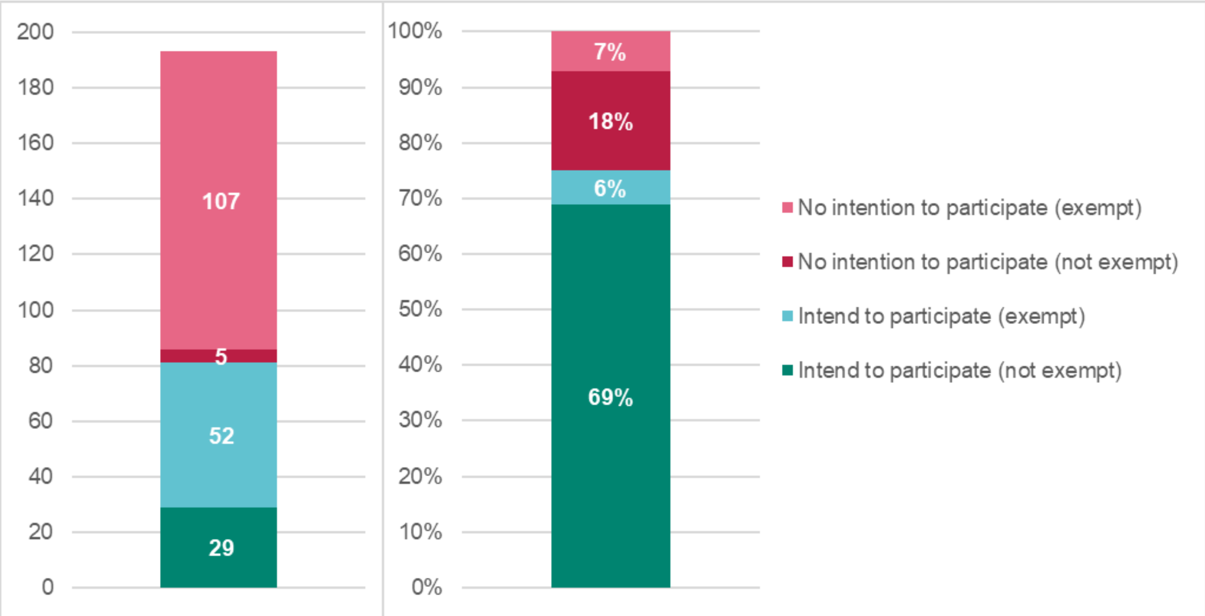

Figure 5. Initial assumed participation from 2021 (as of July 2019) by count (left) and share of total RTKs (right)

The coverage of CORSIA is determined on a route basis. Flights fall under the regulation of CORSIA if they fly a route which both takes-off and lands in participating States. If either the departure State or the arrival State, or both, are not participating in CORSIA then that route – and all flights on it – are not covered by CORSIA. This means that estimating the global coverage of the scheme according to proxy metrics such as the share of emissions from States' departing flights or from the RTKs of registered aeroplane operators is likely to overestimate the actual coverage. A simple example illustrates this. If we assume a world in which there are just two States - State A and State B - and they each account for 50% of global international aviation activity. If both States participate in CORSIA the coverage of the scheme is 100% of global emissions, which also reflects the aggregated sum of their aviation activity. However, if only State A participates then the coverage of the scheme would fall to 0%, despite State A accounting for 50% of global aviation activity.

Analysis forecasting flight routes indicates that CORSIA's coverage of the aviation sector's global – i.e. domestic and international – carbon dioxide emissions across all phases from

2021-2035 would be approximately 35%[135] if actual participation reflects the 81 States[136] listed as volunteering to participate on the ICAO website (see Section 2.3.1.2 on CORSIA coverage). If actual participation increases the share will be higher, while if it decreases the share will be lower.

2.3.1.3 Indicative non-participation from the start

Many of the ICAO Member States that have not indicated they will participate from the start of CORSIA are either SIDS, LDCs, or LLDCs, or they account for less than 0.5% of global aviation activity, meaning that they are anyway exempt from participation in the second phase. As we note above there are five States that have not indicated they will participate, and which are not exempt in the second phase. We discuss the available evidence which sets out their respective concerns with the scheme in the following paragraphs. These concerns with the scheme are typically communicated through statements of reservations, or the filing of differences. The ICAO secretariat has not published filed differences, thus limiting transparency regarding any such differences to third parties.

China

China is the State with the largest share of global international aviation activity (12.4%), as measured in RTKs (91 million in 2018). Its participation therefore has an important impact on the overall coverage of CORSIA.

China has long been critical of the option of establishing a global market-based measure for international aviation. After the 38th triennial ICAO Council Assembly in 2013, China filed a reservation to operating clause 7 of Resolution 17/2, which states that ICAO and its Member States will cooperate to strive to achieve a collective medium term aspiration goal of keeping global net carbon emissions from international aviation from 2020 at the same level.[137] China considered that developed countries should take the lead in 'taking reduction measures in order to offset the growth of emissions from international aviation of developing countries'.[138] After the 39th triennial ICAO Council Assembly in 2016, China filed a reservation[139] against the goal of "carbon neutral growth" set out in paragraph 6 of

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[135] Informed by our modelling set out in Section 0 under nominal demand growth assumptions: CORSIA would cover approximately 351 $MtCO_2$ of the total aviation sector emissions of 977 $MtCO_2$ in 2025 (or 36%); 386 $MtCO_2$ of the total of 1,139 $MtCO_2$ in 2030 (or 34%) and 417 $MtCO_2$ of the total of 1,270 $MtCO_2$ in 2035 (or 33%).

[136] Over the course of this project Afghanistan, Benin, Côte d'Ivoire, Honduras, Kazakhstan, Madagascar and Rwanda were added to ICAO's list, bringing the total number of participating countries to 88. We were unable to include these seven States in our modelling.

[137] ICAO, "Assembly Resolutions in Force. Doc 10022" (Montreal, 2013), https://www.icao.int/Meetings/GLADs-2015/Documents/A38-18.pdf. Resolution A38-18 (17-2) paragraph 7.

[138] China, "Statement of Reservation of China Regarding Resolution 17/2 of the 38th Session of the Assembly: Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection - Climate Change," 2013, https://www.icao.int/Meetings/a38/Documents/Resolutions/China_en.pdf.

[139] China, "The Statement of the Chinese Delegation on the ICAO Resolutions on the Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection - Climate Change and on The Consolidated Statement of Continuing ICAO Policies And Practices Related to Environemtnal Protection - Global Market-Based Measures Scheme."

Resolution A39-2, arguing it 'is short of scientific justification fairness and feasibility'[140], as well as against paragraph 23 of Resolution A39-3 – which sets out that CORSIA will use emission units that meet the Emissions Unit Criteria set out in the Resolution.[141]

While ICAO Secretariat has not published notified differences, China publicly referred to differences notified in Accordance with Article 38 of the Chicago Convention[142].

In a working paper submitted to the ICAO Assembly in August 2019, China and Russia describe the goal of "carbon neutral growth" from 2020 and CORSIA as 'morally unfair' towards developing countries, noting that developing and emerging economies have immature aviation industries and expect significant growth in emissions in future years.[143]

During ICAO's 40th Assembly China opposed the Assembly Resolutions A40-18[144] and A40-19[145] and submitted a reservation[146] against them. China opposes the combined global aspirational goals of improving fuel efficiency by 2% annually and keeping global net carbon emissions from international aviation from 2020 at the same level. China considers it 'neither necessary nor feasible' to develop the long-term fuel efficiency goal in a top-down manner before its feasibility, economic viability and impact on aviation are proven.[147] China argues the 2009 goal of improving fuel efficiency by 2% per year is 'ambitious enough'.[148]

Further, China again rejected the goal of "carbon neutral growth" from 2019-2020 levels on the grounds that the goal is unfair, lacks a scientific justification and is not feasible.[149] China opposes using the CORSIA baseline and maintains that all States determine

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[140] China, "The Statement of the Chinese Delegation on the ICAO Resolutions on the Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection - Climate Change and on The Consolidated Statement of Continuing ICAO Policies And Practices Related to Environemtnal Protection - Global Market-Based Measures Scheme."

[141] ICAO Assembly, Resolution A39-3: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Global Market-based Measure (MBM) scheme.

[142] China, "The Statement of the Chinese Delegation on the ICAO Resolutions on the Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection - Climate Change and on The Consolidated Statement of Continuing ICAO Policies And Practices Related to Environemtnal Protection - Global Market-Based Measures Scheme."

[143] China and Russia, "Perspectives on the fair and equitable CORSIA implementation pathway (A40-WP/306)" 2019. Paragraph 3.3

[144] ICAO Assembly, "Resolution A40-18: Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection - Climate Change," 2019.

[145] ICAO, "Resolution A40-19: Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection - Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)."

[146] China, "Statement of the Chinese Delegation on the 'Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection - Climate Change' and the 'Consolidated Statement of Continuing ICAO Policies and Practices Related to Environemtnal Protection - Global Market-Based Measures Scheme.".''

[147] China, "Statement of the Chinese Delegation on the 'Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection – Climate Change' and the 'Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection – Carbon Offsetting and Reduction Scheme for International Aviation'", section I, paragraph 1.

[148] Ibid, section I, paragraph 9.

[149] Ibid, section I, paragraph 7.

CORSIA's baseline themselves and gradually reinforce their actions to decrease emissions from international aviation, based on national circumstances.[150] Moreover, China affirms that 'sovereign States', and not ICAO, should determine the certification of eligible emission units and eligible sustainable aviation fuels. China further considers that, as the UNFCCC is the main forum for global actions against climate change, emission units that are endorsed by the UNFCCC should be eligible for CORSIA and the ICAO Council need not make different decisions.[151]

Russia

Russia has the ninth largest share of global international aviation activity (2.9%). As noted above, in August 2019, Russia and China presented a working paper to the ICAO Assembly in which they state that the goal of "carbon neutral growth" from 2020 and CORSIA are morally unfair, because most growth in international aviation emissions is expected to occur in developing countries. China and Russia argue that developing countries would be 'deprived of or constrained' in their 'legitimate priority needs' for aviation growth, unless international aviation emissions from developed countries would significantly decline, and developed countries would provide substantial finance and technology support to developing countries.[152] They also stated that "ICAO insists on granting itself with the power to certify carbon credit and the sustainability of aviation fuel, which is not related to air navigation and international air transport at all. Therefore, Annex 16 Volume IV is not legitimate or justifiable enough to guarantee the achievement of the objectives to ensure a level playing field to all countries".[153]

Further, Russia filed a reservation[154] against Assembly Resolutions A40-18[155] and A40-19[156] in October 2019, towards the end of the 40th Session of the ICAO Assembly. In its reservation, Russia asserted that implementing CORSIA will: (i) result in an increase in emissions from international aviation; (ii) cause 'serious distortions in market relationships and stimulate unscrupulous competition'; and (iii) become a 'tool for using international civil aviation as a funding source for climate-activity in other industrial sectors.'[157] Considering the large number of disagreements with the proposed text for Resolution A40-19, Russia 'does not find [it] affordable to join [the] Resolution as whole'.[158] In the Annexes attached to its reservation, Russia suggests alterations to the text in Resolutions A40-18

[150] Ibid, section II, paragraphs 6, 8.

[151] Ibid, section II paragraph 16.

[152] China and Russia, "Perspectives on the fair and equitable CORSIA implementation pathway (A40-WP/306)" 2019. Paragraph 3.3

[153] Idem, Paragraph 3.2.1

[154] Russia, "Statement: The Russian Federation's Reservations on the Text of Resolutions: '16/1. Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection - Climate Change' and '17/1. Consolidated Statement of Continuing ICAO," 2019. Page 1

[155] ICAO Assembly, "Resolution A40-18: Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection - Climate Change."

[156] ICAO, "Resolution A40-19: Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection - Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)."

[157] Russia, "Statement: The Russian Federation's Reservations on the Text of Resolutions: '16/1. Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection - Climate Change' and '17/1. Consolidated Statement of Continuing ICAO." Page 1

[158] Ibid, Page 2

and A40-19. These relate for the most part to feasibility of the goal of "carbon neutral growth"[159] and state sovereignty.[160]

India

India's share of global international aviation activity is 1.4%. Like China, India opposes the global aspirational goal of "carbon neutral growth" from 2020 as it considers it being against the growth of international aviation in developing countries.[161] India also 'registers its strong reservations to the decision that the mechanism for Emission Units Criteria (EUC) established under the UNFCCC and the Paris Agreement will be accepted only if it is aligned with the decisions by the ICAO Council'. Rather, India argues that the mechanism for the EUC shall be consistent with the mechanisms established under the UNFCCC.[162] However, India participates in the EU-South Asia Aviation Partnership Project that also covers capacity building on CORSIA.

Brazil

Brazil accounts for 0.8% of global international aviation activity. Brazil expressed its reservation[163] to Resolutions A40-18[164] and A40-19[165] against the use of carbon offset credits generated outside of the UNFCCC framework (i.e. the country only endorses the use of carbon offset credits from the Clean Development Mechanism (CDM) or Article 6.4 projects) and stated that the Brazilian government has to approve any transfer from emission units generated in Brazil.[166]

Vietnam

Vietnam accounts for 0.54% of global international aviation activity, so is only marginally above the 0.5% activity-related threshold for participation in CORSIA's second phase. Vietnam has not filed any reservations to ICAO Assembly Resolutions and we have not identified any public statements indicating whether or not Vietnam anticipates participating in CORSIA and at what stage. However, Vietnam participates in the EU-South East Asia Cooperation on Mitigating Climate Change impact from Civil Aviation (EU-SEA CCCA CORSIA) project initiated in August 2019.

United States of America (USA)

Finally, while the USA - which has the second largest share of global international aviation activity (11.4%), behind China - has expressed its intention to participate, it stressed that

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[159] Ibid, Page A2, A5

[160] Ibid, Page A6

[161] India, "Declaration of Reservation of the Republic of India in Relation to Resolution A40-19: Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection - Carbon Offsetting and Reduction Scheme for International Aviation," 2019. Page 2

[162] Ibid,. Pages 2-3

[163] Brazil, "Statement of the Permanent Delegation of Brazil to the International Civil Aviation Organization. Verbal Note No.: 2019-082 / BRASICAO," 2019. Brazil.

[164] ICAO Assembly, "Resolution A40-18: Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection - Climate Change."

[165] ICAO, "Resolution A40-19: Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection - Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)."

[166] Brazil, "Statement of the Permanent Delegation of Brazil to the International Civil Aviation Organization. Verbal Note No.: 2019-082 / BRASICAO."

its continued support for CORSIA assumes 'a high level of participation by other countries, particularly by countries with significant aviation activity, as well as a final CORSIA package that is acceptable to, and implementable by, the United States'.[167] This suggests that the USA may not participate in CORSIA if other countries with high shares of international aviation activity, such as China and Russia, also do not participate.

Figure 6 shows the 88 countries which ICAO expects to participate in the scheme from the beginning of 2021 (shaded in green) as well as major aviation countries that have not committed to participate in CORSIA from the start of the pilot phase (shaded red) and the LDCs, LLDCs and SIDS that are exempted from participation (shaded turquoise). Flights on routes between the 81 countries included in our modelling are projected to account for approximately 50% of total CO_2 emissions from international aviation between 2021 and 2035 (see section 2.3.1.5 below).[168,169]

[167] U.S. Federal Aviation Administration, "Notice of CORSIA Monitoring, Reporting, and Verification Program," 2019, https://www.faa.gov/about/office_org/headquarters_offices/apl/research/environmental_policy/media/corsia_mrv_program_statement.pdf.

[168] CORSIA is projected to cover 52.8% of global aviation emissions in 2025, 50.3% in 2030 and 48.9% in 2035.

[169] Over the course of this research project, seven additional states indicated they will participate in CORSIA in 2021: Afghanistan, Benin, Côte d'Ivoire, Honduras, Kazakhstan, Madagascar and Rwanda. Our modelling includes 81 states as we were not able to incorporate the more recent additions. Considering that the seven states combined accounted for approximately 0.03% of global RTKs in 2018, their inclusion would not materially alter our findings.

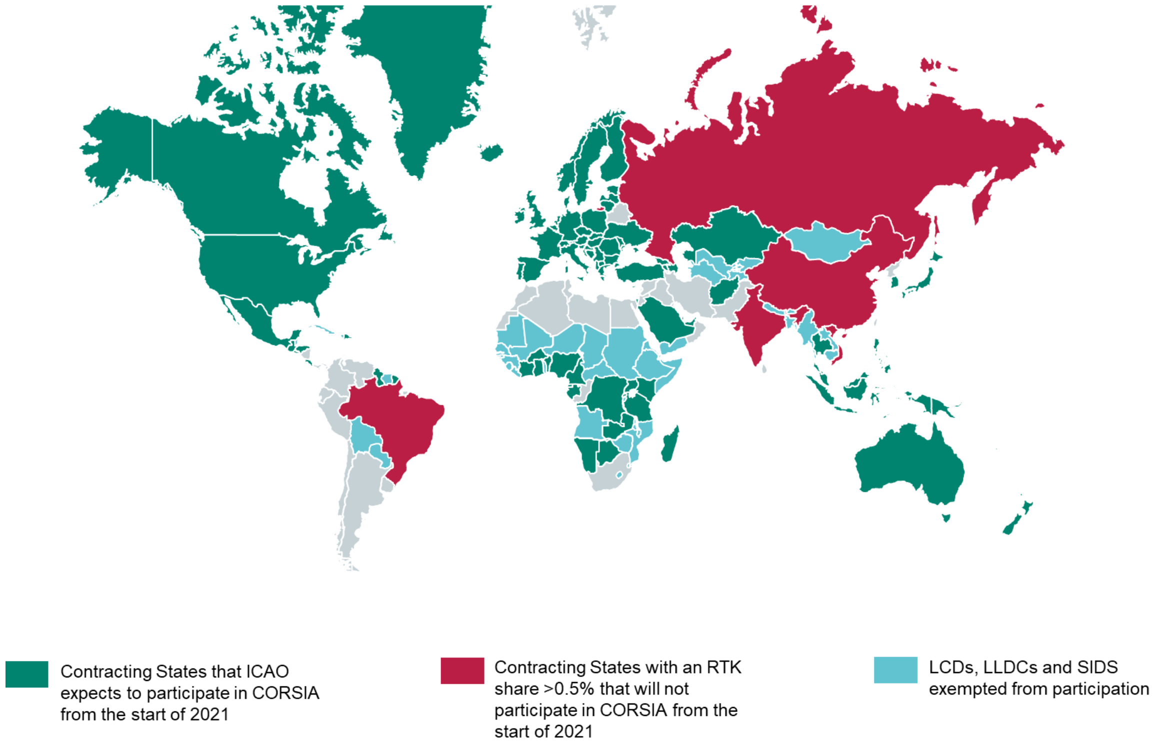

Figure 6. Expected country participation in CORSIA from the start of 2021

2.3.1.4 Implementation of MRV as an indication of participation

The variety of regulatory processes that countries go through and what can be done without legislative mandates varies. The extent to which countries have participated in and started to implement CORSIA rules for MRV may provide an indication of their intent to participate. While the MRV rules for CORSIA are implemented in the EU through a package of regulations[170], implementation of MRV regulatory measures has varied among countries. In the United States, the Federal Aviation Administration implemented the MRV rules through a voluntary program[171] - likely to avoid having to pass the rules through the legislative process.

Following the adoption of the CORSIA SARPs (Annex 16, Volume IV) in June 2018, ICAO launched a capacity building programme to support States that needed targeted support in implementing the CORSIA MRV system: ACT CORSIA (Assistance, Capacity-building and Training for CORSIA). An important feature of this programme is the establishment of 'CORSIA Buddy Partnerships'. Under the first phase of these partnerships, donor State technical experts worked together with focal points of recipient States to provide on-site

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[170] Commission Implementing Regulation (EU) 2018/2066 of 19 December 2018 (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R2066&from=EN); Commission Implementing Regulation (EU) 2018/2067 of 19 December 2018 (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.334.01.0094.01.ENG); and Commission Delegated Regulation (EU) 2019/1603 of 18 July 2019 (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2019.250.01.0010.01.ENG)

[171] US FAA 2019. https://www.faa.gov/about/office_org/headquarters_offices/apl/research/environmental_policy/media/corsia_mrv_program_statement.pdf

training and closely follow-up on the preparation and implementation of the recipient States' CORSIA MRV system.

The second phase, which took place in 2019, focused on the implementation of reporting and verification requirements under the CORSIA SARPs.[172] From 2021 onwards, a third phase of the ACT CORSIA Buddy Partnerships will begin. This phase will focus on eligible emissions units and CORSIA eligible fuels.[173]

To date, 17 States as well as representatives of the European Civil Aviation Conference (ECAC) provided technical experts across phases 1 and 2. And 119 States signed-up to receive assistance – most of them in both phases. Of the five countries that have not indicated they will participate in CORSIA and which are not exempt in the second phase, two have actively participated in ACT CORSIA: Vietnam and Brazil. Vietnam received assistance from the Republic of Korea in both phases and Brazil provided assistance to a number of countries again in both phases. This investment of time and resources could be taken as an indication that both Vietnam and Brazil[174] are more likely to participate in CORSIA at some point. This contrasts with China, Russia and India, who have not participated in ACT CORSIA to date.

2.3.1.5 Scenarios for state-level participation

To assess the impact of different levels of participation under CORSIA we analyse the following three scenarios:

1. **Initial assumed participation**: Participation throughout the period 2021-2035 of the 81 States listed by ICAO on its website in July 2019. This assumes none of China, Russia, India, Brazil or Vietnam participate in any of CORSIA's phases.
2. **High participation**: Participation throughout the period 2021-2035 of the 81 States listed by ICAO on its website in July 2019, plus participation from 2027 of the currently five additional States - China, Russia, India, Brazil and Vietnam - which are not exempt from CORSIA's second phase.
3. **Low participation**: Participation throughout the period 2021-2035 of 81 States listed by ICAO on its website in July 2019, excluding the USA.

[172] ICAO, "Destination Green: The Next Chapter - 2019 Environmental Report."

[173] ICAO.

[174] Brazil also voluntarily hosted the twelfth GMTF meeting from 23-27 October 2017 in Brasilia with heavy corporate promotion from Brazilian biofuel companies, which may suggest that Brazil shows interest in providing CORSIA compliant alternative fuels.

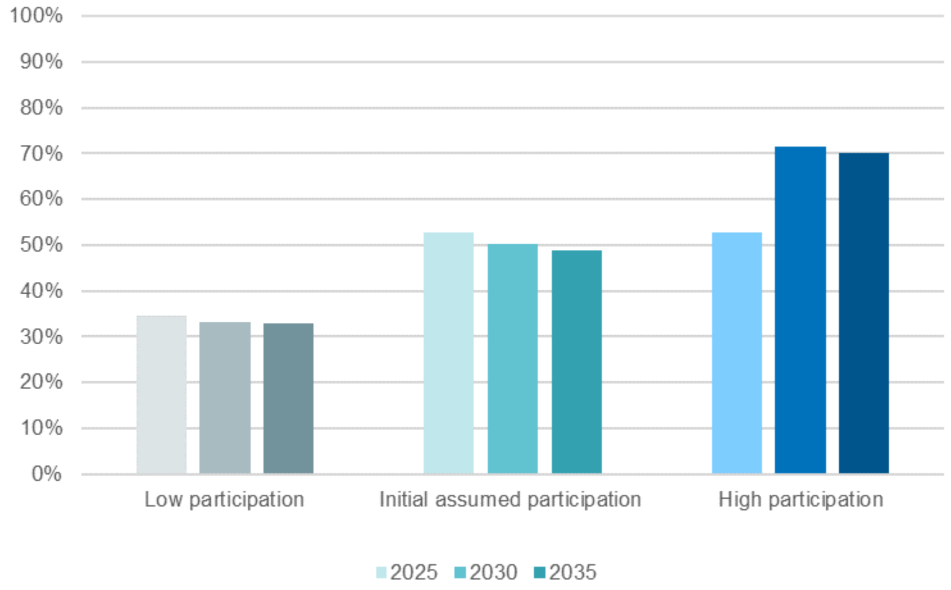

Figure 7. Estimated projections of CORSIA's coverage of global carbon dioxide emissions from international aviation under different scenarios for participation

Figure 7 shows estimated projections of CORSIA's coverage of total carbon dioxide emissions from international aviation for each of the scenarios in 2025, 2030 and 2035. Whilst participation does not change between phases in the scenarios reflecting initial assumed participation and low participation, the coverage can change as a result of different growth trends for aviation traffic and emissions across routes.

The **initial assumed participation** scenario reflects ICAO's understanding of the countries that expressed a willingness to participate in CORSIA by July 2019. In this case coverage of the scheme is 53% of international aviation emissions in 2025, falling slightly to 50% in 2030 and 49% in 2035. The four largest States – in terms of international aviation activity – excluded from this scenario have all expressed reservations with critical features of the design of CORSIA. Whilst it is possible that other States, accounting for a much smaller share of aviation activity, elect to participate either from the start or at some point during the scheme, their participation is unlikely to have a particularly material impact on the overall coverage of the scheme.

The **high participation** scenario is the same as the initial assumed participation scenario for the pilot and first phase and adds China, Russia, India, Brazil and Vietnam to the list of participating States for the second phase. The coverage of the scheme is again 53% in 2025, and rises to 71% in 2030, after which it slightly decreases to 70% in 2035. Even under this "high" participation scenario in CORSIA's second phase, which includes all States that are not exempt from the scheme along with a number of additional States which volunteer to participate throughout, approximately 30% of global CO_2 emissions from the sector remain unregulated after 2027.

In the **low participation** scenario, we show the impact of the USA not participating in CORSIA. This is the only change to the initial assumed participation scenario yet it causes the coverage of the scheme to fall to 34% of the sector's emissions in 2025, to 33% in 2030 and to 33% in 2035. In such a case it is highly likely that other States would also withdraw their participation or the scheme, in its current form, would be abandoned.

As a comparison, the current EU ETS scope (intra-EEA flights only, excluding the United Kingdom and including Switzerland) covers 5% of global international aviation emissions in 2020. Informed by the modelling set out in Section 3 we estimate that the full scope EU ETS will cover 33% of global international aviation emissions in 2025, 30% in 2030 and 28% in 2035.

2.3.2 Transparency

2.3.2.1 EU principles for transparency and public participation

On 15 April 2019, the European Commission released its principles for Better Regulation[175] including a number of initiatives in order to ensure that decision making is open and transparent; that citizens and stakeholders can contribute throughout the policy and law-making process; that EU actions are based on evidence and understanding of the impacts; and that regulatory burdens on business, citizens or public administrations are kept to a minimum.

The principles of transparency and public participation has a longer history in European policymaking, in particular with regard to environmental matters. The European Union and all EU Member States ratified the United Nations Economic Commission for Europe Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters (Aarhus Convention).[176] This Convention provides the public with rights of access to information, participation in decision-making and access to justice in environmental matters. The Aarhus Convention requires Parties to allow and facilitate public participation in environmental decision-making (Article 7). Further, the Almaty Guidelines, which provide guidelines on the implementation of the Aarhus Convention, state that in the application of the Aarhus Convention, "There may be *a need to adopt and structure international processes and mechanisms in order to ensure meaningful and equitable international access"*[177]*.* The Aarhus Convention is implemented in EU law through Directive 2003/4/EC of the European Parliament and of the Council of 28 January 2003 on public access to environmental information.[178] This sets a high standard for transparency, access to information, public participation in decision-making and access to justice that the EU must ensure in its policy-making, including in the implementation of CORSIA in the EU.

The European Ombudsman, when examining the complaint of a Dutch Member of the European Parliament, found that "documents held by the Commission and drawn up in the context of decision-making on ICAO SARPs should, as a matter of principle, benefit from the wider public access granted to environmental information and legislative documents under Regulation 1049/2001" and that "the Ombudsman expects the European Commission to promote actively a greater level of transparency within ECAC, ICAO and

[175] European Commission, "Better Regulation: Taking Stock and Sustaining Our Commitment," 2019, https://doi.org/10.1057/9780230321359_10.

[176] UNECE, "Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters (Aarhus Convention)" (1998).

[177] United Nations, Almaty Guidelines on Promoting the Application of the Principles of the Aarhus Convention in International Forums. 2005. https://www.unece.org/fileadmin/DAM/env/documents/2005/pp/ece/ece.mp.pp.2005.2.add.5.e.pdf

[178] European Parliament and the Council of the European Union, "Directive 2003/4/EC of the European Parliament and of the Council of 28 January 2003 on Public Access to Environmental Information and Repealing Council Directive 90/313/EEC," Official Journal of the European Union § (2003).

CAEP."[179] However, because the working papers outlining the "European position" submitted to ICAO are co-authored by the European Commission working with the ECAC; several EU Member States working in ECAC; as well as a number of non-EU ECAC members, the Commission may refuse access to the documents "if disclosure seriously undermine the protection of international relations".

2.3.2.2 General transparency and public participation in ICAO

The 1944 Chicago Convention[180] that established ICAO does not mention transparency or public consultation in the regulatory function of the organisation. ICAO does not have a freedom of information policy and has no mechanism for members of the public to request documents. This compares dis-favourably with other UN bodies and fora, such as the UNFCCC, where official submissions of Parties and observers are posted online[181], registration as an observer is fairly straightforward and a large variety of observers attend negotiation sessions, official documents and decisions are immediately publicly posted online and the press has extensive access to proceedings.

In 2017, ICAO published a document to "assist States and the aviation industry, in particular airports, airlines and Air Navigation Service Providers (ANSPs), to engage local communities and to mainly address environmental matters" where it cited "lessons learned and best practice" to include: "Providing an open and transparent exchange of information as the basis for building long-term trust"; and "Ensuring the process is as inclusive and collaborative as possible, informing and seeking input from as many stakeholders as appropriate and practicable, taking into consideration the scale and scope of the project".[182] ICAO's rules of procedure for committees set out a transparent default for access to documents and opportunities for public participation.[183] However this is generally not reflected in ICAO's own policy-making process with regard to CORSIA: neither the public nor the press has access to ICAO Council meetings, documents of meetings of the Committee on Aviation and Environmental Protection (CAEP) are not freely available in the public domain, and meetings and discussions in technical sub-committees and sub-groups are shielded from public scrutiny through non-disclosure agreements signed by all participants(further details below).

There are formally two significant ICAO decision-making bodies relevant to CORSIA: the ICAO Assembly and the ICAO Council. The Assembly provides high level mandates in Assembly Resolutions every three years, while the Council meets more often and adopts the majority of the rules relevant for CORSIA. In practice, most relevant technical rules

[179] European Ombudsman, 2019. Decision in case 236/2019/TE on the European Commission's decision not to disclose documents related to the EU's participation in the environment committee of the UN International Civil Aviation Organisation. https://www.ombudsman.europa.eu/en/decision/en/119024

[180] ICAO, "Convention on International Civil Aviation (Chicago Convention)" (1944), http://www.icao.int/publications/Documents/7300_9ed.pdf.

[181] See https://www4.unfccc.int/sites/submissionsstaging/Pages/Home.aspx

[182] ICAO, "Circular 351 Community Engagement for Aviation Environmental Management" (Montreal: ICAO, 2017), https://www.icao.int/environmental-protection/Documents/COMMUNITY_ENGAGEMENT_FOR AVIATION ENVIRONMENTAL_ MANAGEMENT.EN.pdf.

[183] Aoife O'Leary, "Transparency and ICAO's Aviation Offsetting Scheme: Two Separate Concepts?" (New York: Sabin Center for Climate Change Law, Columbia Law School, 2017), http://columbiaclimatelaw.com/files/2017/11/Oleary-2017-11-Transparency-and-ICAOs.pdf.

with regard to CORSIA are negotiated and prepared by the CAEP,[184] and submitted for Council approval. ICAO lists a number of organisations that are "able to be invited to ICAO meetings" - the list includes a number of other international organisations and industry groups, and notably no environmental Non-Governmental Organisations. It is noted that ICAO does not officially consider them "observers".[185] In practice, selected other observers[186] are allowed to attend triennial ICAO Assembly and other meetings, but access is restrictive both for the general public, for the press, or any other civil society organisation. While triennial Assemblies receive some press attention, and official Assembly resolution documents as well as reservations are freely available to public, public access to more specific policy documents is restricted (see Table 1).

Table 1. Access to documents relevant to CORSIA

Relevant Document	Freely available to the public?
Assembly Resolutions	Yes
Reservations to Assembly Resolutions	Yes
ICAO Council decisions	No
Draft SARP Package	No
Final SARPs	Not in readily accessible form[187]
Differences	No
State Letters	No
Responses to State Letters	No[188]
CAEP Directives	No

[184] O'Leary.

[185] ICAO, "Organizations Able to Be Invited to ICAO Meetings," Website, 2020, icao.int/about-icao/Pages/Invited-Organizations.aspx#idIONonGov.

[186] Including the International Coalition for Sustainable Aviation (ICSA), an umbrella organisation of environmental NGOs.

[187] An online version is available (but cannot be printed or saved offline), it is otherwise available for purchase at https://store.icao.int/collections/annex-16-environmental-protection/products/annex-16-environmental-protection-volume-iv-carbon-offsetting-and-reduction-scheme-for-international-aviation-corsia?utm_campaign=open-access&utm_content=buy-button&utm_medium=web&utm_source=Annex-16-IV-flowpaper.

[188] Although not common practice, the European Commission published its response to the ICAO State Letter AN 1/17.14 – 17/129. https://ec.europa.eu/transport/sites/transport/files/2018-03-01-eu-reply-to-corsia-state-letter.pdf

Relevant Document	Freely available to the public?
CAEP Recommendations	No[189]
TAB Nominations	No
TAB Members	Yes
Emissions unit programme applications for CORSIA eligibility	Yes
Public comments submitted to ICAO on CORSIA emission unit programme applications	Yes[190]
TAB Recommendations on eligible programmes	(In redacted form)[191]

The ICAO Council, taking its mandate from various Assembly Resolutions,[192] is the main decision-making body with regard to CORSIA. The ICAO Assembly Resolutions call for the ICAO Council to work with the technical contribution of CAEP. Assembly Resolution A37-19 set "guiding principles for the design and implementation of market-based measures (MBMs) for international aviation" including that "MBMs should be transparent and administratively simple"[193]. This was echoed by a statement from the European Parliament, the Council and the Commission stating that "The outcome of the work of ICAO on the implementation of the global market-based measure is key for its effectiveness and for the future contribution of the aviation sector to the achievement of the objectives under the Paris Agreement. It is important that ICAO member states, aircraft operators and civil society continue to be engaged in this work of ICAO. It will be necessary in this context for ICAO to act in full transparency and to reach out to all stakeholders to inform them about

[189] CAEP reports are available for purchase, often with a long delay because they are only published every three years. The reports are not however available through the "ICAO Store" (https://store.icao.int/) and a recent attempt to access the link for purchase leads to a dead web page: https://store.icao.int/catalogsearch/result/?category_id=2&q=caep/10.

[190] https://www.icao.int/environmental-protection/CORSIA/Documents/TAB/TAB_Public%20comments_Consolidated.pdf

[191] https://www.icao.int/environmental-protection/CORSIA/Documents/TAB/Excerpt_TAB_Report_Jan_2020_final.pdf

[192] ICAO Assembly, Resolution A39-3: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Global Market-based Measure (MBM) scheme; ICAO Assembly, "Resolution A40-18: Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection - Climate Change"; ICAO, "Assembly Resolutions in Force. Doc 10022."

[193] ICAO. 2010. Resolutions Adopted by the Assembly Page 62, https://www.icao.int/Meetings/AMC/Assembly37/Documents/ProvisionalEdition/a37_res_prov_en.pdf

progress and decisions in a timely manner"[194]. Despite these statements, ICAO practice has not been in keeping with this principle.

While ICAO Council member countries are elected fairly transparently from the ICAO Assembly on a triannual basis,[195] the selection process of the current 26 ICAO members for the CAEP is done in secret within the ICAO Council.[196] There are a further eight observer States and 11 observer organisations including two UN organisations (UNEP and the UNFCCC), six industry associations (representing everything from airlines to biofuels to aircraft manufactures), one labour organisation representing airline pilots, and the International Coalition for Sustainable Aviation (ICSA), and "regional state organisations" such as the European Union.[197] This suggests a significant imbalance between aerospace industry organisations and civil society organisations. Especially considering each observer must agree on and submit a single input for meetings. Further civil society organisations that are not members of ICSA have no access and they face significant barriers to participating or submitting a view on ongoing decision-making.

CAEP operates on the basis of "CAEP Directives", which are approved by the ICAO Council and, which are also not freely accessible to the public.[198] Only CAEP members have access to documents and CAEP meetings are generally closed to non-members, including non-CAEP member ICAO States, and the public.[199] On an exceptional basis, all African States were invited to the CAEP, though there is no public record of who may be invited or who attends these meetings. A delegation of the European Parliament was refused access to a CAEP meeting in January 2016.[200] CAEP meeting attendees agree to not disclose any information from the meetings and have to sign non-disclosure / indemnification agreements to participate.[201] Records of CAEP proceedings and recommendations to the ICAO Council are not made publicly available in a timely manner, although are included in the CAEP report, published every three years, which is made available for a fee.

CAEP has a number of working groups and task forces. Specifically with respect to help develop recommendations for various components of what became CORSIA, CAEP created a Global Market Based Measure Task Force (GMTF) in 2013 to develop recommendations on the development of a Global Market Based Mechanism (GMBM) and an Alternatives Fuels Task Force (AFTF) until 2018 and a Fuels Task Group since 2018. Members of the GMTF and AFTF/FTG were selected as technical experts, these experts consisted of a mix

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[194] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CONSIL:ST_15640_2017_INIT&from=EN, page 29.

[195] For current members, elected on 1 October 2019, see: https://www.icao.int/Newsroom/Pages/ICAO-Assembly-elects-new-Council-for-three-year-term-A40.aspx.

[196] Sarabjeet Hayer, "Decision-Making Processes of ICAO and IMO in Respect of Environmental Regulations" (Brussels: European Parliament, 2016), https://www.europarl.europa.eu/RegData/etudes/STUD/2016/595332/IPOL_STU(2016)595332_EN.pdf.

[197] ICAO, "Committee on Aviation Environmental Protection (CAEP)," 2020, https://www.icao.int/environmental-protection/Pages/Caep.aspx.

[198] Sanra Laville, "Critics Attack Secrecy at UN Body Seeking to Cut Global Airline Emissions," *The Guardian*, February 11, 2019, https://www.theguardian.com/business/2019/feb/11/critics-attack-secrecy-at-un-body-seeking-to-cut-global-airline-emissions.

[199] O'Leary, "Transparency and ICAO's Aviation Offsetting Scheme: Two Separate Concepts?"

[200] O'Leary.

[201] O'Leary.

of government and industry representatives, as well as representatives from the International Coalition for Sustainable Aviation Members of the GMTF and the AFTF/FTG were required to sign the same CAEP non-disclosure clause that prohibits the release of information outside the ICAO process.[202] The exact membership of these groups is not public and their selection did not go through any public scrutiny. The GMTF has since been replaced by a Working Group.

2.3.2.3 Transparency of the carbon offset programme eligibility process

In addition to the GMTF, the ICAO Council created an "Interim Program Assessment Group" (IPAG) in 2017. IPAG served as a preliminary expert group to provide the ICAO Council with recommendations on the design of the application process for carbon offset crediting programmes to apply for CORSIA eligibility. IPAG was later replaced with a "Program Testing Group" (PTG) of experts that was tasked with developing a number of elements of the design of the application process through which offset programs would apply and be considered for eligibility to provide emissions units to CORSIA. Nominations of members to both IPAG and PTG were not made public, nor was their selection process transparent. Further, IPAG and PTG's deliberations were not public, nor were any of the recommendations they made to the ICAO Council with regard to the programme selection process.

Although not necessarily a direct successor, the Technical Advisory Body (TAB) later took over the work processes discussed in IPAG. In contrast to IPAG, TAB has a clearer mandate, membership, and workplan. TAB was established based on a request from the ICAO Council in the CORSIA assembly resolution.[203] Its terms of reference, membership, high-level work plan and timeline are published on the ICAO website.[204] The nomination and selection of TAB members was however not transparent or subject to any public or stakeholder input.

Although a first round of invitations for offset programmes to apply for CORSIA eligibility were published on the ICAO website from 14 June to 12 July, 2019, and some portions of the offset programme applications are published, as well as comments on those applications, the actual deliberations of the TAB with regard to what extent offset programmes comply with the Emissions Unit Criteria were secret. It was not clear at the time that the programmes originally applied, that their applications were only going to be evaluated for eligibility for the pilot phase until 2023, but their eligibility was none the less limited to the pilot phase. Its recommendations sent from TAB to the ICAO Council are typically not public, although following a recommendation by the TAB itself, ICAO published a redacted version of TAB's recommendations to the ICAO Council related to eligible emissions units for CORSIA's pilot phase.[205] Schneider et al.[206] further note that ICAO does not have a transparent procedure for program approval, program surveillance, and termination of program eligibility.[207] TAB procedures are available on the TAB webpage,

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[202] Ibid

[203] ICAO Assembly, Resolution A39-3: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Global Market-based Measure (MBM) scheme. Paragraph 20.d.

[204] See: https://www.icao.int/environmental-protection/CORSIA/Pages/TAB.aspx

[205] https://www.icao.int/Newsroom/Pages/ICAO-Council-adopts-CORSIA-emissions-units.aspx

[206] Lambert Schneider et al., "Lessons Learned from the First Round of Applications by Carbon-Offsetting Programs for Eligibility under CORSIA" (Öko-Institut e.V., 2019),

[207] Lambert Schneider et al., "Lessons Learned from the First Round of Applications by Carbon-Offsetting Programs for Eligibility under CORSIA" (Öko-Institut e.V., 2019).

but whether or not the ICAO Council has approved the TAB procedures is not publicly available on the ICAO website.

A second invitation for offset programmes to apply for eligibility for CORSIA compliance was launched in March 2020 with an application deadline of 20 April 2020. In response, ICAO received eight applications, and two material updates to previously assessed programmes. Portions of these applications are publicly available and there was a request for public comments.[208]

2.3.2.4 Transparency of CORSIA compliance

In accordance with Volume IV of Annex 16 of the Chicago Convention, the reporting requirements do not only apply to aeroplane operators but must be done by the States to the ICAO through the transmission of an aggregate report.

The transparency of such reporting is affected by the confidentiality of the information that is reported as well as the aggregation of data.

As such, CORSIA SARP "Appendix 5. Reporting Section 3" stipulates that States report the following information to ICAO:

- State Report of aeroplane operators and verifiers
  - List of aeroplane operators attributed to the State;
  - List of verification bodies accredited in the State.
- Emissions Report
  - For 2019 and 2020
  - Total annual CO_2 emissions on each State pair aggregated for all aeroplane operators attributed to the State;
  - Annually after 2021
  - Total annual CO_2 emissions for each aeroplane operator attributed to the State;
  - Total aggregated annual CO_2 emissions for all State pairs subject to offsetting requirements;
  - Total aggregated annual CO_2 emissions for all State pairs not subject to offsetting requirements.
- CORSIA eligible fuels
  - Production year of CORSIA eligible fuels claimed;
  - Producer of CORSIA eligible fuel;
  - Batch number(s) of each CORSIA eligible fuel claimed;
  - Total mass of each batch of CORISA eligible fuel claimed (in tonnes);
  - Fuel types and total mass of neat CORSIA eligible fuel per type being claimed by all the aeroplane operators attributed to the State;
  - Total emission reductions claimed from the use of a CORSIA eligible fuel (in tonnes) both by fuel type and aggregated reductions claimed by all aeroplane operators attributed to the State;
- Emissions Unit Cancellation Report
  - Aeroplane operators attributed to the State;
  - Compliance period years reported;
  - Total aggregated aeroplane operators' final offsetting requirements (in tonnes);

[208] See: https://www.icao.int/environmental-protection/CORSIA/Pages/TAB.aspx

- Total aggregated quantity of emissions units cancelled to reconcile the total final offsetting requirements;
- Consolidated identifying information for cancelled emission units.

In addition to the reporting by States to the ICAO, a verification body will be competent to verify the accuracy and compliance of CORSIA by the aeroplane operators. Such bodies are however also obliged to observe the confidential nature of the reported data. This confidentiality clause means that neither ICAO, nor other airlines, nor the general public will know any of the following pieces of information: the ratio of alternative fuels to emissions units surrendered for compliance, what kind of emission units have been surrendered, or if the aeroplane operator has surrendered sufficient emissions units or used enough alternative fuel to fulfil its CORSIA obligations.[209] The SARPs, in Chapter 4 Section 4.3.3, recommend – but do not require – that States publish total final offsetting requirements for each aeroplane operator attributed to the State and total quantity of emissions units cancelled over the compliance period by each aeroplane operator. This leads to questions of competition and fairness as important stakeholders will not know if a level playing field is established where all CORSIA participating States are enforcing CORSIA equally robustly. An overview of information availability can be found in Table 2.

Table 2. Access to key compliance relevant information[210]

	INFORMATION REQUIRED TO BE AVAILABLE TO			
TYPE OF INFORMATION	**State of Aeroplane Operator**	**ICAO Secretariat**	**Other ICAO Member State governments**	**General public**
List of aeroplane operators attributed to the State[211]	Yes, states issue Air Operator Certificate though some are attributed via ICAO designators	Yes	Yes	Yes
List of verification bodies accredited in each State[212]	Yes, State is responsible for accreditation	Yes	Yes	Yes

[209] The SARPs do stipulate that aeroplane operator shall "request each CORSIA Eligible Unit Programme registry to make visible on the registry's public website, information on each of the aeroplane operator's cancelled CORSIA Eligible Emission Units for a given compliance period" (Chapter 4.2.2.b), however with at least six eligible offset programmes and six registries in different languages, this stipulation is unlikely to lead to transparency of aeroplane operators use of eligible emission units.

[210] See further discussion in Section **Error! Reference source not found.**.

[211] Current CORSIA Aeroplane Operator to State Attributions can be found here: https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA%20Aeroplane%20Operator%20to%20State%20Attributions_Dec2019_v20200106b.pdf

[212] Current Verification Bodies Accredited in States can be found here: https://www.icao.int/environmental-protection/CORSIA/Documents/CCR%20Information%20and%20Data%20for%20Transparency_Apr2020_FINAL_web.pdf

Total annual CO_2 emissions for each aeroplane operator attributed to the State	Reported directly to State of aeroplane operator	Yes	Yes	Yes[213]
Total aggregated annual CO_2 emissions for all State pairs subject to offsetting requirements for each aeroplane operator	Yes	Yes	Yes	Yes
Total aggregated annual CO_2 emissions for all State pairs not subject to offsetting requirements	Yes	Yes	Yes	Yes
Aeroplane operator annual use of alternative fuels[214]	Reported directly to State of aeroplane operator	No	No	No
Aeroplane operator's cancelled eligible emission units[215]	Reported directly to State of aeroplane operator	No	No	No
Aeroplane operator compliance obligation	State of aeroplane operator informs aeroplane operator	No	No	No
Aeroplane operator's compliance with CORSIA obligation	(Yes)	No	No	No
Aggregated information of all Aeroplane operators on State and global level including emissions, total offsetting requirements over compliance period, total quantity of emissions units cancelled over compliance period, and consolidated identifying	(Yes)	Yes	Yes	Yes

213 SARP Annex 5: Reporting; Section 3.2 Emissions Report from a State to ICAO; Note 1

214 Information on use of alternative fuels is to be reported to ICAO and made public on a State aggregated basis, not on an individual aeroplane operator basis.

215 Information on cancelled eligible emission units is to be reported to ICAO on a State aggregated basis, not on an individual aeroplane operator basis.

information of cancelled emissions units[216]				

While each Member State of ICAO is free to include in national legislation the publication of non-compliant aeroplane operators, neither the relevant Assembly Resolutions, nor the SARPs provide any requirement to do so. The United States already made clear that no sanction would apply as the MRV program is presented as completely voluntary.[217]

2.3.2.5 Transparency of offset programs

A degree of transparency is proposed by the ICAO in respect of the Emissions Unit Eligibility Criteria, including: the programs should define and publicly disclose the level at which activities are allowed under the program, the program should publicly disclose who is the responsible for administration of the program and how decisions are made, the program should publicly disclose the sustainable development criteria used.[218]

As part of the Program Design Element, "Programs should publicly disclose (a) what information is captured and made available to different stakeholders; and (b) its local stakeholder consultation requirements (if applicable) and (c) its public comments provisions and requirements, and how they are considered (if applicable). Conduct public comment periods and transparently disclose all approved quantification methodologies"[219].

In its report, the TAB used a generic formulation for each eligible program saying that procedures, standards, and related governance arrangements that were in place and assessed by TAB were consistent. This makes it difficult to analyse more closely the transparency of the programmes based on the report. According to a study[220] that looked at the baseline and the transparency of programmes that applied, "Several program applications, mostly those that build to a large extent on CDM rules, have a clear and detailed process in place and provide for the necessary transparency". However for the China GHG Voluntary Emission Reduction Program, one of the appendicies of the report which includes the comments sent by Perspectives Climate Group to the TAB noted that "methodologies and procedure are purely available in Chinese language, the conservativeness of the methodologies could not be checked. In order to be eligible, the program would have to translate both methodologies and procedures in English and make these translations publicly available"[221].

Further comparisons across the programmes would be useful but not many studies look at this issue in a consistent manner. Another issue that is closely linked to the transparency and accountability issue relates to the governance of the programmes. The eligible

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216 Once available, this information will be available on the ICAO CORSIA webpage: https://www.icao.int/environmental-protection/CORSIA/Pages/CCR.aspx

217 Notice of CORSIA monitoring, reporting, and verification program, US Department of Transportation, Federal Aviation Administration, p. 3.

218 ICAO document – CORSIA Emissions Unit Eligibility Criteria, March 2019.

219 CORSIA Emissions Unit Eligibility Criteria https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO_Document_09.pdf

220 Schneider and al., Lessons learned from the first round of applications by carbon-offsetting programs for eligibility under CORSIA, October 2019

221 Idem. Appendix: Comments submitted to ICAO, Submission by Perspectives Climate Group

programmes have very different governance which can be centralized or decentralized, with public or private governance body and different supervision[222].

Finally, the SARPs stipulate that aeroplane operators shall "request each CORSIA Eligible Unit Programme registry to make visible on the registry's public website, information on each of the aeroplane operator's cancelled CORSIA Eligible Emission Units for a given compliance period" (Chapter 4.2.2.b). However, with at least six eligible offset programmes and six registries in different languages, this stipulation is unlikely to lead to transparency of aeroplane operators use of eligible emission units.

2.3.3 Enforceability

2.3.3.1 Choice of legal instrument

Several options were available to ICAO as to the legal instrument chosen for the establishment and implementation of CORSIA, including the amendment of the Chicago Convention, the adoption of a treaty, the adoption of a resolution and the adoption of Standard and Recommended Practices (SARPs) [223]. The choice among those instruments is not exclusive: a "*mixed approach*" means that instruments can be combined. The efficiency of such combination is conditioned by the fact that "*each individual instrument is legally sound and has strong political support from all States, without reservations or notification of differences*"[224]. This political support depends on factors such as the perceived urgency, political circumstances, formulation, and enforceability[225].

The complexity of the environmental debate as well as the necessity to ensure a large application of CORSIA around the world are key arguments in favour of legal instruments having a lower binding effect, such as the resolution and/or the SARPs.

From a legal perspective, an amendment of the Chicago Convention, together with adoption of Standards or the adoption of a new treaty to which technical annexes are attached, would have been two options ensuring legal certainty and enforceability of the GMBM. However, Treaty changes would be subject to a potentially lengthy ratification process and uncertainty as to its outcome.

The legal instrument that has been chosen by ICAO is a mix between the Resolution, the SARPs and technical provisions:

- The Resolution instrument:

Generally speaking, a resolution is not legally binding but could be considered as "quasi law" or "soft law". Provisions of "soft law" may, under certain circumstances, achieve a certain degree of legal force and enforcement.

In practice, two ICAO Resolutions include a proper "*decision*" relating to CORSIA.

Firstly, at the 39th Assembly, the ICAO Assembly decided to "implement a GMBM scheme in the form of the Carbon Offsetting and Reduction Scheme for International Aviation

[222] A study on the « Overview and comparison of existing carbon crediting schemes" has analysed the differences in governance for some of the programmes now eligible under CORSIA. See from pages 18 and following https://www.nefco.org/wp-content/uploads/2019/05/NICA-Crediting-Mechanisms-Final-February-2019.pdf

[223] Mendes de Leon et al., "Possible Legal Arrangements to Implement a Global Market Based Measure for International Aviation Emissions."

[224] Mendes de Leon et al., "Possible Legal Arrangements to Implement a Global Market Based Measure for International Aviation Emissions.", p. VI.

[225] Mendes de Leon et al., "Possible Legal Arrangements to Implement a Global Market Based Measure for International Aviation Emissions.", p. VI.

(CORSIA) to address any annual increase in total CO2 emissions from international civil aviation (i.e. civil aviation flights that depart in one country and arrive in a different country) above the 2020 levels, taking into account special circumstances and respective capabilities.

Secondly, at the 40th Assembly, the ICAO Assembly adopted a consolidated statement of continuing ICAO policies and practices related to environmental protection – Carbon offsetting and reduction scheme for international aviation (CORSIA).

The study led by Professor Mendes de Leon on the possible legal arrangements to implement a GMBM refers to different factors which strengthen the legal effect of Resolutions:

- *The need for a rule:* this criterion is linked to the recognition by a large part of the ICAO member states that there is a need to legislate in a specific sector[226]. This is clearly the case for CORSIA as most countries recognize the necessity to adopt a GMBM. ICAO member states are however less unanimous as to the content and details of such framework.
- *The formal acceptance of the resolution*: if ICAO member states clearly recognize the value of a resolution, it can show the emergence of an *opinion juris*. This criteria has been used in the past, notably in the *Nicaragua Case*, in which the International Court of Justice confirmed that Resolutions "*can, in certain circumstances, provide evidence important for establishing the existence of a rule or the emergence of an opinion juris"*[227]. Applied to CORSIA, the resolution adopted at the 40th Assembly does not – as of today – reach a "*general community agreement*", so that the criteria of the *formal acceptance* does not increase the enforcement level of the Resolutions for now.
- *The vocabulary employed in the Resolutions:* this criterion is related to the strength of the words used by the Assembly in a given Resolution. It reveals to which extent the ICAO Assembly wishes to give to the Resolutions adopted a legal force and enforcement, without going beyond the effect determined by the constitutional effect[228]. The Resolution adopted at the 38th Assembly did not include "strong" words in the paragraphs referring to the recommendations to its member States ("resolves", "agrees", "invites", etc.). The choice of words is clearly different in the Resolutions respectively adopted at the 39th and the 40th Assembly. In the Resolution adopted at the 39th Assembly, the word "decides" is used 13 times, including when referencing to the decision to implement CORSIA[229], the decision to use a phased implementation (including the details of those phases)[230], the decision that CORSIA shall apply to all aircraft operators on the same routes between States[231], the decision related to the calculation of the amount of CO_2 emissions

[226] Schermes, Blokker, 2003, International Institutional Law: Unity within Diversity, Martinus Nijhoff Publishers, 774.

[227] ICJ, Legality of the Threat or Use of Nuclear Weapons, Advisory Opinion, ICJ Reports 1996, 226.

[228] Amerasingue, 2005, Principles of the institutional law of international organizations, Cambridge University Press, 175.

[229] Paragraph 5 of the Resolution adopted at the 39th General Assembly of ICAO., the General Assembly "decides" to implement a GMBM scheme in the form of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

[230] Paragraph 9 of the Resolution adopted at the 39th General Assembly of ICAO.

[231] Paragraph 10 of the Resolution adopted at the 39th General Assembly of ICAO.

required to be offset by aircraft operator annually[232], the decision on the conditions under which new entrants are exempted[233] and the decision on the conditions relating to the exemptions of small emitters, small aircraft and limited non-commercial operations[234]. The Resolution adopted at the 40th Assembly "recalls" the decisions adopted at the previous Assembly and adopts a new decision, which is related to the implementation of CORSIA: the Assembly "*decides that ICAO and the Member States take all necessary actions in providing the capacity building and assistance and building partnerships for implementation of the CORSIA, in accordance with the timeline set forth in Annex 16* […]"[235]. The wording used by the Assembly therefore clearly demonstrates its wish to give to those two Resolutions a strong political force.

- *The value of the voting behaviour:* such criteria intends to consider that a member State is bound by the resolution on which it voted in favour of. Such criteria is however largely debated[236]. In practice, some of the reservation made to the Resolutions do not lead to an increased strength of legal force. As an example, the reservation of the Republic of China[237] underlines that, from his point of view, the resolution has not been adopted after a proper debate. Similarly, the delegation of the Russian Federation also expressed, in its reservation, its disappointment and "*notes that its proposal to a number of provisions of the aforementioned draft Resolutions, drafted in cooperation with the delegation if the People's Republic of China and the Republic of India, were rejected without due discussions in violation of Rules 38 and 39 of the Standing Rules of Procedure of the Assembly of the International Civil Aviation Organization (Doc 7600), despite the fact that they have been supported by number of delegations of Member States in the course of the Executive Committee*."[238] The Russian delegation qualify this situation as "*a sign of disrespect for the position of sovereign States, officially expressed during the Assembly*"[239].
- *The repetition factor:* this criterion pertains to one of the conditions to qualify a rule as customary rule, which is its continuity in time and repetition in a number of Resolutions. So far, this factor is difficult to apply to the Resolutions related to CORSIA since most of the provisions have been adopted during the 39th Assembly.

In the case of the preliminary ruling before the European Court of Justice in the context of the claim introduced by the Air Transport Association of America against the EU ETS in

[232] Paragraph 11 of the Resolution adopted at the 39th General Assembly of ICAO.

[233] Paragraph 12 of the Resolution adopted at the 39th General Assembly of ICAO.

[234] Paragraph 13 of the Resolution adopted at the 39th General Assembly of ICAO.

[235] Paragraph 21 of the Resolution adopted at the 40th General Assembly of ICAO.

[236] Schermes, Blokker, 2003, International Institutional Law: Unity within Diversity, Martinus Nijhoff Publishers, 770 and 778.

[237] "[…] *The comments and positions of States are not reflected in the resolutions in a balanced manner. This situation has never been seen in previous sessions of the Assembly. The Chinese delegation is deeply perplexed and disappointed by it. In view of the above, the Chinese delegation makes the following statement for the record:*

1. This delegation opposes the adoption by this session of the Assembly, without discussions and negotiations, of the two resolutions […]"

[238] Letter accompanying the Statement of the Russian Federation's Reservations on the text of the Resolutions.

[239] Statement: The Russian Federation's Reservations on the text of the Resolutions.

2011, the Advocate General Kokott recalled the absence of legal binding effect of ICAO's resolution and in particular to the resolution adopted at the 37th Assembly of the ICAO in respect of the envisaged global market based measure to be applied in the aviation sector.

Besides the clear wish of the ICAO to urge member States to observe and implement the CORSIA system, the enforcement of such Resolutions is limited by the concrete enforcement powers in the hands of the Assembly, which remains political towards the Member States.

- **The adoption of SARPs** included in volume IV of the Annex 16 – Environmental Protection, of the Chicago Convention.

The SARPs are not part of the Chicago Convention itself but included in annexes to the Convention, so that they do not have the same nature as treaty provisions[240]. SARPs related to the environment form the Annex 16 to the Chicago Convention. The SARPs only receive binding force through their implementation in national law[241], in the absence of which they can be considered as 'soft law'.

The SARPs are referred to in the Chicago Convention in three main provisions.

Article 37 of the Chicago Convention provides for a requirement to collaborate, in view of achieving a high level of uniformity: "*Each contracting State undertakes to collaborate in securing the highest practicable degree of uniformity* […] *To this end the International Civil Aviation Organization shall adopt and amend from time to time, as may be necessary, international standards and recommended practices and procedures* […]".

Article 90 of the Chicago Convention provides that "*The adoption by the Council of the Annexes described in Article 54, subparagraph l), shall require the vote of two-thirds of the Council […]. Any such Annex or any amendment of an Annex shall become effective within three months after its submission to the contracting States or at the end of such longer period of time as the Council may prescribe, unless in the meantime a majority of the contracting States register their disapproval with the Council.*"

This effectiveness is however limited by Article 38 of the Chicago Convention, enabling member States not to observe the SARPs through the notification of differences. In this respect, Article 38 of the Convention provides that each ICAO member State is required to notify any difference between a Standard and its own legislation: "*Any State which finds it impracticable to comply in all respects with any such international standard or procedure, or to bring its own regulations or practices into full accord with any international standard or procedure after amendment of the latter, or which deems it necessary to adopt regulations or practices differing in any particular respect from those established by an international standard, shall give immediate notification to the International Civil Aviation Organization of the differences between its own practice and that established by the international standard*." States may therefore choose to deviate from SARPs by giving ICAO notification of the differences between their national regulations and the prescribed international standard. Such notification process is *stricto sensu* not applicable to recommendations. However, the SARPs clearly states that such notifications process shall also be applicable: "*Although differences from Recommended Practices are not notifiable under Article 38 of the Convention, the Assembly has urged Contracting States to extend*

[240] Mendes de Leon et al., "Possible Legal Arrangements to Implement a Global Market Based Measure for International Aviation Emissions.", p. 47.

[241] Mendes de Leon et al., "Possible Legal Arrangements to Implement a Global Market Based Measure for International Aviation Emissions.", p. 41.

the above considerations to Recommended Practices contained in Annexes to the Convention, as well."[242]

According to Mendes de Leo et al.,[243] 'the right to notify differences has become a duty to justify non-compliance' with SARPs, therefore meaning that the absence of notification could be interpreted as giving to the SARPs a legal value, except for those provisions for which differences are notified.

- Implementation Elements, even if approved by the ICAO council, will neither be in the Assembly Resolution or in the SARPs itself. The Implementation Elements are related to five different sectors (States Pairs, Estimation and Reporting Tool, CORSIA Eligible Fuels, CORSIA Eligible Emissions Units and CORSIA Central Registry) and include in total 14 different ICAO documents available online[244].
- Technical provisions, such as the "Environmental Technical Manual - Volume IV", provide information to states and airlines about how to implement the SARPs. This manual is not in the SARPs although the SARP refers to it and does not have a legal standing[245].
- The choice for a mixed approach that does not include a proper adoption of Treaty or amendment of the Chicago Convention has consequences on the legal force of CORSIA.

Historically, attempts to enforce resolution of the ICAO or SARPs have been complex.

In the absence of an amendment to the Chicago Convention or the adoption of a new Treaty, CORSIA will not, alone, have a (strong) binding effect and it is accepted that the resolution and the SARPs can be qualified as soft law, the latter being however better placed.

2.3.3.2 Enforcement of CORSIA

In practice, the SARPs are often largely complied with by ICAO Member States. Such compliance is – due to its nature of 'soft law' - largely voluntary and does not derive from the direct enforcement nature of the SARPs. The complexity therefore lies with the ICAO Member States that are not willing to enforce the SARPs, or at least part of them.

The Chicago Convention did not create a strong nor direct mechanism or procedure to enforce compliance with SARPs. No strong procedure or direct mechanism exists – so far - to enforce compliance with CORSIA's rules, which are codified in SARPs.[246]

In those cases, enforcement can only be achieved by means of an external instrument to the SARPs itself that will be further detailed below. However it is important to observe that in the case of CORSIA, the SARPs state that enforcement may only be undertaken by a State in respect of its attributed aeroplane operators: "*The State shall not delegate enforcement of the requirements in this Volume, or their administrative tasks towards ICAO, to another State. The State may delegate administration processes of this Volume to another State through an administrative partnership based on bilateral agreement*

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[242] Section 1.5. of Annex 16 of the Chicago Convention.

[243] Mendes de Leon et al., "Possible Legal Arrangements to Implement a Global Market Based Measure for International Aviation Emissions."

[244] https://www.icao.int/environmental-protection/CORSIA/Pages/implementation-elements.aspx.

[245] https://www.icao.int/environmental-protection/CORSIA/Pages/ETM-V-IV.aspx

[246] Milde, *International Air Law and ICAO*.

among the respective States."[247] This is explained in the CORSIA FAQ as follows: *"the State shall not delegate enforcement of CORSIA requirements, or its administrative tasks towards ICAO, to another State."*[248]

This a key difference with the EU ETS that was highlighted in the EU Decision notifying of differences: "*In respect of both, the scope of application of Directive 2003/87/EC as it currently stands shall be recalled. The Directive applies irrespective of the nationality of the aeroplane operator and in principle covers flights which depart from or arrive in an aerodrome situated in the territory of a Member State to which the Treaty applies. Directive 2003/87/EC applies without distinction to flights within and between Member States and/or EEA countries*."[249] The EU and its Member States have repeatedly emphasised that they reserve the right under the Chicago Convention to enact and apply market based measures of the type referred to in Appendix L, on a non-discriminatory basis to all operators of all States providing services to, from or within their territory.[250] Council Decision (EU) 2018/2027 on the notification of differences has maintained the ability of the EU and its Member States to apply equal treatment on routes.

This was also highlighted recently in the Delegated Act on the Swiss linking: "*Directive 2003/87/EC applies irrespective of the nationality of the airline operator and in principle covers flights, which depart from or arrive in an aerodrome situated in the territory of a Member State. The equal treatment of aircraft operators on routes is vital to avoid distortions of competition.*"[251]The application of equal treatment on routes is well established under the EU ETS "*Around 500 aircraft operators reported and complied, including more than 100 commercial aircraft operators based outside the EU which operate flights within the EEA.*"[252]

- **Implementation into national law**:

Each ICAO Member State is competent to adopt the required national rules in order to implement the SARPs and, as the case may be, provide for enforcement reporting and sanctions. The implementation into national law therefore has a double objective: (i) ensuring an adequate level of enforcement of the CORSIA system and (ii) legislating on the practical arrangements for implementation of CORSIA, for which the Member States are competent.

At the time of adoption of the last version of the SARPs, the Council recalled the importance to implement the SARPs into national law and procedures: "*Contracting States are further reminded that compliance with SARPs generally extends beyond the issuance of national*

[247] Annex 16, Volume IV, Part II, Chapter 1, section 1.3.2

[248] FAQ 3.16 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-FAQs.aspx

[249] Council Decision (EU) 2018/2027 of 29 November 2018 on the position to be taken on behalf of the European Union within the International Civil Aviation Organization in respect of the First Edition of the International Standards and Recommended Practices on Environmental Protection — Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32018D2027

[250] See https://ec.europa.eu/commission/presscorner/detail/en/MEMO_07_391 and later statements emphasising this point.

[251] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12226-Exclusion-of-incoming-flights-from-Switzerland-from-the-EU-ETS

[252] https://ec.europa.eu/clima/news/emissions-trading-greenhouse-gas-emissions-reduced-87-2019_en

regulations and requires establishment of practical arrangements for implementation, such as the provision of facilities, personnel and equipment and effective enforcement mechanisms."[253]

In practice, the SARPs do not have the value of a Treaty and the way it should be implemented into national will vary from one Member State to another. In the United States, Standards are generally implemented into national law by the US Department of Transportation (DOT) and the local civil aviation authority (the FAA – the Federal Aviation Authority) and, therefore, does not need the approval from the Congress[254].

For those Member States that are member to the European Union, such national competence shall be read in conjunction with the competence of the EU to legislate – in the case of CORSIA - on the question of greenhouse gas emission in the aviation sector (see below). For the scope of competence that still lies with the Member States individually, the competent body /authority differs. For example:

- In the Netherlands, the SARPs are published in the Treaty Gazette and do not require a vote of the Parliament[255].
- In France, the SARPs are adopted by the way of "*Arrêtés*", which are administrative decision taken by a Minister.
- In Belgium, the SARPs will be implemented at national level through different procedures, depending on the authority competent to implement a given SARP (Parliament of the Federal States or the regional States, ministerial Decree or *circulaire* of the national civil aviation authority - DGTA).

In comparison with CORSIA, the implementation of the EU ETS led to the adoption, in many of the European Member States, of strict sanctions to the inobservance of the EU ETS, ranging from administrative fine to the potential blacklisting of the operator.

In respect of CORSIA, and in accordance with the compliance timeline for 2019-2020 period, all participating states are supposed to legislate on the implementation of CORSIA, including in respect of the MRV requirements, which began on 1 January 2019. For example, each aeroplane operator should have submitted an Emission Monitoring Plan by 28 February 2019 and have it approved by the State to which it is attributed by 30 April 2019.

Without clear legal provisions binding on Member States and operators, the calendar of implementation provided for in Resolution A40-19 may not be observed (see below the Section assessing example of States having incorporated the SARPs (including the MRV) into national law).

- **Enforcement through the application of the Chicago Convention:**

The Chicago Convention can – in itself – provide for some enforcement techniques, mainly designed for those States which do not (properly) implement the CORSIA scheme within their national legal framework.

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[253] Section 2.1. of Annex 16 to the Chicago Convention.

[254] Mendes de Leon et al., "Possible Legal Arrangements to Implement a Global Market Based Measure for International Aviation Emissions.", p.47.

[255] Mendes de Leon et al., "Possible Legal Arrangements to Implement a Global Market Based Measure for International Aviation Emissions." p.47.

The first option is to rely on the audits conducted by the ICAO. The findings of such audits lead to recommendations[256].

The second option is to rely on a link between the SARPs and the Chicago Convention. In some situations, SARPs can be legally binding – and thus enforced - as their violation would also imply a direct violation of one or several provisions of the Chicago Convention. This position has been largely accepted for some of the Annexes to the Convention.

In this respect, Annex 2 to the Chicago Convention, which relates to the rules of the air, is a direct application of Article 12 of the Chicago Convention, which provides that "*Each contracting State undertakes to adopt measures to insure that every aircraft flying over or maneuvering within its territory and that every aircraft carrying its nationality mark, wherever such aircraft may be, shall comply with the rules and regulations relating to the flight and maneuver of aircraft there in force. Each contracting State undertakes to keep its own regulations in these respects uniform, to the greatest possible extent, with those established from time to time under this Convention. Over the high seas, the rules in force shall be those established under this Convention. Each contracting State undertakes to insure the prosecution of all persons violating the regulations applicable*." The SARPs relating to the rules of the air – as included in the Annex 2 to the Chicago Convention, are therefore adopted through a direct mandate given by the Chicago Convention and have a legal binding force[257].

The same reasoning can be applied to the Annex 8, which prescribed the minimum airworthiness standards which form the basis for mutual recognition by contracting States of a certificate of airworthiness under Article 33 of the Chicago Convention. Such link gives to the provisions of Annex 8 a "*sound legal strength*"[258] since the ICAO Member States are entitled to revoke traffic rights authorisation on such legal basis. As underlined by Professor Mendes de Leon, in "*doing so, Article 33 of the Chicago Convention provides for a strong mechanism fostering the implementation of the most important safety standards*"[259]

Applying the same reasoning to Annex 16 relating to the environmental measures implies that a link can be done to a specific provision of the Chicago convention.

Such direct link between the Chicago Convention and its Annex 16 does not exist[260]. The impact of the environment was not under discussion at the time of the adoption of the Chicago Convention and the Annex 16 has been adopted on the basis of the catch all provision of Article 37: "[…] *the International Civil Aviation Organization shall adopt and amend from time to time, as may be necessary, international standards and recommended practices and procedures* […] *and such other matters concerned with the safety, regularity, and efficiency of air navigation as may from time to time appear appropriate*."

The reporting requirement set forth in the CORSIA system could be seen as an application of the general reporting requirement laid down in Article 67 of the Chicago Convention, which provides that "*Each contracting State undertakes that its international airlines shall,*

[256] Mendes de Leon et al., "Possible Legal Arrangements to Implement a Global Market Based Measure for International Aviation Emissions." p.50.

[257] R. Abeyratne, Aviation and Climate Change: In Search of a Global Market Based Measure, Sprinker, Canada, 2014.

[258] Mendes de Leon et al., "Possible Legal Arrangements to Implement a Global Market Based Measure for International Aviation Emissions." p.44.

[259] Mendes de Leon et al., "Possible Legal Arrangements to Implement a Global Market Based Measure for International Aviation Emissions." p.44.

[260] Mendes de Leon et al., "Possible Legal Arrangements to Implement a Global Market Based Measure for International Aviation Emissions." p.41.

in accordance with requirements laid down by the Council, file with the Council traffic report, costs statistics and financial statements showing among other things all receipts and the sources thereof".

Such Article indeed makes reference to a reporting requirement that "*shall*" be imposed by ICAO Member States to their airlines.

Any reporting requirement implies the prerequisite to measure the data concerned by the reporting and, equally, the verification of such reporting. The MRV requirements could therefore be seen as an application of Article 67 of the Chicago Convention. Some level of enforcement could therefore be found in such link.

At the time of the drafting of this report, we are however not aware that such link has been supported or recognized by the ICAO.

- **Enforcement through the application of bilateral (or multilateral) agreements:**

Enforcement of the CORSIA system through the application of bilateral or multilateral agreements entered into between states is also an option that - in some circumstances – ensure a higher degree of enforcement of the CORSIA when States do not voluntary implement the scheme.

As the content of such agreements are not standardised and are freely determined by the States, a case-by-case assessment is required.

Bilateral and multilateral agreements are of crucial importance for States as they provide the necessary authorisation (traffic rights and allied/ancillary rights) to operate and access international markets. Besides the basic granting of traffic rights (including the capacity and frequencies provisions), these agreements also include reference to other obligations (often referred to as "*soft rights*"), to ensure high standards of safety and security in international air transport bilateral and multilateral agreements and have a vocation to address more effectively the impact of aviation on the environment, namely.

Enforcement of those standards are however addressed differently by the States, which reveals the level of importance that is granted to one element (security and safety) compared to others (such as environment is often in ASA) and the sovereignty that states want to secure in certain domain.

Security and safety

In terms of security and safety, most of bilateral and multilateral agreements require at least compliance with the minimum safety standards established pursuant to the Chicago Convention and its annexes, and with a non-exhaustive list of several well-known conventions[261;262].[263]

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[261] Some bilateral agreement refers to specific safety agreement entered into between the parties, such as the Canada – EU agreement which refers to the Agreement on Civil Aviation Safety entered into between Canada and European Union.

[262] The Tokyo convention, the Hague Convention, Convention on Offences and Certain Other Acts Committed on Board Aircraft, done at Tokyo, 14 September 1963, the Convention for the Suppression of Unlawful Seizure of Aircraft, done at The Hague, 16 December 1970, the Convention for the Suppression of Unlawful Acts against the Safety of Civil Aviation, done at Montreal, 23 September 1971, and the Protocol for the Suppression of Unlawful Acts of Violence at Airports Serving International Civil Aviation, done at Montreal, 24 February 1988.

[263] See Article 8 §§1 and 2 and Article 9 §§ 1 and 3 of the ***US-EU open sky agreement***; Articles 6 and 7 of the agreement entered into between European Union and Canada.

Therefore, in terms of security and safety, States parties to an ASA make clear that they want to ensure the same minimum requirements between them. Moreover, enforcement of such minimum safety and security standards are guaranteed through the fact that non-compliance with such safety and security requirements could lead to the authorisations not being granted, being suspended or revoked.

Environment

Bilateral and multilateral agreements also have a vocation to address more effectively the inclusion of the environment in the aviation sector. In that sense, agreements can include environmental provisions which generally refer to the standards adopted by the ICAO but can also refer to other specific regulations such as European ones. Inclusion of such clause is a preliminary step in view of assessing whether CORSIA could be enforced through bilateral and multilateral agreements.[264]

Contrary to what has been assessed regarding security and safety provisions, when referring to ICAO standards, environmental provisions generally give primacy to the sovereignty of States by recognizing – and legitimizing - the possibility to file differences against the aviation environmental standards adopted by ICAO:

[…]

3. When environmental measures are established, ***the aviation environmental standards adopted by the International Civil Aviation Organisation in Annexes to the Convention shall be followed except where differences have been filed****.*

[…]"[265]

Other agreements provide that "*the Contracting Parties shall act in conformity with Community legislation relating to air transport* specified" and specify it in annexes. Those however mainly relate to noise issues.[266]

Agreement such as the one entered into between Israël and the European Union slightly differs in the way the provision is drafted (mainly by referring to a minimum level) but also leads to the European legislation, relating to noise regulation, being specified in the annexes: "*the Contracting Parties shall ensure that their relevant legislation, rules or procedures deliver, at minimum, the regulatory requirements and standards relating to air transport specified in Part C of Annex IV as detailed in Annex VI*".

Therefore, as long as differences have been duly filed by one party or another, these would prevail above any minimum standards. Environmental provisions, hence, do not impose the parties to comply with minimum requirements included in the SARPs and do not impose a common level playing field in that domain. Rather, sovereignty of each state takes precedence on a common environmental position in these agreements.

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[264] Some agreements do not include such environment provision. We namely refer to the bilateral agreement entered into between Australia and Russia dated 11 July 1994 or between Australia and Brazil dated 21 April 2010.

[265] Article 15 of the US-EU open sky agreement.

[266] Euro-Mediterranean Aviation Agreement between the European Community and its Member States and the Kingdom of Morocco, OJ L 386, 29.12.2006, p.57, Article 17; Common Aviation Area Agreement between the European Union and its Member States and the Republic of Moldova OJ L 292, 20.10.2012, p. 3, Article 17.

These articles refer namely to Council Directive n°89/62; Directive 2002/30, Directive 2002/49/EC or directive 2006/93/EC.

Such provision in ASA could therefore increase the level of enforceability of the SARPs, but only to the extent a Party breaches a SARP for which no difference has been filed. However, bilateral and multilateral agreements do not provide for hard sanctions in case of breach of the environmental clause, such as revocation or suspension of authorisations (as it is the case for breach of security and safety requirements).

In that sense, the EU-US open sky agreement for example lists exhaustively the conditions based on which the authorisation can be refused, revoked or suspended[267]:[268]

"*Article 4 - Authorisation*

On receipt of applications from an airline of one Party […] *the other Party shall grant appropriate authorisations and permissions* […]*, provided:*

[…] *(d) the provisions set forth in Article 8 (Safety) and Article 9 (Security) are being maintained and administered.*

Article 5 - Revocation of authorisation

1. Either Party may revoke, suspend or limit the operating authorisations or technical permissions or otherwise suspend or limit the operations of an airline of the other Party where:

[…] *(c) that airline has failed to comply with the laws and regulations referred to in Article 7 (Application of Laws) of this Agreement.*

3. This Article does not limit the rights of either Party to withhold, revoke, limit or impose conditions on the operating authorisation or technical permission of an airline or airlines of the other Party in accordance with the provisions of Article 8 (Safety) or Article 9 (Security)."

Under the US-EU agreement, it is therefore unlikely that non-compliance with Annex 16 would result in strict and effective sanction. Revocation or suspension of the authorisation would mainly concern violations of *(i)* safety and security standards or *(ii)* the *Application of laws* clause which refers to the laws and regulations governing namely the admission to or departure from its territory of aircraft, passengers, crew or cargo[269].

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[267] Decision of the Council and the representatives of the governments of the member states of the European Union, meeting within the Council of 25 April 2007 on the signature and provisional application of the Air Transport Agreement between the European Community and its Member States, on the one hand, and the United States of America, on the other hand, OJ 25.05.07, L 134/1.

[268] The same provisions are included in the Euro-Mediterranean Aviation Agreement between the European Community and its Member States, of the one part and the Kingdom of Morocco, of the other part.

[269] EU-US open sky; Article 7 - Application of laws:

1. The laws and regulations of a Party relating to the admission to or departure from its territory of aircraft engaged in international air navigation, or to the operation and navigation of such aircraft while within its territory, shall be applied to the aircraft utilised by the airlines of the other Party, and shall be complied with by such aircraft upon entering or departing from or while within the territory of the first Party.

2. While entering, within, or leaving the territory of one Party, the laws and regulations applicable within that territory relating to the admission to or departure from its territory of passengers, crew or cargo on aircraft (including regulations relating to entry, clearance, immigration, passports, customs and quarantine or, in the case of mail, postal regulations) shall be complied with by, or on behalf of, such passengers, crew or cargo of the other Party's airlines.

For some air services agreement, the violation of the CORSIA scheme could lead to more concrete consequences. The air services agreement entered into the European Union and Canada provides that designation and authorisation are provided and can be maintained as long as the "*airline complies with the* ***laws and regulations*** *of the Party granting the authorisations and permissions*", without referring to a specific clause such as the one mentioned here above and without being defined elsewhere in the agreement so as they shall receive a common sense interpretation. These terms also refer to the laws and regulations "*of the Party*", which means the state, party to the agreement, and do hence refer to the comprehensive legal framework adopted by such state and not only part thereof.[270] These terms could therefore refer to the implementation that each party will do of CORSIA into their own national order (ICAO standards are indeed not binding *per se* and need to be implemented in national law to receive such force). Terms used to implement the SARP's in national law could hence be of importance as this could lead to imposing the environmental standards of one party to the other one through the execution of the bilateral agreement (if for example national law provides that airlines departing from the country shall observe environmental standards of that country, without differentiating the airlines in function of the country granting the AOC for example).

Finally, the recently initialled air services agreement between the European Union and Qatar (still pending signature from both sides)[271] is interesting enough to assess since, according to the EU, the agreement "*will upgrade the rules and standards for flights between Qatar and the EU, and will set a new global benchmark by committing to strong, fair competition mechanisms, and including provisions not normally covered by bilateral air transport agreements, such as social or environmental matters*"[272]. Its emphasis on environmental protection namely reflects its modern character[273]. Parties to cooperate on the implementation of instruments such as CORSIA in view of enhancing cooperation in relation to greenhouse gas measures associated with air transport and, by such, recognising "*the importance of addressing climate change*" in the air transport industry. In that regard, they moreover commit themselves to exchanging information and maintaining a regular dialogue when it comes to environmental matters such as research and development of 'environmentally-friendly aviation technology' and 'sustainable alternative fuels for aviation'.[274]

It is however too early to assess the success of this agreement as it has not yet entered into force. Looking at the commitments made by the parties, one should note that no concrete goals have been set (no concrete (numerical) targets for example), leaving space to the parties to interpret the provisions and initial will of the parties.[275] Nevertheless, if

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[270] The following terms "*the air carrier meets the conditions prescribed under the laws and regulations normally applied by the authority competent for the operation of international air transport*" could indeed to our view lead to a stricter interpretation of the provision.

[271] European Commission, EU and Qatar Reach Aviation Agreement (2019), https://ec.europa.eu/trans

port/modes/air/news/2019-03-04-eu-and-qatar-reach-aviation-agreement_en (accessed 1 July 2020).

[272] *Ibid.*

[273] Kučko, Magdalena. '*The EU-Qatar Air Transport Agreement: Bound to Succeed?*'. Air & Space Law 45,

no. 3 (2020): 236.

[274] *Ibid.*

[275] *Ibid*, p.236 and 237.

the agreement is enacted, it will set an important precedent for future agreement and the implementation of the CORSIA mechanism.

Interestingly as well is that some agreements permits each party to impose to the other party *higher* requirements than the minimum ones prescribed by the SARPs. We refer to the EU-Canada agreement which provides for such possibility regarding security standards[276]:

"*The Parties shall act in conformity with the aviation security provisions established by the International Civil Aviation Organisation and designated as Annexes to the Convention on International Civil Aviation* ***to the extent that such security provisions are applicable to the Parties****. The Parties shall require that operators of aircraft of their registry, operators of aircraft who have their principal place of business or permanent residence in their territory, and the operators of airports in their territory act in conformity with such aviation security provisions. Accordingly, each Party, upon request,* ***shall provide the other Party notification of any difference between its regulations and practices and the aviation security standards of the Annexes referred to in this paragraph, where these differences exceed or complement such standards and have relevance for the operators of the other Party****.* […]

5. *With full regard and mutual respect for the sovereignty of states, each Party agrees that operators of aircraft referred to in paragraph 4 of this Article* ***may be required to observe the aviation security provisions referred to in that paragraph required by the other Party for entry into, departure from, or while within the territory of that other Party****. Each Party shall ensure that adequate measures are effectively applied within its territory to protect the aircraft and to exercise security controls on passengers, crew members, baggage, carry-on items, cargo, mail and aircraft stores prior to boarding or loading.*

As far as security and safety is concerned, it is therefore accepted that an ASA can impose on contracting parties' requirements that are higher than those provided in the SARPs. Such mechanism could be envisaged for the implementation of CORSIA.

2.3.3.3 Example of enforceability and oversight of MRV by States

Given the absence of binding nature of the SARPs, the enforceability of MRV largely depends on the provisions of national laws implementing the SARPs.

This section assesses some example of ICAO Member States who did legislate to incorporate – sometimes with differences - the MRV regulations into national law.

- **Example of the Member States of the European Union**

In so far as EU Member States are concerned, CORSIA's monitoring, reporting and verification emissions system has been implemented directly at the European Union level, the EU being amongst the first jurisdictions to adopt legally binding provisions to ensure the effective enforcement of CORSIA[277].

[276] Agreement on Air Transport between Canada and the European Community and its Member States, OJ L 207 6.8.2010, p. 32, Article

[277] https://ec.europa.eu/transparency/regdoc/rep/3/2019/EN/C-2019-1644-F1-EN-MAIN-PART-1.PDF

As a first step, Directive 2003/87/EC[278] has been amended to incorporate Article 28c which conferred delegated powers to the Commission to adopt provisions for the appropriate monitoring, reporting and verification of emissions for implementing ICAO's global market-based measure on all routes covered by it.

Article 28c provides that "*The Commission is empowered to adopt delegated acts in accordance with Article 23 to supplement this Directive concerning the appropriate monitoring, reporting and verification of emissions for the purpose of implementing the ICAO's global market-based measure on all routes covered by it. Those delegated acts shall be based on the relevant instruments adopted in the ICAO, shall avoid any distortion of competition and be consistent with the principles contained in the acts referred to in Article 14(1), and shall ensure that the emissions reports submitted are verified in accordance with the verification principles and criteria laid down in Article 15*".

Based on this provision, the Commission then adopted Delegated Regulation 2019/1603 of 18 July 2019[279] which defined the scope of CORSIA. This Regulation is binding in its entirety and directly applicable in all Member States of the EEA.

The purpose of this delegated act is to draw on existing rules and frameworks so far as possible in order to reduce the aircraft operators and verifiers' administrative burden and to specify how the relevant information will be transmitted to the ICAO's secretariat[280].

Pursuant to article 3 of this Regulation, emissions must be reported in accordance with the conditions laid down in the Implementing Regulation 2018/2066[281], with effect from 1 January 2021. This Implementing Regulation which contained the rules applying to the ETS system, has been adapted to take the CORSIA system into account.

Similarly, according to Article 4 of the Regulation, the verification of the data transmitted will be carried out in accordance with the rules prescribed for the ETS system as amended to take CORSIA into account[282].

- **Example of the United States**

Another example is the one of the United States, who made clear that the MRV was to be implemented on a voluntary basis:

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[278] Directive 2003/87 of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC.

[279] Commission Delegated Regulation (EU) 2019/1603 of 18 July 2019 supplementing Directive 2003/87/EC of the European Parliament and of the Council as regards measures adopted by the International Civil Aviation Organisation for the monitoring, reporting and verification of aviation emissions for the purpose of implementing a global market-based measure, C/2019/5206, OJ L 250, 30.9.2019, p. 10–13.

[280] https://ec.europa.eu/transparency/regdoc/rep/3/2019/EN/C-2019-1644-F1-EN-MAIN-PART-1.PDF

[281] Commission Implementing Regulation (EU) 2018/2066 of 19 December 2018 on the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council and amending Commission Regulation (EU) No 601/2012, OJ L 334, 31.12.2018, p. 1–93.

[282] Article 15 et annex V, part B of Directive 2003/87 and Implementation Regulation 2018/2067 (Commission Implementing Regulation (EU) 2018/2067 of 19 December 2018 on the verification of data and on the accreditation of verifiers pursuant to Directive 2003/87/EC of the European Parliament and of the Council, OJ L 334, 31.12.2018, p. 94–134).

"*The CORSIA MRV Program is completely voluntary, and Program Participants may request to be removed from the program at any time*"[283].

In order to avoid any misunderstanding as to the potential binding nature of the MRV within the United States, the FAA clarifies that the "*Use of the term "will" in this document is aspirational only, and is not intended to be read as imposing any obligation or right on either the FAA or Program Participants. Use of the terms "must," "require," "shall," "has to," or "mandatory" and references to "requirements" or "standards" refer generally to the CORSIA SARPs. The FAA anticipates that, if appropriate, it will conduct rulemaking or take other action to implement the offsetting and other mandatory provisions of the CORSIA*"[284].

Given this latter assertion, the FAA clearly stated that the actual national implementation of the SARPs into national US law does not lead to any form of enforceability. Taking into account that the MRV requirements are organised between the aeroplane operator and its competent State (as opposed to ICAO directly), this means that aeroplane operators for which the United States is the competent State would not be subject to any sanction or enforcement actions in case of non-compliance with CORSIA MRV. This could create discrimination among States participating in CORSIA, between those who provide for national law enforcement measures and, as the case may be, sanction's regime, and, on the other hand, States (such as the United States) that do not provide for any enforcement action.

In terms of collection of data, according to the Section 2.5.2 of the SARPS, "*if the aeroplane operator does not provide its annual Emission Report (…) the State shall estimate the aeroplane operator's annual emissions (…)*".

- **Example of Canada**

In Canada, the CORSIA system – including the MRV requirements – have been implemented in Part X of the Canadian Aviation Regulations[285].

Most of the SARPs, as well as the technical documentation, are implemented in the Canadian Aviation Regulations, sometimes even by including, by reference, the SARPs or its appendixes in the Canadian act.

Interestingly, some differences can however be found, namely:

- Canada does not recognize the possibility for a State to request disclosure of internal verification documentation by the verification body. For the Canadian operators, those information disclosed to the Verification Body will therefore remain confidential to the reporting State.
- The verified emissions report does not have to include all of the information referenced in Appendix 5 to the Annex 16 of the Chicago Convention[286], such as the number of international flights per aerodrome pairs (see Field 7, b) of Table A5-1 of Appendix 5), the number of CO_2 for international flights per aerodrome pairs (see

[283] Notice of CORSIA monitoring, reporting, and verification program, US Department of Transportation, Federal Aviation Administration, p. 3.

[284] Notice of CORSIA monitoring, reporting, and verification program, US Department of Transportation, Federal Aviation Administration, p. 3.

[285] https://lois-laws.justice.gc.ca/eng/regulations/SOR-96-433/FullText.html#s-1000.10

[286] Section 1000.20.1a) of the Canadian Aviation Regulations.

Field 7, b) of Table A5-1 of Appendix 5)[287], and all information relating to the CORSIA eligible fuel (Field 12 of Table A5-1 of Appendix 5).

2.3.3.4 Enforcement of CORSIA as an exclusive GMBM

Paragraph 18 of the Resolution A40-19 provides that CORSIA is the only global market-based measure applying to CO_2 emissions from international aviation, in order to avoid a possible patchwork of duplicative State or regional MBMs, thus ensuring that international CO_2 emissions should be accounted for only once.

Some voices raise concerns as to the potential conflicts between the cumulative application of CORSIA and the EU ETS system.[288]

However, these issues shall firstly be tempered by the non-legal nature of the Resolution and, in particular, its lack of mandatory enforcement.

Secondly, the European Union made it clear through an oral Declaration that *'Fully in line with our positions taken at the last Assembly and in our interventions in ICAO Council meetings, Paragraph 18 of Draft Resolution is to be read in light of the Chicago Convention as well as in line with certain Contracting Parties' legal obligations to pursue efforts to limit the temperature increase in line with the Paris Agreement on climate change. One of the principles of the Convention is that each Contracting State may apply on a non-discriminatory basis its laws and regulations to all aircraft operating within its jurisdiction. This principle also applies to environmental measures such as the ones we have in the EU and its Member States*'[289].

According to this statement, the European Union takes the stance that the Chicago Convention – whose binding nature is not doubtful – provides for the possibility for each member state (and thus the EU Member States) to regulate aircraft operations within its own airspace, as long as it does not discriminate.

Furthermore, the EU Member States have notified ICAO that certain differences exist between Directive 2003/87/EC and CORSIA[290]. The EU ETS Directive applies irrespective of the nationality of the aeroplane operator and in principle covers flights which depart from or arrive in an aerodrome situated in the territory of a Member State to which the Treaty applies. These differences limit the scope of CORSIA application.

This position is line with the position previously adopted by the European Union, including in the reservation made in respect of the resolution A36/22 adopted at the 36th Assembly of ICAO, according to which: "the Chicago Convention recognizes expressly the right of

[287] So that only figures related to State pairs shall be referenced.

[288] 'It would be an egregious contradiction of this if a regional market-based system such as the EU ETS subjected emissions from international flights (including flights between EU Member States) to a second regulatory system.', Uwe M. Erling, "How to reconcile the European Union Emissions Trading System (EU ETS) for aviation with the Carbon Offsetting and Reduction Scheme for the International Aviation (CORSIA)", *Air & Space Law*, 2018, pp. 382-383.

[289] Oral Declaration of the European Union towards the draft Resolution.

[290] Council Decision (EU) 2018/2027 of 29 November 2018 on the position to be taken on behalf of the European Union within the International Civil Aviation Organization in respect of the First Edition of the International Standards and Recommended Practices on Environmental Protection — Carbon Offsetting and Reduction Scheme for International Aviation, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32018D2027

each Contracting Party to apply on a non-discriminatory basis its own air laws and regulations to the aircraft of all States"[291].

The specific provision of the Chicago Convention that is referred above is Article 11, stating that "*Subject to the provisions of this Convention, the laws and regulations of a contracting State relating to the admission to or departure from its territory of aircraft engaged in international air navigation, or to the operation and navigation of such aircraft while within its territory, shall be applied to the aircraft of all contracting States without distinction as to nationality, and shall be complied with by such aircraft upon entering or departing from or while within the territory of that State*".

It has indeed been asserted that one of the main arguments of the EU's reservation made on resolution A36/22 in favour of the validity of the EU ETS system is that "the EU ETS is devised as a non-discriminatory measure that is applicable to all flights in and out of the EU and thus compliant to Article 11 of the Convention"[292].

2.3.3.5 Enforceability and oversight of cancellation of Emissions Unit

In its letter to the Secretary General of the ICAO, the European Commission recalled that 'CORSIA will be effective only if the growth of aviation emissions from 2020 is effectively compensated by projects on the ground generating emission units that represent real, additional, permanent and verified reductions of greenhouses gases that are accounted for only once towards any climate mitigation obligation or voluntary action.'[293]

The general legal basis of the Emissions Unit is included in the Resolution A40-19, notably in paragraph 22 which provides that "*the CORSIA will use emissions units that meet the Emissions Unit Criteria (EUC)".*

More detailed provisions related to the Emissions Units are included in the SARPs, notably that aeroplane operator shall meet its offsetting requirements by cancelling CORSIA Eligible Emissions Units in a quantity equal to its total final offsetting requirements for a given compliance period.

As stated in Resolution A40-19, the Assembly also requested the ICAO Council to develop and update the ICAO document referenced in Annex 16, Volume IV related to the eligible emissions units for use by the CORSIA, considering the recommendations of the TAB ("Technical Advisory Body"). The quality and integrity of the system requires the careful assessment of the eligibility of the emissions units in order to verify whether the criteria listed in the "CORSIA Emissions Unit Eligibility Criteria" document are observed.

The provisions related to the Emissions Unit are therefore located in three types of legal instruments: the Resolution A40-19, the SARPs included in the Annex 16 of the Chicago Convention and *the Implementation Elements documents* (in practice *the CORSIA Emissions Unit Eligibility Criteria (EUC)* and the *CORSIA Eligible Emissions Units*).

In addition, Technical Provisions and the templates, *i.e.* the Environmental Technical Manual (Doc 9501), Volume IV — Procedures for demonstrating compliance with the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) Technical Provisions, are intended to make the most recent information available to administrating

[291] Written Statement of Reservations on behalf of the member states of the European Community (EC) and the other states members of the European Civil Aviation (ECAC) [made at the 36th Assembly of the International Civil Aviation Organization in Montreal, 18-28 September 2007].

[292] D. Freestone; C. Streck, "Legal aspects of Carbon Trading – Kyoto, Copenhagen and beyond", Oxford, 2009, p.615.

[293] Letter of the European Commission to the Secretary General of the International Civil Aviation Organization, 1 March 2019.

authorities, aeroplane operators, verification bodies and other interested parties in a timely manner, aiming at achieving the highest degree of harmonisation possible.

These are adopted by the ICAO Committee on Aviation Environmental Protection (CAEP) and will be periodically revised under the supervision of the CAEP Steering Group. Environmental Technical Manual, Volume IV is approved by and published under the authority of the ICAO Secretary General.

All conditions regarding Eligible Emissions Units are therefore directly provided by the ICAO, which is an advantage regarding the uniform implementation of the Emissions Units system.

However, those provisions do not benefit from a legal force and are, therefore, not enforceable as such. ICAO Member States are therefore free to deviate from those provisions when implementing the CORSIA into their national legislation. The willingness of individual ICAO Member States to implement such provisions into national law will therefore impact the level of enforcement of those technical guidance and implementation elements.

In addition, the purchase, use and cancellation of emissions units is done at national level by the air operators themselves, who are due to report to their reporting State. While harmonized templates are made available to the Member States in the Environmental Technical Manual, each Reporting Member State remains authorised to develop and distribute to its air operators its own template of Emissions Report and Emissions Units Cancellation Report.

Having the entire cancelling, reporting and verification requirements accomplished at a national level, by the operator itself, implies potential disparities among ICAO Member States, highly increased by the absence of legal force of most of the regulations related to the EUC (in so far as EUC are concerned, the SARPs on its own are not sufficiently detailed to enable enforcement). As an example, the national implementation of such technical guidance in Canada includes some deviation in respect of the information that shall be included in the verified emissions report (which shall include the information referenced in Appendix 5 to the Annex 16 of the Chicago Convention[294], except in respect of the number of international flights per aerodrome pairs (see Field 7, b) of Table A5-1 of Appendix 5), the number of CO^2 for international flights per aerodrome pairs (see Field 7, b) of Table A5-1 of Appendix 5)[295], and all information relating to the CORSIA eligible fuel (Field 12 of Table A5-1 of Appendix 5).

For those ICAO Member States who voluntary comply with CORSIA, the question will principally depend on whether disparities will arise in the way national authorities will verify and, as the case may be, sanction, discrepancies committed by operators.

For those ICAO Member States who are not going to volunteer to CORSIA and/or made reservations and/or notified differences, the situation is more complex.

As an example, China has made several references to the implementation of the units' system of CORSIA in the reservations made to the Resolution adopted at the 40th Assembly, including:

- A reservation on paragraph 19 of the Resolution related to the implementation of CORSIA: "The Council should establish a mechanism of technical dialogue and

[294] Section 1000.20.1a) of the Canadian Aviation Regulations.

[295] So that only figures related to State pairs shall be referenced.

consultation between States and ICAO on States' approaches to implement the CORSIA, including nationally determined baselines and standards to certify emissions units/SAF in light of their national circumstances and scientific research, in a facilitative, non-intrusive manner and respectful of their national sovereignty"[296].

- A reservation made on paragraph 20 of the Resolution which recognize that "emissions units generated from mechanisms established under the UNFCCC and the Paris Agreement are eligible for use in CORSIA, provided that they align with decisions by the Council, with the technical contribution of TAB and CAEP, including on avoiding double counting and on eligible vintage and timeframe". According to the Chinese delegation, such conditional reservation shall not be made: "As the UNFCCC is the main arena for global actions against climate change, States should be encouraged to give priority to the use of emission units endorsed by UNFCCC and the Paris Agreement. There is no need for ICAO Council to make different decisions in this regard."[297]
- A reservation made on Paragraph 22 of the Resolution recalling the decision "that the CORSIA will use emissions units that meet the Emissions Unit Criteria (EUC)". According to the Chinese delegation, "China affirms that certification of eligible emission units and eligible SAF should be determined by sovereign States according to related criteria. ICAO can recommend offsetting products for preferred consideration but should not make decisions for sovereign States."[298]

Brazil also made reservations on the Resolution adopted at the 40th Assembly, which are related to the EUC:

- The first reservation relates to the conditional recognition of the emission units generated under the Paris Agreement and the UNFCCC, by confirming its "*understanding that emissions units generated through multilaterally-agrees mechanisms established under the United Nations Framework Convention on Climate Change, namely the Clean Development Mechanism of the Kyoto Protocol and the mechanism established by Article 6, paragraph 4 of the Paris Agreement, are already eligible for CORSIA*."[299] Brazil therefore opposes to any condition or criteria that would exclude from CORSIA an emission unit otherwise recognized in the Paris Agreement or the UNFCCC system.
- The second reservation relates to paragraph 22 of the Resolution adopted at the 40th Assembly, by which ICAO Assembly recalled its decision that "*CORSIA will use emissions units that meet the Emissions Unit Criteria (EUC)* […]". The reservation based on this provision is twofold: firstly, the Government of Brazil express reservation in respect of emissions units generated from mechanisms outside of the UNFCCC. Secondly, the Government of Brazil wishes to control the rights and benefits arising from actions made on its soil, and therefore declared that "*any transfer of unit resulting from mitigation outcomes achieved in the Brazilian territory will be subject to prior and formal consent of the Federal Government*"[300].

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[296] Reservations of the Chinese Delegation to the 40th session of the Assembly, paragraph 15.

[297] Reservations of the Chinese Delegation to the 40th session of the Assembly, paragraph 16.

[298] Reservations of the Chinese Delegation to the 40th session of the Assembly, paragraph 18.

[299] Reservations of the Delegation of Brazil to the 40th session of the Assembly, p. 1, Verbal Note No. 2019-082/BRASICAO.

[300] Reservations of the Delegation of Brazil to the 40th session of the Assembly, p. 1, Verbal Note No. 2019-082/BRASICAO.

The Russian Delegation made a reservation on the entire Resolution A40-19 adopted at the 40th Assembly, by declaring that the "*it does not find possible to join this resolution as a whole and intends, when it sees fit, to apply the provisions of Article 38"* relating to the notification of differences with the SARPs included in the Annex 16 to the Chicago Convention.

Saudi Arabia, India and Venezuela also made reservations which could – by their broad scope – have an impact of the enforceability of the EUC

It arises from those reservations that the enforcement of the EUC in ICAO Member States having made reservation will be highly difficult.

One element that might – to some extent - ease the voluntary enforcement of the EUC is the fact that all States having made reservations on the EUC – except Venezuela – are States having a TAB member, which is competent to make recommendation on the CORSIA Eligible Emissions Units.

2.3.3.6 Enforceability and oversight of the use of CORSIA eligible fuels

As a preliminary remark, a more detailed technical overview of CEF is provided in Section 2.3.7 of the present report. In this Section, we only expose a short overview permitting to assess the enforceability of the framework for CORSIA eligible fuels.

2.3.3.6.1. Oversight of the use of CORSIA Eligible (CEF)

Under the CORSIA system, aeroplane operators can claim emission reductions from the use of CORSIA eligible fuels. To claim such reductions, aeroplane operators shall provide information as described in Appendix 5 Table A5-2 of Annex 16, *i.e.* mainly*:*

- Purchase of the neat CORSIA eligible fuel;
- Identification of the producer of the neat CORSIA eligible fuel;
- Fuel type; and
- Evidence that the fuel satisfies the CORSIA Sustainability Criteria.

What is considered as CEF

During the CORSIA pilot phase (2021-2023), to be considered as CEF, fuels shall comply with the following conditions:

1. CEF include "sustainable aviation fuels" (renewable or waste-derived aviation fuels) and "lower carbon aviation fuels" (fossil-based aviation fuel) that comply with the CORSIA sustainability criteria, which are provided directly by the ICAO on its website on a document named "CORSIA Sustainability Criteria for CORSIA Eligible Fuels"[301]:

- Greenhouse Gases: CORSIA eligible fuel needs to achieve net greenhouse gas emission reductions of at least 10% compared to conventional jet fuel on a life cycle basis.
- Carbon stock:
    - CORSIA eligible fuel shall not be made from biomass obtained from land with high carbon stock obtained from land converted after 1 January 2008 that was primary forest, wetlands, or peat lands, and/or contributes to degradation of the

[301] https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2005%20-%20Sustainability%20Criteria.pdf

carbon stock in primary forests, wetlands, or peat lands as these lands all have high carbon stocks.

- In the event of land use conversion after 1 January 2020, as defined based on IPCC land categories, direct land use change (DLUC) emissions, shall be calculated. If DLUC greenhouse gas emissions exceed the default induces land use change (ILUC) value, the DLUC value shall replace the default ILUC value.

2. CEF can only be bought from fuel producers which are certified by an approved Sustainability Certification Scheme (SCS):

- SCS are organisations that certify that economic operators (feedstock producers, processing facilities and traders) against sustainability criteria, and ensure that economic operators calculate actual life cycle emissions values using the agreed methodology or apply the default values provided by the ICAO;
- Approved SCS are validated by ICAO Council following the technical assessment and recommendation of the CAEP, which will assess the compliance of the SCS with the eligibility requirements listed in the detailed document named "*CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes*"[302]. The evaluation of the Sustainability Certification Schemes is currently ongoing and will result shortly in the list of approved SCS. The list of approved SCS will be published on the ICAO website.

Importantly, the sustainability criteria listed above apply during the CORSIA pilot phase. The CAEP has been recommended to the ICAO Council to adopt a list of 12 sustainability themes and 17 sustainability criteria to be applicable to Sustainable Aviation Fuels beyond the pilot phase. In March 2020, the ICAO Council has approved the full set of 12 sustainability themes and 17 sustainability criteria. State consultation is ongoing prior to the definitive adoption of this sustainability framework by the ICAO Council, in all likelihood in November 2020.

Furthermore, the CAEP is tasked to develop by the end of the CORSIA pilot phase a sustainability framework containing additional and/or strengthened sustainability criteria for Lower Carbon Aviation Fuels. This work is ongoing at ICAO.

How to claim emission reductions from the use of CEF

To claim emission reductions for using CEF for a given year, Aeroplane operator shall provide in its annual reporting the Emission reductions claimed, using the following formula[303]:

[302] https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2003%20-%20Eligibility%20Framework%20and%20Requirements%20for%20SCS.pdf

[303] Annex 16, Volume IV, Article 3.3

3.3.1 The aeroplane operator that intends to claim for emissions reductions from the use of CORSIA eligible fuels in a given year shall compute emissions reductions as follows:

$$ER_y = FCF * \left[\sum_f MS_{f,y} * \left(1 - \frac{LS_f}{LC}\right)\right]$$

where:

ER_y	=	Emissions reductions from the use of CORSIA eligible fuels in the given year y (in tonnes);
FCF	=	Fuel conversion factor, equal to 3.16 kg CO_2/kg fuel for Jet-A fuel / Jet-A1 fuel and 3.10 kg CO_2/kg fuel for AvGas or Jet-B fuel;
$MS_{f,y}$	=	Total mass of a neat CORSIA eligible fuel claimed in the given year y (in tonnes), as described and reported in Field 12.b in Table A5-1 from Appendix 5;
LS_f	=	Life cycle emissions value for a CORSIA eligible fuel (in gCO_2e/MJ); and
LC	=	Baseline life cycle emissions values for aviation fuel, equal to 89 gCO_2e/MJ for jet fuel and equal to 95 gCO_2e/MJ for AvGas.

Consequently, emissions reduction that can be claimed depend on the CEF used and its actual impact on CO_2 emissions. To do so, aeroplane operators shall determinate the Life cycle emissions of the CEF (LS_f), which will be compared to the Baseline life cycle emissions values of aviation fuel. The LS_f of a CEF takes into account the emission during all fuel life, from the production at source (e.g., feedstock cultivation), to the fuel combustion in an aircraft engine.

Aeroplane operators may use two different values as LS_f in the above formula:

1. the Default Life Cycle Emissions value for the concerned CEF, which are provided by the ICAO directly on its website[304];
2. the actual Life Cycle Value of the CEF used, calculated according to the methodology also provided by the ICAO on its website[305]. Such a LS_f is essentially used when a fuel producer can demonstrate that its CEF has a lower core life cycle emissions compared to the Default LS_f.

   If an aeroplane operator uses an actual LS_f, it has to select a SCS, which will ensure that the analysis is in accordance with the methodology settled by the ICAO and that relevant information on GHG emissions is transmitted through the chain of custody.

Finally, the emissions reduction claimed by an aeroplane operator is verified by the independent Verification Body when conducting the verification of its Emission Report[306] before submitting its emissions report to the competent State which will perform an order or magnitude check of the emissions reported[307] (indeed, the State does not need to review the Emissions Report in detail but should perform checks to ensure that the information in the report is plausible and complete) before transmitting it to report the data to the CORSIA Central Registry (CCR).

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[304] https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2006%20-%20Default%20Life%20Cycle%20Emissions.pdf

[305] https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2007%20-%20Methodology%20for%20Actual%20Life%20Cycle%20Emissions.pdf

[306] Annex 16, Volume IV, Appendix 6, 3.3.1.

[307] Annex 16, Volume IV, 2.4.1.5.

2.3.3.6.2 Enforceability of the use of CORSIA eligible fuels

The implementation elements put into place by ICAO enables to ensure the enforceability of the use of CEF and a uniform application across the States since:

1. all conditions to meet to constitute a CEF are directly provided by the ICAO on its website and are therefore the same regardless of the aeroplane operator or the country concerned;
2. the same can be said regarding the LS_f needed to calculate the emission reductions that can be claimed by for the use of the CEF, since the Life Cycle Analysis (LCA) provides both the Default LS_f and the methodology to determinate the actual LS_f of a given CEF;
3. all these requirements are verified by SCS (compliance with Sustainability criteria and determination of the LS_f), which are directly nominated by the ICAO following the technical assessment and recommendation of the CAEP[308] according to rules also directly provided by the ICAO on its website. All SCS will therefore comply with the same rules.
4. SCS are also controlled by the CAEP after their certification in order to verify whether they maintain compliance with the certification requirements via[309]:
   - the planning of review of the SCS by the ICAO periodically, or after a complaint;
   - a system of transparency according to which SCS have to make public certain data such as the list of fuel producers it has certified;
   - the obligation to provide to the ICAO an annual report;
   - etc.

To that extent, the risks of a race to the bottom[310] depending on the country regarding these fuels could be considered rather low. On the contrary, the enforceability of the use of CEF appears to be robust and it may be assumed that, with these rules, the use of CEF will be enforced uniformly across the States and will enhance the use of CEF which, by definition, achieve net greenhouse gas emission reductions of at least 10% compared to conventional jet fuel on a life cycle basis.

However, the following aspects may reduce the effectiveness of the system:

- Reservations from ICAO Member States

Several ICAO Member States have already made reservations which will render the implementation of the CEF System highly difficult in these countries.

As an example, China, made:

- a reservation on paragraph 6 of the Resolution adopted at the 40th Assembly specifically related to the implementation of CEF system, China considering this system to "*lack of fairness, scientific justification and feasibility*", and that "*the definition of CORISA eligible fuels as no scientific basis*"[311].

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308 CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes, p.11

309 CORSIA Eligibility Framework and Requirements for SCS

310 The race to the bottom refers to a competitive state where a company, state or nation attempts to undercut the competition's prices by sacrificing quality standards or worker safety, defying regulations, or paying low wages. https://www.investopedia.com/terms/r/race-bottom.asp

311 Reservations of the Chinese Delegation to the 40th session of the Assembly, paragraph 15.

- A reservation on paragraph 19 of the Resolution adopted at the 40th Assembly relating to the implementation of the CORSIA System as a whole (including CEF System)[312].

India, as China, made a reservation on paragraph 19 of the Resolution adopted at the 40th Assembly relating to the implementation of CORSIA System as a whole[313].

Saudi Arabia[314] and Venezuela[315] both made reservations on the aspirational goal of keeping the global net carbon emissions from international aviation from 2020 as the same level, which of course may have an impact on the implementation of CEF System in these countries.

The Russian Delegation made a reservation[316] on the entire Resolution A40-19 adopted at the 40th Assembly, by declaring that the "*it does not find possible to join this resolution as a whole and intends, when it sees fit, to apply the provisions of Article 38*" relating to the notification of differences with the SARPs included in the Annex 16 to the Chicago Convention.

Such reservations constitute a major downside for the implementation of CEF System.

SCS may assess differently the fuels which could constitute CEF

One of the risks which may affect the functioning of the CEF System is if the CEF are not assessed the same way by all SCSs. If the interpretation of the sustainability criteria differs between SCSs, some aeroplane operators could potentially claim emissions reductions by using a fuel that would not comply with Sustainability criteria to the same extent as others. This would tilt the level-playing field and have environmental consequences if operators choose more lenient SCSs.

The origin of such a risk is the fact that CEF system is not completely centralized. It is not CAEP, but SCS, who grant CEF certification and verify the application of the actual LSf methodology. The occurrence of such a risk will depend on different factors, such as the number of SCSs that will be approved and how ICAO (CAEP) will carry out the controls of the SCS set out in the "CORSIA Eligibility Framework and Requirements for SCS".

The definition of CEF itself may reduce the impact of the use of CEF

The impact of the CEF System may be reduced due to the definition of CEF itself.

Indeed, following the position of countries such as Saudi Arabia and the United States[317], ICAO Council agreed to allow aeroplane operators to reduce their offsetting requirements through the use of so-called "Lower Carbon Aviation Fuels" (LCAF). LCAF are fossil-based jet fuels required to comply with the CORSIA sustainability criteria and achieving emission savings at least as high as those required from SAF of 10%. Some fuels might be already in the position to produce some fuels. The sustainability criteria for LCAF, including how to apply the emissions reductions criterion, are under discussions in ICAO and will not be operational for the pilot phase.

312 Reservations of the Chinese Delegation to the 40th session of the Assembly, paragraph 15.

313 Reservations of the Indian Delegation to the 40th session of the Assembly, page 2.

314 Reservations of the Saudi Arabian Delegation to the 40th session of the Assembly.

315 Reservations of the Venezuelan Delegation to the 40th session of the Assembly.

316 Reservations of the Russian Delegation to the 40th session of the Assembly

317 https://www.transportenvironment.org/press/airlines-can-count-oil-%E2%80%98green%E2%80%99-under-latest-weakening-un-carbon-scheme; https://www.greenaironline.com/news.php?viewStory=2499.

The risk of including LCAF in CORSIA is mitigated by the fact that emission reductions that can be claimed from the use of fuel under CORSIAs is directly proportionate to the GHG performance of the fuel on a life cycle basis (via the formula settled by the ICAO). The carbon intensity of fossil based fuels being high (and no lower than the engine combustion emissions of 74geCO_2/MJ), the benefits to be claimed from the use of LCAF under CORSIA is small per quantity of LCAF, but if scaled up, could constitute a massive reduction of offsetting requirements, as only emissions above the baseline need to be offset in CORSIA. Importantly, it should be noted that the definition of a methodology for the accounting of LCAF under CORSIA is currently ongoing. Until a methodology has been defined and adopted for the use of LCAF, this type of fuel cannot claim benefits under CORSIA.

If aeroplane operators wish to claim more emission reductions, they will therefore use fuels which achieve higher emission savings, i.e. the sustainable fuels.

2.3.4 The EUC and quality of offset credits

To achieve CORSIA's headline goal of delivering "carbon neutral growth" for the international aviation sector from 2020, there are essentially four options available to aeroplane operators:

- Growth in sector emissions can be avoided by avoiding any increase in aggregated global aviation traffic without altering the emissions' intensity of flights;
- Growth in sector emissions can also be avoided by reducing the emissions' intensity of flights, for example with more fuel-efficient aircraft;
- Growth in sector emissions can be reduced through the use of alternative fuels, allowing for a corresponding increase in global activity;
- Finally, international aviation sector emissions can grow, with any growth offset via the purchase of a corresponding volume of carbon offset credits. These credits – referred to as 'emission units' – reflect the delivery of emission reductions primarily in other sectors.[318]

For carbon credits to effectively offset the actual emissions that aircraft release into the atmosphere, it is critical that they offer a firm guarantee to represent emission reductions that would not have occurred otherwise; are accurately measured, reported, and verified; are permanent; ensure that they will not lead to any increase in emissions elsewhere; and are only claimed once towards any climate target. Consideration of the 'quality' of carbon credits reflects the extent to which they are likely to fulfil this guarantee.

Under most scenarios global aviation traffic is expected to grow over the coming years and decades at a rate that will exceed technological and operational improvements to reduce the emission's intensity of flights. Depending on criteria determining the eligibility of emissions units and the strictness of their application, the use of "alternative fuels" towards an aeroplane operator's CORSIA compliance obligation is likely to be significantly more expensive than purchasing carbon offset credits: IATA estimates that alternative biofuels cost between two and three times more than conventional fuel[319]; the IEA confirms this and estimates that novel advanced aviation biofuels cost between two and a half to over

[318] The number of existing emission reduction crediting methodologies in the aviation sector are very limited and do not represent a large volume of currently available offsets. This may however change over the course of CORSIA. One example of an offset methodology in the aviation sector is however: "AM0116: Electric taxiing systems for airplanes" available here: https://cdm.unfccc.int/methodologies/DB/DH4MT0YS5TCNEZIO1UO61M0Q5OLHU2

[319] https://airlines.iata.org/analysis/the-cost-of-going-green

four times more than conventional fuels[320]. The ICCT projected a range of €217 to over €4,000 per tonne of CO_2e reduced for biofuels in the EU. It is therefore likely that the obligations placed on aeroplane operators under CORSIA will be met largely through the purchase and cancellation of carbon offset credits[321]. As a consequence, assessing the quality of the credits that might be used for compliance under CORSIA is critically important to evaluating the overall climate impact of the scheme.

2.3.4.1 Eligibility of carbon offset programmes and credits for use under CORSIA

Through the ICAO GMTF workstream on 'Emissions Unit Criteria' (EUC),[322], a set of emissions unit eligibility criteria were developed to measure the quality of emissions units – its term for carbon offset credits - eligible for compliance. The criteria were approved by the ICAO Council in March 2019. The EUCs set out by ICAO provide high-level guidance related to the carbon offset credits that may be eligible for use under CORSIA and their application, both individually and as a whole have the potential to determine the extent to which offsets purchased will result in actual emission reductions to compensate for any increased emissions above the CORSIA baseline.

While the criteria relate to the characteristics of emission reduction projects, they should be applied at the offset programme level "as the expertise and resources needed to develop and implement ICAO emissions criteria at a methodology and project level is likely to be considerable".[323] There are therefore two sets of eligibility criteria: design elements for the required programmes that eligible programmes should fulfil, and those of the emission units that can be used for compliance. ICAO's "Program Design Elements" and descriptions of these elements are listed in Table 3 and the "Carbon Offset Credit Integrity Assessment Criteria" are listed in Table 4 along with some guidance on how each criterion is to be interpreted.

Table 3. CORSIA Emissions Unit Eligibility Criteria – Program Design Elements

1. Clear Methodologies and Protocols, and their Development	Programs should have qualification and quantification methodologies and protocols in place and available for use as well as a process for developing further methodologies and protocols. The existing methodologies and protocols as well as the process for developing further methodologies and protocols should be publicly disclosed.
2. Scope Considerations	Programs should define and publicly disclose the level at which activities are allowed under the program (e.g., project-based, program of activities, etc.) as well as the eligibility criteria for each type of offset activity (e.g., which sectors, project types, or geographic locations are covered).
3. Offset Credit Issuance and Retirement Procedures	Programs should have in place procedures for how offset credits are: (a) issued; (b) retired or cancelled; (c) subject to any discounting; and, (d) the length of the crediting period and whether that period is renewable. These procedures should be publicly disclosed.

320 https://www.iea.org/commentaries/are-aviation-biofuels-ready-for-take-off

321 Nikita Pavlenko, Stephanie Searle, and Adam Christensen, "The Cost of Supporting Alternative Jet Fuels in the European Union," 2019, https://theicct.org/publications/cost-supporting-alternative-jet-fuels-european-union.

322 https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2009.pdf

323 https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2009.pdf

4. Identification and Tracking	Programs should have in place procedures that ensure that: (a) units are tracked; (b) units are individually identified through serial numbers: (c) the registry is secure (i.e., robust security provisions are in place); and (d) units have clearly identified owners or holders (e.g., identification requirements of a registry). The program should also stipulate (e) to which, if any, other registries it is linked; and, (f) whether and which international data exchange standards the registry conforms with. All of the above should be publicly disclosed information.[324]
5. Legal Nature and Transfer of Units	The program should define and ensure the underlying attributes and property aspects of a unit, and publicly disclose the process by which it does so.
6. Validation and Verification procedures	Programs should have in place validation and verification standards and procedures, as well as requirements and procedures for the accreditation of validators and verifiers. All of the above-mentioned standards, procedures, and requirements should be publicly disclosed.
7. Program Governance	Programs should publicly disclose who is responsible for administration of the program and how decisions are made.[325]
8. Transparency and Public Participation Provisions	Programs should publicly disclose (a) what information is captured and made available to different stakeholders; and (b) its local stakeholder consultation requirements (if applicable) and (c) its public comments provisions and requirements, and how they are considered (if applicable). Conduct public comment periods and transparently disclose all approved quantification methodologies.
9. Safeguards System	Programs should have in place safeguards to address environmental and social risks. These safeguards should be publicly disclosed.
10. Sustainable Development Criteria	Programs should publicly disclose the sustainable development criteria used, for example, how this contributes to achieving a country's stated sustainable development priorities, and any provisions for monitoring, reporting and verification.
11. Avoidance of Double Counting, Issuance and Claiming	Programs should provide information on how they address double counting, issuance and claiming in the context of evolving national and international regimes for carbon markets and emissions trading.

The "Carbon Offset Credit Integrity Assessment Criteria" (see Table 4) reflect and are mostly a collection of principles related to quality and environmental integrity of emission reduction and removal credits that have established precedent in international agreements such as the Kyoto Protocol[326], the Paris Agreement[327], as well rules and regulations that

[324] Some further information on the interpretation of the "Identification and Tracking" criterion is provided in the CORSIA Application Form, Appendix A – Supplementary Information: https://www.icao.int/environmental-protection/CORSIA/Documents/TAB/TAB%202020/Programme_Application_Form_Appendix_A_Supplementary_Information_2020.docx

[325] As for "Identification and Tracking" some further information is provided in the aforementioned Appendix A

[326] https://unfccc.int/documents/2409

[327] https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf

various jurisdictions have set out in rules and regulations for example in sub-national cap-and-trade programs such as California.[328] The International Carbon Reduction & Offset Alliance, an industry body of carbon offset and offset providers also lists many of them in their code of best practice.[329] Previous studies carried out on behalf of the European Commission have in particular examined questions of additionality and baseline testing; contribution to sustainable development; as well as governance including transparent and consistent decision making.[330,331] A number of these criteria have also been the subject of significant academic study and debate.[332]

[328] See for example, the European Emissions Trading Scheme Regulation COMMISSION REGULATION (EU) No 550/2011 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32011R0550 ; the California Air Resources Board General Requirements for ARB Offset Credits (https://ww3.arb.ca.gov/cc/capandtrade/ct_reg_unofficial.pdf)

[329] ICROA. ICROA Code of Best Practice, https://www.icroa.org/The-ICROA-Code-of-Best-Practice

[330] Ruthner et al. Study on the Integrity of the Clean Development Mechanism (CDM). https://ec.europa.eu/clima/sites/clima/files/ets/markets/docs/final_report_en_0.pdf

[331] Cames et al. How additional is the Clean Development Mechanism?. Available at: https://ec.europa.eu/clima/sites/clima/files/ets/docs/clean_dev_mechanism_en.pdf

[332] Broekhoff et al. curing Climate Benefit: A Guide to Using Carbon Offsets. 2019. Available at: http://www.offsetguide.org/wp-content/uploads/2020/03/Carbon-Offset-Guide_3122020.pdf

Table 4. ICAO Carbon Offset Credit Integrity Assessment Criteria

Stipulation that emission reductions, avoidance, or sequestration that:	Further explanation of the criterion[333]:
1. Are additional	Additionality means that that the carbon offset credits represent greenhouse gas emissions reductions or carbon sequestration or removals that exceed any greenhouse gas reduction or removals required by law, regulation, or legally binding mandate, and that exceed any greenhouse gas reductions or removals that would otherwise occur in a conservative, business-as-usual scenario. Eligible offset credit programs should clearly demonstrate that the program has procedures in place to assess/test for additionality and that those procedures provide a reasonable assurance that the emissions reductions would not have occurred in the absence of the offset program. If programs pre-define certain activities as automatically additional (e.g., through a "positive list" of eligible project types), then they have to provide clear evidence on how the activity was determined to be additional. The criteria for such positive lists should be publicly disclosed and conservative. If programs do not use positive lists, then project's additionality and baseline setting should be assessed by an accredited and independent third-party verification entity and reviewed by the program.
2. Are based on a realistic and credible baseline	Offset credits should be issued against a realistic, defensible, and conservative baseline estimation of emissions. The baseline is the level of emissions that would have occurred assuming a conservative "business as usual" emissions trajectory i.e., emissions without the emissions reduction activity or offset project. Baselines and underlying assumptions must be publicly disclosed.
3. Are quantified, monitored, reported, and verified	Emissions reductions should be calculated in a manner that is conservative and transparent. Offset credits should be based on accurate measurements and quantification methods/protocols. Monitoring, measuring, and reporting of both the emissions reduction activity and the actual emissions reduction from the project should, at a minimum, be conducted at specified intervals throughout the duration of the crediting period. Emissions reductions should be measured and verified by an accredited and independent third-party verification entity. Ex-post verification of the project's emissions must be required in advance of issuance of offset credits; Programs that conduct ex-ante issuance (e.g., issuance of offset units before the emissions reductions and/or carbon sequestration have occurred and been third-party verified) should not be eligible. Transparent measurement and reporting is essential, and units from offsetting programs/projects eligible in a global MBM should only come from those that require independent, ex-post verification.

[333] Some further guidelines for the interpretation of these criteria is provided in Programme Application Form Appendix A Supplementary Information: https://www.icao.int/environmental-protection/CORSIA/Documents/TAB/TAB%202020/Programme_Application_Form_Appendix_A_Supplementary_Information_2020.docx

Stipulation that emission reductions, avoidance, or sequestration that:	Further explanation of the criterion[333]:
4. Have a clear and transparent chain of custody	Offset credits should be assigned an identification number that can be tracked from when the unit is issued through to its transfer or use (cancellation or retirement) via a registry system(s).
5. Represent permanent emission reductions	Carbon offset credits must represent emissions reductions, avoidance, or carbon sequestration that are permanent. If there is risk of reductions or removals being reversed, then either (a) such credits are not eligible or (b) mitigation measures are in place to monitor, mitigate, and compensate any material incidence of non-permanence.
6. Assess and mitigate against potential increase in emissions elsewhere	Offset credits should be generated from projects that do not cause emissions to materially increase elsewhere (this concept is also known as leakage). Offset credit programs should have an established process for assessing and mitigating leakage of emissions that may result from the implementation of an offset project or program.
7. Are only counted once towards a mitigation obligation	Measures must be in place to avoid: a) Double issuance (which occurs if more than one unit is issued for the same emissions or emissions reduction). b) Double use (which occurs when the same issued unit is used twice, for example, if a unit is duplicated in registries). c) Double claiming (which occurs if the same emissions reduction is counted twice by both the buyer and the seller (i.e., counted towards the climate change mitigation effort of both an airline and the host country of the emissions reduction activity)). In order to prevent double claiming, eligible programs should require and demonstrate that host countries of emissions reduction activities agree to account for any offset units issued as a result of those activities such that double claiming does not occur between the airline and the host country of the emissions reduction activity.
8. Do no net harm	Offset projects should not violate local, State/provincial, national or international regulations or obligations. Offset programs should show how they comply with social and environmental safeguards and should publicly disclose which institutions, processes, and procedures are used to implement, monitor, and enforce safeguards to identify, assess and manage environmental and social risks.

The application of these criteria to the programme applications can be carried out to various degrees of stringency. Rather than attempt to build the capacity within the ICAO secretariat to assess projects and credits units against these criteria, the ICAO Council decided to leave this assessment to the "eligible programs" and instead provide guidance regarding the provisions that the programs should have in place in order to ensure that their projects meet these criteria. In order to 'assess the programs' ability to fulfil these criteria, the ICAO Council created a "Technical Advisory Body"[334] to provide the ICAO Council with recommendations for eligible programs.

Based on the January 2020 TAB report entitled "Recommendations on CORSIA Eligible Emission Units"[335] it is clear that some criteria have not been uniformly and consistently applied with regard to an assessment of the programme applications.

In a press release dated 13 March 2020, ICAO stated that "following the recommendations it received from the Technical Advisory Body"[336] the ICAO Council had approved six programmes: the American Carbon Registry (ACR); the China GHG Voluntary Emission Reduction Program (CCER); the Clean Development Mechanism (CDM); the Climate Action Reserve (CAR); the Gold Standard (GS); and the Verified Carbon Standard (VCS) to supply emission units for CORSIA compliance. Subsequently, an official document reiterating the approval decision was posted on the ICAO website confirming the press release[337].

One critical study analysing the performance of the various applicant programmes with regard to five of the eight ICAO carbon offset credit integrity criteria found that none of the 14 offset programme applicants fulfil all the criteria, although the performance of programmes compared to the criteria vary substantially.[338] This assessment is echoed in several of the comments submitted to ICAO in response to the offset programme applications.[339]

Our assessment here reviews the recommendations of the TAB as posted on the ICAO website which were directly adopted by the ICAO Council without changes. The following provides an overview of the TAB's assessment of the six programmes that it recommended for eligibility for activities that started their first crediting period from 1 January 2016 and for emission reductions that occurred through 31 December 2020 for the 2021-2023 CORSIA compliance cycle.

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[334] See: https://www.icao.int/environmental-protection/CORSIA/Pages/TAB.aspx

[335] ICAO Technical Advisory Body. Recommendations on CORSIA Eligible Emission Units. January 2020. Available at: https://www.icao.int/environmental-protection/CORSIA/Documents/TAB/Excerpt_TAB_Report_Jan_2020_final.pdf

[336] ICAO 2020. News Release: ICAO Council adopts CORSIA emissions units https://www.icao.int/Newsroom/Pages/ICAO-Council-adopts-CORSIA-emissions-units.aspx

[337] https://www.icao.int/environmental-protection/CORSIA/Documents/TAB/TAB%202020/ICAO_Doc_CORSIA_Eligible_Emissions_Units_March_2020.pdf

[338] https://www.oeko.de/fileadmin/oekodoc/Lessons-learned-from-CORSIA-applications.pdf

[339] https://www.icao.int/environmental-protection/CORSIA/Documents/TAB/TAB_Public%20comments_Consolidated.pdf

Table 5. Overview of TAB findings in the application of EUC to applicant programmes (based on author's assessment of TAB report)

	Design Elements											Carbon Offset Credit Integrity Assessment Criteria							
Programmes recommended for immediate eligibility	Methodologies and Protocols	Scope	Issuance and Retirement Procedures	Identification and Tracking	Legal Nature	Validation and Verification	Governance	Transparency and Public Participation	Safeguards	Sustainable Development	Double Counting	Additionality	Baselines	Quantified / MRV	Chain of Custody	Permanence	Leakage	Double Counting	No Net Harm
ACR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✗	✓
CCER	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	✗	✓
CDM	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	✓	✗	✓	✗	✗
CAR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	✗	✓	✓	✓	✗	✓
GS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	✓	✗	✓
VCS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓	✗	✗	✗	✓
Programmes recommended for conditional eligibility or to re-apply																			
FCPC	✓	✓	✓	✓	✓	✗	✗	✓	✓	✓	✗	✓	✓	✓	✓	✗	✓	✗	✓
GCC	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	✓	✓	✓	✗	✓
BCOP	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✓	✓	✓	✓	✓	✓	✗	✗
T-VER	✓	✓	✓	✗	✓	✓	✓	✓	✗	✓	✗	✗	✓	✓	✓	✓	✓	✗	✗

✓ Criteria fulfilled ✗ Criteria not fully fulfilled

Notable aspects of the TAB assessment process

The TAB assessment process has showed that overall, the eligible programmes meet the majority of criteria and design elements. However, this evaluation has revealed some inconsistency in the application of the emission unit criteria (EUC). None of the programmes that were recommended for eligibility to supply emissions units to CORSIA fulfil all the EUC, notably the avoidance of double counting (Table 5). The CDM was recommended for eligibility despite the TAB's finding that it did not fulfil multiple criteria, including various criteria that appear to have led to a recommendation to not recommend programmes for eligibility in other cases. The TAB's findings appear to have put an emphasis on the programme design element criteria rather than on the "Carbon Offset Credit Integrity Assessment Criteria". Among the programmes recommended for eligibility, other than the CDM, those that did not completely fulfil the design element criteria, namely the VCS and CAR, had those methodologies excluded from eligibility.

With regard to "Carbon Offset Credit Integrity Assessment Criteria", the CDM and "programmes modelled after the CDM, at least in their initial stages" – Gold Standard and CCER – were recommended for eligibility although the TAB assessment found that they failed to fully meet criteria for additionality and baseline setting. Subsets of programmes that failed to satisfactorily address permanence and leakage were in some cases excluded.

In several cases, programmes expressed the intention to fulfil criteria in the future, but their eligibility was not made conditional on their fulfilment of the criteria that they do not currently meet. In some cases, TAB recommended programmes for eligibility for the pilot period with the exclusion of credits coming from projects based on certain methodologies[340] – however in a number of areas where TAB finds that a programme does not meet a criterion, the TAB recommendations do not call for the exclusion of credits from certain methodologies. In some cases, but not in others, the TAB evaluation only reviewed if an offset programme had a certain approach or rule to address and issue, but not if these approaches and rules were effective in their intended purpose.

Application of the additionality criterion

The TAB's recommendations recognise that multiple programmes do not fulfil the additionality criteria and make a clear decision to not apply it for several programmes[341]. The CORSIA Emissions Unit Eligibility Criteria's clarification of the additionality criterion explicitly specifies that emission reductions must "*exceed any greenhouse gas reduction or removals required by law, regulation, or legally binding mandate, and that exceed any greenhouse gas reductions or removals that would otherwise occur in a conservative, business-as-usual scenario*".[342] Although the EUC vary in detail with regard to guidance with which the criteria should be interpreted, the guidance on this aspect is among the most clear and most explicit – with a clear addition of consideration of regulatory additionality regardless of regulatory enforcement in certain jurisdictions.

The TAB found that several programmes meet this criterion and do not credit emission reductions where the emission reductions are anyway required by law. The TAB also

[340] See exclusions for example for multiple specific CCER methodologies, CAR and Gold Standard ex-ante crediting (which the respective programmes specifically excluded from requested TAB evaluation), VCS jurisdictional and nested REDD+ (JNR), VCS credits that have not reported on their contribution to sustainable development, and CDM CER's from afforestation and reforestation activities.

[341] See excerpt from the TAB report of January 2020 https://www.icao.int/environmental-protection/CORSIA/Documents/TAB/TAB_JANUARY_2020_REPORT_EXCERPT_SECTION_4.EN.pdf

[342] https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2009.pdf

specifically notes that the CCER[343], the CDM[344], and the Gold Standard[345] do not meet this criterion, but recommend their eligibility anyway for the pilot phase. The CCER and Gold Standard methodologies are largely based on CDM methodologies which the TAB notes is likely responsible for this result "at least in their initial stages".

While the CDM modalities and procedures specify that baselines "shall be established taking into account relevant national and/or sectoral policies and circumstances" (decision 3/CMP.1, para 45(e)), in 2005 the CDM Executive Board (EB) decided to not consider policies that took effect after 1997 that benefit emissions intensive technologies, or policies that took effect after 2001 which benefit less emissions intensive technologies. The EB's decision was taken in order to address perverse incentives to support emission intensive activities and discourage emissions savings activities in order to make crediting activities additional, but at the same time undermined the environmental integrity of the additionality testing. A small revision in 2013 called for disregarding policies that favour less emission intensive technologies for only the first seven years from the implementation date of a given policy (CDM-EB73, para. 70).

In a study carried out for the European Commission, Cames et al. find that "the large majority of the projects registered and CERs issued under the CDM are not providing real, measurable and additional emission reductions"[346]. Namely that "73% of the potential 2013-2020 CERs have a low likelihood that emission reductions are additional and not over estimated".[347]

As an explanation for its recommendation of the CCER, CDM, and Gold Standard despite their failure to meet the criteria, the TAB report cites that "the EUC were only finalized in 2019" and that "programmes and their stakeholders would benefit from more time to familiarize themselves with the criterion and its implications". The TAB report does not mention that all programmes had an equal amount of time to familiarise themselves with the criterion.

Application of the baseline criterion

The TAB recommendations only mention that the Gold Standard does not meet the emission unit criteria with regard to baselines – finding that: "*the Gold Standard allows small-scale projects to use a baseline setting approach that boosts crediting in contexts where supressed demand for energy services due to, e.g., under-development can lead to smaller (and fewer) projects. The Gold Standard applies a CDM tool to determine that these projects are small-scale, whereas the application of the tools can result in issuance volumes that exceed conventional definitions of small-scale. Experts noted that this tool does not resolve underlying concerns about the conservativeness of the baselines, in line with TAB's interpretation of this criterion*." As mentioned, the Gold Standard's approach is based on CDM tools, but the TAB report omits that the CDM also fails to meet the baseline criterion for the same reasons as the Gold Standard.[348]

At the same time, as a result of their development process under the UNFCCC, CDM methodologies and the approach taken to estimate baselines is a relatively transparent process open to public scrutiny. It has further been the subject of a significant amount of

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343 See excerpt from TAB Report Section 4.2.3.2

344 See excerpt from TAB Report Section 4.2.4.4

345 See excerpt from TAB Report Section 4.2.6.3

346 https://ec.europa.eu/clima/sites/clima/files/ets/docs/clean_dev_mechanism_en.pdf

347 Ibid.

348 Although the CCER also generally uses CDM methodologies, CCER projects are carried out in China and the inflation of baselines to account for supressed demand is primarily for projects in poorer developing countries and LDCs.

academic study – and critique. This is not the case with regard to some of the other programmes which neither provide information on their processes in their CORSIA applications, nor on their websites – or do not make information available in English.[349] The TAB report failed to recognise or comment on this fact. Because of this lack of transparency and stringency of examination it is unclear if other offset programmes are significantly better than the Gold Standard or the CDM, despite TAB's assessment of their baseline setting approaches.

Application of the quantified, monitored, reported, and verified criterion

The TAB did not find that any offset programme failed to fulfil the "quantified, monitored, reported, and verified" criterion. However, Schneider[350] points out that various programmes use different Global Warming Potentials (GWP) for various gasses, which leads to different quantification results when non-CO_2 GHG are converted into CO_2 equivalents and used for compliance under CORSIA. IPCC recommendations to estimate GWP have evolved over time based on the advancement of scientific research but have become codified differently by different offset programmes. This heterogeneous approach to quantification of the GWP of different gases leads to market distortion within the CORSIA system.

Application of permanence criterion

With respect to the criterion that emissions units must "represent permanent emissions reductions" or to have "mitigation measures are in place to monitor, mitigate, and compensate any material incidence of non-permanence". In the context of the programmes that applied for CORSIA eligibility, this mostly relates to forestry and land use projects, in many cases what is known as reducing deforestation and land degradation (REDD) as well as afforestation and reforestation. This is important because once emitted, CO_2 from aircraft fuels will stay in the atmosphere for thousands of years according to some estimates – though shorter estimates exist depending on accounting and estimates of terrestrial and oceanic uptake of atmospheric CO_2 which themselves are in a state of flux[351]. Any effort to offset such an emission – for example through preserving or planning forests – should ensure that it corresponds to a similar timeframe.[352] This is challenging since there are multiple dynamic drivers of deforestation, both human and natural, and measures to reduce deforestation today may not be effective in the future. Notably, climate change is predicted to be a major driver of deforestation with a potential net global loss of 223 million hectares by 2050 under Business as Usual (BaU) scenario (RCP 8.5).[353] The TAB report includes a lengthy discussion of the application of the permanence criterion noting that: "the criterion and guidelines only define permanence by function"[354], but not whether the provisions in place "to monitor, mitigate, and compensate any material incidence of non-permanence" are effective or sufficient to ensure permanence.

[349] https://www.oeko.de/fileadmin/oekodoc/Lessons-learned-from-CORSIA-applications.pdf

[350] https://www.oeko.de/fileadmin/oekodoc/Lessons-learned-from-CORSIA-applications.pdf

[351] Archer, D. et al. (2009). „Atmospheric Lifetime of Fossil Fuel Carbon Dioxide". Annual Review of Earth and Planetary Sciences. Available: http://climatemodels.uchicago.edu/geocarb/archer.2009.ann_rev_tail.pdf

[352] Schneider, Conway, Kachi, & Hermann, 2018. Crediting Forest-related Mitigation under International Carbon Market Mechanisms. Available at: https://newclimate.org/2018/09/19/crediting-forest-related-mitigation-under-international-carbon-market-mechanisms/

[353] Bastin, JF et al. 2019. The global tree restoration potential. Science 365, 76–79. Available at: https://science.sciencemag.org/content/365/6448/76/tab-figures-data

[354] See excerpt from TAB Report section 4.3.2.4

The TAB report notes a discussion on "the timeframe for which activities are required to monitor and compensate for reversals" and arrives at a compromise timeframe of at least the "period of time between when the programmes were assessed (2019) and the end of CORSIA's implementation period (2037). This is the only point on which the TAB report notes dissent among the experts in the group: "a few experts expressed the view that permanence CO_2 generally stays in the atmosphere for more than 100 years, most of it much longer, and noted that only one programme assessed requires measures that provide for permanence over such a timeframe."

Even with this shortened time horizon of 2037, the TAB recommended excluding the VCS Jurisdictional and Nested REDD+ Framework (JNR), which only monitors permanence for the duration of the 10 year crediting period (renewable twice); and the FCPF, which cannot guarantee its existence past 2025.[355] Further, the CDM's approach of issuing temporary credits was deemed not to meet the required criteria and was also excluded, representing the only instance where the CDM failed to meet a criterion which led the TAB to recommend an exclusion from eligibility.

Application of the leakage criterion

The IPCC defines leakage as "the unanticipated decrease or increase in GHG benefits outside of the project's accounting boundary (the boundary defined for the purposes of estimating the project's net GHG impact) as a result of project activities[356]", for which the corresponding emissions unit criteria is if a programme "assess and mitigate against potential increase in emissions elsewhere criterion."

The TAB assessment mentions this criterion twice with regard to the applicant programmes. In both cases the assessment only checked to see if the applicant programme has measures to assess and mitigate against an increase in emissions elsewhere rather than if these measures are effective in doing so. With regard to the VCS, the TAB members found that JNR projects allow for a "nesting" into a jurisdictional baseline without jurisdiction-level monitoring and therefore fail to meet the criteria and are excluded, although the VCS programme as a whole was accepted. The British Colombia Offset Program (BCOP) is found to meet the criteria but was not recommended for eligibility because of a failure to meet other criteria.

Aukland et al.[357] categorise leakage into primary and secondary leakage. With primary leakage, the actors responsible for the original primary baseline emissions shift their activities elsewhere. Secondary leakage refers to when a project's outputs create incentives, for example through price fluctuations in international commodity markets, that lead to increased emissions elsewhere. Leakage can also occur between sectors, for example, if in order to reduce deforestation, land is protected, but in order to allow similar levels of agricultural production, more fertiliser is applied to existing fields. In this case the reduced deforestation emissions lead to an increase in emissions in nitrous oxides from fertiliser.

For forestry projects, Kissinger et al. found that some programmes apply a discount factor of up to 40%, reflecting the difficulty of measuring the actual net emission reductions after leakage considerations. Such a discount factor is an approach used by ACR, VCS, and

[355] https://www.icao.int/environmental-protection/CORSIA/Documents/TAB/Excerpt_TAB_Report_Jan_2020_final.pdf

[356] https://archive.ipcc.ch/ipccreports/sres/land_use/index.php?idp=263

[357] Aukland, L., Costa, P. M., & Brown, S. (2003). A conceptual framework and its application for addressing leakage: the case of avoided deforestation. Climate Policy, 3(2), 123–136. https://doi.org/10.3763/cpol.2003.0316 https://www.winrock.org/wp-content/uploads/2016/03/leakage.pdf

CAR.[358] Kissinger et al. further find that because leakage is related to the drivers of deforestation, and that such drivers change over time, it is particularly difficult to quantify the risk of leakage. Lambin and Meyfroidt[359] find that leakage may be global and likely impossible to entirely account for and therefore mitigate. This is particularly the case for globally traded commodities that are the primary drivers for deforestation.[360]

Application of the avoidance of double counting criterion

"As part of its assessment, TAB found that most programmes have not yet put in place procedures, provisions or measures to obtain and make publicly available attestations from national governments' designated agency contact which recognize and confirm that the units can be used under CORSIA, and in relation to accounting for the mitigation from the activities that supply these units"[361]. According to our analysis, none of the applying programmes currently have provisions in place to avoid double counting. The EUC stipulate that the host countries of emission reduction activities should "*agree to account for any offset units issued as a result of those activities such that double claiming does not occur between the airline and the host country of the emissions reduction activity*".[362] It is important to note that the EUC do not specifically refer to Nationally Determined Contributions, but instead use broader language of "a mitigation obligation", which could also be interpreted to include other targets and pledges that host countries have made.

The TAB report notes that "programmes were not originally designed to support activities in national contexts that would necessitate such an attestation or any form of a national government". This is likely a reference primarily to the Kyoto Protocol and the associated Marrakech Accords, under which developing countries did not make mitigation commitments against which emission reductions could have been double counted.

The TAB recommendation to only allow emissions reduction units generated from activities through 31 December 2020 suggests that TAB made an interpretation of the drafted EUC that narrows the scope of the EUC to only consider NDCs as the type of mitigation obligation for which emission units should avoid double counting. However at least 36 non-Annex 1 countries pledged mitigation actions under the Copenhagen Accord[363], and more countries communicated pledges in Cancun in 2010 for emission reductions in the period to 2020. Schneider et al estimate that 77% of CDM CERs generated between 2013 and 2020 came from countries with a target or a pledge made in Copenhagen or Cancun.[364] Additionally, CAR and ACR have a significant number of credits from projects in the United States and Canada which also made pledges in Copenhagen and Cancun.

The TAB report notes that "most programmes expressed willingness to put in place measures" to avoid double counting and recognised that "some programmes' efforts to do

[358] https://newclimate.org/wp-content/uploads/2018/09/Studie_2018_REDD_and_carbon_markets.pdf

[359] Lambin, E. F., & Meyfroidt, P. (2011). Global land use change, economic globalization, and the looming land scarcity. Proceedings of the National Academy of Sciences, 108(9), 3465–3472. https://doi.org/10.1073/pnas.1100480108 Available at https://www.pnas.org/content/108/9/3465

[360] https://newclimate.org/wp-content/uploads/2018/09/Studie_2018_REDD_and_carbon_markets.pdf; https://www.ucsusa.org/resources/whats-driving-deforestation

[361] TAB report, 4.3.5.1

[362] https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2009.pdf

[363] OECD 2010. http://www.oecd.org/environment/cc/45441364.pdf

[364] https://www.atmosfair.de/wp-content/uploads/sei-pr-2017-using-the-clean-development-mechanism.pdf

so were well-advanced, and in some cases administered directly by the relevant national government agency". However, in the TAB's recommendations, the offset programmes' eligibility to supply units to aeroplane operators for CORSIA compliance was not made conditional on actually avoiding double counting for the 2016-2020 period. Also, Verra which manages the VCS made it clear in a press release accompanied by a webinar in reaction to its approval as an eligible programme that its interpretation is that the double counting criteria do not apply to vintages from 2016-2020.[365]

Although some countries have started to enter into bilateral agreements that include commitments to avoid double counting for internationally transferred mitigation outcomes (ITMOs), a uniform approach among host countries and offset programmes would best be codified in the final rules for carbon markets under the Paris Agreement. Here, Parties to the Paris Agreement have as yet been unable to agree on such rules, and with the postponement of COP26 to end of 2021, any new rules that Parties may be able to agree on will not be established in time for the TAB's review of the second round of offset programme applications for CORSIA, that will be carried out by the end of 2020.

Application of the safeguard and no net-harm criteria

Though not necessarily directly related to the question of the quality of the emission reduction in terms of global warming potential, with regard to a number of CDM projects headlines were made where project implementation was associated with human rights violations. Although no systematic review of the CDM has been conducted to date, this prompted calls for policy reforms and the implementation of environmental and social safeguards especially in the EU and the UNFCCC.[366]

In the TAB assessment, the "safeguard" criterion was grouped together with "no-net harm" criterion. "Net-harm" is a fairly novel term in the context of offset programmes, which have otherwise used the term "do no harm"[367]. The Verra VCS Standard however uses the term "net-harm" and implies that "negative environmental and socio-economic impacts" are acceptable if steps are taken to "mitigate them" in some way[368], the EUC description of how to interpret the criterion rather says that offset projects should comply with

[365] Verra. 2020. "The Verified Carbon Standard Program Has Been Accepted to Supply Carbon Credits under CORSIA" 15 March 2020. Available: https://verra.org/the-verified-carbon-standard-program-has-been-accepted-to-supply-carbon-credits-under-corsia/ (Accessed 24 April 2020).

[366] Examples of CDM projects that have attracted international attention include the Alto Maipo hydroelectric project in Chile, the Barro Blanco hydroelectric power project in Panama, the Bujagali hydropower project in Uganda, the Kachung forest project in Uganda (Timperley, 2019 - https://www.climatechangenews.com/2019/12/09/carbon-offsets-patchy-human-rights-record-now-un-talks-erode-safeguards/), the Santa Rita hydroelectric project in Guatemala (Nelsen, 2015 - https://www.theguardian.com/environment/2015/mar/26/santa-rita-green-dam-killings-indigenous-people-guatemala), Wind farms Oaxaca I, Oaxaca II, Oaxaca III, and Oaxaca IV, in Mexico (Mills et al., 2016 - https://d2oc0ihd6a5bt.cloudfront.net/wp-content/uploads/sites/1738/2016/05/Equitable_Origin_Case_Study_Wind_Development_in_Oaxaca_JAN_2016_1.pdf), the Olkaria IV Geothermal Project in Kenya (Schade, 2017 - https://www.ssoar.info/ssoar/bitstream/handle/document/51409/ssoar-2017-schade-Kenya_Olkaria_IV_Case_Study.pdf?sequence=1), the Sasan Power Ltd coal fired power plant in India (Sierra Club, 2014 - https://content.sierraclub.org/creative-archive/sites/content.sierraclub.org.creative-archive/files/pdfs/0856-DirtyDollars_02_web_pages.pdf), and the Aguan biogas project in Honduras (Nelsen, 2011 - https://www.theguardian.com/environment/2011/oct/03/eu-carbon-credits-murders-honduras).

[367] See for example: Gold Standard Annex H – GUIDANCE QUESTIONS FOR THE 'DO NO HARM' ASSESSMENT (https://www.goldstandard.org/sites/default/files/v2.2_annex-h_0.pdf).

[368] See Verra 2018. VCS Standard v3.7: https://verra.org/wp-content/uploads/2018/03/VCS_Standard_v3.7.pdf

applicable regulations and obligations and that programmes should have safeguards to guard against environmental and social risk.

As with the other criteria, TAB only assessed if a certain programme had some kind of approach or rule to address an issue, but not if these approaches and rules were effective in their intended purpose. Indeed, even the programmes that were found to fulfill the criteria are highly heterogeneous and offer a wide variety of safeguards, and approaches to avoid and mitigate environmental and social risk.

According to the TAB assessment, the CDM failed to fully meet these criteria as the CDM does not have programme level safeguards but rather only procedural rules such as environmental impact assessment that are applied subject to "expert judgement". The TAB further notes that social safeguards are considered "a host Party prerogative". Despite this, the TAB recommended the CDM for eligibility along with the Gold Standard and VCS. The GCC, BCOP and T-VER were excluded in part because of their failure to meet this criterion.

Safeguards further varied among standards deemed eligible but that TAB found to comply with the criteria. The VCS, managed by Verra, does not have a grievance mechanism and instead has a complaints policy that states that anyone filing a complaint must cover Verra' costs to address the complaint[369], an important dissuasion measure especially for disadvantaged communities which likely undermines any provisions to provide a check on the effectiveness of VCS' ability to comply with the "no-net harm criteria", but it was still recommended for eligibility. In contrast, the Gold Standard, similarly recommended for eligibility, has a comparatively comprehensive list of safeguarding principles and requires demonstration of compliance with those principles on an ongoing basis. Additionally, the Gold Standard has a transparent grievance procedure where submitted grievances are publicly displayed on their website with updates on how Gold Standard intends to address them.[370]

Application of the sustainable development criterion

Another criterion not necessarily directly related to the climate impact of an emission reduction project is the EUC requirement that eligible programmes "should publicly disclose the sustainable development criteria used, for example, how this contributes to achieving a country's stated sustainable development priorities, and any provisions for monitoring, reporting and verification". In its assessment of the extent to which the applicant programmes fulfilled this criterion, the TAB was not consistent across programmes.

The TAB found that the CDM did not meet this criterion and that the CDM instead "assigns host Parties the responsibility to define sustainable development priorities in their respective national contexts". A voluntary sustainable co-benefits tool enabling project proponents to report on benefits has been used for approximately 0.008% of registered projects. Despite this, the CDM was recommended for eligibility with no restrictions with regard to its projects fulfilment of the sustainable development criterion.

A similar finding was made for the CAR. The CAR encourages the use of voluntary sustainable development reporting frameworks but which is not mandatory. The TAB found that the VCS requires "activity proponents to report on how their activities contribute to achieving any nationally-stated Sustainable Development priorities" but does not provide guidance if such priorities are not stated. This is different for a number of projects that also either use the programme's Verra SD Vista or Climate Community Biodiversity Standards. Despite the recommendation for the CDM, the VCS and CAR had the eligibility

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[369] Verra. 2020. Complaints and Appeals Policy. https://verra.org/project/vcs-program/complaints-and-appeals-policy/

[370] Gold Standard. 2020. Grievances and Deregistration. https://www.goldstandard.org/our-story/grievances-deregistration

of their units limited to those that had reported on their contribution to sustainable development.

In comparison, failure to meet the sustainable development criterion was cited as a reason why GCC, and BCOP were not recommended for immediate eligibility.

2.3.5 MRV of emissions

2.3.5.1 Alignment between EU ETS MRV and CORSIA following the Implementing Regulation

Through the EU ETS Directive, the EU has gained experience in monitoring, reporting and verifying aviation emissions since 2010. The CORSIA provisions are largely similar to the EU ETS MRV. The EU decided to implement CORSIA provisions through the EU ETS in order to limit administrative burden for airlines while providing legal certainty. For that purpose the EU adopted a legally binding MRV package consisting of,

- Delegated Regulation[371] (EU) 2019/1603 of 18 July 2019 supplementing Directive 2003/87/EC was introduced. It addresses the scope of the MRV obligations for the purpose of implementing a global market-based measure, covering the flights addressed under CORSIA in addition to some flights already covered by the EU ETS under its reduce scope..
- Implementating Regulation (EU) 2018/2066 amending Commission Regulation (EU) 601/2012 (commonly referred to as the Monitoring and Reporting Regulation (MRR)
- Implementating Regulation (EU) 2018/2067 amending the Commission Regulation (EU) 600/2012 regarding Accreditation and Verification (referred to as AVR).
- Updated EU ETS monitoring plan template and report templates for aircraft operators

In the EU scheme and CORSIA, the operator is administered by a State. Both schemes only include CO_2 emissions and have a similar approach to the MRV requirements: flight by flight monitoring, annual reporting of CO_2 emissions based upon an approved monitoring plan, annual third party verification, two identical monitoring methods (method A and method B)[372], similar estimation methods and approaches for closing data gaps.

The MRV package has removed some of the differences between schemes. The most important alignments are discussed below.

- **Density**

The amount of fuel uplift or the amount of fuel remaining in the tanks is determined in units of volume, expressed in litres, the aircraft operator shall convert that amount from volume to mass by using density values. As indicated in the implementing Regulation (EU) 2018/2016, the aircraft operator shall use the fuel density (which may be an actual or a standard value of 0.8 kg per litre) that is used for operational and safety reasons similar to Annex 16, Volume IV.

- **Emission Factor for fuel Jet Kerosene (Jet A1 or Jet A)**

MS shall transmit to the Secretariat of the ICAO the relevant emissions data that have been reported under Art. 14 of Directive 2003/87/EC and pursuant of the Delegated

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[371] Delegated regulations are directly applicable and need not be transposed into national legislation. This should lead to a uniform implementation througout the European Union. Delegated regulations can be used to supplement existing legislation on non-essential parts or amend specific and non-essential elements of a legislative act. Implementing regulations (directly applicable in all MS) deal with very specific policies and often address highly technical details of legislation.

[372] See "Session 2: CORSIA MRV System: Monitoring of CO_2 Emissions" for more details. https://www.icao.int/Meetings/RS2018/Documents/2_1_CORSIA%20MRV%20System_Monitoring.pdf

Regulation EU 2019/1603. For the purpose of transmission to ICAO, the emissions factor specified in SARPs (3.16 tCO_2/t) fuel shall be used.

- **Tier requirements for fuel consumption/Uncertainty levels for fuel consumption**

The Tier requirements setting the maximum uncertainty for measurement devices to determine the activity data-fuel consumption has been removed in (EU) 2018/2066 as no operator would have the control for such devices. The CORSIA Annex 16, Volume IV, does not include the tiered approach.

Art. 56 of the Implementation Regulation 2018/2066 requires the aircraft operator to consider sources of uncertainty and their associated levels of uncertainty when selecting the monitoring methodology including control activities. The ICAO Annex 16, Volume IV does not require uncertainty analysis but refers to the assessment of the risks associated with the data management process and means for addressing significant risks.

- **Definition of data gap threshold**

Within the initial MRR no data gap threshold was included. The Implementing Regulation (EU) 2018/2066 Art. 66 now includes a paragraph on the treatment of data gaps: "Where the number of flights with data gaps referred to in the first two sub-paragraphs exceed 5% of the annual flights that are reported, the operator shall inform the competent authority thereof without undue delay and shall take remedial action for improving the monitoring methodology." The SARPS for CORSIA implementation indicates data gaps during a compliance period do not exceed a threshold for the period 2019-2020 of 5% of international flights defined in section 2.1. From 2021, CORSIA MRV applies the 5% threshold to 5% of international flights subject to offsetting requirements as defined in section 2.1.

- **Small Emitters**

Regulation 2017/2392 further simplified the MRV requirements for operators emitting less than 3000 tonnes of CO_2 per year under the current geographic scope (intra-EEA) of the EU ETS, allowing the use of the small emitters tool underpinned by Eurocontrol and exempt them from verification. If AOs meet the EU ETS thresholds for the use of Small Emitters Tool (SET) (<3000 tonnes CO_2 full scope; <25000 tonnes CO_2 reduced scope; for data gaps), then they can also use SET for their CORSIA related data.

Art.55 of the Implementation Regulation (2018/2066) defines 'small emitters' as aircraft operators operating fewer than 243 flights per period for three consecutive four-month periods and aircraft operators operating flights with a total annual emission's lower than 25 000 tonnes CO_2. In this situation the aircraft operator is allowed to estimate the fuel consumption using tools implemented by Eurocontrol or another relevant organisation once their use is approved by the Commission. The Delegated Act 2019/1603 also requires commercial operators operating fewer than 243 flights departing in or arriving in an aerodrome situated in the territory of a MS to report their emissions for flights meeting Art.2.1 of the Delegated regulation.

- **Reporting Template**

The EU emission report template has been revised to be applicable to all reportable flights for the purposes of the EU ETS and for aeroplane operators with an obligation to report under the Delegated Regulation (EU) 2019/1603 for implementation of CORSIA.

2.3.5.2 Remaining MRV differences between EU ETS and CORSIA

- **State Implementation**

It is important to note that CORSIA MRV first has to be transposed within national law, hence leaving room for potential differences in implementation between States. The EU ETS applies irrespective of the nationality of an operator. Last year more than 100 commercial aircraft operators outside the EU which operates flights with the EEA reported and complied[373] .

- **Scope and Applicability**

Similar to the criteria included within the Commission Delegated Regulation (EU) 2019/1603, the CORSIA MRV is applicable to an aeroplane operator producing annual CO_2 emissions greater than 10000 tonnes from international flights conducted by aeroplanes with a maximum certificated take-off mass greater than 5 700 kg from 1 January 2019 onwards.

The Commission Delegated Regulation (EU) 2019/1603 art.2 para 4 excludes certain types of flights which are subject to CORSIA (e.g. flights for training or search and rescue, flights under visual flight rules, international training flights, flights for scientific research and testing, public service …). The requirements to verify and report emissions between aerodromes located in two different third countries is recommended, but not required under the integrated MRV framework. The EU ETS includes certain flights in MRV, which are exempted under CORSIA (e.g. helicopter flights).

- **Applicable Thresholds**

Under CORSIA, operators with annual CO_2 emission of less than 500 000 tonnes are eligible for simplified monitoring in the baseline period (use CERT). From 2021 onwards, operators with annual CO_2 emissions from international flights subject to offsetting requirements of less than 50 000 tonnes, are eligible for simplified monitoring. Article 28a(6) for the EU ETS allows an aircraft operator has total annual emissions lower than 25 000 tonnes of CO_2, or where an aircraft operator has total annual emissions lower than 3 000 tonnes of CO_2 from flights fulfilling the criteria that its emissions shall be considered to be verified emissions if determined by using the small emitters tool approved under Commission Regulation (EU) No 606/2010 (1) and populated by Eurocontrol with data from its ETS support facility.

- **Monitoring Methods**

The MRR includes two methods for the determination of the fuel consumption: Method A and Method B. The Implementing Regulation (EU) 2018/2066 did not provide for other monitoring methods than A or B since they were considering as delivering good results. According to the Article 21 Report on the application of the EU ETS Directive, most aircraft operators use Method B[374].

Under CORSIA, the monitoring methods are subject to review and approval by the State. The SARPs allow jurisdictions to choose which methods administered operators may use from the five methods included in the SARPs (including besides Method A and B, monitoring methods Block-off/Block-on, Fuel uplift and Fuel Allocation with block hour)[375].

CORSIA requires that operators performing flights attributed to another operator on an ad-hoc basis provide data for the block-off/block-on method.

To our knowledge no data is already available on the preferred method by aeroplane operators under CORSIA. In the past, concerns were raised on the block-off/block-on

[373] https://ec.europa.eu/clima/news/emissions-trading-greenhouse-gas-emissions-reduced-87-2019_en

[374] Application of the European Union Emission Trading Scheme Directive, Analysis of national responses under Article 21 of the EU ETS Directive in 2018. https://op.europa.eu/en/publication-detail/-/publication/4c3f7bf0-7d08-11e9-9f05-01aa75ed71a1

[375] See "Session 2: CORSIA MRV System: Monitoring of CO_2 Emissions" for more details. https://www.icao.int/Meetings/RS2018/Documents/2_1_CORSIA%20MRV%20System_Monitoring.pdf

method that could not capture Auxiliary Power Unit emissions[376]. This is also the case for the fuel uplift method.

- **Use of CERT for data gaps and small emitters**

For the purpose of filling data gaps and for small emitters ICAO has developed a CORSIA Estimation and Reporting tool. (see above the thresholds for using it). The EU allows the use of an emission estimation tool for data gaps filling and for small emitters.

- **Use of biofuels/alternative fuels**

The reporting of CORSIA eligible fuels will start from 2021 onwards. The last version of the EU Annual Emissions Report of aircraft operators for EU ETS and CORSIA[377] already includes a subsection on CORSIA eligible fuels claimed as well as information on alternative fuels under the EU ETS.

See further section 2.3.7 for the different approaches used by the EU and ICAO

- **Internal reviews and validation of data**

Both schemes require the operator together with the monitoring plan to perform a risk assessment that the proposed control activities and procedures for control activities are commensurate with the identified inherent and control risks.

Within the EU ETS Art. 59 (4) and Art. 63 (EU) 2018/2066, aircraft operators are required on the basis of the inherent risks and control risks to monitor and review the effectiveness of the control system and validate data resulting from flow activities. By using the word ‘should’ the CORSIA MRV section 2.3.5 refers to a recommendation the aeroplane operator performs an internal pre-verification of its emissions report prior to the verification by a verification body

- **Accreditation and Verification (AVR)**

The requirements for verification of data and the accreditation of verifiers pursuant to Directive 2003/87/EC have been detailed within the AVR and the Implementation Regulation 2018/2067.

In general, both schemes are very similar with respect to requirements for verification bodies and competence requirements. The amendments and provisions of the AVR apply to the ETS and CORSIA related data. The requirement for rotation of the lead verifier every 6 year has been introduced by the Implementation Regulation amending the AVR.

Under CORSIA, in order to be eligible to verify Emissions reports, a verification body must be accredited to ISO14065:2013. As per section 2.4.1.3 of the SARPs, a verification body shall conduct the verification according to ISO14064-3:2006 and relevant requirements included in Appendix 6 Section 3.

Section 2.4.2.1 of the SARPS notes that an aeroplane operator may engage a verification body accredited in another State, subject to rules and regulations affecting the provision of the verification services in the State to which the aeroplane operator is attributed.

For meeting the obligations of the integrated MRV framework, the verifying body needs to be accredited according to the requirements set by the EU Regulation on accreditation and verification (AVR). The Delegated Regulation enables verifiers accredited under the EU ETS to verify CORSIA emission reports for AOs holding EU/EEA AOCs. CORSIA accredited

[376] Netherlands, reply to ICAO State letter 17-129: Proposal for the First Edition of Annex 16, Volume IV, concerning standards and Recommended Practices relating to the Carbon Offsetting and Reduction Scheme for international Aviation (CORSIA), www.rijksoverheid.nl › 2018/04/18

[377] https://ec.europa.eu/clima/policies/ets/monitoring_en#tab-0-1

verifiers have to meet the requirements laid down in Directive 2003/87/EC and the Implementation Regulation (EU) 2018/2067.

In the integrated MRV framework, the verifier may decide not to carry out a site visit of the small emitter referred to in Article 55(1) of the Implementation Regulation (EU) 2018/2066 if based upon the risk analysis all relevant data can be accessed remotely and not to carry out checks (verification activities, data verification, correct application of monitoring methodology and verification of methods applied for missing data) if the report has been generated using the tools by Eurocontrol of another relevant organisation.

Within the EU ETS, the norm EN/ISO17011[378] on the requirements for accreditation bodies have been detailed in the AVR and the accreditation framework established by the Accreditation Regulation 765/2008. Within the EU ETS specific requirements concerning accreditation bodies for the accreditation of ETS verifiers are stipulated, including a regular peer evaluation process, mutual recognition of verifiers, data and information exchange and communication of accreditation work programmes and management reports. SARPs section 2.4.2 only makes reference to the ISO17011 with no further guidance.

2.3.5.3 Status of MRV provisions in third country ICAO States

As aeroplane operators had to report the verified 2019 CO_2 emissions to States for the first time in May 2020, there needs to be enough number of verification bodies accredited by National Accreditation Bodies, and available for undertaking the verification of 2019 emissions reports for aeroplane operators.

Based upon the information available on the ICAO website, the ICAO Secretariat developed early 2019, a three-day CORSIA Verification Course to provide training on how to verify CO_2 Emissions Reports prepared by aeroplane operators, in accordance with Annex 16, Volume IV. The training course is targeted for potential verification bodies, with a view to facilitating more availability and accessibility of accredited verification bodies. Up to the end of September 2019, the course had been successfully delivered in 10 different locations around the world with the participation of 104 experts. By the end of November 2019, 24 verifications bodies were already accredited by eight States. Three more deliveries were scheduled by the end of 2019 and it was expected that approximately 150 experts would be trained in total, expecting more verifications bodies to be accredited. In cooperation with the International Accreditation Forum (IAF), the course would also be offered to representatives of National Accreditation Bodies.

As part of the ACT-CORSIA programme, the ICAO Council encouraged the establishment of CORSIA Buddy Partnerships among States. Through such partnerships, a donor State is to help a recipient State to build its national capacity to implement CORSIA. As of October 2019, a total of 17 donor States were providing support to more than 100 recipient states under the Buddy Partnerships. The exact status regarding preparedness/implementation of MRV provisions has not been updated/made available upon the ICAO website and therefore unknown.

Due to the COVID-19 outbreak, all 2020 ICAO CORSIA regional seminars have been postponed to a later date in 2020.

With regard to the MRV implementation in specific States, no information is available on the ICAO website which makes it difficult to conduct an assessment of implementation at national level. As raised already in section 2.3.3.3, in the US, CORSIA MRV program is completely voluntary[379].

[378] Conformity assessment — Requirements for accreditation bodies accrediting conformity assessment bodies

[379] Notice of CORSIA monitoring, reporting, and verification program, US Department of Transportation, Federal Aviation Administration, p. 3.

2.3.6 Registries

The CORSIA Central Registry (CCR) is one of the key implementation elements of CORSIA.

2.3.6.1 Overview and goals of the CCR

The CCR is the registry through which ICAO Member States are required to report CORSIA-related information and data to ICAO. The purpose of the CCR is to enable the reporting of relevant information from Member States to ICAO.

Information to be reported by States to ICAO through the CCR includes aeroplane operators, verification bodies, and CO_2 emission. In the future it will also include CORSIA eligible fuels and cancelled emissions units. For the first time in 2020, States shall transmit an annual Emission report to the CCR which shall contain, when applicable:

For years 2019 and 2020, the total annual CO_2 emissions per State pair aggregated for all aeroplane operators attributed to the State[380];

- After 2021[381]:
  - Total annual CO_2 emissions on each State pair aggregated for all aeroplane operators attributed to the State;
  - Total annual CO_2 emissions for each aeroplane operator attributed to the State;
  - Total aggregated annual CO_2 emissions for all State pairs subject to offsetting requirements for each aeroplane operator attributed to the State
  - Total aggregated annual CO_2 emissions for all State pairs not subject to offsetting requirements for each aeroplane operator attributed to the State.
- Information about the use of CORSIA Eligible Fuels (CEF) in the State such as the production of CEF, the CEF claimed by all the aeroplane operators attributed to the State, CEF Batch number, etc.[382]
- An emission unit cancellation report which shall contain (i) the name of the aeroplane operators attributed to the State, (ii) the compliance period years reported, (iii) the total final offsetting requirements, (iv) the total quantity of emissions units cancelled and (v) consolidated identifying information for cancelled emissions units.

For ICAO, the data collected from each ICAO Member States through the CCR has two additional goals.

Firstly, to analyse and aggregate all the data received in order to calculate (i) the baseline CO_2 emissions (2019-2020) for international aviation in 2021 and (ii) each year from 2022 onwards, to determine the Sector's Growth Factor (SFG) for the previous year and report back to the States. States will use the SFG to determine the CO_2 offsetting requirements for each of their aeroplane operators.

Secondly, to publish certain data on its website for the sake of transparency. More particularly, the ICAO publishes directly on its website[383] a document named "*CORSIA Central Registry (CCR): Information and Data for Transparency*" will progressively contain the following information:

- The list of the Aeroplane Operator and the State to which they are attributed;
- The list of verification bodies accredited in each State;
- Total average CO_2 emissions for 2019 and 2020 aggregated for all aeroplane operators on each State pair;

[380] Annex 16, Volume 4, Appendix 5, Table A5-4

[381] Annex 16, Volume 4, Appendix 5, Table A5-5

[382] Annex 16, Volume 4, Appendix 5, Table A5-6

[383] https://www.icao.int/environmental-protection/CORSIA/Pages/CCR.aspx

- Total annual CO_2 emissions aggregated for all aeroplane operators on each State pair (with identification of State pairs subject to offsetting requirements)
- For each aeroplane operator:
  - Aeroplane operator name;
  - State in which aeroplane operator is attributed;
  - Reporting year
  - Total annual CO_2 emissions
  - Total aggregated annual CO_2 emissions
  - Total aggregated annual CO_2 emissions for all State pairs subject to offsetting requirements
  - Total aggregated annual CO_2 emissions for all State pairs not subject to offsetting requirements
- Regarding CEF, the ICAO will publish the following information to avoid any double claiming of CEF:
  - Production year of the CEF claimed;
  - Producer of the CEF claimed;
  - Type of fuel, feedstock and conversion process for each CEF;
  - Batch number(s) of each CEF claimed
  - Total mass of each batch of CEF claimed
- Finally, ICAO will also make available the following information at a State and global aggregate level for a specific compliance period:
  - Total final offsetting requirements over the compliance period;
  - Total quantity of emissions units cancelled over the compliance period to reconcile the total final offsetting requirements; and
  - Consolidated identifying information for cancelled emissions units

For the time being, the only information published in the ICAO's website are (i) the list of Aeroplane Operators and the State to which they are attributed[384] in the document named "CORSIA Aeroplane Operator to State Attribution", and (ii) the list of the Verification bodies accredited in States[385] in the document named ”Information and Data for Transparency".

2.3.6.2 Components and features of the CCR

The CCR is being implemented as an online web application supported by a database and a workflow engine, and comprises of the following components as illustrated by Figure 8 below provided by the ICAO[386]:

a) Web application with predefined forms and automated checks;
b) Data transfer and storage;
c) Administrative console to perform internal checks and manage data and user;
d) ICAO website for the publication of information.

[384] https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA%20Aeroplane%20Operator%20to%20State%20Attributions_Dec2019_v20200106b.pdf

[385] https://www.icao.int/environmental-protection/CORSIA/Documents/CCR_Information_and_Data_for_Transparency_4%20Mar%202020_for%20web.pdf

[386] https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2019/ENVReport2019_pg224-227.pdf

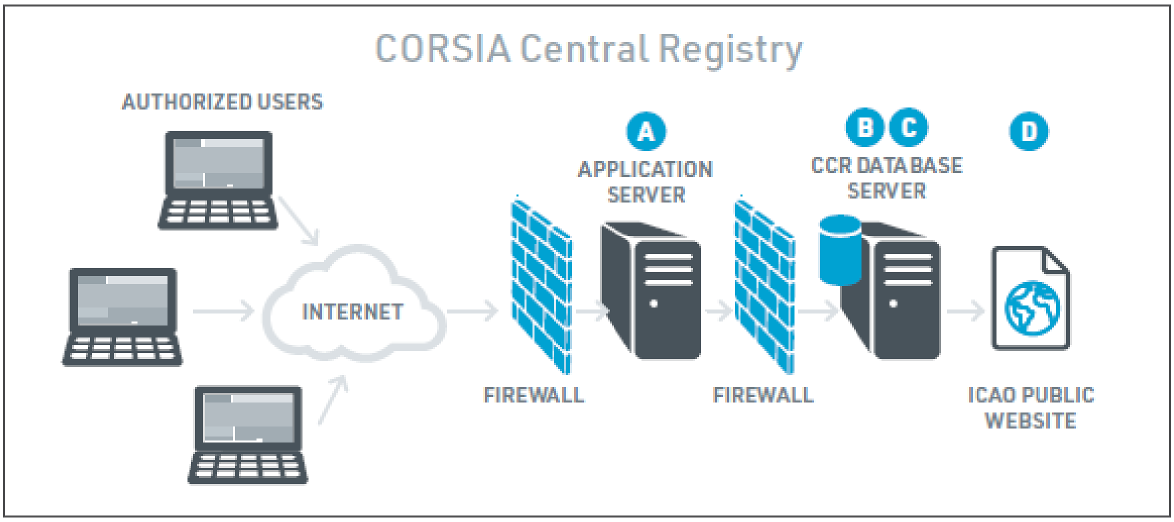

Figure 8. Main components of the CCR

Each ICAO Member State has an account in the CCR. Access to this account will be granted only to limited authorized users by each State, in order to provide information and their reports to the CCR. The access to the CCR is protected by a password and an authentication protocol. All actions are time-stamped and recorded (including electronic signature of the user who initiated an action) to ensure traceability and data integrity.

Assessment of the CCR and of its enforceability

Creating such a consolidated central registry under the auspices of ICAO is essential for the implementation of the CORSIA System, since it ensures (i) the possibility to calculate the baseline (CO_2 emissions for the years 2019-2020) and after that the SFG, and (ii) to ensure the transparency of the CORSIA System via the " CORSIA Central Registry (CCR): Information and Data for Transparency[387]. Such goals could not be reached without the CCR.

Indeed, since the CCR is a centralized registry, all provisions relating to its implementation, its use, or its goals are provided directly by the ICAO and ensure that the CCR system will be correctly implemented[388].

Furthermore, the system based on one central registry is also used in the EU ETS (even if the Union Registry have different functions than the CCR), where aeroplane operators shall report their CO_2 emissions to the Administering Member State, which then transmit these information to the Union Registry for the EU ETS. Such a system has therefore proven its worth and it appears to be well suited to CORSIA.

Nevertheless, the CCR system is still likely to encounter several problems due to the legal nature and lack of automatic enforceability of the CORSIA, which shall be implemented properly in each State to be fully operational.

Accordingly, the CCR permits ICAO to compile, aggregate and publish correct data, and to calculate SGF only if all aeroplane operators transmit all the relevant data in time to the State to which they are attributed.

[387] Annex 16, Volume 4, Appendix 5, Section 3.2.; https://www.icao.int/environmental-protection/CORSIA/Documents/CCR%20Information%20and%20Data%20for%20Transparency_Apr2020_FINAL_web.pdf

[388] See Sections 2.3.6.1. and 2.3.6.2.

This mainly depends on how each State implements MRV rules in their national law to enforce aeroplane operator to report correctly their emissions data. Most of the States have not implemented such rules yet. The United States, for example, made clear that the reporting would only be made on a voluntary basis by the Aeroplane Operators.[389]

To prevent potential negative effects of the lack of implementation of MRV rules, Article 2.5 of Annex 16, Volume IV provides a set of provisions in case of "data gaps", i.e. missing data relevant for the determination of the fuel use for one or more international flights:

- each aeroplane operator shall detail in their report the procedures they have established to prevent data gaps;
- when data gaps are identified by the verification body, it may be unable to obtain sufficient evidence to determine compliance with requirements. The verification may consider the Emission report to be unsatisfactory in case of severe data gaps.
- If an aeroplane operator does not provide its annual Emissions Report in time, the competent State shall engage with the aeroplane operator to obtain the necessary information. If this proves unsuccessful, the State shall estimate the aeroplane operator's annual emissions using the best available information and tools, such as the ICAO CORSIA CO_2 Estimation and Reporting Tool (CERT)[390];
- If a State does not provide its annual aggregated Emissions Report to the ICAO in time, then the data provided by ICAO shall be used to fill these gaps and calculate the total sectoral CO_2 emissions in a given year and the Sectoral Growth Factor

Consequently, ICAO should be able to calculate the SGF (based on estimation in case of data gaps) to be reported back to the States to determine the CO_2 offsetting requirements for each of their aeroplane operators.

2.3.6.3 Programme registries to avoid double counting

Under CORSIA, aeroplane operators are required to cancel Eligible Emissions Units to meet their carbon offsetting requirements. CORSIA Eligible Emissions Units shall comply with the *CORSIA Emissions Unit Eligibility Criteria*[391][392]. This CORSIA Emissions Unit Eligibility Criteria include Program Design Elements and Carbon Offset Credit Integrity assessment Criteria that apply at the programme level[393]. Aeroplane operator shall meet its offsetting requirement by cancelling CORSIA eligible Emissions Units in a quantity equal to its total final offsetting requirements of a given compliance period. To fulfil such obligation aeroplane operator shall[394]:

1. Cancel CORSIA Eligible Emissions Units within a registry designated by a CORSIA Eligible Unit Programme; *and*
2. Request each CORSIA Eligible Emissions Unit Programme registry to make visible on the registry's public website, information on each of the aeroplane operator's cancelled CORSIA Eligible Emissions Units for a given compliance period.

[389] Notice of CORSIA monitoring, reporting, and verification program, US Department of Transportation, Federal Aviation Administration, p. 3. https://www.faa.gov/about/office_org/headquarters_offices/apl/research/environmental_policy/media/corsia_mrv_program_statement.pdf

[390] Annex 16, Volume IV, Appendix 3. https://www.icao.int/environmental-protection/CORSIA/Pages/CERT.aspx;

[391] https://www.icao.int/environmental-protection/CORSIA/Documents/TAB/TAB%202020/ICAO_Doc_CORSIA_Eligible_Emissions_Units_March_2020.pdf

[392] Annex 16, Volume IV, Article 4.2.1.

[393] CORSIA_Emissions Unit Eligibility Criteria_

[394] Annex 16, Volume IV, Article 4.2.2.

One of the goals of the CORSIA eligibility criteria is to ensure that an Eligible Emission Unit is not counted more than once in the context of aeroplane operators' carbon offsetting requirements under a mitigation obligation.

On 16 March 2020, ICAO approved six CORSIA Eligible Units Programmes pursuant to the recommendations of the Technical Advisory Body (TAB)[395]:

However, as stated in Section 3.3.4.1, all Eligible Units Programmes approved by the ICAO Council do not comply with all the requirements set within the CORSIA Emissions Unit Eligibility Criteria document[396].

The TAB found that all the six approved Programmes did not demonstrate technical constancy with all contents of the criterion "are only counted once towards a mitigation obligation" (meaning the avoidance of double issuance, double use and double claiming). Despite this, the TAB recommended the ICAO to approve these programmes since they "*expressed their willingness to put in place measures (if they were not already "in place"), as described and interpreted under the criterion, for making publicly available any national government decisions related to accounting for the underlying mitigation associated with units used in ICAO, including the content of host country attestations; for updating information pertaining to host country attestations; for monitoring for double-claiming by relevant government agencies; and for reporting to ICAO's relevant bodies any performance information related to double claiming.*"[397]

Consequently, since measures preventing double counting are not fully put in place by the Programmes yet, double counting cannot be considered as being satisfactorily tackled within the CORSIA System for "*vintages from 2016 to 2020*", as it is recognized by the VCS[398].

2.3.6.4 The risk of double issuance

A double issuance can occur when more than one unit is issued for the same emissions reduction.

Failing to prevent such double issuance would greatly mitigate the CORSIA System's efficiency, since an aeroplane operator would be able purchase Eligible Emissions Units that do not correspond to any GHG emissions reduction.

It is CORSIA Eligible Units Programmes' responsibility to prevent such double-counting. The six approved Programmes have been considered by the TAB as not being able to fulfil all contents of the criterion "*Are only counted once towards a mitigation obligation*". However, this claim seems to relate specifically to the double claiming issue. No other information is available on the double issuance.

As an example, the Avoidance Double Counting Working Group (involving the American Carbon Registry (ACR), Gold Standard, Climate Action Reserve (CAR) and Verra) provides "*Guidelines on avoiding double counting for the Carbon Offsetting and Reduction Scheme for International Aviation*"[399]. In this guidelines, the Working Group provides that, "*in order to avoid double issuance, programs should adopt a series of standards and procedures, including protocols for offset credit issuance that ensure that offset credits are only issued after final program approval of verification reports and any other supporting*

[395] https://www.icao.int/environmental-protection/CORSIA/Documents/TAB/Excerpt_TAB_Report_Jan_2020_final.pdf

[396] TAB Recommendation on CORSIA Eligible Emissions units

[397] TAB Recommendations on CORSIA Eligible Emissions units, p.18, Section 4.3.5.

[398] https://verra.org/the-verified-carbon-standard-program-has-been-accepted-to-supply-carbon-credits-under-corsia/

[399] https://americancarbonregistry.org/carbon-accounting/guidance-tools-templates/guidelines-for-adc-with-corsia-june-2019.pdf

documentation related to a project's asserted emissions reduction or removal; quantification standards and project eligibility criteria that ensure that different projects cannot be issued credits for the same emissions reduction or removal; and standards and procedures that avoid double issuance due to double registration projects (both within the same registry system and across multiple registries)."

A study on the Lessons learned from the first round of applications by carbon-offsetting programs for eligibility under CORSIA assessed the double issuance issue. The Authors found that: "*Double issuance can also occur indirectly, through overlapping claims by different entities involved in carbon offset projects, for example, if one program credits the production of biofuels, whereas another program credits the use of biofuels. With the exception of the Climate Action Reserve, none of the programs have procedures in place that fully avoid such overlapping claims, in particular with projects registered under other programs*."[400] Also the joint submission by Öko-Institut and Stockholm Environment Institute, raised the point that among the eligible programmes, the CDM does not have procedure in place to avoid double registration of the same project under two different programs[401]. Other programs have these procedures in place.

2.3.6.5 The risk of double use

A risk of double use occurs when the same issued unit is used twice, for example, if a unit is duplicated in registries or is not cancelled after it has been used.

This risk is linked to the requirement to permanently cancel a CORSIA Eligible Emissions Unit in a designated registry once such unit has been used to offset an emission[402]. Such risk, if not adequately tackled, could put the entire impact of CORSIA system at risk as it would enable the use of the same unit several time to offset different emissions.

As an example, major airlines have put in place a voluntary offset program, which vary in terms of typology (offsetting being made by the operator or the customer), registries (each airline – or group/alliance – referring to different registries), or participants (the main participants to these voluntary programs are often not the airlines but large corporate entities meeting their "carbon neutrality" claims via offsetting)[403].

In such case, the ICAO addresses how the prevention of the risk of double use should be assessed by a verification body in accordance with Section 3.3.6.2 of the "Environmental Technical Manual" provided by the ICAO[404]. However, this "Environmental Technical Manual" only constitutes recommendations, which are not binding.

Generally speaking, the European Commission raised this risk to the ICAO in a reply from 1 March 2019 to ICAO State Letter AN1/74.14-17/129[405] and proposed to amend the Draft SARPs in order to add additional information that should be provided by aeroplane operators, and which would then be included in CORSIA Central Registry, namely: the total final offsetting requirement over the compliance period, the total quantity of emissions units cancelled over the compliance period to reconcile the total final offsetting

[400] Schneider and al, Lessons learned from the first round of applications by carbon-offsetting programs for eligibility under CORSIA, October 2019, page 14.

[401] Idem, pages 49-50

[402] Annex 16, volume IV, paragraph 4.2.

[403] Elizabeth Zelljadt, Offsetting in the aviation sector Evaluating voluntary offset programs of major airlines, 10 October 2016.

[404] file:///C:/Users/TXG/Downloads/icao_doc_9501_environmentaltechnicalmanual.pdf

[405] https://ec.europa.eu/transport/sites/transport/files/2018-03-01-eu-reply-to-corsia-state-letter.pdf;

requirements and consolidated identifying information for cancelled emissions units[406]. This amendment has not been adopted.

In their study, Schneider and al. noted that "*However, none of the programs currently have procedures in place that effectively avoid that a single unit cancellation could be claimed for more than one purpose. Programs should therefore develop cancellation procedures that ensure that a cancellation is clearly indicated, irreversible and unambiguously designated for a specific purpose*.[407]"

At this stage, the risk of double use is tackled by the ICAO in the following ways:

1. Firstly, it is of CORSIA Eligible Units Programmes' responsibility to ensure that the same Unit is only cancelled once.;
2. Secondly, Eligible Units Cancellation Reports shall be verified by independent verification body, which shall ensure that an aeroplane operator did not use the same Eligible Unit twice.
3. Thirdly, all Eligible Emission Units cancelled by aeroplane operators shall be included in their Emissions Units Cancellation Reports as well as their identification information such as the identification unit number. After having received information from the States, the CCR assesses electronically whether an Eligible Units has been used once or multiple times under CORSIA. . However it will not be in a position to assess this with other systems as it has no access to them.

2.3.6.6 Prevention of the risk of double claiming

A risk of double claiming arises if the same emissions reduction is counted twice by both the buyer and the seller.

To avoid such issues, the EUC lays down that eligible programs should require and demonstrate that host countries of emissions reduction activities (referred to as "adjustments") agree to account for any offset units issued as a result of those activities such that double claiming does not occur between the airline and the host country of the emissions reduction activity[408].

In its recent analysis, the TAB assessed whether and how the proposed Programmes were addressing the requirement to avoid double claiming. For 6 of the Programmes, the TAB confirmed that the issue of the double claiming was, or will be properly addressed.

As an example, the TAB has noted in respect of the China GHG Voluntary Emission Reduction Programme (CCER) that "*the programme representative, specifically, the Ministry of Ecology and Environment, Department of Climate Change, indicated its willingness to put in place the measures to ensure that emissions reductions resulting from its activities are consistent with the EUC contents and guidelines pertaining to the avoidance of double-claiming, in the context of the Paris Agreement and decisions taken under the UNFCCC*.".

However, as explained above, the TAB "*found that most programmes have not yet put in place procedures, provisions or measures to obtain and make publicly available attestations from national governments' designated agency contact which recognize and confirm that the units can be used under CORSIA, and in relation to accounting for the mitigation from the activities that supply these units*."[409] The compliance with the

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[406] Letter of the European Commission to the Secretary General of the International Civil Aviation Organization, 1 March 2019.

[407] Schneider and al, Lessons learned from the first round of applications by carbon-offsetting programs for eligibility under CORSIA, October 2019, page 14.

[408] ICAO document – CORSIA Emissions Unit Eligibility Criteria, March 2019.

[409] Technical Advisory Body – Recommendations on Corsia Eligible Units, section 4.3.5.1.

requirement to avoid double claiming is therefore based – at this stage – on the declaration of willingness of the 6 validated programmes: "*TAB's assessment reflected the extent to which each programme has already, or has expressed its willingness to, put in place procedures to provide for its consistency with the criterion, recognizing that some programmes' efforts to do so were well-advanced, and in some cases administered directly by the relevant national government agency*."[410]

For the programmes that have not been recommended by the TAB, one is mainly due to the absence of provision to avoid the double claiming. Indeed, in the case of the British Columbia Offset Program (BCOP), the TAB noted that "*the BCOP's explanation that it was unable to address double claiming at this time, given that the information relates to national governments, and the BCOP is administered by a sub-national government.*"[411] The BCOP has therefore been invited to renew its application with an assessment of how it would mitigate double claiming.

Finally, as the ICAO approved these six programmes without demonstrating they comply with all contents of mitigation obligation of double counting, it seems that such measures will only apply for the future.

On the contrary, it seems that the Programmes are not able to fully prevent double counting for projects dating from 2016 to 2020, as it is recognised by the VCS, reducing the immediate impact of the CORSIA System and its effectiveness in offsetting emissions.

2.3.7 Rules on fuels

CORSIA has developed a framework to reduce offsetting requirements from the use of aviation fuels subject to compliance with sustainability criteria. Based on the sustainability criteria, CORSIA eligible fuels include Sustainable Aviation Fuels (SAF) defined as a renewable or waste-derived aviation fuel that meets the CORSIA sustainability criteria under Volume IV and Lower Carbon Aviation Fuels (LCAF) defined as a fossil-based aviation fuel that meets the CORSIA Sustainability Criteria under Volume IV. However, as of November 2019, no low carbon aviation fuels (LCAF) and only SAF's associated with five pathways have been defined as eligible fuels. The following section analyzes CORSIA's sustainability criteria and identified eligible fuels.

2.3.7.1 Sustainability Criteria

Table 6 shows the two sustainability themes and three sustainability criteria for CORSIA Eligible Fuels applicable during the pilot phase of CORSIA (2021-2023).

Table 6. CORSIA's sustainability themes for eligible fuels

Theme	Principle	Criteria
Greenhouse Gases (GHG)	Principle: CORSIA eligible fuel should generate lower carbon emissions on a life cycle basis.	Criterion 1: CORSIA eligible fuel shall achieve net greenhouse gas emissions reductions of at least 10% compared to the baseline life cycle emissions values for aviation fuel on a life cycle basis.
Carbon stock	Principle: CORSIA eligible fuel should not be made from biomass	Criterion 1: CORSIA eligible fuel shall not be made from biomass obtained from land converted after 1 January 2008 that was primary forest,

[410] Technical Advisory Body – Recommendations on Corsia Eligible Units, section 4.3.5.4.

[411] Technical Advisory Body – Recommendations on CORSIA Eligible Emissions Units, section 4.2.13.4.

	obtained from land with high carbon stock.	wetlands, or peat lands and/or contributes to degradation of the carbon stock in primary forests, wetlands, or peat lands as these lands all have high carbon stocks.
		Criterion 2: In the event of land use conversion after 1 January 2008, as defined based on IPCC land categories, direct land use change (DLUC) emissions shall be calculated. If DLUC greenhouse gas emissions exceed the default induced land use change (ILUC) value, the DLUC value shall replace the default ILUC value.

The updated Renewable Energy Directive (RED II) requires raising the overall EU renewable energy consumption to 32% by 2030. Similar to the Fuel Quality Directive (FQD) 2009/30/EC, RED II includes two sustainability criteria for biofuels; one for a GHG emission reduction threshold and the other for biofuel feedstocks. The GHG emissions from biofuels must be lower than the baseline fossil fuel by at least 50% (for installations in operation before October 2015) and 60% for installations starting operation after that date (Table 7). Moreover, feedstocks used in biofuel production shall not be obtained from land with a high biodiversity value in or after January 2008. Land with high biodiversity is defined as primary forest and other wooded land, highly biodiverse forest and other wooded land, protected land, and highly biodiverse grassland spanning more than one hectare. Detailed specifications of eligible feedstocks can be found in Directive (EU) 2018/2001 of the European Parliament and of the Council[412].

Table 7. GHG emissions reduction of biofuels under RED II

Plant Operation Start Date	Transport biofuels	Transport renewable fuels of non-biological origin	Electricity, heating and cooling
Before October 2015	50%	-	-
After October 2015	60%	-	-
After January 2021	65%	70%	70%
After January 2026	65%	70%	80%

The GHG emissions reduction requirements defined by CORSIA are 10% meaning that the GHG emissions (life cycle basis) of eligible fuels should be ≤ 90% of fossil aviation fuel. While the 10% sustainability threshold enables CORSIA to potentially include a wide variety of biofuels as eligible fuels (pending that they meet the entire set of sustainability criteria), it could be seen as setting a low sustainability threshold. However, it should be noted that the CORSIA mechanism for CORSIA Eligible Fuels allows airlines to claim benefits (reduction of offsetting requirements) only in proportion with the GHG performance of the CORSIA Eligible Fuel used. This means that airlines are encouraged to

[412] https://eurlex.europa.eu/legalcontent/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG&toc=OJ:L:2018:328:TOC

use CORSIA Eligible Fuels which achieve important emissions reductions, in order to consequently reduce their offsetting requirements. On the other hand, RED II has defined the reduction cut-off as 50% and eventually 65% but under the ETS, airlines are allowed to claim the benefits (reduction of offsetting requirements) for the full volume of fuel used, for fuels meeting RED II thresholds.

In that sense, CORSIA ensures that actual emission reductions can be claimed in order to create incentives for the uptake of with higher GHG savings while REDII ensures a high minimum GHG emissions saving threshold, and the EU ETS rating offer higher incentives to use these fuels. While the current CORSIA's sustainability criteria are applicable for batches of CORSIA eligible fuel produced before January 2024, the Committee on Aviation Environmental Protection (CAEP) developed a list of 12 sustainability principles and themes with 17 associated sustainability criteria that should be met for a sustainable aviation fuels to generate carbon offset reductions under CORSIA from the start of CORSIA first phase on 1 January 2024. CAEP developed these criteria based on the existing sustainability criteria included in other sustainability frameworks such as FAO Sustainability Assessment of Food and Agriculture systems (SAFA), International Sustainability and Carbon Certification (ISCC), EU RED II, and Global Bioenergy Partnership (GBEP). At its 219th session, the ICAO Council agreed to bring a set of additional 10 sustainability themes and associated sustainability criteria for consultation with ICAO Member States.

If adopted as proposed, this sustainability framework will also clarify that certified CEF producers under CORSIA can only produce certified batches for a period of 365 days, following which a recertification is necessary in compliance with the sustainability criteria applicable at the time of recertification. This provision (colloquially referred to as protection against grandfathering) clarifies that beyond the CORSIA pilot phase, only CEF which comply with the full set of sustainability themes and criteria will be eligible.

It should also be noted that CAEP is tasked to develop additional and/or strengthened sustainability criteria specifically applicable to lower carbon aviation fuels (fossil-based jet fuels) by the end of the pilot phase. This work is ongoing.

Importantly, it is worth noting that the CORSIA SAF sustainability criteria which will be tabled for adoption in November 2020 relate to GHG threshold, high carbon stock areas, direct land use change, water quality, water use, soil health, air pollution, conservation, waste and chemicals, human and labour right, land use rights and land use, water use rights, local and social development and food security. These CORSIA sustainability criteria will be required for compliance once adopted.

The RED II European legislation includes legally binding sustainability and greenhouse gas saving criteria set out in Article 29(2) to (7) and (10) for the following areas: soil quality and soil carbon, biodiversity, peatland, forest biomass, land with high-carbon stock, LULUCF and GHG. Certification criteria for biofuels, bioliquids and biomass fuels with low indirect land-use change-risk are set out in Commission Delegated Regulation ((EU) 2019/807). Article 25 of RED II includes a further GHG savings criteria of Renewable liquid and gaseous transport Fuels of Non-Biological Origin of 70%. In addition, article RED II 30(4) empowers the Commission to recognise certifications schemes for additional criteria. However, compliance is not legally required. Finally, the Governance regulation (REGULATION (EU) 2018/1999) includes reporting requirements on bioenergy sustainability.

Table 8. Additional sustainability themes that ICAO Council has agreed to bring for consultation with ICAO Member States

Theme	Principle	Criteria
1. Greenhouse Gases (GHG)	Principle: CORSIA SAF should generate lower carbon emissions than conventional kerosene on a life cycle basis.	Criterion 1.1: CORSIA SAF shall achieve net greenhouse gas emissions reductions of at least 10% compared to fossil jet fuel on a life cycle basis.
2 Carbon stock	Principle: CORSIA SAF should not be made from biomass obtained from land with high carbon stock.	Criterion 2.1: CORSIA SAF shall not be made from biomass obtained from land converted after 1 January 2008 that was primary forests, wetlands, or peat lands and/or contributes to degradation of the carbon stock in primary forests, wetlands, or peat lands as these lands all have high carbon stocks.
		Criterion 2.2: In the event of land use conversion after 1 January 2008, as defined based on IPCC land categories, direct land use change (DLUC) emissions shall be calculated. If DLUC greenhouse gas emissions exceed the default induced land use change (ILUC) value, the DLUC value shall replace the default ILUC value.
3. Water	Principle: Production of CORSIA SAF should maintain or enhance water quality and availability.	Criterion 3.1: Operational practices shall be implemented to maintain or enhance water quality.
		Criterion 3.2: Operational practices shall be implemented to use water efficiently and to avoid the depletion of surface or groundwater resources beyond replenishment capacities.
4. Soil	Principle: Production of CORSIA SAFs should maintain or enhance soil health.	Criterion 4.1: Agricultural and forestry best management practices for feedstock production or residue collection shall be implemented to maintain or enhance soil health, such as physical, chemical and biological conditions.

Theme	Principle	Criteria
5. Air	Principle: Production of CORSIA SAF should minimize negative effects on air quality.	Criterion 5.1: Air pollution emissions shall be limited.
6. Conservation	Principle: Production of CORSIA SAF should maintain or enhance biodiversity, conservation and ecosystem services.	Criterion 6.1: CORSIA SAF shall not be made from biomass obtained from areas that are protected for their biodiversity, conservation value, or ecosystem services unless evidence is provided that shows the activity does not interfere with the protection purposes.
		Criterion 6.2: Low invasive-risk feedstock shall be selected for cultivation and appropriate controls shall be adopted with the intention of preventing the uncontrolled spread of cultivated non-native species and modified microorganisms.
		Criterion 6.3: Operational practices shall be implemented to avoid adverse effects on areas that are protected for their biodiversity, conservation value, or ecosystem services.
7. Waste and Chemicals	Principle: Production of CORSIA SAF should promote responsible management of waste and use of chemicals.	Criterion 7.1: Operational practices shall be implemented to ensure that waste arising from production processes as well as chemicals used are stored, handled and disposed of responsibly.
		Criterion 7.2: Operational practices shall be implemented to limit or reduce pesticide use.
8. Human and labour rights	Principle: Production of CORSIA SAF should respect human and labour rights.	Criterion 8.1: CORSIA SAF production shall respect human and labour rights.
9. Land use rights and land use	Principle: Production of CORSIA SAF should respect land rights and land use rights including indigenous and/or customary rights.	Criterion 9.1: CORSIA SAF production shall respect existing land rights and land use rights including indigenous peoples' rights, both formal and informal.

Theme	Principle	Criteria
10. Water use rights	Principle: Production of CORSIA SAF should respect prior formal or customary water use rights.	Criterion 10.1: CORSIA SAF production shall respect the existing water use rights of local and indigenous communities.
11. Local and social development	Principle: Production of CORSIA SAF should contribute to social and economic development in regions of poverty.	Criterion 11.1: CORSIA SAF production shall strive to, in regions of poverty, improve the socioeconomic conditions of the communities affected by the operation.
12. Food security	Principle: Production of CORSIA SAF should promote food security in food insecure regions.	Criterion 12.1: CORSIA SAF production shall, in food insecure regions, strive to enhance the local food security of directly affected stakeholders.

2.3.7.2 Sustainability Certification Schemes (SCS)

According to CORSIA, SCS are organizations that certify economic operators against the sustainability criteria and ensure that economic operators calculate actual life cycle emissions values (if default values are not applied) using the agreed methodology by controlling and auditing the documents and records and monitoring their operations. CORSIA has a thorough description of responsibilities for the SCS on how to evaluate the economic operators against sustainability criteria and certify the fuels. Similarly, RED II requires the Member States to supervise the operation of certification bodies that are conducting independent auditing under a voluntary scheme. The certification bodies are required to check if economic operators fulfil the sustainability and greenhouse gas emissions saving criteria.

California Air Resource Board (CARB) also has a similar procedure to audit the methodology used to determine the carbon intensity (CI) of fuels and control the documents and records and finally determine if a biofuel is eligible to generate California Low Carbon Fuel Standard (LCFS) credit[413].

2.3.7.3 Life-Cycle Emissions

To calculate the GHG emissions of bio-jet fuels, CORSIA used two references. One of the references is the study by the Massachusetts Institute of Technology (MIT) on GHG emissions of alternative jet fuels[414]. The MIT study conducted a life cycle assessment of the upstream (well-to-tank) emissions[415] for various bio-jet fuels using the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model. GREET model, developed at Argonne National Laboratory[416] is an analytical tool that simulates the fuel lifecycle, also known as well-to-wheels (WTW), energy use and emissions output of vehicle/fuel systems. GREET model is widely recognized as a reliable tool for life-cycle

[413] https://ww3.arb.ca.gov/fuels/lcfs/fro_oal_approved_clean_unofficial_010919.pdf

[414] Stratton, R. W. (2010). Life cycle assessment of greenhouse gas emissions and non-CO_2 combustion effects from alternative jet fuels (Master dissertation, Massachusetts Institute of Technology).

[415] The upstream emissions include emissions prior to combustion and use of the fuel.

[416] https://greet.es.anl.gov/index.php

analysis of transportation fuels and has been used by several regulatory agencies (e.g., US Environmental Protection Agency for the Renewable Fuel Standard and the LCFS) for evaluation of various fuels[417].

The other reference used by CORSIA is a study by the Joint Research Centre (JRC) which was assigned to define input values to be used for the calculation of default GHG emissions for biofuels, bioliquids, solid and gaseous biomass pathways for RED and FQD[418]. The JRC model is based on the GREET model, E3database, and results of peer-reviewed publications. E3database[419] developed by Ludwig-Bölkow-Systemtechnik GmbH (LBST) in Germany is a tool for assessing the WTW energy and GHG emissions of various products including transportation fuels.

CAEP experts calculated the GHG emissions resulting from various parts of biofuel supply chain, including feedstock cultivation and collection, feedstock transportation, fuel production, and fuel transportation. The summary of the results is shown in Table 9. Based on the carbon intensity (CI) values listed in Table 9, all biofuels meet the sustainability criteria defined by CORSIA except Hydro-processed esters and fatty acids (HEFA) produced from palm oil in open pond and Ethanol Alcohol-to-jet (ATJ) from corn grain.

Table 9. Default life cycle emissions values for CORSIA eligible fuels [420].

	Region	Feedstock	GHG emissions (gCO_2e/MJ)	ILUC (gCO_2e/MJ)	CI (gCO_2e/MJ)
Fischer-Tropsch (FT)	Global	Agricultural residues	7.7	0	7.7
	Global	Forestry residues	8.3	0	8.3
	Global	Municipal solid waste	5.2	0	5.2
	USA	Poplar	12.2	-5.2	7.0
	USA	Miscanthus	10.4	-32.9	-22.5
	EU	Miscanthus	10.4	-22.0	-11.6
	USA	Switchgrass	10.4	-3.8	6.6
	Global	Tallow	22.5	0	22.5

[417] https://www.energy.gov/sites/prod/files/2014/06/f16/fcto_sa_factsheet_greet.pdf

[418] Edwards, R., Padella, M., Giuntoli, J., Koeble, R., O'Connell, A., Bulgheroni, C., Marelli,

L. (2017). Definition of input data to assess GHG default emissions from biofuels in EU legislation, Version 1c, EUR 28349 EN, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-64617-1,

doi:10.2790/658143, JRC104483.

[419] http://www.lbst.de/index.html

[420] ICAO document (2019). CORSIA default life cycle emissions values for CORSIA eligible fuels. https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2006%20-%20Default%20Life%20Cycle%20Emissions.pdf (accessed 02/05/2020).

	Region	Feedstock	GHG emissions (gCO_2e/MJ)	ILUC (gCO_2e/MJ)	CI (gCO_2e/MJ)
Hydro-processed esters and fatty acids (HEFA)	Global	Used cooking oil	13.9		13.9
	Global	Palm fatty acid distillate	20.7		20.7
	Global	Corn oil	17.2		17.2
	USA	Soybean oil	40.4	24.5	64.9
	Brazil	Soybean oil	40.4	27.0	67.4
	EU	Rapeseed oil	47.4	24.1	71.5
	Malaysia & Indonesia	Palm oil-Closed pond	37.4	39.1	76.5
	Malaysia & Indonesia	Palm oil-Open pond	60.0	39.1	99.1
Iso-butanol Alcohol-to-jet (ATJ)	Global	Agricultural residues	29.3	0	29.3
	Global	Forestry residues	23.8		23.8
	Brazil	Sugarcane	24.0	7.3	31.7
	USA	Corn grain	55.8	22.1	77.9
	USA	Miscanthus	43.4	-54.1	-10.7
	EU	Miscanthus	43.4	-31.0	12.4
	USA	Switchgrass	43.4	-14.5	28.9
Ethanol Alcohol-to-jet (ATJ)	Brazil	Sugarcane	24.1	8.7	32.8
	USA	Corn grain	65.7	25.1	90.8
Synthesized Iso-Paraffins (SIP)	Brazil	Sugarcane	32.8	11.3	44.1
	EU	Sugar beet	32.4	20.2	52.6

While the main focus of CORSIA is on calculating the GHG emissions of bio jet-fuels, other sustainability schemes such as RED II and the FQD focused on all types of biofuels and reported the carbon intensity of those biofuels. The difference in GHG emissions between the fuel production stage for bio jet-fuels compared to on-road transportation using the same process do not vary significantly. Thus, the estimated LCA GHG emissions by CORSIA can be roughly compared with those of RED II. Table 10 shows that GHG emissions estimated by CORSIA are close to RED II's estimates, however, in most cases CORSIA's estimates are lower, by at least 13%, than those of RED II.

Table 10. GHG emissions of biofuels reported by RED II[421].

Fuel	Feedstock	CI (g CO_2e/MJ)*	
		REDII	CORSIA**
FT Diesel	Wood waste	13.7	8.3
FT Diesel	Farmed wood	16.7	12.2
Ethanol	Sugarcane	28.6	24.1
Ethanol (natural gas as process fuel in conventional boiler)	Corn grain	56.8	65.7
Hydrotreatment	Soybean oil	46.5	40.4
Hydrotreatment	Used cooking oil	16.0	13.9
Hydrotreatment	Tallow	21.8	22.5

* Carbon intensity (CI) values do not include ILUC.
**CI values are for aviation fuels.

CORSIA defined five eligible technologies for bio jet fuel production including Fischer-Tropsch (FT) synthesis in which carbon monoxide (CO) and hydrogen (H_2) in the syngas are converted into liquid hydrocarbons in the presence of metal catalysts. CORSIA assumed that the GHG emissions during FT synthesis is offset by self-generating electricity (using biomass) and using carbon capture and sequestration (CCS) technology. While self-generating electricity and employing CCS technology are feasible and used by several biofuel plants, they have their own challenges, are often are very hard to implement, and are not the prevailing technology and configuration at FT biofuel plants. Moreover, clean fuel programs such as LCFS have rigorous protocols for offsetting the GHG emissions using CCS technology such that regulatory burden of implementing CCS can be difficult to achieve and, in some locations, almost impossible. Therefore, an FT synthesis plant which self-generates electricity and uses CCS technology is an extremely optimistic scenario and likely should not be used as a default scenario to estimate the carbon intensity of FT fuels.

2.3.7.4 Rules on Indirect land use change (ILUC)

While most sustainability policies across the world require to decrease the use of fossil fuels and replace them with biofuels, the rise in demand for biofuels can displace the production of food and feed crops with biofuel feedstocks, and the conversion of environmentally sensitive lands such as forests and wetlands into agricultural land, which leads to increase in greenhouse gas emissions. Therefore, to accurately estimate the carbon intensity of biofuels the GHG emissions associated with ILUC should be included in the LCA of biofuels. In order to calculate the GHG emissions associated with ILUC, CORSIA employed two models including GTAP-BIO and GLOBIOM. While GTAP-BIO and GLOBIOM have different assumptions and require different sets of inputs, they have similar

[421] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG&toc=OJ:L:2018:328:TOC

principles, and both are commonly used to predict land-use changes associated with increased biofuel production. GTAP-BIO was developed at Purdue University and uses a number of Agro-ecological Zones (AEZ) as land use types to analyse the impact of biofuel expansion on each land use type. GLOBIOM developed by the International Institute for Applied Systems Analysis (IIASA) is rooted in the Forestry and Agricultural Sector Optimization Model (FASOM) except that FASOM is US-focused and GLOBIOM is used globally. Both GTAP-BIO and FASOM are extensively used by researchers and clean fuel programs. For instance, FASOM was used by EPA's Regulatory Impact Analysis (RIA) to estimate the domestic land use change resulting from biofuel production in the US[422] and GTAP-BIO was used by California for the LCFS to estimate the GHG emissions related to ILUC both within the United States and globally [423].

While CORSIA accounts for GHG emissions from ILUC, RED rules do not take ILUC effects into account in the calculation of the total lifecycle emission values of biofuels. The EU uses another approach for ILUC by applying limits to the amount of conventional biofuels that can be counted towards the emission reduction targets (based on their share in 2020) and by making the contribution of conventional biofuels towards the RED target in transport optional.

For CORSIA 28 pathways were assessed based on various technologies, feedstocks and regions and all pathways were simulated in both GTAP-BIO and GLOBIOM. For CORSIA, the AFTF conducted sensitivity and uncertainty analyses to better capture the differences in regional results, market-mediated responses, and the decomposition of land use change and emissions. The estimated ILUC varied across different crops and regions. Table 9 shows that the ILUC for some crops such as palm, corn grain and soybean were the highest while herbaceous energy crops such as miscanthus and switchgrass have negative ILUC due to inclusion of carbon sequestration through biomass growing. The same approach was used by GREET1 and CA_GREET models and similar results were reported (Table 11). However, while CA_GREET and GREET1 models estimated the carbon sequestration using GTAP and CCLUB[424] and included carbon sequestration in ILUC, RFS2 and LCFS programs have not included the carbon sequestration of biomass in calculating the carbon intensity of biofuels. The reason programs like RFS2 and LCFS have not included the carbon sequestration through biomass growing in their LCA is the high level of uncertainty involved in calculating the carbon stock of soil over time. The soil organic carbon storage is affected by numerous factors including climate, soil properties, and farm management practices. The carbon sequestration is usually estimated over a long period of time (20-30 yeas) and in this context the stability of sequestered soil carbon over time is crucial. Any change in sensitive factors like climate or management practices impact the soil carbon storage. Giving biofuels carbon credit due to carbon sequestration through biomass growing should be done cautiously. Table 9 also shows that some feedstocks have zero ILUC. Generally, the feedstocks categorised as residue, waste or by-products have land use change of zero which results in a lower overall carbon intensity compared to purpose grown biofuel feedstocks such as corn grain or soybean oil.

SAF feedstocks with low ILUC can be produced using two approaches, increasing the yield and producing feedstocks on marginal lands. The increase in yield (compared to baseline) causes producing more feedstock without using additional land which results in no ILUC emissions. Moreover, converting marginal land (land that was not used for a minimum of

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[422] EPA, (2010). Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. EPA-420-r-10-006.

February 2010.

[423] https://ww3.arb.ca.gov/fuels/lcfs/lcfs.htm

[424] Dunn, J. B., Qin, Z., Mueller, S., Kwon, H. Y., Wander, M. M., & Wang, M. (2017). Carbon calculator for land use change from biofuels production (CCLUB) users' manual and technical documentation (No. ANL-/ESD/12-5 Rev. 4). Argonne National Lab.(ANL), Argonne, IL (United States).

3 years before the start of the feedstock production) to produce SAF feedstock results in no ILUC emissions.

Table 11. GHG emissions from ILUC

	GHG emissions from ILUC (g CO_2e/MJ)				
	Ethanol				Biodiesel
	Corn grain	Corn Stover	Miscanthus	Switchgrass	Soybean
CA_GREET3[425]	19.8	-0.6	-20	-3.1	29.1
GREET1 2019[426]	7.5	-0.6	-20	-2.9	9.3

2.3.7.5 Emission Credits

CORSIA allows to calculate the avoided emissions credit for municipal solid waste (MSW) diverted from landfills. Landfill emission credits (LEC) and recycling emission credits (REC) are calculated for diverted MSW. CORSIA has a detailed methodology for calculating the LEC and REC based on characteristics of each MSW component[427]. Economic operators who want get LEC and REC for their feedstock should show that the emission credits claimed are permanent, directly attributable to the production of SAF, exceed any emissions reductions required by law, regulation or legally binding mandate; avoid double counting of such credits, and exceed emissions reductions that would otherwise occur in a business-as-usual scenario[428].

2.3.7.6 Impact of the inclusion of CORSIA lower carbon aviation fuels as CORSIA Eligible fuels

Annex 16 Volume IV defines the Lower Carbon Aviation Fuel (LCAF) as "a fossil-based aviation fuel that meets the CORSIA Sustainability Criteria". During its pilot phase, CORSIA has two sustainability themes and three sustainability criteria, one regarding the GHG emissions of the biofuels (10% reduction in GHG emissions) and the other focused ensuring that feedstocks used do not come from high carbon stock land. CAEP is tasked with developing additional or strengthened sustainability criteria specifically applicable to LCAF to apply beyond the pilot phase. LCAF are not operational under CORSIA until a sustainability framework and an accounting methodology have been adopted for their use.

From the technical standpoint, a small portion of GHG emission of fossil-based aviation fuels is attributed to the fuel production stage while most of the GHG emissions is coming from burning the fuels. Thus, there is only small room for improving the carbon intensity of fossil fuels. There are some technologies which allow the production of fossil fuels with a smaller carbon footprint, such as flaring, CCS and the use of renewable energy in oil refineries[429].

As LCAF relates to reductions in emissions associated with the production of the fuel, there is a risk that the use of LCAF leads to double counting as these reductions could be used under CORSIA and appear in the inventories reported to the UNFCCC.

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[425] https://ww3.arb.ca.gov/fuels/lcfs/ca-greet/ca-greet.htm

[426] https://greet.es.anl.gov/index.php?content=greetdotnet

[427] CORSIA Methodology for Calculating Actual Life Cycle Emissions Values. https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2007%20-%20Methodology%20for%20Actual%20Life%20Cycle%20Emissions.pdf

[428] An Airline Handbook on CORSIA. https://www.iata.org/contentassets/fb745460050c48089597a3ef1b9fe7a8/corsia-handbook.pdf

[429] https://www.icao.int/environmental-protection/Pages/innovative-fuels.aspx

2.3.7.7 Impacts on indirect land use change

While CORSIA prohibits converting lands with high carbon stock such as forestland, peatlands, and wetlands to sources of feedstock for bio jet fuel, a more detailed description of lands with high carbon stocks and discussing site-specific regulations regarding feedstock sourcing will help airlines and biofuel developers who want to participate in this program to better understand the constraints and limitations.

It should be noted that the reduction benefits can be claimed only for the portion of GHG emission reductions achieved through using the eligible fuels. Thus, the economic incentive to purchase SAF from feedstock which achieve little GHG emission savings is negligible.

Displacement and substitution can impact the emissions associated with ILUC and should be considered in CORSIA's sustainability analysis. Substitution emissions are emission credits from non-biofuel products substituting or displacing existing economic products in the market. These emissions are quantified for primary product feedstocks where their production processes result in secondary products with economic value. For instance, Distillers Grain Solubles (DGS) is a by-product of the corn ethanol production process and receives an emissions credit equal to the emissions generated to produce the quantity of animal feed substituted by the DGS produced. Moreover, displacement emissions are the additional emissions to produce a replacement material when an economically valuable feedstock is used for biofuel production[430].

The RED II defines "high ILUC-risk" biofuels as those produced from feedstocks for which a significant expansion onto high carbon stock land is observed. On the other hand, "Low ILUC-risk" biofuels are those biofuels produced from feedstocks that avoid displacement of food and feed crops through improved agricultural practices or through cultivation of areas not previously used for crop production. Under RED II the consumption of high ILUC risk biofuels will be phased out.

2.3.7.8 Impact on biodiversity

If biomass used to produce CORSIA sustainable aviation fuels is obtained from protected lands or lands with high biodiversity, it will have adverse impact on biodiversity. CORSIA's current criteria for feedstocks used for sustainable aviation fuels are more concerned about carbon stock of lands and do not address enhancing the biodiversity. In order to preserve biodiversity, biomass used for sustainable fuels should not be obtained from protected lands and lands with high biodiversity. Although, currently, the biodiversity is not part of CORSIA's sustainability criteria, it will be added to the criteria after January 2024. CORSIA will require biofuel producers not to source their feedstock from areas that are protected for their biodiversity, conservation value, or ecosystem services and use Low invasive-risk feedstock. This can help to reduce the impact of biofuels on biodiversity.

2.3.7.9 REDII requirements/rules (including how biofuels are incentivised in the aviation ETS)

Under RED II, the overall EU target for Renewable Energy Sources consumption by 2030 has been raised to 32%. According to RED II, "member States must require fuel suppliers to supply a minimum of 14% of the energy consumed in road and rail transport by 2030 as renewable energy". The RED II has defined a set of sustainability and GHG emission criteria that biofuels must comply with to be counted towards the overall 14% target. Protecting land with high biodiversity value and land with high-carbon stock are among these criteria. ILUC also has been added as a sustainability criterion such that the use of fuels produced from feedstocks with high ILUC-risk are limited and the use of fuels

430 https://theicct.org/sites/default/files/publications/ICF_LCFS_Biofuel_Categorization_Final_Report_011816-1.pdf

produced from feedstocks with low ILUC-risk are encouraged. Moreover, the share of biofuels and bioliquids produced from food and feed crops is limited.

While aviation and maritime sectors are not included in the mandatory fuel volumes, they will receive incentives to use more renewable fuels; the contribution of non-food renewable fuels supplied to these sectors will count 1.2 times their energy content (i.e. 1 ton of fuel counts for 1.2 tons of fuel towards the mandated targets, on an energy content basis)[431]. Thus, the biofuel suppliers have a bonus of 20% to produce aviation biofuels which can be traded in EU ETS.

2.4 Demand, supply and cost of carbon offset credits

In this section we set out estimates of the demand for carbon offset credits; the potential supply of credits from existing emission reduction projects – reflecting the recommendations by the TAB on emissions unit eligibility for CORSIA's pilot phase approved by the ICAO Council; and projections for the cost of carbon offset credits that airlines might face over the period to 2035.

The COVID-19 pandemic emerged towards the end of the duration of this study and its ongoing effects remain uncertain, both for the initial years of CORSIA as well as over the medium-to-long term. The discussion in this section is based on evidence and analysis conducted prior to COVID-19 and the associated changes to CORSIA's emissions baseline for the pilot phase.

2.4.1 Demand for carbon offset credits

The demand for carbon offset credits under CORSIA depends on the following three factors:

1. Participation of States and their respective compliance with the scheme;
2. The emissions' intensity of aviation traffic - including the use of sustainable alternative fuels - on regulated routes; and
3. Growth in aviation traffic on regulated routes above the baseline.

As discussed in Section 2.3.1, as of July 2020 ICAO expects 88[432] State will participate in CORSIA from 1 January 2021, including the European Union; the G7 countries such as the United Kingdom and the United States; but not China, Brazil, India and Russia. Moreover, there is a risk that the United States will not participate if countries like China, India, Brazil and Russia do not participate. The fewer States participate in CORSIA, the fewer routes will be covered under the scheme and the smaller the demand for carbon offset credits.

Demand is also influenced by the emissions' intensity of aviation traffic on routes regulated by CORSIA. Aeroplane operators can reduce the emissions' intensity of flying by operational improvements, such as adjusting route distances and altitude, and limiting the carriage of unnecessary fuel. Technological improvements, such as reducing aeroplanes' weight and using sustainable aviation fuels, can lead to a further reduction in emissions' intensity. Operational and technical improvements are, however, unlikely to lead to a sufficient reduction in emissions' intensity to offset growth. ICAO projects that even in the most optimistic scenario, international aviation fuel efficiency (expressed in terms of

[431] https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii

[432] Over the course of this study, seven States indicated they will participate in CORSIA in 2021: Afghanistan, Benin, Côte d'Ivoire, Honduras, Kazakhstan, Madagascar and Rwanda. Our modelling includes 81 states as we were not able to include these countries. Considering that the seven states combined accounted for approximately 0.03% of global RTKs in 2018, their inclusion would not materially alter our findings.

volume of fuel per RTK) is expected to improve by only 1.37% a year over the period to 2050.[433]

The limited contribution of improvements in flight emissions' intensity has two main reasons. First, it takes time for such improvements to be delivered due to the coordination of revised operational procedures and the relatively long lifetime of aircraft that means the turnover of the fleet is slow. Second, the costs of many technological improvements are significant and therefore prohibit rapid, large-scale implementation. As noted above in Section 2.3.4, costs for fuel switching for instance, fall in the range of €217/tonne CO_2e for UCO HEFA to more than €4,000/tonne CO_2e for corn grain ATJ according to Pavlenko 2019.[434] Even the low end of this range is materially higher than the likely costs of purchasing carbon offset credits (see Section 2.4.3). This means that it is likely significantly cheaper for aeroplane operators to purchase credits, rather than invest in measures to reduce their own emissions, to meet CORSIA's sectoral target of "carbon neutral growth".[435]

The third factor determining demand for carbon offset credits is the growth in aviation traffic on regulated routes, relative to the baseline. At the time of finalising this study, the COVID-19 pandemic was ongoing and had already significantly cut aviation activity in the first months of 2020. The effects of COVID-19 on both the level of aviation traffic in 2020 - which influence the determination of the baseline - as well as traffic in subsequent years remain highly uncertain. Existing projections of aviation traffic growth pre-date the effects of COVID-19 and are based on an assumption of business-as-usual operations in 2019 and 2020 and thereafter. ICAO previously projected that passenger traffic in terms of Revenue Passenger Kilometres (RPKs) would increase by 4.1% annually between 2015 and 2045.[436] This growth would outweigh the expected increase in fuel efficiency. ICAO projected that international emissions would increase by 220-310% by 2045, compared to 2015.[437] The ICCT found that all aviation – domestic and international – increased by 32% between 2013 and 2018. Although only for a five-year period coinciding with a recovery from the financial crisis, this increase implies an annual compound growth rate of 5.7%, which is 70% higher than those used to develop ICAO's projections.[438]

The demand for carbon offset credits will be affected by COVID-19's impact on aviation traffic if the baseline level of emissions, against which future emissions' growth is offset, is lower than it would have been if 2020 aviation traffic were unaffected by the pandemic. In June 2020, the ICAO Council decided that during CORSIA's pilot phase, 2019 emissions shall be used to define the baseline instead of the average between 2019 and 2020 emissions.

Estimated demand for carbon offset credits

Based on 2016CAEP analyses, ICAO estimated that to achieve "carbon neutral growth" from 2020, 142-174 million tonnes of CO_2 released in 2025 must be offset; 288-376 million

[433] ICAO, "Destination Green: The Next Chapter - 2019 Environmental Report." Pages 18-22.

[434] Pavlenko, Searle, and Christensen (2019), "The Cost of Supporting Alternative Jet Fuels in the European Union."

https://theicct.org/sites/default/files/publications/Alternative_jet_fuels_cost_EU_20190320.pdf

[435] Some countries have mandate or targets with various levels of enforcement or update depending on the country which could reduce offsetting requirements – See ICAO (2017). Sustainable Aviation Fuel Guide: https://www.icao.int/environmental-protection/knowledge-sharing/Docs/Sustainable%20Aviation%20Fuels%20Guide_vf.pdf page 38

[436] ICAO, "ICAO Long-Term Traffic Forecasts: Passenger and Cargo," 2018, https://www.icao.int/sustainability/Documents/LTF_Charts-Results_2018edition.pdf.

[437] ICAO, "Destination Green: The Next Chapter - 2019 Environmental Report." Page 21.

[438] Graver, Zhang, and Rutherford, "CO_2 Emissions from Commercial Aviation, 2018." Page 4.

tonnes of CO_2 in 2030 and 443-596 million tonnes CO_2 in 2035.[439] These numbers reflect expected emissions above the 2019-2020 baseline, but since not all States are likely to participate in CORSIA, demand for carbon offset credits will be lower. In our initial assumed participation scenario, the scheme covers 53% of global international aviation CO_2 emissions in 2025, 50% in 2030 and 49% in 2035. This implies that annual demand for carbon offset credits would be approximately 75-90 million in 2025; 145-190 million in 2030; and 215-290 million units in 2035.

Based on CAEP analysis presented in 2019, ICAO estimates a demand of 104 million for carbon offset credits in CORSIA's pilot phase.[440].

Healy (2017) estimated that carbon offset credit demand under CORSIA would range between 1.6-3.7 billion units in the period 2021-2035.[441] This estimate was based on the assumption that China participates in CORSIA from 2021, and that Russia, India, Brazil, South Africa, Chile and the Philippines all participate in the second phase.

In our modelling analysis – set out in Section 3 – we estimate carbon offset credit demand under nominal scenario assumptions of between 1.2-2.2 million in CORSIA's pilot phase, 25-29 million in the first phase, and 360-899 million in the second phase.[442] The range of estimates reflects different participation scenarios. Under high emissions growth scenario assumptions demand for carbon offset credits is somewhat higher and more aligned with the estimates from the literature mentioned above. Demand rises to 33-48 million in CORSIA's pilot phase; 124-182 million in the first phase; and 929 – 2,210 million in the second phase. Total demand for carbon offset credits over the period 2021-2035 in the initial assumed participation scenario is 493 million under nominal scenario assumptions and 1.6 billion under high emissions growth scenarios.

As explained above, this analysis is pre-COVID. Recently Schneider and Graichen (2020) estimated that "a 2019 baseline would delay mitigation obligations for the industry by several years and most likely waive any offsetting requirements in the pilot phase, and possibly even in the first phase of the scheme".[443]

2.4.2 Potential supply of eligible carbon offset credits

In this section we set out estimates of the potential supply of carbon offset credits from existing emission reduction projects under different scenarios. Understanding the potential supply – in combination with demand estimates – can help inform both potential costs of compliance under CORSIA as well as the likely climate impact of the scheme; in particular the extent to which CORSIA may incentivise the development of new emission reduction projects that would not otherwise have been implemented in the absence of the scheme.

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[439] ICAO, "What Would Be the Impact of Joining CORSIA?," 2020, https://www.icao.int/environmental-protection/Pages/A39_CORSIA_FAQ3.aspx

[440] CORSIA FAQ 5.1 What is the estimated quantity to be offset under the CORSIA? https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-FAQs.aspx

[441] Sean Healy, "CORSIA: Quantification of the Offset Demand" (Berlin: Öko-Institut e.V., 2017), www.oeko.de.

[442] The analysis does not fully capture the potential effects of COVID-19 and associated adjustments to the CORSIA emissions baseline, although we do not anticipate these to have a particularly material impact on the carbon offset credit demand estimates included here. The short-term reduction in aviation activity as a result of COVID-19, coupled with the revision of the CORSIA baseline to reflect only 2019 emissions for the pilot phase, increases the likelihood that the carbon offset credit demand in CORSIA's pilot phase is zero.

[443] Lambert Schneider and Jakob Graichen, Should CORSIA be changed due to the COVID-19 crisis?, May 2020.

2.4.2.1 CORSIA eligible emissions units

In March 2020 ICAO approved - based on recommendations by the TAB - an initial list of six programmes to supply carbon offset credits for compliance use under CORSIA and set out the restrictions on the eligibility of credits for CORSIA's pilot phase. The six approved programmes include the CDM, VCS, Gold Standard, CAR, ACR and the China GHG Voluntary Emission Reduction Programme ("CCER"). The TAB recommended that the Forest Carbon Partnership Facility and the Global Carbon Council are approved as conditionally eligible, subject to further review by the TAB of their updated procedures. In addition, a second round of applications for approved programmes is underway, which may accept further programmes and expand the pool of eligible credit supply.[444]

The TAB put forward its recommendations on CORSIA eligible emissions units to the ICAO Council's 219th Session in March 2020.[445] These recommendations - which relate to 'general eligibility parameters', 'programme-specific eligibility parameters', and 'enabling recommendations' - were approved by the Council.

1. The **general eligibility parameters** require that carbon offset credits can be used for compliance during CORSIA's pilot phase if they are issued to projects that started their first crediting period on, or after, 1 January 2016 (according to the crediting period start date specified at the time of registration with the relevant programme) and as long as they reflect emission reductions that occur up to the end of 2020.
2. The **programme-specific eligibility parameters** set out the six programmes that are approved to supply CORSIA eligible emissions units as well as the two programmes that were recommended for conditional eligibility, subject to further assessment and approval by the ICAO Council. These eligibility parameters also detail a number of programme level restrictions.
3. The **enabling recommendations** relate to means of communication, the notification of conditions and exclusions, commitments for programmes to maintain consistency with the EUCs and publication of recommendations by the TAB.

To date, ICAO has not approved detailed emissions unit eligibility restrictions for the first and second phases of CORSIA.

2.4.2.2 Overview of method to estimate supply of carbon offset credits

We have carried out detailed – project level – estimates of the potential supply of carbon offset credits for the four largest programmes, all of which are approved to supply CORSIA eligible emissions units: the CDM, the VCS; Gold Standard and the CAR. We supplement these detailed estimates with indicative estimates for other approved programmes based on a review of relevant literature.

The analysis included here does not provide a forecast of the likely amount of carbon credits that might supply the market under current, or expected future, market conditions. Instead we consider a realistic *potential* supply of carbon offset credits from existing projects in the case that project owners have sufficient economic incentives to proceed to the issuance of carbon offset credits. The realistic potential supply is lower than a

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[444] The 2020 TAB Assessment requested applications submitted by 20 April 2020 (https://www.icao.int/environmental-protection/CORSIA/Pages/TAB.aspx - accessed on 14 April 2020).

[445] Technical Advisory Board, Recommendations on CORSIA Eligible Emissions Units: TAB Report, January 2020.

theoretical maximum as we incorporate practical constraints that could limit the ability of a project to generate carbon offset credits.[446]

To estimate the supply potential of carbon offset credits we use a bottom up model which calculates the potential annual emission reductions for each programme at the project level. The model covers all years over the period from 2013 to 2035 and is configured to match the definition of scenarios, such as vintage restrictions. This modelling framework has been used in previous studies to estimate the supply potential of offset credits for both the CDM[447] as well as the three other programmes.[448] Further details of the methodology are provided in Fearnehough, et al. (2019)[449] with updated assumptions set out in Annex 2. In general, to the extent that information is available, we draw on project and project-type level information on the following key parameters to inform our quantification of the supply potential:

1. The **technical implementation and operation status** of projects, including whether the project is likely to have been implemented and continues GHG abatement;
2. The **crediting periods and emission reduction calculations**, including the length of crediting periods and any conditions and restrictions on their renewal, such as the use of revised methodologies at renewal that may change the number of carbon credits a programme can generate;
3. The **availability of data to monitor emission reductions**, which could in some instances limit the ability of project owners to issue carbon credits (e.g. if a full monitoring system has not been in place for a period due to lack of carbon credit demand); and
4. The **project performance**, including whether the project belongs to a project type that typically underperforms or overperforms as compared to ex-ante emission reduction estimates prepared when registering the project.[450]

Our analysis for the CDM is based on the latest project-level information from the beginning of February 2020. For the VCS, Gold Standards and CAR the analysis is based on project-level information from March and April 2020 (detailed information sources and dates are included in Annex 2).

The estimates set out in the following sections aim to reflect the main programme-specific eligibility restrictions approved by the ICAO Council to the extent that relevant information is captured in each programme's public registries and any supplementary data shared directly by the programmes. The restrictions we applied are reflected in the following bullet points:

- **CDM**: The ICAO Council endorsed TAB recommendation that all carbon offset credits issued to afforestation and reforestation activities should be excluded from

[446] Fearnehough, Warnecke, Schneider, Broekhoff, La Hoz Theuer, Offset credit supply potential for CORSIA, October 2019.

[447] For example, Warnecke et al., "Robust Eligibility Criteria Essential for New Global Scheme to Offset Aviation Emissions," *Nature Climate Change* (Nature Publishing Group, March 1, 2019), https://doi.org/10.1038/s41558-019-0415-y.

[448] Fearnehough, Warnecke, Schneider, Broekhoff, La Hoz Theuer, Offset credit supply potential for CORSIA, October 2019.

[449] Fearnehough, Warnecke, Schneider, Broekhoff, La Hoz Theuer, Offset credit supply potential for CORSIA, October 2019.

[450] Fearnehough, Warnecke, Schneider, Broekhoff, La Hoz Theuer, Offset credit supply potential for CORSIA, October 2019.

eligibility. We therefore exclude the supply potential from all activities categorised as either "afforestation" or "reforestation" within the CDM project database.

- **Gold Standard**: The ICAO Council endorsed TAB recommendation that all carbon offset credits issued for emission reductions on an ex-ante basis are excluded from eligibility. Our analysis indicates that approximately 3.6 million of the 130 million credits already issued by the Gold Standard by the end of March 2020 were issued for emission reductions on an ex-ante basis (labelled as Planned Emission Reductions, or PERs). These are all excluded from our supply potential estimates.
- **VCS**: The ICAO Council endorsed a number of TAB recommended exclusions for carbon offset credits from AFOLU sector activities. These relate to Jurisdictional and Nested REDD+ project activities as well as standalone AFOLU project activities, with restrictions determined by the specific methodologies used by the programme to assess the projects. As the project level information from the VCS registry does not allow us to readily filter all of the restricted projects we take a conservative approach and exclude all AFOLU sector projects from our supply potential estimates.

In addition to the above, the ICAO Council endorsed the TAB recommendation to exclude project activities that have not reported their sustainable development contributions or co-benefits from the CAR and VCS. Information on the projects that would be excluded according to these restrictions is not readily available via the programme registries. As these projects could retrospectively report an assessment of their sustainable development contributions or co-benefits according to established methods we do not exclude any projects from the supply potential estimates on these grounds.

2.4.2.3 Potential supply of carbon offset credits for CORSIA's pilot phase (2021-23)

In submitting its recommendations on eligible emissions unit for CORSIA's pilot phase, the TAB estimated available supply from existing projects for CORSIA's pilot phase could be in the range of 128 to 144 million credits based on information shared by the respective programmes during the application process, noting that this is considered conservative. Indeed, the estimates excluded the potential issuance of new carbon offset credits by the CDM as well as other assumptions that would tend to underestimate the potential supply that could be made available. Nevertheless, the TAB's own supply estimates are well in excess of CAEP's estimate for demand for carbon offset credits of 104 million during the pilot phase.

We estimate that existing projects that are already registered under the four programmes we have analysed in detail could supply approximately 240 million new credits for emission reductions up to the end of 2020. All of these projects meet the eligibility criteria to supply carbon offset credits for compliance under CORSIA's pilot phase. The supply potential estimates, broken down by programme, are shown in Figure 9.

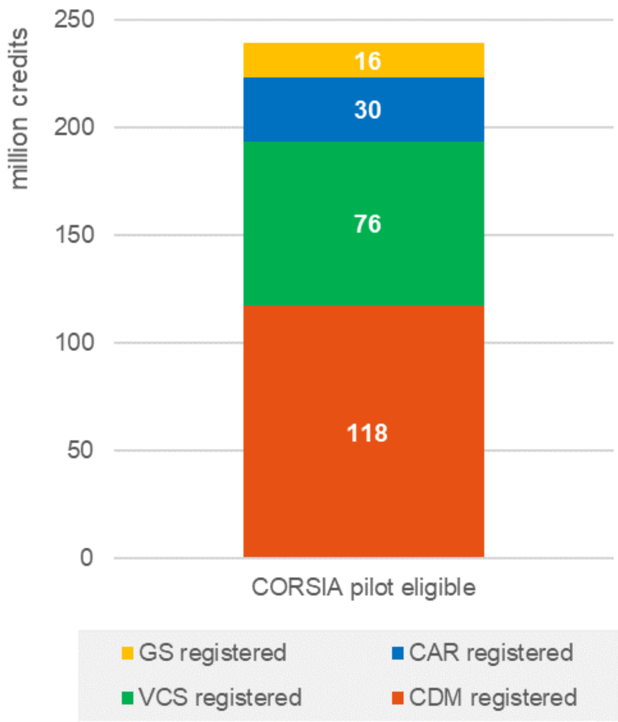

Figure 9. Supply potential for new carbon offset credits eligible for CORSIA's pilot phase

The CDM provides the largest source of potential credit supply, accounting for 118 million eligible credits, followed by the VCS (76 million), the CAR (30 million) and the Gold Standard (16 million). The potential supply of new credits for CORSIA's pilot phase is well in excess of our estimates of demand, which range between 1.2-2.2 million under nominal scenario assumptions and 38-48 million under high growth assumptions, depending on assumptions regarding the list of participating states.

The estimates in Figure 9 are for new carbon offset credits that have not yet been issued to project owners. Credits that have already been issued to eligible projects for historic emission reductions and not yet retired or cancelled could also be used for compliance under CORSIA's pilot phase. The information on the available stock of credits is limited. We set out indicative estimates of the current stock of CORSIA eligible credits, where possible, for each of the four programmes.

- **CDM**: We do not have detailed information on the cancellation of issued credits under the CDM at project level to be able to determine the exact stock of eligible certified emission reduction credits, or CERs. As of 31 March 2020, there were 258 million CERs in the CDM's pending account - where credits are issued to and kept until they are forwarded to the holding account of project participants - for emission reductions since 2013. However, CDM projects which started their first crediting period after 1 January 2016 only account for 1.2% of the total issuance of credits for emission reductions since 2013. This would imply that there could be an existing stock of approximately 3 million CERs eligible for use in CORSIA's pilot phase.[451]
- **VCS**: Project level credit issuance and retirement data was not available to export (for all projects) from the VCS public database at the time of conducting the analysis. Information published on the programmes website in April 2020 indicated

[451] Information on the volume of CERs in the CDM pending account was obtained from the CDM Registry (https://cdm.unfccc.int/Registry/index.html, accessed on 15 April 2020). The calculation of the share of issuances that may be eligible was conducted by the authors, based on issuance and credit period information in the CDM project database.

that there was a total stock of VCS credits from all projects and vintages of 219 million (457 million issuances and 237 million retirements). AFOLU projects account for approximately 40% of all credit issuances. We have not been able to identify what share of the non-AFOLU credit stock is from projects that are eligible to supply carbon offset credits in CORSIA's pilot phase.

- **Gold Standard**: Based on an analysis of credits issued and retired in the Gold Standard registry approximately 5.6 million of the total volume of unused credits of 65 million would be eligible for used in CORSIA's pilot phase.
- **CAR**: Based on information in the CAR project registry, there is a stock of approximately 140 thousand Climate Reserve Tonnes, or CRTs, issued by the CAR and not yet retired from eligible projects as well as a further 17 million Registry Offset Credits, or ROCs, which are used for compliance under California's Cap-and-Trade Program, but which in theory could be converted to CORSIA eligible units.

Eligible emissions units for CORSIA's pilot phase need to reflect emission reductions delivered up to the end of 2020. Whilst the projects are typically not located in countries that have adopted climate targets under the Kyoto Protocol and its subsequent Doha Amendment, a number of eligible projects are located in countries which made pre-2020 emission reduction pledges under the Cancun Agreements. As there are no provisions to avoid double-counting with Cancun Pledges there is a risk that emission reduction outcomes are used both by the host country towards its Cancun Pledge and an aeroplane operator towards it compliance obligation under CORSIA. Based on an analysis of the projects that are eligible for use in CORSIA's pilot phase, we estimate that up to 113 million of the 240 million new credits for emission reductions to the end of 2020 shown in Figure 9 are at risk of being double-counted because they are based in countries and sectors that are covered by emission reduction pledges under the Cancun Agreements.

In addition to the potential supply from registered projects, it is possible that projects that are still in the registration pipeline (i.e. at different stages of validation by the programme before they are approved to be registered and issued with credits), could successfully register and supply carbon offset credits for emission reductions delivered before the end of 2020. However, given the limited period of time before the end of the year, we do not include any potential supply from non-registered projects within our estimates.

Our detailed project-level analysis of four programmes does not include supply potential from either the ACR or China's GHG Voluntary Emission Reduction Program. These approved programmes – as well as any further programmes approved by ICAO following the ongoing second round of applications, or any subsequent rounds - could expand the pool of available supply further. Analysis published by EDF China indicates that approximately 70 projects within the China GHG Voluntary Emission Reduction Program could be eligible for use in CORSIA's pilot phase, generating just over 40 million carbon offset credits for emission reductions up to the end of 2020.[452] This is based on the assumption that China will restart the programme - currently on hold pending updates to its rules - and would issue credits dating back to 2016. This potential supply is therefore uncertain. It may also be influenced by China's decision on whether or not it elects to participate in CORSIA's pilot phase.

Ecosystem Marketplace also conducted an analysis of the potential supply of carbon offset credits for CORSIA's pilot phase, published before the ICAO Council decision on eligible emissions unit was made public. It included all six approved programmes in its assessment, estimating that under a 2016-2020 vintage scenario, the existing supply of eligible carbon offset credits as of March 2020 was 386 million credits (of which 168 million

[452] The EDF report does not appear to be publicly available, but the analysis was reported by the carbon pricing and climate policy news outlet, Carbon Pulse: Carbon Pulse, China could supply 40mln early offsets to CORSIA – report, 18 March 2020.

are issued by the CDM), with a total potential supply 569 million credits.[453] The Ecosystem Marketplace report does not provide full details of their approach and calculation assumptions so it is not possible to directly compare to our estimates. However, its assessment supports our general finding that the supply of CORSIA eligible carbon offset credits is likely to be well in excess of demand levels for CORSIA's pilot phase.

The potential supply of credits for CORSIA's pilot phase set out in this section is not exclusively reserved for use under CORSIA. Indeed, all of the programmes currently supply alternative sources of demand – both for compliance as well as voluntary purposes. In particular, the voluntary market for carbon offset credits has grown in recent years. Voluntary market demand for carbon offset credits – reflected in data on credit retirements - ranged between approximately 30-40 million per year between 2013 and 2017.[454] More recent data on annual retirements is not available although an assessment of the transacted volume of credits for voluntary purposes in 2018 suggested a rise of approximately 50% compared to 2016 levels.[455] This would imply voluntary market demand in 2018 on the order of 50 million carbon offset credits. Voluntary market buyers however are not necessarily constrained to purchasing credits from projects that starting their first crediting period after 1 January 2016 and there is a large stock of issued, but unused credits available in the market at present. It is therefore possible that demand for credits for alternative sources to CORSIA will partially erode the available supply for use under CORSIA. However, it is unlikely to materially alter the finding that there is likely to be an excess supply of carbon offset credits during CORSIA's pilot phase.

2.4.2.4 Potential supply of carbon offset credits for CORSIA's first and second phases (2024-35)

The ICAO Council has not yet determined what emissions units will be eligible for compliance use during CORSIA's first and second phases. The TAB's recommendations on eligible emissions units excluded the use of credits for emission reductions delivered after the beginning of 2021, presumably due to concerns that avoiding double counting of the emission reductions with the NDCs of project host countries could not be avoided and to allow further time for progress in establishing international rules and process for avoiding double counting under UNFCCC-led negotiations.

Previous analysis of the potential supply of credits for emission reductions achieved between 2013 and 2035 found that - without eligibility restrictions - existing projects (both registered and in the registration pipeline) could supply approximately 18 billion offset credits.[456] Updating this analysis with the latest project information indicates that this unrestricted supply potential has increased slightly to almost 20 billion offset credits. A large share of this supply is from projects that would have continued their emission reduction activity regardless of the introduction of CORSIA because they do not depend on ongoing revenues from the sale of carbon credits to continue emissions abatement.[457]

The ICAO Council's decision to limit the supply of credits for CORSIA's pilot phase suggests it is unlikely that projects which started their first crediting period before 2016 would be

[453] Ecosystem Marketplace, Carbon markets are well-positioned to meet CORSIA demand projections, March 2020.

[454] Hamrick, K. and Gallant, M., Voluntary Carbon Markets Insights: 2018 Outlook and First-Quarter Trends, August 2018, Washington DC.

[455] Forest Trends' Ecosystem Marketplace. Financing Emission Reductions for the Future: State of Voluntary Carbon Markets 2019. Washington DC: Forest Trends, 2019.

[456] Fearnehough, Warnecke, Schneider, Broekhoff, La Hoz Theuer, Offset credit supply potential for CORSIA, October 2019.

[457] Fearnehough, Warnecke, Schneider, Broekhoff, La Hoz Theuer, Offset credit supply potential for CORSIA, October 2019; Warnecke et al., "Robust Eligibility Criteria Essential for New Global Scheme to Offset Aviation Emissions," Nature Climate Change (Nature Publishing Group, March 1, 2019), https://doi.org/10.1038/s41558-019-0415-y.

considered eligible to supply future phases of CORSIA demand. These projects make up a large share of the unrestricted supply potential estimates - notably projects registered or in the registration pipeline of the CDM. In Figure 10 we show the supply potential of carbon offset credits from existing projects that started their first crediting period after 1 January 2016 for emission reductions delivered in the period to 2035. This would be the potential eligible supply for CORSIA's first and second phases if ICAO were to extend the existing eligibility restrictions in place for the pilot phase, but allow emission reductions delivered by these projects after 2020 to be used for compliance. We also report estimates of the potential supply from non-registered projects with the four programmes in the right-hand chart (note the different axis values). These estimates include conservative adjustments to reflect the likelihood that projects within the registration pipeline are able to successfully register with the programme in the future.

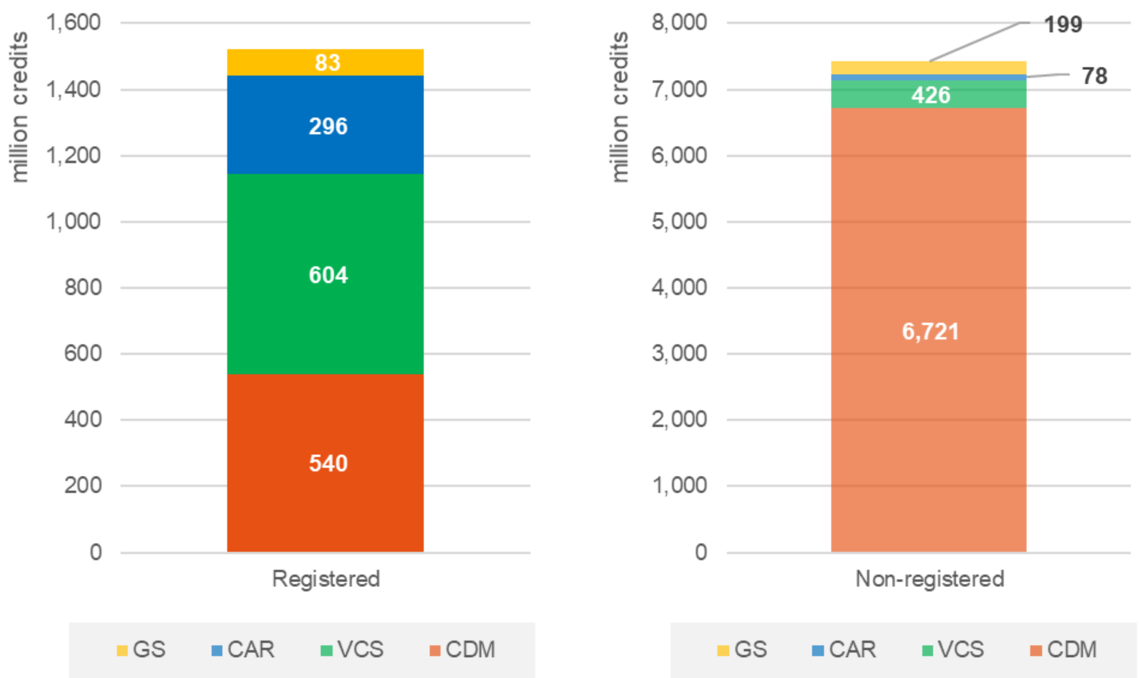

Figure 10. Supply potential from existing projects (registered and non-registered) that started their first crediting period after 1 January 2016 for emission reductions delivered in the period to 2035.

If ICAO were to allow carbon credits from projects considered eligible to supply units for CORSIA's pilot phase, extending eligibility to emission reductions delivered up to 2035 for use in the scheme's first and second phases, existing registered projects could supply approximately 1.5 billion credits. This is considerably higher than the demand of 493 million credits we estimated over the duration of CORSIA based on the initial assumed participation scenario and under nominal scenario assumptions. And it is similar to the level of demand of 1,600 million credits estimated under high growth assumptions.

Non-registered existing projects (shown on the right hand chart of Figure 10) could supply a further 7 billion credits with the vast majority coming from the CDM pipeline where there are a large number of projects that have submitted a prior notice of consideration to give them the option to seek registration and begin crediting at a future point in time. Excluding the CDM pipeline, projects in the registration pipeline of the other three programmes could supply approximately 700 million credits for emission reductions to 2035. This supply potential would be further expanded if estimates for the China Voluntary Emission Reduction Program and the ACR were added, as well as potential further programmes that are approved to supply CORSIA eligible carbon offset credits following the ongoing second, and any subsequent, programme assessment processes.

A key risk under the scenario that credits from existing projects are accepted for compliance use in CORSIA's first and second phase is that the emission reduction outcomes are also used towards achievement of the project host country's NDC targets, thereby double-counted. Indeed, a large share of existing projects are delivering emission reductions in sectors that are covered by their respective country's current NDC targets[458] and this share would rise as countries increase the scope of their NDCs over time, in line with the requirements of the Paris Agreement. The TAB's recommendations on eligible emissions units already identified this risk. However, it remains unclear if, and to what extent, future eligibility restrictions will be able to adequately avoid the risk of double-counting. Further, negotiations on final rules for implementing Article 6 of the Paris Agreement, including the avoidance of double counting for the Article 6.4 mechanism, continue in the UNFCCC and it is unclear when they will conclude, especially given the postponement of COP26 until the end of 2021.

If ICAO were to adopt robust eligibility restrictions that further constrain the potential supply of carbon offset credits from existing projects for use in CORSIA's first and second phases, this will better incentivise the development of new emission reduction projects. Developing high quality new emission reductions projects in the Paris Agreement era will be considerably more challenging than in the period up to 2020, given that all countries now have their own emission reduction pledges. Credited emission reduction projects will need to go beyond national efforts to urgently cut their GHG emissions and should avoid disincentivising countries from making ambitious pledges. As all countries increase the scope and degree of challenging mitigation options in their NDC targets over time, the available options to deliver additional emission reduction projects is expected to decline.

2.4.3 CORSIA compliance costs

Aeroplane operators flying routes covered by CORSIA will need to procure and cancel eligible carbon offset credits to meet their compliance obligations. Forecasting prices for carbon offset credits after 2020 is highly uncertain. As noted above in Section 2.3.4, the ICAO Council has approved - based on TAB recommendations - the use of credits from the CDM as well as a number of other programmes for CORSIA's pilot phase. CERs issued by the CDM are traded on exchange platforms, which provide a source of pricing information, although there is currently no distinction for CERs that might be considered eligible for use under CORSIA. Price information for carbon offset credits from other programmes is less transparent. Transactions are typically arranged bilaterally between buyers and project developers, or through market intermediaries, with prices varying according to factors such as volume, project type and sustainable development co-benefits.

The CDM is currently the largest source of carbon offset credits. The price of CERs in February 2020, traded on the EEX exchange, is €0.22 per unit.[459] There is a significant oversupply of CERs available to the market, meaning that the price essentially reflects the administrative costs of verifying emission reductions and issuing credits. Previous analysis of the marginal cost of supplying CERs from registered CDM projects found that up to 3.8 billion new CERs reflecting emission reductions over the period 2013-2020 could supply the market at prices below €1 per unit.[460] If some or all of these existing projects were able to transition to a new mechanism, established under Article 6.4 of the Paris

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[458] Fearnehough et al., "Offset Credit Supply for CORSIA" (NewClimate Institute, 2019).

[459] https://www.eex.com/en/market-data/environmental-markets/derivatives-market/certified-emission-reductions-futures; settlement price for 12 February 2020 for CERs delivered at the end of 2020, accessed on 13 February 2020.

[460] Fearnehough et al., "Discussion Paper: Marginal Cost of CER Supply and Implications of Demand Sources" (Berlin, 2018), https://newclimate.org/wp-content/uploads/2018/03/Marginal-cost-of-CER-supply.pdf.

Agreement, or to alternative crediting programmes, and continue issuing carbon offset credits for emission reductions after 2020, this low cost volume of supply could increase further.

Carbon offset credits for CORSIA's pilot phase are eligible if they are sourced from projects that began their crediting period on or after 1 January 2016, according to the crediting period start date specified at the time of registration and reflect emission reductions delivered up to the end of 2020. Our analysis indicates that existing projects registered under the CDM alone would be able to meet all the demand for CORSIA's pilot phase at prices at or below €1.

A survey of transactions on the voluntary carbon market - covering carbon offset credits from CORSIA eligible programmes, such as the Climate Action Reserve, Gold Standard and the Verified Carbon Standard - reported by Ecosystem Marketplace found that the average price of units has been relatively stable at approximately $3 between 2016 and 2018, or slightly less than €3.[461] The order of magnitude of prices, however, can vary materially. Atmosfair – a project developer as well as market intermediary – currently offers carbon offset credits at the significantly higher price level of €23 per tonne of carbon dioxide reduced.[462]

Compliance costs for aeroplane operators under CORSIA depend on the interaction of demand and supply. Participation of States, developments in traffic and the eligibility of carbon offset credits are likely the most critical determinants of demand and supply, respectively. As these elements are highly uncertain, we only set out projected estimates of two carbon offset credit price scenarios under CORSIA over the period to 2035.

In **price scenario 1**, we assume that prices remain at €1 per unit in constant 2017 prices over the full duration of CORSIA. For CORSIA's pilot phase, this reflects the findings that the potential supply of eligible emissions units from registered CDM projects alone could meet all of the expected demand at, or below, this price level. The TAB has not yet recommended which emissions units should be eligible beyond the pilot phase, and there remains a risk that all of the demand under CORSIA could be met from existing CDM projects that are able to supply credits at, or below €1 per unit,.

In **price scenario 2**, we assume that prices remain at €1 per unit in constant 2017 prices for CORSIA's pilot phase. However, from 2024 we assume that the eligibility of emissions units, ensure that at least some of the demand for credits incentivises emission reductions from new projects. Under this scenario the price for carbon offset credits over the period 2024-2035 would be determined by the marginal abatement cost for new emission reduction projects. The likely cost of delivering emission reduction projects after 2020 is highly uncertain.

A High-Level Commission on Carbon Prices appraised a range of evidence on carbon prices consistent with keeping within the temperate limits of the Paris Agreement and concluded that price levels would need to be at least within the range of $40-80 per tonne of carbon dioxide by 2020 and $50-100 USD by 2030.[463] The International Energy Agency publishes projections of carbon prices in its annual World Energy Outlook (WEO) report under different scenarios.[464] In the 2019 WEO the price projection for selected developing

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[461] Forest Trends' Ecosystem Marketplace, "Financing Emissions Reductions for the Future: State of Voluntary Carbon Markets 2019" (Washington, 2019).

[462] https://www.atmosfair.de/en/offset/fix; based on price offered via website on 13 February 2020.

[463] High-Level Commission on Carbon Prices, "Report of the High-Level Commission on Carbon Prices" (Washington D.C, 2017), https://static1.squarespace.com/static/54ff9c5ce4b0a53decccfb4c/t/59244eed17bffc0ac256cf16/1495551740633/CarbonPricing_Final_May29.pdf.

[464] International Energy Agency, World Energy Outlook 2019, 2019; Table B.5

economies in their Sustainable Development scenario is $75 in 2030, rising to $125 in 2040.

Historically carbon credit prices have tended to be lower – and often considerably lower – than the level of carbon taxes or emission allowances under cap-and-trade schemes, such as the EU ETS. This can be attributed to a number of factors, including lower GHG abatement costs in the countries where emission reduction projects are based, issues related to the quality of credits and a fundamental imbalance between the supply of, and demand for, carbon credits. In price scenario 2 we assume that the price of CORSIA eligible carbon offset credits reaches €22 per unit (in constant 2017 prices) in 2035, or half the level of the lower end of the range for carbon prices compatible with the Paris Agreement as recommended by the High-Level Commission on Carbon Prices of $50. For the years between 2023 and 2035, we set a price trajectory based on a linear interpolation between €1 in 2023 and €22 in 2035.

Figure 11 shows our two price scenarios for carbon offset credits over the period 2020 to 2035, along with the price ranges recommended by the High-Level Commission on Carbon Prices (HLCCP), interpolating between the 2020 and 2030 values, as well as the IEA's Sustainable Development carbon pricing scenario, interpolating between a price of zero in 2020, $75 in 2030 and $125 in 2040.

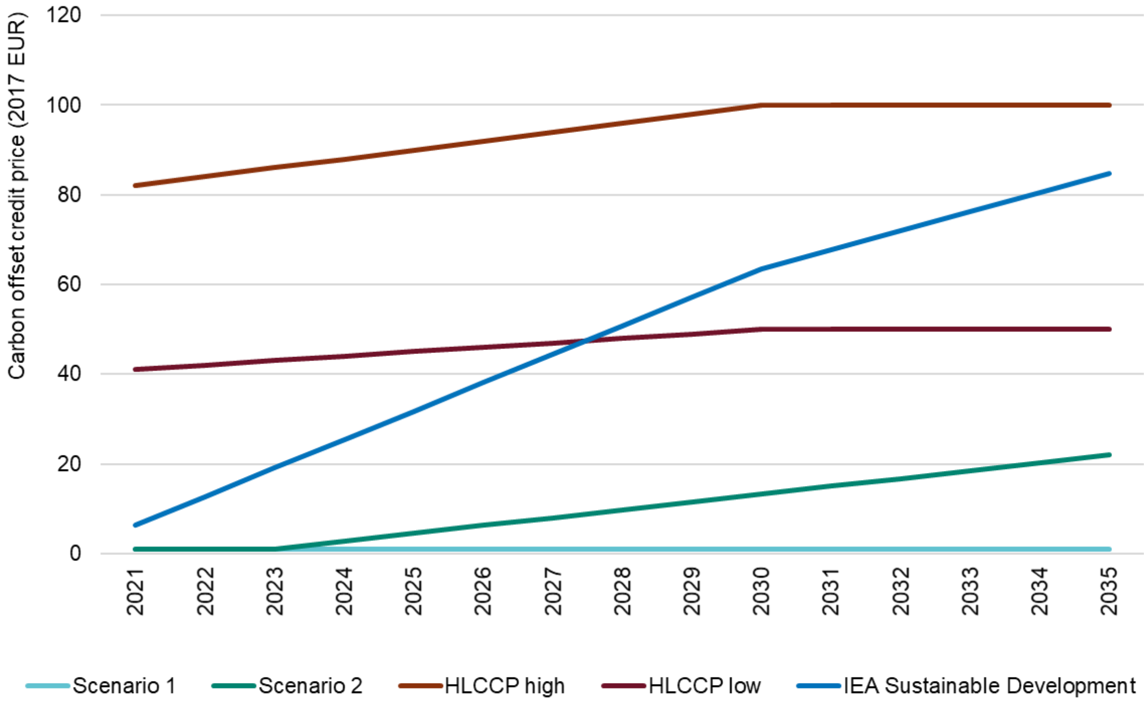

Figure 11. Carbon offset credit price estimates under scenarios 1 and 2, along with alternative Paris Agreement compatible carbon price projections

2.5 Potential economic, social and environmental implications of CORSIA

In this final section of the assessment of CORSIA, we identify a number of impacts that the scheme may have. We first set out some of the potential socioeconomic impacts of CORSIA. These are explored in further detail, based on economic modelling of scenarios and assessment of cost pass-through, in Sections 3 and 4. We then examine the potential climate impact of the scheme under a range of different scenarios, including the case that CORSIA is not implemented at all.

As noted in previous sections, the analysis was largely conducted prior to the COVID-19 pandemic. Due to the timing of the work as well as ongoing uncertainties it does not fully reflect the potential effect of COVID-19 on factors such as the growth of emissions over time and associated demand for carbon offset credits.

2.5.1 Socioeconomic impacts

The implementation of CORSIA is unlikely to materially impact on international aviation traffic as the costs of compliance are expected to be a relatively minor share of airlines overall costs (see section 3.2 below for further details) and will therefore neither affect demand for air travel, nor key decisions regarding aviation operations. This means that the scheme is unlikely to lead to economic impacts on the continuation and development of key actors involved in and dependent on the aviation sector; for example, the construction and operation of infrastructure such as airports, aircraft and their related supply chains, or the wider business and leisure travel industries, as well as international trade in general. It is also unlikely to lead to social, or environmental impacts deriving from reduced air pollution or noise, both of which can lead to health and associated productivity benefits.

In the following bullet points we identify certain key impacts for different actors that may occur and briefly describe them qualitatively.

- **Aeroplane operators will face increased administrative burden**: Under CORSIA all aircraft operators are required to undertake MRV of their emissions from international flights. For aeroplane operators undertaking certain routes where there are already MRV requirements – such as in the EEA - CORSIA may not present a particularly high additional administrative burden, but for those that had not engaged in MRV activities prior to 2019, complying with CORSIA requirements may add administrative effort and associated cost for tasks such as data collection, reporting, quality assurance and verification. In addition, to comply with CORSIA, aeroplane operators on participating routes will likely need to engage in procuring and surrendering carbon offset credits. For many aeroplane operators this activity is likely to be outsourced at a cost.

  The size of an aeroplane operator, including the number of flights and routes it operates, is likely to have an effect on the relative scale of the cost they face to meet administrative requirements under CORSIA as a share of their overall costs. Whilst some costs, including emissions data collection, reporting and quality control, typically increase in-line with the number of flights, larger operators may be better placed to benefit from economies of scale by investing in automated IT solutions that reduce manual effort. Larger operators will tend to face relatively lower one-off costs as a share of their total costs, than smaller operators. These one-off costs include tasks such as setting up administrative systems and internal processes; understanding the detailed design and rules of CORSIA; as well as establishing knowledge of the carbon offset credit market in general and, specifically, the procurement of credits.

- **Aeroplane operator profit margins may be reduced**: Complying with the MRV and offsetting requirements under CORSIA will impose a cost (as noted in the previous bullet). This cost is expected to be a relatively small share of their overall operating costs. However, as the aviation sector is competitive particularly on popular routes, airlines typically operate with tight profit margins per flight. These profit margins may be squeezed by the additional regulatory burden of complying with CORSIA. We discuss the ability of aeroplane operators to pass through such costs in Section 4.
- **National and international regulators will face an increased administrative burden**: ICAO – as the administrator of CORSIA – and national experts who have participated in the CORSIA design process have already incurred administrative costs in establishing the design of CORSIA and will continue to need to commit

resources to continued governance of the scheme over its full duration. Similarly, national regulators responsible for governing the operation of the scheme and the compliance of their registered aeroplane operators will also face an administrative burden throughout the duration of CORSIA. This is likely to include setting up and resourcing teams to carry out tasks including: preparation and implementation of national regulations; ongoing engagement with CORSIA decision-making (including reviews) at ICAO; calculating the offsetting obligations for aeroplane operators, as well as monitoring and enforcing compliance.

Whilst all states will need to monitor and enforce compliance with MRV requirements, national regulators from states with registered aeroplane operators with high levels of international aviation activity, flying predominantly on participating routes, will face a higher administrative burden than regulators from those states whose registered operators either have fewer flights or operate flights largely on non-participating routes.

- **Carbon market intermediaries, emission reduction project owners and related stakeholders may benefit from increased sales of carbon offset credits**: CORSIA is likely to increase the demand for carbon offset credits which would provide economic benefits, including jobs, to actors involved in the design, implementation, operation and management of emission reduction projects that are eligible for compliance use under CORSIA. Where credits are sourced from existing projects, CORSIA may provide additional revenue streams to these actors. Under certain scenarios it may also stimulate the development of new emission reduction projects.

  Whilst the procurement of carbon offset credits may provide economic benefits to actors in low carbon industries, or working on low carbon technologies, they may also lead to economic losses in other industries, whose activities are displaced by the implementation of emission reduction projects (e.g. workers in fossil fuel sectors). The overall *net* economic impact of channelling funding to emission reduction projects may therefore be more limited and could even be negative. This is however highly dependent on the additionality of the projects, or in other words if such projects are likely to have happened anyway (see Section 2.3.4). Various studies have demonstrated that a vast majority of existing carbon offset credits are unlikely to represent additional and uninflated emission reductions, which implies that their underlying activities would have likely occurred with or without the revenue from the sale of offset credits.[465]

- **Communities and governments may receive wider benefits from the implementation of emission reduction projects**: In the event that CORSIA stimulates demand for new emission reduction projects, these projects typically deliver co-benefits and support sustainable development objectives beyond the mitigation of climate change to the communities where they are located. These can include positive impacts to biodiversity as well as positive health impacts from cleaner air or access to clean water, which in turn can both benefit society and reduce government health care costs.
- **The production of CORSIA Eligible Fuels may have negative social and environmental consequences**: The ICAO Council approved two criteria that CORSIA Eligible fuels must meet: (1) fuels must result in at least a 10% reduction in lifecycle GHG emissions, compared to standard aviation fuel; (2) fuels must not be made from biomass obtained from land converted after 2008 with a high carbon stock; and (3) in the event of land use conversion after 1 January 2008 the DLUC

[465] For example, Cames et al., 2016. How additional is the Clean Development Mechanism?https://ec.europa.eu/clima/sites/clima/files/ets/docs/clean_dev_mechanism_en.pdf

value shall replace the ILUC value.[466] These criteria do not guarantee that the production of alternative fuels will avoid negative consequences for e.g. food security, land rights and biodiversity. Although the Council will approve additional sustainability criteria at the end of CORSIA's pilot phase,[467] there is a risk that the production of eligible fuels in the near future will be unsustainable. However, this risk is also linked to whether CORSIA provides a financial incentive to use CORSIA eligible fuels.

The socioeconomic impacts of CORSIA as well as different policy options, including the regulation of aviation emissions through the EU ETS, are analysed in further detail, including quantitative assessments for certain impacts, in section 3.3 below.

2.5.2 Climate impacts

The headline climate objective, to which CORSIA is intended to contribute as one of the four measures in the ICAO 'Basket of Measures', is 'carbon neutral growth' of the international aviation sector from 2020. This target is unlikely to be achieved because participation in CORSIA is likely to be partial, rather than complete (Section 2.3.1), and the ability of ICAO to enforce compliance with the scheme is limited (Section 2.3.3). Furthermore, it is challenging to guarantee that the carbon offset credits used to offset the actual growth in international aviation emissions reflect accurately measured real and permanent emission reductions that would not otherwise have occurred, i.e. that they are of high environmental integrity(Section 2.3.4).

CORSIA is unlikely to materially alter the climate impact associated with air travel as the price signal that airlines will face under the scheme is not expected to provide sufficient financial incentives for them to reduce emissions beyond those that would occur anyway. The ICAO Council has not yet determined which fuels are CORSIA eligible and which fuel producers may produce fuels for compliance under CORSIA. However, the carbon dioxide abatement cost of synthetic and bio jet fuels is likely to be well in excess of the price of eligible carbon offset credits.

CORSIA may however drive GHG emission reductions in other sectors through its requirement for aeroplane operators to purchase carbon offset credits from eligible emission reduction projects. The extent to which CORSIA contributes to mitigating climate change through emission reductions in other sectors depends on the volume of carbon offset credits that are procured by airlines for compliance use with the scheme, the extent to which this volume drives demand for new projects, as well as the environmental integrity, or 'quality', of these carbon offset credits. Determining the quality of carbon offset credits that might be used by aeroplane operators is highly uncertain, particularly as ICAO is yet to set out what emissions units will be eligible for compliance in CORSIA's first and second phases. In particular, clear and adequate procedures for ensuring that emission reductions after 2020 are both additional and avoid double-counting are currently lacking from the main programmes that issue carbon offset credits. In assessing the climate impact of the scheme, we consider three scenarios in relation to the quality of the carbon offset credits used for compliance:

1. **Low-quality credits**: In this case the carbon offset credits used for compliance under CORSIA are of low quality and do not guarantee the delivery of accurately measured emission reductions that would otherwise not have occurred. This would

[466] ICAO Council, "CORSIA Sustainability Criteria for CORSIA Eligible Fuels," 2019. Available at: https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2005%20-%20Sustainability%20Criteria.pdf (accessed 2 July 2020).

[467] ICAO Council, "CORSIA Sustainability Criteria for CORSIA Eligible Fuels," 2019. Available at: https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2005%20-%20Sustainability%20Criteria.pdf (accessed 2 July 2020).

be the case where there is a high risk that credits are double-counted towards the achievement of climate targets by other entities; where they are not additional; present high risks of reversal (i.e. they are non-permanent) and/or the leakage of emissions to other countries or sectors. Where only low-quality credits are eligible to be used for compliance we assume they have no impact in delivering emission reductions in other sectors.

2. **Medium-quality credits**: In this case our assumption is that each carbon offset credit used for compliance under CORSIA represents the reduction of half a tonne of CO_2, on average. This reflects the fact that there is a degree of variation in the quality of carbon offset credits across programmes, different project types and the circumstances of individual projects. There are currently no established procedures to practically avoid double-counting emission reductions after 2020 and negotiations have stalled in the UNFCCC, the main body for doing so. Whilst this risk is recognised by the TAB and ICAO, it is unclear to what extent the risk can be completely addressed in the coming years. The TAB recommendations for CORSIA's pilot phase did not address the risk of double-counting carbon offset credits used for CORSIA with emission reduction outcomes counted towards the achievement of Cancun Pledges.
3. **High-quality credits**: In this case all of the carbon offset credits reflect high quality emission reductions equating to a tonne of CO_2 that are accurately measured and would not have been achieved otherwise. Under this scenario double-counting with other climate targets is avoided and the credits are sourced from new emission reduction projects which address challenging mitigation options that are clearly inaccessible to the project host countries they are delivered in, thereby ensuring they would not have been achieved otherwise.

In our modelling analysis described below in Section 3, total emissions from the international aviation sector are 666 $MtCO_2$ in 2025, 770 $MtCO_2$ in 2030 and 857 $MtCO_2$ in 2035 under nominal scenario assumptions and 746 $MtCO_2$ in 2025, 917 $MtCO_2$ in 2030 and 1,112 $MtCO_2$ in 2035 under high growth scenario assumptions where CORSIA is the only policy in place to regulate sector emissions (policy option 3).

In Figure 12 we show the total international aviation emissions in each year as well as the net CO_2 impact for the medium- and high-quality credit scenarios, which takes into consideration the emission reductions associated with carbon offset credits purchased for CORSIA compliance. In the low-quality credit scenario, the net CO_2 impact is virtually the same as the gross CO_2 impact, or total international aviation sector emissions, i.e. CORSIA would have no impact on reducing global climate impacts. This represents the volume of offsets used in the **initial assumed participation** scenario.

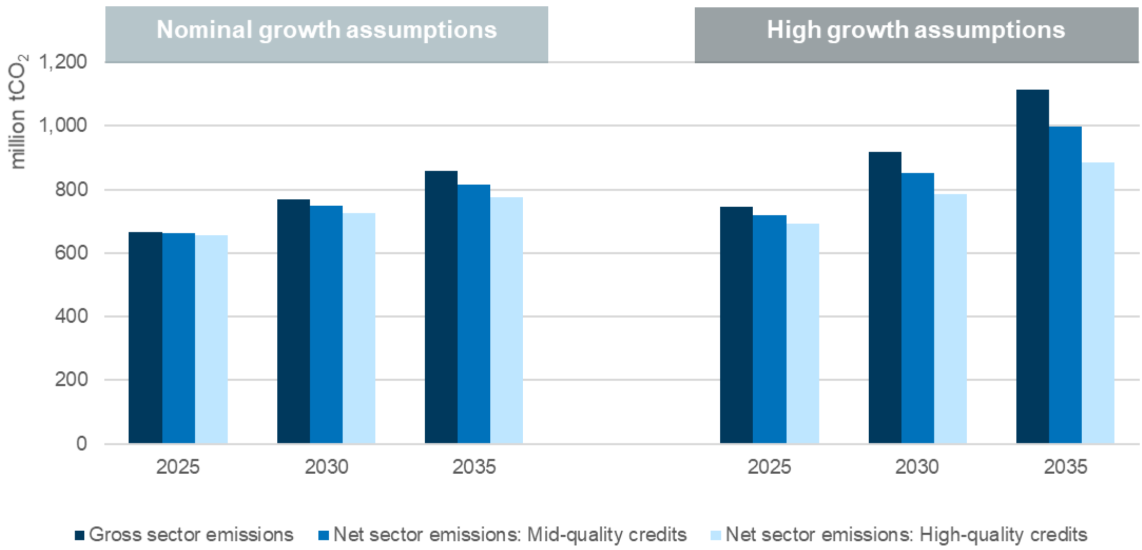

Figure 12. Net climate impact of CORSIA with initial assumed participation and under different credit quality assumptions

In Figure 13 we show the same information, but here reflect the volume of offsets used in the **high participation** scenario, in which China, Russia, India, Brazil and Vietnam join CORSIA for its second phase from 2027.

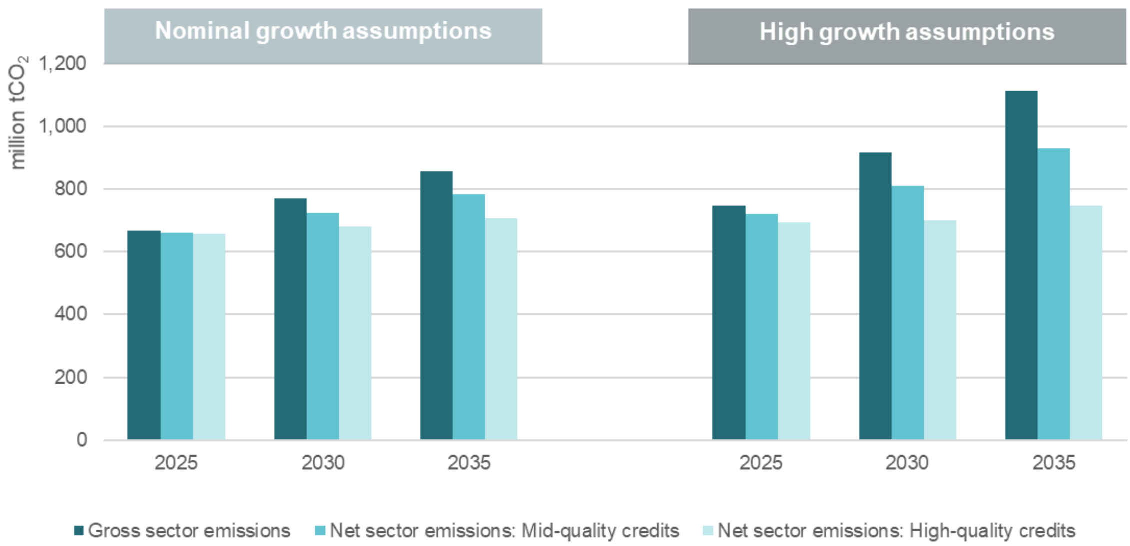

Figure 13. Net climate impact of CORSIA with high participation and under different credit quality assumptions

In the initial assumed participation scenario (Figure 12), CORSIA may incentivise the annual reduction of up to 45 million tCO_2, or 6% of international aviation emissions in 2030, and 83 million tCO_2, or 10% of sector emissions in 2035, under nominal growth assumptions and assuming all carbon offset credits are high-quality. These impacts are halved if the credits instead reflect our definition of mid-quality. Under high growth assumptions, the international aviation sector drives a larger overall negative impact to the climate. If all carbon offset credits reflect high-quality emission reductions then CORSIA may incentivise the annual reduction of up to 133 million tCO_2, or 14% of international aviation emissions in 2030, and 229 million tCO_2, or 21% of sector emissions in 2035.

CORSIA's impact in reducing global CO_2 emissions, compared to the counterfactual case in which the scheme is not implemented (and there is no alternative regulation of international aviation emissions in addition to the other elements of the 'Basket of Measures'), is higher under the high participation scenario. In the high participation scenario (Figure 13), CORSIA may incentivise the annual reduction of up to 91 million tCO_2, or 12% of international aviation emissions in 2030, and 149 million tCO_2, or 17% of sector emissions in 2035, under nominal growth assumptions and assuming all carbon offset credits are high-quality. Under high growth assumptions, if all carbon offset credits reflect high-quality emission reductions then CORSIA may incentivise the annual reduction of up to 216 million tCO_2, or 24% of international aviation emissions in 2030, and 364 million tCO_2, or 33% of sector emissions in 2035. Again, these impacts are halved if the credits instead reflect our definition of mid-quality.

Under all scenarios emissions from the international aviation sector rise over the duration of CORSIA to levels on the order of 1 billion tCO_2 by 2035. The sector's net contribution to atmospheric CO_2 levels is reduced the most when State participation in CORSIA is highest and the carbon offset credits used for compliance are of high quality. In this case CORSIA may reduce the sector's net contribution to atmospheric CO_2 levels in 2035 by approximately 20-30% but net emissions would still be considerably higher than the CO_2 impact of the sector in 2020. Given uncertainties regarding the participation of key sources of international aviation traffic as well as the quality of carbon offset credits, the net contribution of the aviation sector to atmospheric CO_2 levels under CORSIA is likely to be higher and there is a risk the scheme may only provide a limited climate benefit compared to the case in which international aviation emissions remain unregulated.

Finally, as we note above in section 2.3.4, CORSIA does not address any of the non-CO_2 impacts from the aviation sector.

3 Assessing the economic, social and environmental impacts of the different policy options

This assessment uses the AIM global aviation systems model, and the E3ME global macro-economic model, to quantify the impacts of different potential ways of combining the EU ETS for aviation and CORSIA, both within the aviation sector and more generally. This involves four stages:

- Assessment of uncertain variables for modelling input (e.g. GDP growth, oil prices, EUA prices), including a literature review of past impact assessments and other relevant projections of aviation activity;
- Running the Aviation Integrated Model (AIM) for each policy option across a grid of uncertain variables to assess likely aviation sector outcomes and associated ranges of uncertainty;
- For selected scenarios, using output from AIM as input to the global macro-economic model E3ME, to check wider socio-economic impacts; and
- Analysis and presentation of final model outputs.

Summaries of the AIM and E3ME model methodologies are given in Annex 3 and Section 3.3.1, respectively. The modelling phase also uses extensive inputs from Section 2 (e.g. participation, CORSIA-eligible credit prices) and Section 4 (cost pass-through estimates). This section of the final report discusses the inputs to, outputs from and conclusions of the modelling phase.

3.1 Review of existing literature and establishment of a model baseline

There are multiple studies looking at global and European aviation system growth and response to policy. This includes previous assessment reports looking at aspects of the EU ETS for aviation by the European Commission and other bodies, academic studies, and industry reports. As the purpose of this section is to establish a consistent baseline for aviation system characteristics and growth rates with previous work, and to investigate which input variables have the most impact on output uncertainty, we consider studies from each of these sources. Literature which relates to the EU ETS, CORSIA and more generally to the impact of carbon pricing is discussed in this section. Literature which relates primarily to uncertainty in demand growth rates and other system characteristics is discussed in the following section, including discussion of the impact of COVID-19 (which was not included directly in the modelling as the situation was still developing at the time that the model runs were taking place).

3.1.1 Previous assessment reports and related work

The process of initially adding aviation into the EU ETS, assessing the change from full scope to reduced scope, and evaluating the initial potential for interactions with CORSIA has been accompanied by impact assessments at each stage. These assessments reflect the prevailing conditions in the European and global aviation system at the time that they were produced. For example, the initial impact assessments were carried out before the global financial crisis of 2007-08 and so do not reflect its impact on demand. Improvements in CO_2 per revenue passenger kilometre (RPK) over the 2007-2017 time period have also been more rapid than initially anticipated, prompted in part by high fuel prices and the availability of new models of narrow body aircraft. This means that the initial impact assessments typically projected faster aviation CO_2 growth to 2020 than has been observed. In contrast, during the 2015-2018 period, global aviation RPK growth has been faster than anticipated by most projections (e.g. 7.1% growth 2017-2018; ICAO, 2019[468]), although there are indications that this may be a temporary fluctuation with year 2019 RPK growth rates closer to 3-4% (e.g. IATA, 2019)[469].

The initial proposal to add aviation into the EU ETS was assessed by CE Delft (2005),[470] and an updated assessment considering a range of design options was assessed by European Commission (EC) (2006)[471]. These reports concluded that costs for both the aviation sector and the EU were lowest when aviation was integrated into the wider EU ETS rather than being subject to an emissions tax or an aviation sector-specific MBM, and recommended a scope covering all flights to, from and within the EEA. A 'main variant' approach was taken in modelling in which variations in different design parameters were explored around one central scenario. For example, in EC (2006) three main options for the scope of aviation within the EU ETS were considered:

- Main variant: all flights arriving at or departing EU airports,
- Alternative 1: intra-EU flights only, and
- Alternative 2: all flights departing EU airports.

Other design options considered in EC (2006) included coverage of non-CO_2 emissions via an uplift factor, options for the treatment of outermost regions (including no special provision, special provision for outermost regions only, and special provision for outermost regions and other region types as well); options for inclusion of domestic flights; treatment of new entrants; and methods of allowance allocation (no allowances/ auctioning/ grandfathering/ benchmarking). Although an open scheme incorporating aviation into the EU ETS was recommended, and different technical options for achieving this explored, analysis was also conducted to investigate the impact of a closed scheme (i.e. where emissions reductions must be made solely within the aviation sector, leading to a substantially higher allowance price). Two scenarios for demand growth were run, specified directly in demand growth terms rather than socioeconomic drivers:

- An AERO-MS baseline based on ICAO FESG projections with 1%/year ATM improvements with 82% growth in EEA-related direct aviation CO_2 between 2005 and 2020, and
- An alternative PRIMES baseline with 30% growth in EEA-related direct aviation CO_2 between 2005 and 2020.

Additionally, the TREMOVE model was used to assess impacts across the rest of the transport sector for the EU-15 countries plus Czechia, Hungary, Poland and Slovakia. Two allowance prices were tested, based on output from PRIMES: €6 and €30. Cost increases were assumed fully passed on to consumers, including the opportunity costs of freely allocated allowances, leading to windfall profits for participating airlines. The study found that the majority of emissions reductions due to aviation emissions trading were made in non-aviation sectors. For example, for an allowance price of €30 and main variant all departing flights scope, direct CO_2 emissions from aviation declined by around 2% compared to an all-sectors aviation ETS-related reduction of around 40% of aviation CO_2. Most of the aviation sector reduction in CO_2 (1.5-1.9%) was due to decreases in demand

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468 ICAO, 2019. The World of Air Transport in 2018. https://www.icao.int/annual-report-2018/Documents/Annual.Report.2018_Air%20Transport%20Statistics.pdf

469 IATA, 2019. Passenger Demand Continues on Moderate Upward Path. https://www.iata.org/en/pressroom/pr/2019-11-07-01/

470 CE Delft, 2005. "Giving Wings to Aviation – inclusion of aviation under the EU emission trading system: design and impacts". http://europa.eu.int/comm/environment/climat/pdf/aviation_et_study.pdf.

471 EC, 2006. Impact Assessment of the inclusion of aviation activities in the scheme for greenhouse gas emission allowance trading within the Community. COM(2006) 818 FINAL. https://ec.europa.eu/clima/sites/clima/files/transport/aviation/docs/sec_2006_1684_en.pdf

due to increased costs (typically below €10 per round trip, but up to €40 for long-haul round-trip journeys, or up to €80 if using a climate impacts multiplier of 2). The overall impact on other ETS sectors was forecast to be 'very limited' under most combinations of assumptions. The PRIMES model was also used to assess allowance prices under different assumptions about policy design. In the case of a closed (aviation-only) scheme for aviation, year-2020 allowance prices of up to €560 (year 2005 euros) were projected for the high-growth main variant scenario. However, for all open variants of the scheme tested allowance prices remained below €50.

At the time, reports expressing an alternative view were also commissioned by airline industry stakeholders, including the Association of European Airlines (AEA; Ernst & Young and York Aviation, 2007, 2008)[472]. These reports examined emissions impacts, potential carbon leakage and impacts on airline costs as a result of the aviation ETS proposals and projected future increases in the level of auctioning for aviation sector allowances. Ernst & Young and York Aviation (2007) projected allowance prices of between €15-30/tCO_2 for 2011-2012, and €6-30/tCO_2 for 2013-2022. This was accompanied by full scope growth in RPK of 5% per year and in CO_2 of 4% per year. The report argued that airlines do not derive windfall profits from free allowances and system constraints (such as congested airports) likely lead to cost pass-through well below 100%, with the projected result being a substantial decrease in airline profit. The following 2008 report, motivated by increases in the ambition of EU emissions goals, projected allowance prices of €30-50/tCO_2, yearly administrative costs of €116-187 thousand per airline (€0.04-2.33 per allowance), and year-2020 auctioning rates of 15-100% (an increase in auctioning rates has been suggested as a way of reducing advantages held by existing airlines under grandfathered or benchmarked systems; e.g. Kopsch, 2012)[473]. This resulted in year 2012-2020 aviation sector costs of €40-103 billion, compared to estimated sector operating profits of €106 billion, reduction in demand of 1-4% from the case without increased auctioning, the potential for carbon leakage (assessed via a series of individual case studies) and projected reduced airline capacity to invest in new technologies. However, in practice both European and global airline profits have tended to increase over the 2012-2017 period (e.g. ICAO, 2019; global operating results increased from 2.6% of operating revenues in 2013 to 7.9% of operating revenues in 2017) and fuel efficiency has improved at faster-than-projected rates (e.g. IATA, 2019[474]; global fuel efficiency increased by over 12% between 2010 and 2018). Similar rates of auctioning were examined by Boon et al. (2007)[475] but with the assumption of pass-through of windfall profits; they found a maximum extra ticket price increase per long-haul round-trip flight of €59.4 in the case of full auctioning in 2020 with a €45 allowance price, with overall (RTK) demand reduction from a business-as-usual case of 3.3%.

The first 2012 "stop-the-clock" scope reduction of aviation in the EU ETS (i.e. excluding flights to and from the EEA; decision 377/2013/EC) has been subject to regular review,

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[472] 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. https://www.verifavia.com/bases/ressource_pdf/112/AN-EY-FULL-TEXT-OCT08.pdf.

[473] Kopsch, F., 2012. Aviation and the EU Emissions Trading Scheme: Lessons learned from previous emissions trading schemes. Energy Policy, 49, 770-773.

[474] IATA, 2019. 2018 Airline Industry Statistics. https://www.iata.org/en/pressroom/pr/2019-07-31-01/

[475] Boon, B., Davidson, M., Faber, J., van Velzen A., 2007. Allocation of allowances for aviation in the EU ETS – The impact on the profitability of the aviation sector under high levels of auctioning. A report for WWF UK, Delft, CE Delft, March 2007.

including further impact assessments. EC (2013)[476] carried out an initial impact assessment of ways that the scope reduction could be amended to maximise impact on CO_2 whilst maintaining support for the ICAO development of a global market-based measure (referred to as 'GMBM'). Several options for the EU ETS were considered:

- Option 0: Baseline (full scope EU ETS);
- Option 1: Hybrid option (intra-EEA EU ETS, obligations of extra-EEA flights reduced to reflect distance flown within the EEA only, dependent on treatment of sea boundaries);
- Option 2: Departing-flights option (intra-EEA and extra-EEA departing flights scope) and/or 50/50 option (intra-EEA and 50% of extra-EEA arriving and departing CO_2) – these are sufficiently similar that the same modelling can cover both;
- Option 3: Intra-EEA flights only
- Option 4: Upstream option (change of compliance entity from airlines to fuel providers, and corresponding change towards full auctioning of allowances)

These options were assessed against the objectives of maintaining environmental effectiveness, aviation sector competitiveness and level playing field, limiting additional administrative burden, and maintaining coherence with international law and ICAO Resolutions. Additionally, the impact of different Monitoring, Reporting and Verification (MRV) methodologies, and of simplifications to MRV for small operators, were assessed across all options. In each case, the EU ETS emissions cap for aviation was adjusted to reflect the new scope. The impact assessment carried out was an updated version of that done in EC (2006), i.e., including a high estimate of demand based on AERO-MS using ICAO FESG forecasts, and a low estimate of demand growth based on the PRIMES model. ETS allowance prices were estimated to be €10, with international credits €1, including a sensitivity case in which they were increased by 50%. By 2020, ETS coverage compared to the full-scope was projected to be 62% for the departing flights option, 39-47% for the option depending on treatment of sea boundaries and 25 % for the intra-EEA option, with allowance auctioning revenues behaving. The 'Upstream' option was projected to sharply increase auctioning revenue (333% of baseline) due to the withdrawal of free allowances, but was judged to require significant alterations to MRV as well as being subject to potential legal challenge. Within-sector CO_2 impacts were projected to be increases of up to 2.1% compared to full scope, with small decreases (<0.2%) possible in the 'Upstream' scenario due to the change in allowance allocation. Airline costs were projected to be minimally changed compared to the baseline in all cases (<0.15%) and ticket prices (based on full pass-through of allowance costs assuming no windfall profits from free allowances) to change by -1.1% to -0.1%. Changes in passenger demand were under 2.04% in all cases, with the risk of competitive distortion between airlines or tourist destinations, and negative impact on low income groups, assessed as minimal at projected allowance prices.

EC (2017)[477] analysed the likely impact of CORSIA (referred to as 'GMBM') as part of the decision on whether to continue the scope reduction past 2017. In doing so, the report

[476] EC, 2013. Impact Assessment Accompanying the document Proposal for a Directive of the European Parliament and of the Council 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. COM(2013) 722 final. https://ec.europa.eu/clima/sites/clima/files/transport/aviation/docs/swd_2013_430_en.pdf

[477] EC, 2017. Impact Assessment accompanying the document PROPOSAL FOR A REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community in view of the implementation of a single global market-based measure to international aviation emissions. SWD(2017) 31 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD:2017:0031:FIN

considered both the increases in global ambition necessary to meet the goals of the Paris Agreement, and the widespread desire not to risk setbacks to the ICAO process for developing a global aviation emissions mitigation scheme. It also assessed the impacts of a potential transition between the EU ETS and GMBM on other sectors within the ETS and on airline operators and other stakeholders. The options considered for pre-2020 were ETS full scope; ETS intra-EEA only; and ETS intra-EEA plus departing flights. For the 2020-2030 time period, several combinations of the EU ETS and GMBM were considered:

- Option 0: Baseline (full scope EU ETS, no GMBM)
- Option 1: EU ETS intra-EEA, GMBM for extra-EEA flights
- Option 2: Intra-EEA flights offset emissions above EU ETS cap with EU allowances, GMBM for extra-EEA flights
- Option 2a: GMBM for all flights, but EU ETS applied additionally to intra-EEA flights to address the gap between the EU ETS cap and the GMBM 2020 baseline
- Option 3: GMBM for all flights (including 'opt-in' status for domestic flights) but legal base for EU action is maintained.

Assessment was carried out using the AERO-MS model. As the AERO-MS assessment used ICAO CAEP growth rates, which can be relatively high for Europe, alternative demand projections using PRIMES were also generated, similarly to previous impact assessments. The AERO-MS and PRIMES runs for the study differed in demand growth rates and also differed significantly in what they assumed about improvements in per-flight emissions due to technological and operational developments; both sources of uncertainty have significant impacts on outcomes.

EC (2017) used two scenarios each for EU ETS allowance prices and CER prices to 2030. In both cases, prices remained below 50 €/tCO_2 throughout. The input scenarios for other variables were characterised in terms of demand growth rather than a quantification of factors driving demand growth. Two scenarios for demand were considered. The high demand case was generated by AERO-MS for consistency with ICAO CAEP forecasts. It projected growth in intra- and extra-EU emissions of 36% for the 2010-2020 period, and 86% for the 2010-2030 period. The low demand case was generated by PRIMES, and projected growth in emissions from aviation fuels sold in the EU increasing on average by 18% from 2010 to the 2021-2030 time period.

As with previous analyses, none of the policy options investigated reduced direct aviation-related emissions in absolute terms; however, net aviation CO_2 (when considering allowances and/or offsets purchased from outside the aviation sector) under the scope of the EU ETS was reduced by varying amounts. Impacts on the EU ETS (for example, via changes in demand for allowances and consequent allowance price) were projected to be minor. Similarly, the impact on airline operating costs was projected to be below 3% in all cases, which is well below the level of variability that would be expected, for example, from typical fluctuations in oil price. Whilst the possibility for some competitive distortion (e.g. between EEA and non-EEA tourist destinations) was identified, it was judged that allowance prices were unlikely to be high enough to have a significant impact. Of the options identified, option 0 (return to ETS full scope) was not recommended because of its likely negative impact on EU-ICAO relations. Option 3 (GMBM for all flights) was noted to have a significantly lower impact on CO_2. The other options were assessed as being broadly similar in impact to each other.

3.1.1.1 Academic literature and related studies on the EU ETS and CORSIA impacts

There are numerous academic studies assessing the impacts of aviation in the EU ETS (e.g. Anger & Köhler, 2010; Scheelhaase & Grimme, 2007) and a smaller number examining CORSIA (e.g. ICCT, 2017) and the potential interaction of the EU ETS and CORSIA (CE Delft, 2016; Scheelhaase et al., 2018; Grimme et al., 2019; Van Vuuren 2018). These studies largely show that within-sector impacts are likely to be small at projected allowance prices compared to uncertainties from other sources (e.g., fuel price).

This includes impacts related to CO_2 emissions, aviation demand, airline behaviour, competitive distortion and carbon leakage. However, these studies use widely varying assumptions about the growth rates of demand and demand drivers, cost pass-through rates, and the level of emissions reductions that are likely in other sectors as a result of aviation-related policy. These assumptions are discussed below; where provided on an appropriate scope, input assumptions and output projections are plotted in comparison to each other in the discussion of uncertain variables in Section 3.1.2.

Anger & Köhler (2010)[478] reviewed available impact assessments of the initial inclusion of aviation in the EU ETS, finding limited evidence for any substantial within-sector impact, with a maximum projected decline in within-sector direct CO_2 of 3.8% and projected maximum GDP impact of -0.002%. Most studies examined assume roughly a doubling in EU full scope aviation sector emissions between 2005 and 2020. In fact, EU28 domestic and international bunker aviation fuel-related emissions between 2005 and 2017 rose by only 16% (EC, 2019)[479], due to a combination of the impacts of the financial crisis on demand and faster-than-anticipated improvements in CO_2/RPK flown; even with rapid post-2018 growth (ICAO, 2019) year-2020 emissions would have fallen short of most initial assessment assumptions even before the impacts of the COVID-19 pandemic are included. As with the official impact assessments, this suggests that including a wide range of future assumptions about future developments is important.

Within the set of studies looking at the initial inclusion of aviation into the EU ETS a wide range of methodologies are used, ranging from multi-sector economic models, aviation-specific assessment models, network optimisation modelling and more general 'back of the envelope' calculations based on available aviation system metrics. Anger (2010)[480] modelled the multi-sectoral impact of adding aviation to the EU ETS using the E3ME model, assuming €5-40 (year 2008 euros) allowance prices and finding base case 2.5% per year growth in aviation activity and around 1.5% per year growth in aviation emissions. Adding aviation into the EU ETS resulted in demand reductions of under 1% in all cases but at the high end of allowance prices a 7.4% decrease in aviation CO_2 emissions was projected from the base case by 2020, largely arising from changes in airline technology and operations to promote increased fuel efficiency. The overall GDP impact was -0.002 – 0.03%, with decreases in economic activity in the aviation sector almost completely offset by substitution effects in other sectors. Vespermann & Wald (2011)[481] simulated within-sector financial outcomes for allowance price distributions centred on €25/tCO_2 and found only very limited within-sector impacts on costs, competition and CO_2, with CO_2 reductions of under 1% (within-sector only) or 7.7% (adjusting for allowances sold) to 2020.

Faber & Brinke (2011)[482] similarly reviewed literature on the EU ETS's likely impacts, including carbon leakage and competitive distortion, finding only limited demand and

[478] Anger, A., & Köhler, J., 2010. Including aviation emissions in the EU ETS: much ado about nothing? A review. Transport Policy, 17, 38-46.

[479] EC, 2019. EU Transport in Figures Statistical Pocketbook. https://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2019_en

[480] Anger, A., 2010. Including aviation in the European emissions trading scheme: Impacts on the industry, CO_2 emissions and macroeconomic activity in the EU. Journal of Air Transport Management, 16, 100-105.

[481] Vespermann, J., & Wald, A., 2011. Much Ado about Nothing? – An analysis of economic impacts and ecologic effects of the EU-emission trading scheme in the aviation industry. Transportation Research Part A, 45, 1066-1076

[482] Faber, J., & Brinke, L., 2011. The Inclusion of Aviation in the EU Emissions Trading System: An Economic and Environmental Assessment. ICTSD Global Platform on Climate Change, Trade and Sustainable Energy.

ticket price impact. Although some routes for leakage were identified, in practice the wide scope of the EU ETS area, and the small changes in ticket price identified, is likely to limit routing-based leakage. As discussed in Dray & Doyme (2019)[483], carbon-price related ticket price increases will also lead to reductions in demand from EU-originating transfer passengers, and corresponding reductions in emissions on non-EU segments (e.g. a reduction in demand Paris-Dubai-Sydney will lead to a reduction in emissions on the Dubai-Sydney leg). In practice this impact can be of a similar or greater magnitude to that of transfer passengers switching from EU hubs to non-EU hubs, i.e. the leakage impact (if defining leakage as any change in emissions outside a policy's geographic scope) may well be negative. Brueckner & Zhang (2010)[484] examined whether carbon charges would be sufficient to make airlines change fares, aircraft operations and utilisation, using a theoretical model of duopoly airline competition. Their analysis suggests that airlines will respond primarily by changing fares, frequency load factor or technology and potentially (if charges are large enough) switch away from hub-and-spoke type routing, but are unlikely to change the aircraft sizes used on a given route. A further question is whether cost changes due to the EU ETS will be sufficient to make airlines change their network structure to avoid ETS-impacted regions, for example, to switch from a hub in an EEA country to one in a non-EEA country. Such a move could be associated with significant carbon leakage. Albers et al. (2009)[485] examine the impact on passenger airline networks of €20/tCO_2 carbon prices, finding that this is insufficient to induce network change but that EEA airlines will be more strongly affected than non-EEA ones, with up to 3% reduction in passengers. Derigs & Illing (2013)[486] examine the same case from a cargo viewpoint, assuming costs are not passed on to freight shippers. Carbon prices typically have a greater impact on freight carriers because fuel is a larger fraction of their costs. However, under €15/tCO_2 allowance prices minimal network reconfiguration is observed and reductions in profit are insufficient to make switching hubs a viable option unless full auctioning is assumed. Similarly, Li et al. (2016)[487] examine airline efficiency data to assess whether the EU ETS has impacted airline technology use and operational strategies, with resulting within-sector CO_2 emission reductions. They find that airline efficiency (including fuel efficiency) was typically higher for European than non-European airlines amongst the set of 22 examined airlines, but improved across all airlines over the 2008-2012 period. This change is likely driven mainly by globally high fuel prices over this time period, which had a much greater impact on airline fuel costs than ETS prices (see the discussion in the following section).

Some analyses also examine impacts on individual airlines and whether competitive distortion would arise between EEA and non-EEA carriers. Scheelhaase et al. (2010)[488] compare estimated impacts on Continental Airlines and Lufthansa respectively, finding greater impacts on EEA carriers due to the wider coverage of feeder services; however,

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483 Dray, L. and Doyme, K., 2019. "Carbon Leakage in Aviation Policy", *Climate Policy,* 19 (10), 1284-1296.

484 Brueckner, J. & Zhang, A, 2010. Airline emission charges: Effects on airfares, service quality and aircraft design. Transportation Research Part B, 44, 960-971.

485 Albers, S., Bühne, J.-A. & Peters, H., 2009. Will the EU-ETS instigate airline network reconfigurations? Journal of Air Transport Management, 15, 1-6.

486 Derigs, U. & Illing, S., 2013. Does EU ETS instigate Air Cargo network reconfiguration? A model-based analysis. European Journal of Operational Research, 225, 518-527.

487 Li, Y., Wang, Y.-Z. & Cui, Q., 2016. Has airline efficiency affected by the inclusion of aviation into European Union Emission Trading Scheme? Evidences from 22 airlines during 2008-2012. Energy, 96, 8-22.

488 Scheelhaase, J., Grimme, W. & Schaefer, M., 2010. The inclusion of aviation into the EU Emission Trading Scheme – Impacts on competition between European and non-European airlines. Transportation Research Part D, 15, 14-25.

as in Scheelhaase & Grimme (2007)[489], overall impacts per airline are small compared to other sources of uncertainty. Malina et al. (2012)[490] assess the impacts of the original full-scope EU ETS on US airlines, using linked economy-wide CGE and aviation sector-specific (APMT) models. They include three separate scenarios for cost pass-through: one in which no costs are passed through, one in which full costs including free allowances are passed through, and one where only the costs of purchased allowances are passed through. They find very limited impacts in all cases on US airline operating margin and overall emissions; depending on the pass-through assumption, there is the potential for windfall profits at current auctioning percentages and up to a 1.6% reduction in North Atlantic route CO_2 compared to a no-policy baseline. However, Miyoshi (2014)[491], using a case study of an African airline, finds some evidence for equity impacts for non-EEA carriers, primarily due to more stringent capital constraints affecting airlines' ability to use more fuel-efficient aircraft on ETS-affected routes. Nava et al. (2018)[492] examine the trade-off between free allowance supply and within-sector mitigation for competing airlines, finding more incentive to carry out within-sector mitigation at greater auctioning percentages.

Because CORSIA is a more recent development, fewer studies examining its impacts are available. In general, these studies suggest that CORSIA's impact on direct aviation CO_2 and airline operating costs will be small, driven by offset prices that are likely lower than EUA prices and a less stringent emissions target. ICCT (2017) [493]project CORSIA offset costs as likely being only 0.4% of fuel costs in 2025 and under 5% of fuel costs in all cases in 2035, even when EUA-type prices are assumed. This is much less than changes in fuel costs caused by jet fuel price volatility. Under these circumstances, CORSIA costs in their most likely case are negligible before 2030 and 0.9% of total airline operating costs in 2035. This level of cost change is unlikely to strongly impact demand if passed through to ticket prices. However, it is large in comparison to a typical airline operating margin of 4% (e.g. Ernst and Young & York Aviation, 2008).

Scheelhaase et al. (2018)[494] and Maertens et al. (2019)[495] examine potential ways that the EU ETS and CORSIA could interact. Although CORSIA is less ambitious than the EU ETS, if all CORSIA offsets are assumed fully additional then by 2039 the projected emissions reductions from CORSIA would exceed those from the EU ETS full scope, due to aviation system growth and CORSIA's greater geographic coverage. Based on these outcomes Scheelhaase et al. (2018) supports continuing with EU ETS reduced scope whilst covering other flights with CORSIA (i.e. Option 4 in this report, as discussed in the

[489] Scheelhaase, J., & Grimme, W., 2007. Emissions trading for international aviation – an estimation of the economic impact on selected European airlines. Journal of Air Transport Management, 13, 253-263.

[490] Malina, R., McConnachie, D., Winchester, N., Wollersheim, C., Paltsev, S. & Waitz, I., 2012. The impact of the European Union Emissions Trading Scheme on US aviation. Journal of Air Transport Management 19, 36-41.

[491] Miyoshi, C., 2014. Assessing the equity impact of the European Emissions Tranding Scheme on an African airline. Transport Policy, 22, 56-64.

[492] Nava, C., Meleo, L., Cassetta, E. & Morelli, G., 2018. The impact of the ET ETS on the aviation sector: Competitive effects of abatement efforts by airlines. Trasnportation Research Part A, 113, 20-34.

[493] ICCT, 2017. International Civil Aviation Organisation's Carbon Offset and Reduction Scheme for International Aviation (CORSIA). https://theicct.org/sites/default/files/publications/ICAO%20MBM_Policy-Update_13022017_vF.pdf

[494] Scheelhaase, J., Maertens, S., Grimme, W. & Jung, M., 2018. EU ETS versus CORSIA – A critical assessment of two approaches to limit air transport's CO_2 emissions by market-based measures. Journal of Air Transport Management, 67, 55-62.

[495] Maertens, S., Grimme, W., Scheelhaase, J. & Jung, M., 2019. Options to Continue the EU ETS for Aviation in a CORSIA-World. Sustainability, 11, 5703.

following section). Maertens et al. (2019) assessed four scenarios (CORSIA only, CORSIA with EU ETS for domestic flights, CORSIA with voluntary addition of EEA domestic flights, and EU ETS for intra-EEA flights with CORSIA for all other flights) using ICAO FESG demand growth rates. Of these, the highest CO_2 coverage by 2035 is the combination[496]n of EU ETS for intra-EEA flights and CORSIA for other routes, for which 23% of year-2035 global aviation CO_2 is projected to be addressed by offsets or allowance trading. This compares to roughly 20% for the other options. If CERs are assumed to be only 20% effective, these percentages fell to 8.7% and 4-5% respectively.

CE Delft (2016), using ICAO (FESG) demand growth assumptions, projected that around 82% of 2020-2035 growth in aviation CO_2 will be covered by CORSIA and around 21.6% of cumulative 2021-2035 international aviation CO_2 will be offset. For the EU ETS, options including only intra-EEA, EEA departing flights, or full scope (including the UK) were considered. The study found that, under ICAO projected growth rates, CORSIA offset demand will be greater than EU ETS EUA purchases by aviation in 2022 (intra-EEA EU ETS), 2027 (EEA departing flights EU ETS) or 2032 (full scope EU ETS). However, total demand for EUAs from aviation over the 2021-2035 remained greater than demand for CORSIA offsets in the full scope EU ETS case. Similarly, Van Velzen (2018)[497] applied different CORSIA/EU ETS scenarios (EU ETS for EEA domestic flights, CORSIA for international, and intra-EEA EU ETS with CORSIA on other international routes) to the AERO-MS model, to assess the extent to which EU2030 (40% CO_2 reduction from year-1990 levels across all sectors) targets could be met. 1 – 1.5 % per year reduction in fuel use per RTK is assumed. They found consistency with EU2030 targets will be difficult unless intra-EEA and EEA departing flights are covered by the EU ETS, due to gaps in CORSIA coverage and the likelihood that CORSIA offsets will go towards reducing CO_2 emissions from non-EEA countries.

3.1.1.2 Conclusions of the Literature Review

Based on our assessment of these studies, we anticipate that:

- Assumptions about demand growth and demand growth drivers are likely to make a substantial difference to aviation CO_2 outcomes. Historical assumptions about demand growth have often differed from actual developments. It is important to include a range of assumptions about demand growth in future projections to capture this source of uncertainty.
- There is relatively little discussion in the literature about the impacts of oil prices on outcomes. However, projected carbon prices are typically small compared to the historical level of variability in fuel price. This suggests that oil prices should also be considered as an uncertain variable.
- Literature assumptions about EUA and CORSIA eligible offset prices are relatively consistent and the within-sector impact of varying these prices within the typical range given in the literature is likely small. However, literature-based carbon price assumptions are relatively short-term and well below the upper end of the range of carbon price projections from other sources (e.g. IPCC, 2007). The impact on auctioning revenues of different carbon prices will be significant, and from this viewpoint these prices should also be considered as uncertain variables. Given the longer time horizon of this study and increasing environmental ambitions, it is appropriate to include higher carbon price assumptions than the ones in the existing literature.

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[496] CE Delft, 2016. A comparison between CORSIA and the EU ETS for aviation. https://www.cedelft.eu/publicatie/a_comparison_between_corsia_and_the_eu_ets_for_aviation/1924

[497] Van Velzen, A., 2018. CORSIA, EU ETS and the EU2030 Emissions Target. https://www.transportenvironment.org/sites/te/files/publications/2018_09_Study_CORSIA_EU_ETS_and_EU2030_aviation_emissions_target_Final.pdf

- Similarly, a range of assumptions about future technology characteristics should be used. Assumptions relating to the future development of CO_2 per RPK differ relatively widely in the literature and have the potential to make a moderate difference to outcomes.
- It is likely under most literature assumptions about EUA and CORSIA eligible offset prices that neither the EU ETS nor CORSIA will have substantial structural impacts on airline networks (for example, passenger or freight airlines changing hubs).
- As discussed in Section 4, literature estimates of cost pass-through vary very widely. The sensitivity of model outcomes to different levels of pass-through should be assessed as an additional sensitivity case.
- Some studies in the literature also examine changes in future allowance allocation, typically increases in auctioning percentage. This should be examined as an additional sensitivity case.
- As discussed in Section 2.3.1, uncertainty exists about which countries will participate, and at which stage, in CORSIA.
- As discussed in Section 2.3.4, the effectiveness of CORSIA offsets is also uncertain. However, this uncertainty can be addressed separately from the modelling stage.

The way that this uncertainty is handled in the aviation sector modelling is discussed in the following section. This includes the selection of scenarios for these uncertain variables, including selection of a nominal case for all variables.

3.1.2 How uncertainty is modelled and presented in the aviation sector analysis

As discussed above, uncertainty in aviation system output metrics for different policy options can arise from variation in multiple different uncertain input parameters. These include demand growth, oil prices, carbon prices, CORSIA participation and the rate of improvement of new technology. Each uncertain input will affect different output metrics to different extents. For example, aviation demand for EU ETS allowances is more sensitive to uncertainty in intra-European demand growth than uncertainty in CORSIA participation. Some combinations of uncertain input parameters may have particularly large effects on outputs. For example, CORSIA demand for offsets may be particularly small in the case that CORSIA participation is low *and* global demand growth is low.

Based on the outcomes of the literature review in the previous section, we suggest the following selection of uncertain variables to consider in the modelling stage:

- Main-variant policy option (e.g. EU ETS-only, CORSIA-only and combinations of the two, as discussed in Section 3.1.2.1)
- Demand growth (at nominal values for other variables): high, central and low growth via different scenarios for demand drivers (e.g. GDP/capita, population) and development of elasticities. The selection of scenarios is discussed in Section 3.1.2.3.
- Oil price: high, central low oil price trajectories, as discussed in Section 3.1.2.4.
- Carbon price: separate higher and lower price trajectories for EU ETS allowance price and CORSIA-eligible offsets. This sensitivity case also effectively covers the within-aviation system impacts of changing the types of allowances and credits that are eligible, as this signal feeds through to the model via price. This is discussed in Section 3.1.2.5.
- Technology: optimistic, central and pessimistic lenses for timeline and effectiveness of within-sector emissions mitigation measures, as in Dray et al. (2018)[498]. This is discussed in Section 3.1.2.6.
- CORSIA Participation: Low, Initial Assumed and High as defined in Section 2.3.1,. This is discussed in Section 3.1.2.7.

[498] Dray, L., Schäfer, A. & Al Zayat, K., 2018. The global potential for CO_2 emissions reduction from jet engine passenger aircraft. *Transportation research Record*, 2672(23), 40-51.

The main-variant policy options assessed in this report are discussed in Section 3.1.2.1. To compare the most likely impact of each policy option, we carry out one model run per option in which all uncertain inputs are set to nominal values. Trends for these nominal values are given in Sections 3.1.2.3-3.1.2.7. They represent a (pre-COVID-19) judgement of the most likely trajectory for each variable. The outputs of the runs using these nominal input values are plotted as lines in the figures in the modelling section, and are shown first in larger text in the tables in the modelling section.

To assess the how uncertainty in input variables may affect output metrics, we additionally carry out a grid of model runs for each policy option across the range of combinations of uncertain variables. For example, one combination might be policy option 1 with high demand growth, low oil prices, base carbon prices, low CORSIA participation, and pessimistic technology assumptions. The upper and lower trends modelled for each uncertain variable are also shown in Sections 3.1.2.3-3.1.2.7. From these model runs (approximately 120 per policy option) a possible range in output metric values is derived. These values are reported in the figures in this section as a background shaded range, and are shown in the tables in this section as a range in brackets in smaller type following the nominal projection for each variable. In the interests of transparency, a spreadsheet including a summary of output metrics for each individual model run is also provided alongside the final report. Other uncertain variables which do not require additional model runs (for example, the extent to which emissions reductions from offsets are real and additional) are also used to inform uncertainty ranges.

Where the value of one uncertain variable is particularly important for outputs, the impact of changing this variable may also be discussed individually. For example, the impact of changing CORSIA participation scenario is separated out from the impact of changing the other uncertain variables on the demand for CORSIA offsets in Section 3.2.3. Similarly, where comparing to literature projections for system metrics, individual model runs which have similar input assumptions to those model runs may be presented. In each of these cases, the different assumptions behind the presented numbers are highlighted in the text.

Finally, as well as the main grid of model runs, we run additional sensitivity cases for a small number of variant policy cases, including changes in allowance allocation methodology, and to check the impact of different cost pass-through assumptions. These model runs use only nominal values for the uncertain variables described above. The outcomes for changing allowance allocation methodology are given in 3.2.13. Outcomes for variant policy cases, and changes in cost pass-through assumptions, are discussed in the annexes to this report.

The selection of uncertain variables is summarised in Table 12, below. Variables which are assessed in the main grid of model runs are shown in green, and those that are assessed via additional sensitivity cases are shown in blue.

Table 12. Broad categorisation of AIM model inputs which may lead to differences in outputs (as assessed by total aviation sector CO_2 to 2050 on a global/extra-EU/EFTA/intra-EU/EFTA basis)

Potential impact on outcomes	Level of uncertainty	Low	Mid	High

Low		Biofuel characteristics[499] Carbon intensity of electricity generation	Electricity price
Mid	Participation of Switzerland Allowance allocation methods Urbanisation	EUA/CER prices	Participation of UK Cost pass-through assumptions
High	Population	CORSIA participation Future aircraft technology characteristics Rules on quality of CORSIA credits	GDP/capita Oil price

3.1.2.1 Main-variant policy options

The characteristics of the individual policy options to be considered are derived from the project inception report and the published Inception Impact Assessment on the revision of the EU Emission Trading System Directive 2003/87/EC concerning aviation[500].

1) **EU ETS full legal scope**: In case no amendment is adopted by the European Parliament and Council by December 2023, the EU ETS for aviation would cover flights departing from airports in the EU/EFTA[501] and arriving to other airports in EU/EFTA or to third countries and, if not exempted through delegated legislation, incoming flights to airports in the EU/EFTA from third countries (exercising empowerment in Article 25a of the EU ETS Directive).
2) **Intra-EU/EFTA ETS only:** Maintaining the status quo, the EU ETS would be applied exclusively and confined to the scope of the system as currently applied: allowance surrendering obligations for aircraft operators would be based solely on emissions from flights between aerodromes located in the EU/EFTA, with the exception of flights between EU outermost regions and other regions of the EU/EFTA (including other outermost regions), while including flights within any given outermost region.[502] NB: in this option, CORSIA is neither applied to ETS-exempted routes.

[499] Biofuel characteristics include price, fuel lifecycle CO_2 as compared to fossil-derived Jet A, any limits on blending ratio, and supply available to aviation. To a year-2035 timescale these are likely to have only low impact on outcomes because use of aviation biofuels over this timescale likely represents only a small fraction of total fuel, as discussed in Section 3.1.2.6; impacts in the case that biofuel takeup is much higher than anticipated are discussed in Section 3.2.14.

[500] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12494-Revision-of-the-EU-Emission-Trading-System-Directive-concerning-aviation-

[501] EFTA: Iceland, Liechtenstein, and Norway. For more info: https://www.efta.int/eea

[502] Without prejudice to the exemption in Annex I of Directive 2003/87/EC: "(i) flights performed in the framework of public service obligations imposed in accordance with Regulation (EEC) No 2408/92 on routes within outermost regions, as specified in Article 299(2) of the Treaty, or on routes where the capacity offered does not exceed 30 000 seats per year"

3) **CORSIA only**: Only CORSIA would be applied to international flights, non-domestic intra-EU/EFTA flights, flights to and from the EU/EFTA States (including their outermost regions) and third countries.
4) **ETS-CORSIA "clean cut"**: The EU ETS would continue to apply to the current intra-EU/EFTA scope, as in option 2 above, and CORSIA would be introduced for extra-EU/EFTA flights, i.e. flights to and from EU/EFTA States (including their outermost regions) and third countries. In other words, the EU ETS would be applied as at present and CORSIA would be applied to all other flights (to the extent that CORSIA is applicable to them).
5) **ETS-CORSIA "mix"**: Regarding non-domestic intra-EU/EFTA flights, the EU ETS would apply up to each operator's 2020 emissions. Above the 2020 emissions, CORSIA would apply. Regarding flights between EU/EFTA States (including their outermost regions) and third countries, CORSIA would apply on emissions above 2020 levels. This option would cover domestic flights.
6) **ETS-CORSIA "mix" according to licence of aircraft operators**: The EU ETS would apply to non-domestic, intra-EU/EFTA flights, operated by operators with licences issued by Member States. For operators with licences issued by third countries, only CORSIA would apply on those non-domestic intra-EU/EFTA flights and flights between EU/EFTA States (including their outermost regions) and third countries. This option would not cover domestic flights.

Although technically the Swiss ETS is only linked with the EU ETS rather than fully integrated, for simplicity reasons the options listed here refer to EU/EFTA[503].

For the main model grid, each policy option is run with each combination of uncertain variables to obtain a range of uncertainty in output metrics. The characteristics of each option are compared in Table 13, below. Options 1-5 are broadly consistent with those in the existing institutional and academic literature, whilst Option 6 appears to have not been previously assessed. All options assume Switzerland is fully integrated from 2020 and that the UK participates in CORSIA but not in the EU ETS.

Table 13. Characteristics of main-variant policy options

	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
EU ETS scope	Flights to, from, within EU/EFTA, including domestic (from 2024)	Flights within EU/EFTA, including domestic	No flights	Flights within EU/EFTA, including domestic	EU/EFTA domestic flights. Intra-EU/EFTA flights up to CORSIA baseline	Flights within EU/EFTA, excluding domestic, if operator license issued by an EU/EFTA state
CORSIA scope[504]	Int'l flights between participatin g non-EU/EFTA countries; to/from	Int'l flights between participatin g non-EU/EFTA countries; to/from	All int'l and intra-EU/EFTA (non domestic) flights (excluding	Int'l flights (excluding to/from CORSIA non-participating states),	All int'l and intra-EU/EFTA (non-domestic) flights (excluding to/from	Int'l flights to and from EU/EFTA. Flights within EU/EFTA where operator

503 More information on the Agreement on linking the emissions trading systems of the EU and Switzerland can be found here https://ec.europa.eu/clima/news/agreement-linking-emissions-trading-systems-eu-and-switzerland_en

504 Note that the participation of states in CORSIA in each applicable policy case and phase is modelled by using alternative participation scenarios, as discussed above and quantified in Section 2.

	EU/EFTA not covered	EU/EFTA not covered	to/from CORSIA non-participating states)	intra-EU/EFTA excluded	CORSIA non-participating states)	license issued by a non-EU/EFTA state
EU ETS cap	95% of average full scope year 2004-2006 aviation CO_2; LRF of 2.2% per year from 2021	As option 1 but reduced to reflect reduced scope; LRF of 2.2% per year from 2021	N/A	Same as in option 2.	Same as in option 2.	As option 2 but reduced further to reflect reduced coverage; LRF of 2.2% per year from 2021
EU ETS allocation [505]	Existing[506] situation	Existing situation	N/A	Existing situation	Existing situation	Existing situation
Modelled CORSIA CO_2 emissions eligibility [507]	N/A	N/A	Emissions above CORSIA baseline[508]	Emissions above CORSIA baseline	Emissions above CORSIA baseline	Eligible operator emissions above CORSIA baseline
Outermost regions coverage	Flights to, from and within any given OMR are included	Flights within any given OMR are included, flights to and from OMRs are exempt	International Flights to and from OMRs are included, domestic flights within OMRs are exempt.	Flights within any given OMR included under the EU ETS. Int'l flights to and from OMRs included under CORSIA.	Int'l flights to/ from OMRs inc. in CORSIA. Flights within any given OMR are fully subject to EU ETS (i.e. inc. emissions above CORSIA baseline)	For aircraft operators with licences not issued by EU Member States, non-domestic flights to and from OMRs are included under CORSIA

3.1.2.2 Caps for each policy option

The original cap for aviation in the EU ETS was set at 95% of year 2004-06 full scope CO_2, or 210,349,264 allowances. The full scope cap was also increased by 116,524 allowances in 2014 to account for the inclusion of Croatia. However, the 'stop-the-clock' legislation limiting scope to intra-EU/EFTA aviation from 2013 substantially reduced the amount of allowances supplied. Similarly, omitting flights to and from EU outermost regions (most notably the Canary Islands) also reduced the effective cap. This reduction of scope was handled on a tonne-km basis, with a set amount of free allowances

[505] Note that a sensitivity case to this allocation is also run separately.
[506] I.e., 82% of aviation allowances allocated for free, 3% set aside for the new entrants' reserve,15% auctioned.
[507] CORSIA emission eligibility criteria are partially based on an airline basis and partially on a whole-sector basis, with the balance between the two evolving over time. Initially, airlines' CORSIA offsets will be based on the growth of the (CORSIA-eligible) sector as a whole.
[508] Note that we do not model COVID-19-related disruption. Although the initial intent was to use the average of year-2019 and year-2020 CO_2 to set the CORSIA baseline, this may change. The impact of this is discussed later in the report.

supplied per tonne-km based on the amount that would have been supplied under the full scope cap at full scope tonne-km. However, intra-EU/EFTA and extra-EU/EFTA flights typically emit different amounts of CO_2 per tonne-km. This is because intra-EU/EFTA flights are typically shorter-haul flights performed with smaller aircraft, and extra-EU/EFTA flights are more often long-haul flights performed with larger aircraft. The effective reduced-scope cap over the 2013-2019 period was around 38.7 Mt CO_2, with some fluctuations related to the details of trading (EU ETS data viewer, 2020)[509]. Because of the discrepancy between intra-EU/EFTA and extra-EU/EFTA CO_2/RTK, this is less than 95% of actual intra-EU/EFTA year 2004-2006 aviation CO_2 (this value would be around 44.9 MtCO_2).

Each of the policy options specified above implies a different cap. First, the inclusion of Switzerland and the removal of the UK from the EU ETS will change the appropriate cap for both full scope (Option 1) and reduced scope (Options 2, 4 and 5). Although technically the Swiss ETS is only linked with the EU ETS rather than fully integrated, for the purposes of modelling we include Swiss CO_2 with other intra-EU/EFTA CO_2 in one effective EU ETS cap. Second, option 6 also removes domestic flights and intra-EU/EFTA flights operated by non-EU/EFTA registered airlines. In option 3, the EU ETS ceases to apply to aviation and so no cap is applied. Third, from 2021 a linear reduction factor (LRF) of 2.2% per year is applied in all cases, bringing aviation into line with cap reductions across other sectors (e.g. EC, 2019)[510].

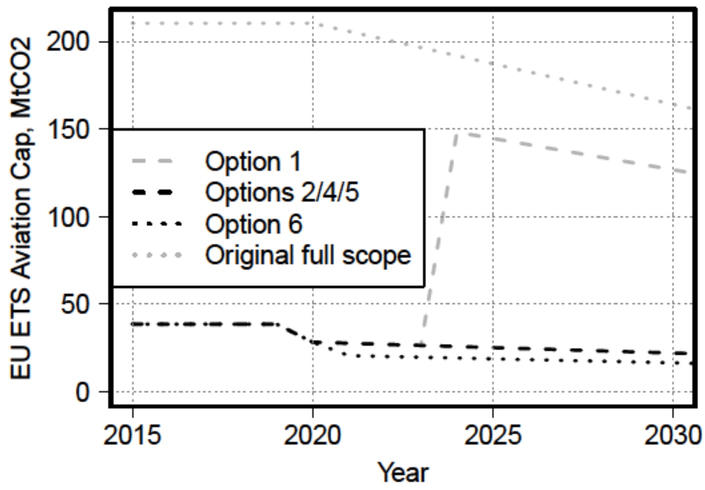

Figure 14. Caps with time to 2030 under different assumed policy options.

There are several different ways that these new caps could in theory be calculated. They could be based on absolute year 2004-06 emissions totals, on year 2004-06 tonne-km shares, or on setting new benchmarks based on different years. Each of these methods would give different results. For the caps used in this report, we assume a tonne-km type method will be used based on years 2004-06.

To calculate approximate cap levels, we use seat-km as a proxy for tonne-km and data on scheduled flights for 2004-06 (Sabre, 2016)[511]. Seat-km will broadly track tonne-km as

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[509] EU ETS Data viewer. _https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1

[510] EC, 2019. Revision for Phase 4 (2021-2030). https://ec.europa.eu/clima/policies/ets/revision_en.

[511] Sabre, 2016. Global schedule data.

total tonne-km carried in aircraft is dominated by passenger weight; approximately 50% of freight is carried in passenger aircraft, restricting it to the same routes that passengers take; and (for 2004-06) the extra tonne-km carried in freighter aircraft on extra-EEA flights will roughly balance out with extra tonne-km carried on intra-EEA unscheduled passenger flights (e.g. ICAO, 2016). Additionally, we check these totals against UK and Swiss reported year-2004-06 emissions. On average, Swiss domestic aviation CO_2 over this period was 0.13 $MtCO_2$, and international flights to and from Switzerland contributed another 7.12 $MtCO_2$ (FOEN, 2019)[512]. UK domestic flights emitted 2.57 $MtCO_2$, and flights to and from the UK emitted 68.2 $MtCO_2$ (BEIS, 2019)[513]. Around 20.5% of UK international seat-km, and 25.7% of Swiss international seat-km were to/from non-outermost region parts of the EEA in 2004-06 (Sabre, 2016). In the case that the EU ETS reverts to full scope and the UK does not integrate the aviation EU ETS, flights from the EU/EFTA countries and from to the UK will be included but domestic flights and flights from the UK to non-EU/EFTA countries will be excluded. In the case that reduced scope is maintained, both UK domestic and international flights will be out of scope.

Given the 2004-06 seat-km data, we estimate that:

- The cap for option 1 (current full scope plus Switzerland, minus UK) will be around 162.6 Mt. This is applied (pre-LRF) from the date that the EU ETS would revert to full scope without further policy action (2024), with an option 2-appropriate cap before this time.
- The caps for option 2, 4 and 5 (reduced scope plus Switzerland, minus UK) will be around 28.4 Mt (pre-LRF).
- The cap for option 6 (reduced scope plus Switzerland, minus UK and minus domestic flights) will be around 21.2 Mt.

These values are shown in Figure 14 (‘Original full scope’ refers to full scope coverage including the UK and excluding Switzerland, and is included for reference only). In all cases, but particularly the reduced scope cases, however, the exact value of the cap will depend on the methodology used to adjust scope and ultimately depends on the political decision-making surrounding the change of scope.

3.1.2.3 Population, GDP and demand growth

Demand growth is one of the largest uncertainties in future aviation CO_2 projections. This encapsulates both uncertainty in demand drivers and in passenger and freight response to developments in demand drivers. For example, passenger and freight demand are typically sensitive to developments in per capita income, but the exact level of sensitivity is relatively uncertain, and may change as aviation systems mature (e.g. Intervistas, 2007)[514]. A further discussion of sensitivity to socioeconomic projections and trends in income elasticity is given in Dray et al. (2019)[515]. Similarly, global scenarios for future GDP developments do not always capture trends that have a large impact on global aviation. For example, GDP projections made pre-1990 often strongly underestimated China’s subsequent GDP growth.

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[512] FOEN, 2019. CO_2 statistics: emissions from thermal and motor fuels. https://www.bafu.admin.ch/bafu/en/home/topics/climate/state/data/co2-statistics.html

[513] BEIS, 2019. Provisional UK greenhouse gas emissions national statistics. https://data.gov.uk/dataset/9a1e58e5-d1b6-457d-a414-335ca546d52c/provisional-uk-greenhouse-gas-emissions-national-statistics

[514] Intervistas, 2007. Estimating Air Travel Demand Elasticities. https://www.iata.org/en/iata-repository/publications/economic-reports/estimating-air-travel-demand-elasticities---by-intervistas/

[515] 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.

At the start of Section 3.1.2, we concluded that uncertainty in population and GDP growth should be assessed via nominal, upper and lower growth scenarios. This section considers what suitable values for these scenarios should be, by comparing growth rates in the absence of policy.

In the previous impact assessment reports, uncertainty in demand was defined directly in terms of demand growth scenarios. In AIM, uncertainty in demand growth is a function of uncertainty in demand drivers. In particular, demand is affected by projected population and GDP per capita, as well as ticket prices (which are affected by oil and carbon prices, as discussed below). Because many of the previous impact assessments were carried out before or during the financial crisis of 2007-08, their upper demand scenarios tended to overestimate RPK and CO_2 growth. Projections can differ strongly depending on the applicable scope. Figure 15 shows historical data and a selection of past and future projections on a global scope, for total global passengers, flights, revenue passenger-kilometres (RPK), freight tonne-kilometres (FTK) and direct aviation CO_2. Where historical projections are given in terms of growth rates, baseline values are sourced from historical data and/or other projections by the same author. Unscheduled flights and freighter flights are included[516]; military and general aviation are excluded[517]. Historical data shown is from ICAO (2019a)[518]; EC (2019)[519]. External projections shown are from ICAO (2019b)[520]; the 2006 and 2013 impact assessments (EC, 2006; EC, 2013); Airbus (2019)[521]; Boeing (2019)[522]; Eurocontrol (2018) Global Growth (GG), Regulation and Growth (RG), Happy Localism (HL) and Fragmented World (FW) scenarios[523]; Ernst and Young and York Aviation 2007 and 2008 (E&Y/York Aviation , 2007, 2008); and IATA's initial estimates of COVID-19 impacts on demand (IATA, 2020)[524]. Note that not all external data and projections are shown in all figures, because some projections are only available for specific geographic contexts. As noted previously, the accuracy of projections from

[516] Non-scheduled flights are accounted for in AIM by adjusting scheduled flows based on country- and region-level data about the proportion of flights that are non-scheduled (e.g. DfT, 2018). On a global basis, this accounted for around 5% of flights in 2015 (e.g. ICAO, 2019). Hold freight is modelled using region-pair level typical passenger-to-freight ratios by RTK (ICCT, 2019). For freight totals including freight carried in freighters, we use intra- and extra-EEA country-pair air freight flows (e.g. Eurostat, 2019) complemented by global country-level freight totals (e.g. ICAO, 2019) and typical literature freight demand elasticities (e.g. Intervistas, 2007) to project global country-pair freight flows given scenario GDP growth and fuel price assumptions. Freight above the amount carried in passenger aircraft holds is assumed carried in freighter aircraft.

[517] These are typically small fractions of total CO_2, and are less relevant in a policy context. General aviation has been estimated as around 2% of total aviation CO_2 and military around 6%. See for example the discussion in ICCT (2019). Note that the IEA global aviation CO_2 totals include kerosene use from military and GA sources.

[518] ICAO, 2019. Presentation of 2018 Air Transport Statistical Results. https://www.icao.int/annual-report-2018/Pages/the-world-of-air-transport-in-2018-statistical-results.aspx

[519] EC, 2019. EU Transport in Figures Statistical Pocketbook. https://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2019_en

[520] ICAO, 2019b. Forecasts of scheduled passenger and freight traffic. https://www.icao.int/sustainability/Pages/eap-fp-forecast-scheduled-passenger-traffic.aspx

[521] Airbus, 2019. Global Market Forecast, 2019-2038. https://www.airbus.com/aircraft/market/global-market-forecast.html

[522] Boeing, 2019. Commercial Market Outlook 2019-2038 https://www.boeing.com/commercial/market/commercial-market-outlook/

[523] Eurocontrol, 2018. European Aviation in 2040: Challenges of Growth. https://www.eurocontrol.int/publication/challenges-growth-2018

[524] IATA, 2020. Covid19: outlook for air travel in the next 5 years. https://www.iata.org/en/iata-repository/publications/economic-reports/covid-19-outlook-for-air-travel-in-the-next-5-years/

different eras over the 2000-2020 period has been affected by several factors: some projections were made before or during the global financial crisis and were able to only partially incorporate its impacts into outcomes; RPK growth in the 2016-2018 period has been more rapid than anticipated given GDP developments, although initial data for 2019 suggests this may have been a temporary fluctuation; and there will be a global impact from COVID-19 in 2020 and subsequent years (as yet not fully quantifiable; see discussion in Section 3.1.2.9).

As well as these projections, we also show sample AIM runs using different socioeconomic projections. These projections use a 2015 base year. For 2015-2017 global country-level population and GDP per capita growth rates from Feenstra et al. (2019) are used[525]. For 2018 and subsequently, growth rates in population and GDP per capita from the IPCC SSP scenarios[526] are used (SSP1-SSP5). Demand growth rates in SSP2 are close to those projected by Airbus and Boeing, which are on the high side of existing projection sets. Note that data from these scenarios is used independently from their associated IPCC policy storylines. We additionally include a scenario using commission-supplied GDP and population projections for Europe, and in which income elasticities are adjusted to broadly match total European RPK growth rates from a Commission-supplied set of growth projections (PE)[527]. The main differences with the SSP2 assumptions in this case are higher growth rates in Eastern Europe; varying growth rates in Western Europe, typically lower; and significantly lower growth rates in a smaller number of aviation-intensive countries in Western Europe. For the PE and SSP3 model runs we also include the option of slightly decoupling demand growth from GDP growth in future years, to simulate maturing aviation systems and changing attitudes to air transport. All AIM test runs shown assume zero carbon price. For oil price and technology characteristics we use nominal scenario values for all runs as defined in Sections 3.1.2.4 and 3.1.2.6.

The AIM projections indicate the typical range of variation that can be expected by changing socioeconomic assumptions within literature ranges. By 2035, global aviation CO_2 differs by roughly a factor of 1.5 between the highest- and lowest-growth scenarios. As is apparent from initial IATA demand projections incorporating the impact of COVID-19, shorter-term trends are more likely to be towards the lower end of the range of growth rates shown.

[525] Feenstra, Robert C., Robert Inklaar and Marcel P. Timmer (2019), "The Next Generation of the Penn World Table" American Economic Review, 105(10), 3150-3182, available for download at www.ggdc.net/pwt

[526] 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.

[527] Note that the match to Commission growth projections is not exact, and includes only intra-EU/EFTA and extra-EU/EFTA RPK total growth rates for 2015-2030 and 2030-2035. Freight demand, and the variation of demand growth by route, is generated using underlying Commission-supplied projections of GDP and population growth. Demand is matched assuming baseline carbon prices, so the projections shown here which assume no carbon price will also be slightly higher. For non-EEA GDP and population growth, we use a compatible set of projections from JRC (2018; Global Energy and Climate Outlook 2018, https://publications.jrc.ec.europa.eu/repository/bitstream/JRC113446/kj1a29462enn_geco2018.pdf; see Annex 3). Typically, freight demand grows faster than passenger demand under these assumptions, so (e.g.) extra-European RTK growth is faster than extra-European RPK growth.

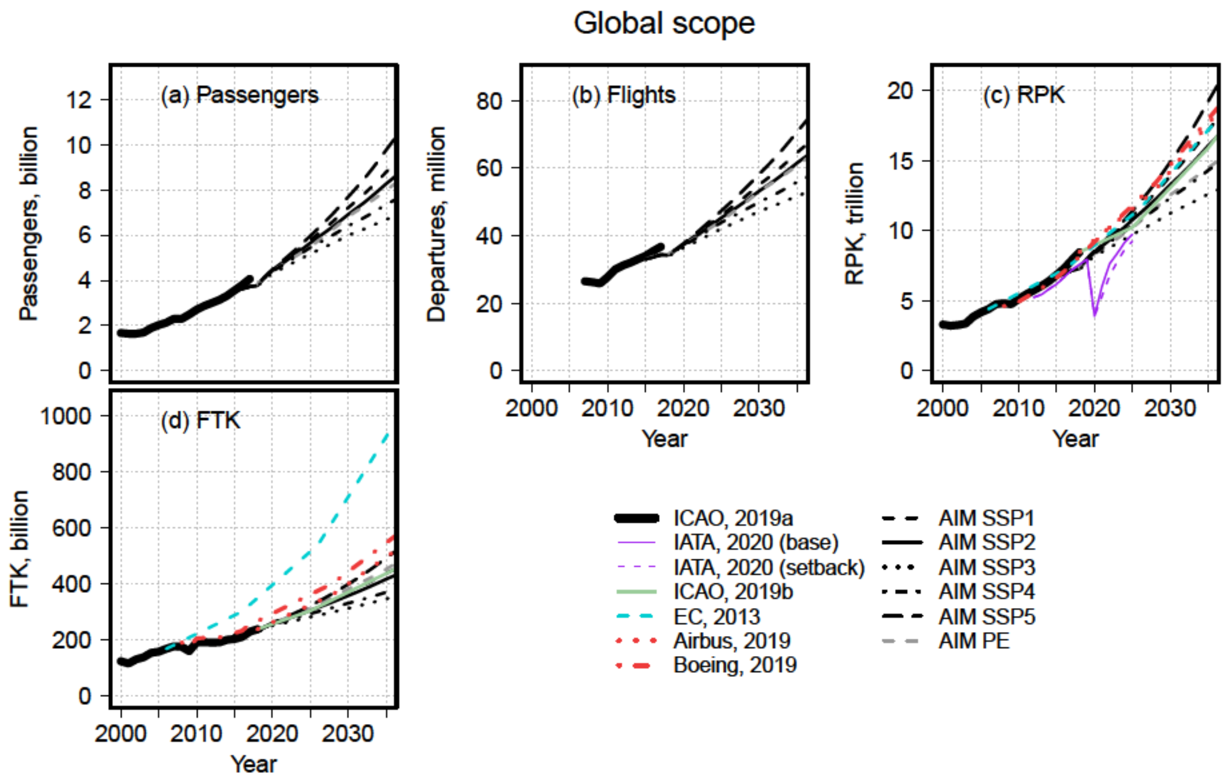

Figure 15. Historical scenarios and future projections on a global scope to 2035, including sample AIM runs.

For this project, projections on extra-EU/EFTA and intra-EU/EFTA scopes are also important. Figure 16 shows similar projections and test model runs on a European departing flights basis. Caution should be taken when interpreting these results as different projections and databases use different definitions of 'Europe'. For example:

- Eurocontrol (2018) projections are for the aggregate of European Civil Aviation Conference (ECAC) states. There are 44 member states, including all the EU/EEA countries, Turkey, Ukraine, the Western Balkan states, Azerbaijan, Armenia and Georgia. These projections explicitly consider infrastructure limitations which may act to reduce growth.
- EC (2018) and past impact assessments (e.g. EC, 2006) consider totals on an EU27, EU28, EEA or EEA + Switzerland scope. These totals will be broadly similar as Norway, Switzerland, Iceland and Croatia account for relatively small percentages of global aviation movements. In the case of CO_2, totals from the ETS data viewer exclude flights to or from outermost regions.
- Boeing projections are for Boeing's 'Europe' region. This includes the EEA, Turkey, and Western Balkan states but excludes Azerbaijan, Georgia, Armenia and Ukraine.
- Airbus provides similar projections for Europe, but split into 'Western Europe' and 'Central Europe' regions.
- ICAO provides projections for its own 'Europe' region. This is a broadly-defined region including Turkey, Ukraine and Russia.
- Literature passenger totals may be calculated on a departing flights basis or on an 'all passenger movements' (arrivals plus departures; e.g. as in Eurostat, 2019[528]) basis, with different strategies for how transfer passengers are treated. For

[528] Eurostat, 2019. Air transport of passengers by country. https://ec.europa.eu/eurostat/databrowser/view/ttr00012/default/table?lang=en

example, a transfer itinerary with two stops may be counted as one OD passenger or up to six passenger movements depending on the definition used.

- Different projections differ in whether they include military, non-scheduled and freight-only flights (for example, military use is included in IEA CO_2 totals derived from total fuel uptake, but most modelling capabilities exclude military flights due to lack of data).
- In some cases (most notably intra-EU freight), reported metrics that are small compared to totals for other transport modes are reported to only a low level of precision.

These differences mean that absolute totals are not directly comparable between different projection sets. In particular, the Eurocontrol and ICAO Europe totals contain significant numbers of non-EEA flights. However, it can still be useful to compare growth rates.

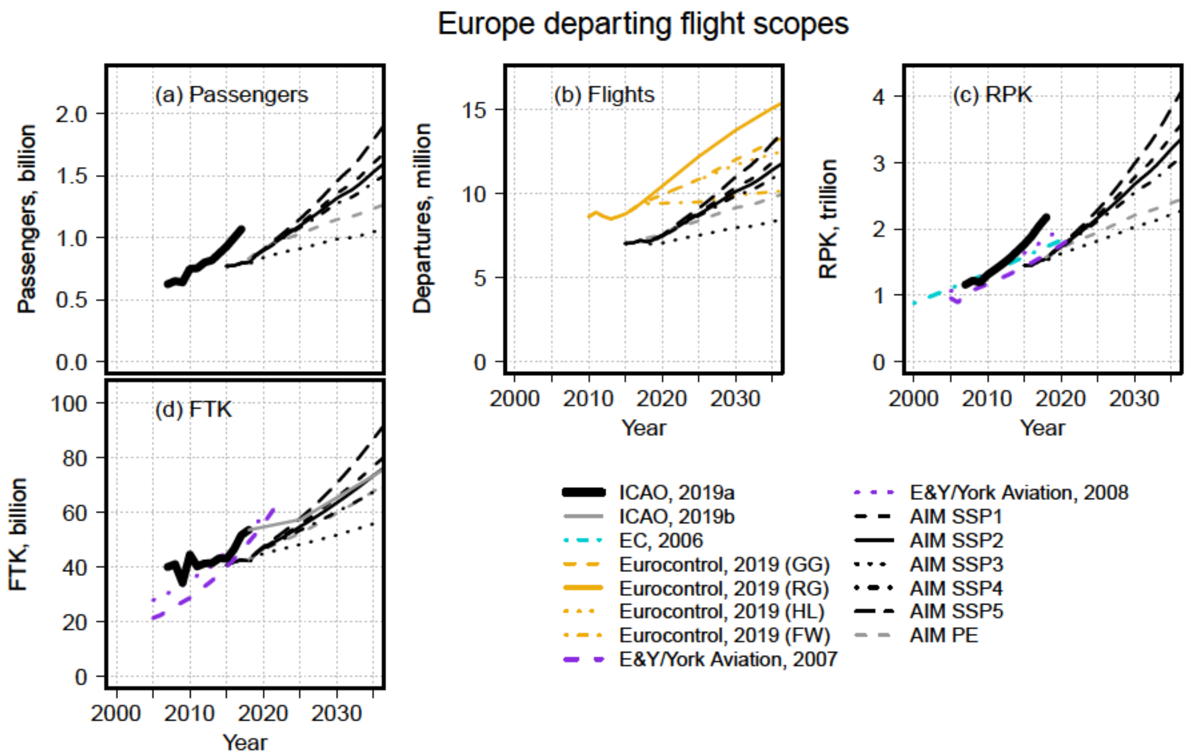

Figure 16. Historical scenario and future projections on extra-Europe scopes. Note that different projections and databases use different definitions of Europe. Totals are given on a departing-flights basis.

Relative uncertainty in year-2035 European departing flight CO_2 is slightly greater than that on a global basis.

Figure 17 shows corresponding projections on an intra-Europe scope. As with the extra-Europe scopes shown above, totals can differ significantly depending on the definition of Europe used, with most external projection sets including non-EEA countries such as Turkey and/or Russia which have substantial domestic and international aviation systems. Uncertainty in year-2035 intra-EU/EFTA aviation CO_2 due to socioeconomic projection is at a similar level to that for extra-EU/EFTA aviation CO_2, i.e. the difference in direct aviation CO_2 between the highest- and lowest-demand growth scenarios investigated is around 70%.

In selecting scenarios for the final model, we need to consider comparability with other impact assessments and the likely range of demand growth given recent assessments. In particular, it seems likely that the COVID-19 pandemic will have some ongoing impact on aviation demand growth via reductions in GDP growth rates. Initial EC projections, not used here because they became available only after model runs had begun, suggest a more than 7% reduction in EU GDP in 2020, rebounding by only 6% in 2021; EC, 2020[529]. Based on these outcomes, we run three scenarios for population and GDP growth to 2035 in this project:

- A nominal case where the model is adjusted to broadly match Commission-provided EU/EFTA RPK growth rates ('AIM PE' in the figures above);
- A low-demand case using SSP3 growth rates as shown above. This could also be used to represent a future where GDP growth rates are higher but aviation demand growth has decoupled from GDP growth, and;
- A high-demand case using SSP2 growth rates. This has similar aviation CO_2 growth rates over time to the Airbus and Boeing demand forecasts; growth rates of around this level are a common literature assumption.

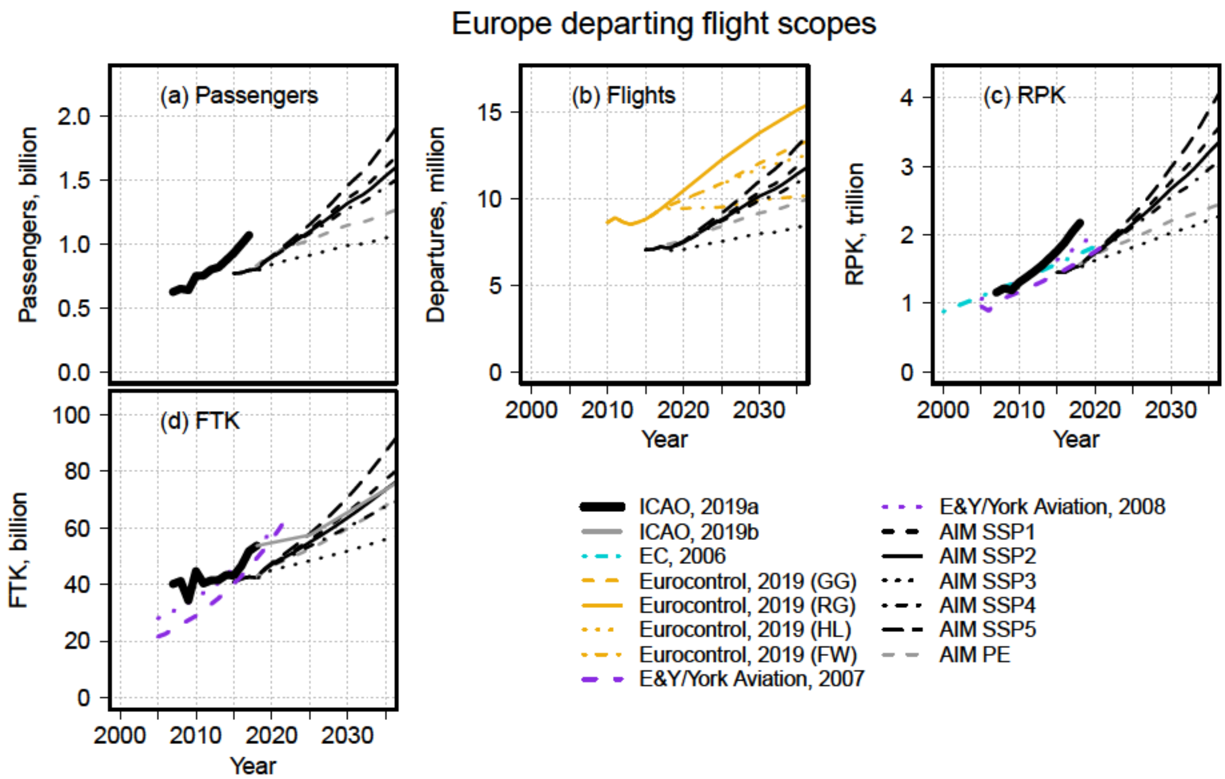

Figure 17. Historical scenario and future projections on intra-Europe scopes. Note that different projections and databases use different definitions of Europe.

A summary of the RTK growth rates for these three scenarios is given in Table 14 for the case where no carbon price is applied. These include passenger RPK (at an assumed weight per passenger with luggage of 100kg), hold freight and freight RTK in dedicated freighter aircraft.

[529] EC, 2020. European Economic Forecast, Spring 2020. https://ec.europa.eu/info/sites/info/files/economy-finance/ip125_en.pdf

Table 14. RTK demand growth by scenario assuming no carbon price and other uncertain scenario variables at nominal values, for global, intra-Europe (EU/EFTA, excluding UK) and extra-European route groups.

Scenario	Average annual growth rate, 2015-2030, %			Average annual growth rate, 2030-2035, %		
	Global	Extra-EU/EFTA	Intra-EU/EFTA	Global	Extra-EU/EFTA	Intra-EU/EFTA
Number of Passengers						
High (SSP2)	4.5	3.9	3.7	3.6	3.5	2.8
Nominal (PE)	4.4	2.7	2.9	3.2	1.7	1.3
Low (SSP3)	3.6	2.2	1.6	2.3	1.7	0.9
Number of Flights						
High (SSP2)	3.2	2.7	2.5	3.0	2.8	2.3
Nominal (PE)	3.2	2.0	1.9	2.7	1.6	1.2
Low (SSP3)	2.4	1.3	0.8	1.9	1.3	0.7
RPK						
High (SSP2)	4.6	4.5	3.8	3.8	4.0	2.9
Nominal (PE)	4.2	2.8	3.1	2.9	1.6	1.5
Low (SSP3)	3.5	2.7	1.7	2.3	2.1	1.0
FTK						
High (SSP2)	3.4	3.0	3.3	3.1	2.8	3.1
Nominal (PE)	3.8	2.8	1.3	3.4	2.5	1.2
Low (SSP3)	2.5	1.8	0.7	2.1	1.5	0.8
RTK (freight + passenger)						
High (SSP2)	4.3	4.0	3.7	3.7	3.7	2.9
Nominal (PE)	4.1	2.8	3.0	3.0	1.9	1.5
Low (SSP3)	3.2	2.5	1.6	2.3	1.9	1.0

3.1.2.4 Oil prices

Historically, projections of oil price have been highly uncertain. Table 15 shows the variation of oil price over time since 1980, in comparison to different projection scenarios

(EIA, 1982-2018[530]; IEA, 2017[531]), projections used in assessing aviation growth scenarios (e.g. Eurocontrol, 2018[532]), and projections provided by DG CLIMA for this project ('Base'). In comparison, Figure 19 shows the typical historical variation of fuel prices for international flights with oil and carbon price, based on data from EIA (2018). Given assumptions about EUA and CORSIA eligible emissions unit price uncertainty, as discussed in the following section, the impact of typical oil price volatility on fuel prices is likely to be similar to or greater than the impact of different assumptions about carbon price. Long-term oil price projections typically consider smooth trends over time only, and omit the shorter-term impact of shocks. As such, mid-2020 oil prices of $30-40/bbl resulting from the COVID-19 pandemic are well outside the range of long-term projections for 2020 and beyond. Current projections of COVID-19 recovery project a gradual return to pre-pandemic or slightly below pre-pandemic prices by 2022-23 (e.g. EIA, 2020)[533]; however, these are uncertain and strongly impacted by currently unknown developments, such as the success or failure of COVID-19 vaccine development. Over the longer term, EIA (2019) project year-2030 oil prices of between $50-200/bbl, whilst IEA (2019) project year-2030 oil prices in the $60-85/bbl range.

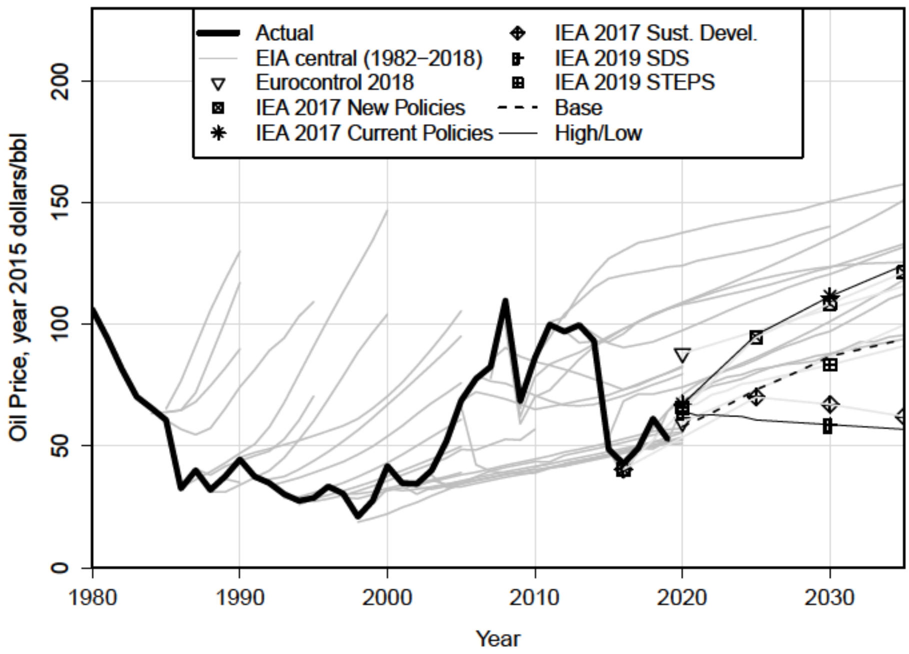

Figure 18. Variation of oil price projections over time, in comparison to actual oil price developments.

Factors other than oil price also affect the amount airlines pay for a given amount of fuel. Because fuel prices are often volatile, and because fuel is 20-30% of airline operating costs, many airlines hedge fuel costs (Morrell & Swan, 2006)[534]. Hedging locks in future fuel purchases (typically 6 months to a year ahead) at a given price. Because aviation fuel is usually priced in US dollars, airlines may also hedge against the risk of changes in

530 EIA Annual Energy Outlook Publications, 1982-2019. https://www.eia.gov/outlooks/archive/aeo18/tables_ref.php

531 IEA World Energy Outlook, 2017. https://www.iea.org/reports/world-energy-outlook-2017

532 Eurocontrol, 2018. European Aviation in 2040: Challenges of Growth. https://www.eurocontrol.int/publication/challenges-growth-2018

533 EIA, 2020. Short-term energy outlook. https://www.eia.gov/outlooks/steo/

534 Morrell, P. & Swan, B., 2006. Airline Jet Fuel Hedging: Theory and Practice. Transport Reviews, 26, 713-739

exchange rate. The main benefit of hedging is to give airlines more certainty about their upcoming operating costs. Over the longer term, airlines typically do not make overall fuel cost savings via hedging (Morrell & Swan, 2006).

Hedging is not explicitly modelled in this work. Because a smooth trend in oil price is modelled, there would be either be almost no impacts from including hedging strategies (in the case that the trend is correctly anticipated by markets) or a slight lag in response to oil price changes of less than a year (in the case that it is not). Alternatively, the smooth oil price trend modelled can be viewed as the price experienced by airlines after hedging in the case that the actual oil price is more volatile. Hedging may, however, have significant short-term impacts on airline behaviour in the case that fuel prices change by large amounts over a short period of time (e.g. oil price falls in 2014-15). Airlines which have hedged fuel costs before a large fall in fuel prices will have much higher fuel costs over the short term than airlines which did not engage in hedging, a factor which caused some airlines faced with losses to cease hedging after 2015 (Swiden & Merkert, 2019)[535]. This will affect system response to the current COVID-19-related disruption and recovery, as many airlines are paying hedged fuel prices similar to pre-pandemic values. However, COVID-19 is not modelled in the current work.

AIM model outcomes are affected by the assumed oil price trajectory to a lesser extent than assumptions about population and income growth, but given the range in oil price uncertainty, the effect on CO_2 can still be significant. For example, the difference in global RPK between running AIM with oil prices of $30/bbl and $170/bbl (year 2015 US dollars) in 2050 is around 22%, and the difference in year-2050 CO_2 is around 30%[536], assuming no carbon price, central technology assumptions, and SSP2 socioeconomic assumptions.

[535] Swidan, H. & Merkert, R., 2019. The relative effect of operational hedging on airline operating costs. Transport Policy, 80, 70-77.

[536] Source: initial model sensitivity runs for this project. The difference in CO_2 emissions is larger than that in RPK because the higher oil price is sufficient to induce changes in technology and operations.

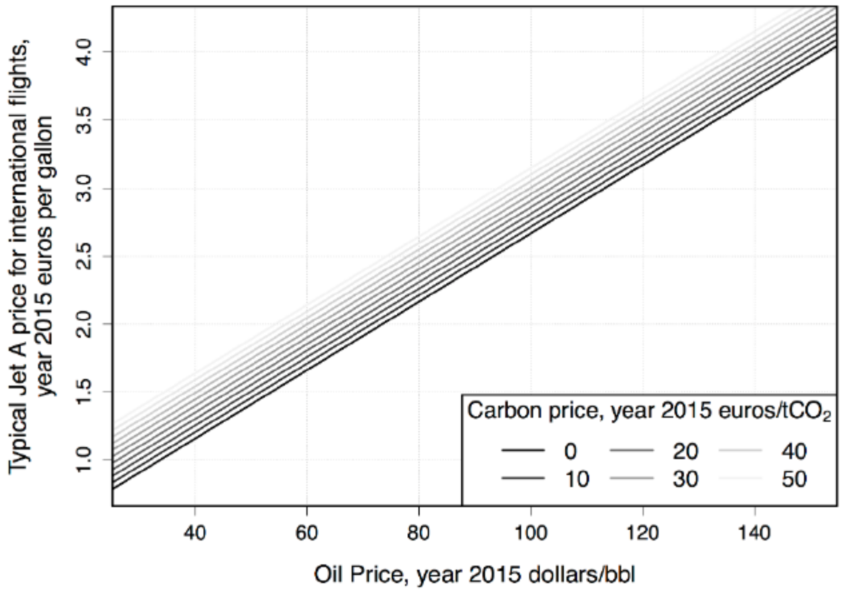

Figure 19. Typical variation of effective fuel price for international flights with oil and carbon prices (a year-2015 exchange rate of 1.11 is used to convert between euros and dollars).

A comparison with the range of projections available suggests that assessing a range of around $60-125/bbl by 2035 is appropriate. This is similar to the range of different projections used in recent IEA reports to represent plausible oil price trajectories (e.g. IEA 2017, 2019)[531]. The 'Base' projections provided by DG CLIMA are close to other recent literature central cases. We use these as a nominal case assumption. High and Low oil price projections are based on the IEA (2017) 'Current Policies' scenario[537], and the IEA (2019) SDS scenario. A summary of the assumed oil prices is given in Table 15. The impact of COVID-19 is not included, i.e. all of these scenarios effectively assume that current oil price lows due to the COVID-19 pandemic are short-lived (see discussion in Section 3.1.2.9).

Table 15. Assumptions about oil price used for the high, nominal and low scenarios.

Scenario	Oil price, year 2015 US dollars				
	2015	2020	2025	2030	2035
High	52	67	96	108	124
Nominal	52	58	73	87	94
Low	52	58	61	59	57

3.1.2.5 Carbon Prices

For modelling, we consider two types of carbon price. EU aviation sector allowances (EUAAs) are free or auctioned allowances issued to aircraft operators, and (up to ETS phase 3) can only be used to compensate for aviation emissions. EU allowances (EUAs) are issued to other sectors, but can be purchased by aircraft operators. Typically, the traded price for both types of allowances is close, so we consider only one trend for

[537] This scenario is used because the corresponding IEA (2019) scenario has lower oil prices than the upper end of our identified range.

EUAs/EUAAs. CORSIA will use international credits (e.g. Certified Emission Reductions (CERs) under the Kyoto protocol), which are typically lower-cost than EUAs and may be associated with lower additionality (e.g. Cames et al., 2016)[538].

As discussed in Section 3.1, projected EUA prices in the literature are typically below €50/tCO_2, and projected CORSIA eligible emissions unit prices are typically well below this value. However, the literature assessments also typically relate to pre-2030 time horizons and lower levels of overall ambition with regard to CO_2 reduction. For comparison, the sub-€50 values in the literature are well below the upper end of the projected range for global carbon prices required to limit temperature increases below 1.5°C (e.g. IPCC, 2007[539]), which in some cases exceed €1000/tCO_2. Figure 20 shows historical prices in comparison to selected literature assumptions (IA 2006, 2013, 2017 are the Commission's official impact assessments; EY2007, 2008 are Ernst & Young & York Aviation 2007, 2008; Malina 2012 is Malina et al. (2012)). The scenarios Base, Ia, Ib, IIa and IIb are provided by DG CLIMA for this project. CORSIA Sc1 and CER Sc2 are derived from the analysis in Section 2 of likely CORSIA eligible emissions unit prices.

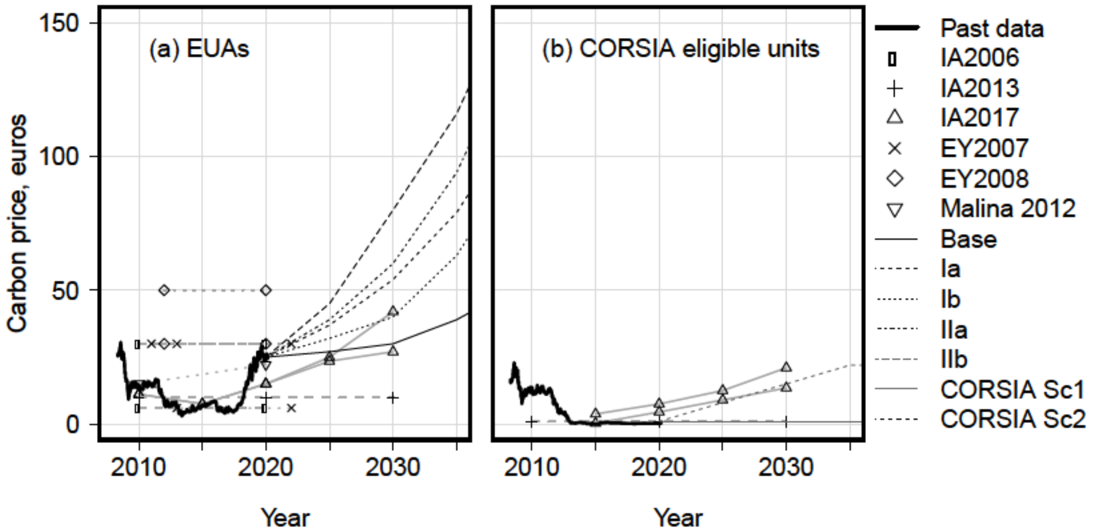

Figure 20. Historical EUA and CER prices, in comparison to assumptions in the literature and past impact assessments.

Carbon prices in the €0-50 range typically have a small impact on demand and CO_2 in AIM. For example, in a 'central' (SSP2) socioeconomic scenario with an oil price of $70/bbl in 2050 and conservative technology assumptions, changing global carbon prices from $0-50/t$CO_2$ (around €0-45/tCO_2) with full auctioning produces a global change in RPK of around -2.6%, and in CO_2 of around -3.1%.[540] In comparison, changing to $500/t$CO_2$ (around €450/tCO_2) has an impact comparable to uncertainty in oil price, leading to a year-2050 change in RPK of -14.8% (-16.6% in CO_2).

To capture the full range of potential variability, we use the lower (Base) and upper (IIb) end of the carbon price scenarios provided in our grid of model runs, with 'Base' being the nominal case. Most post-2020 assessments which include CORSIA eligible emissions units model a price in the range €1-20/tCO_2. For this study, we use the upper and lower end of

[538] Cames et al., 2016. How additional is the Clean Development Mechanism?https://ec.europa.eu/clima/sites/clima/files/ets/docs/clean_dev_mechanism_en.pdf

[539] IPCC, 2007. IPCC Climate Change 2007: Mitigation. Contrbution of Working Ground III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Eds. Metz, B., Davidson, O., Bosch, P., Dave, R. and Meyer, L., Cambridge University Press, Cambridge, 2007.

[540] Source: initial model sensitivity runs for this project.

the CORSIA eligible emissions unit price range assessed in Section 2. The assumptions used here are summarised in Table 16.

Table 16. Carbon price assumptions by scenario and allowance type.

Scenario	Carbon price, year 2018 euros				
	2015	2020	2025	2030	2035
EUA Base (nominal)	6	26	28	31	40
EUA IIb	6	26	47	83	120
CORSIA Sc1 (nominal)	0.2	1	1	1	1
CORSIA Sc2	0.2	1	5	13	22

3.1.2.6 Technology assumptions

Assumptions about technology include the timing, costs and fuel use characteristics associated with new aircraft models; the timing, costs and benefits of improved operations procedures; the conditions under which it becomes cost-effective to retrofit fuel-saving measures (for example, winglets or engine upgrade kits) onto older aircraft; and the availability, costs and benefits of alternative fuels. These can either be incorporated into modelling directly, or can inform background assumptions about the rate of change of fuel burnt per RPK flown over time. Additionally, assumptions and fuel and carbon costs can change the cost-effectiveness of available technologies, leading to faster or slower adoption. In this section, we consider the range of technology characteristics that it is appropriate to consider between now and 2035, assuming no significant change in policies that relate to aircraft fuels, technologies or operations. The potential impact of more significant changes in technology or technology-related policy is discussed in Section 3.2.14.

Historically, assumptions about changes in CO_2 and/or fuel use per RPK or per RTK per year have ranged from around 0.5% to 2%, depending on regional context, aircraft size and time period (e.g. Dray et al. 2018[541]). Yearly global-level fuel use per RTK declined on average by 2.4% between 2009-2014 in comparison to IATA's target of 1.5% (IATA, 2019)[542]. This trend arises partly from new aircraft models with greater fuel efficiency coming into the market (e.g. the Airbus neo aircraft family offers a 15-20% reduction in fuel use per comparable mission compared to their predecessors), partly from changes in operational strategies, and partly from unrelated shifts in typical aircraft size used and towards longer-haul flights. On a comparable-mission basis, recent improvements in fuel use per RPK have typically been lower than this (e.g. Dray et al., 2018). Because a successful aircraft production run can last as long as 20 years, and aircraft lifetimes in the global fleet are of order 30 years (e.g. Dray, 2014)[543], these new aircraft models are likely to still be a significant part of the fleet in 2050 unless there is a substantial change in fleet replacement behaviour.

[541] Dray, L., Schäfer, A. & Al Zayat, K., 2018. The global potential for CO_2 emissions reduction from jet engine passenger aircraft. *Transportation research Record*, 2672(23), 40-51.

[542] IATA, 2019. IATA 2019 end-of-year report. https://www.iata.org/en/iata-repository/publications/economic-reports/airline-industry-economic-performance---december-2019---report/

[543] Dray, 2014. Time constants in aviation infrastructure. Transport Policy, 34, 29-35.

Separately, ICAO in 2017 agreed a CO_2 standard for new aircraft designs (ICAO, 2017)[544]. This standard applies to all new commercial and business aircraft delivered after 1 January 2028. On average, the standard requires a 4% reduction in the cruise fuel consumption of new aircraft starting in 2028 compared to 2015 deliveries (ICCT, 2017)[545]. Analysis by ICCT (2017) suggests that the current generation of new aircraft models (e.g. A320neo, 777X, 737MAX, 787) already pass this standard by a significant margin and as such it is unlikely to have a significant impact on fleet-wide emissions.

In AIM, technology developments are modelled by specifying values for the individual characteristics of candidate technologies per aircraft size class, for nine size classes from Small Regional Jets (SRJ) to Very Large Aircraft (VLA). The resulting change in fuel use per RPK or RTK is then an output of the model. The characteristics of future technologies (e.g. new aircraft models, retrofits, operational measures or alternative fuels) can be highly uncertain. In many cases, estimates of the benefits of technologies depend on engineering breakthroughs that have still to be made. Therefore, the technology adoption model uses a lens approach to assess the impact of uncertainty in technology parameters (e.g. Allaire et al. 2014)[546]. A lens is a set of input parameters which reflect a particular scenario for future technology. For example, the 'pessimistic' technology lens used in this study describes a future in which it is particularly hard to reduce aviation emissions through technology; this assumes the reduction in fuel use from new technologies is at the low end of available estimates, costs are at the high end of available estimates, and the date from which the technology is available is at the late end of available estimates. For this study, we define three lenses using technology parameters, including changes in aircraft operating costs by cost type and changes in fuel burn, as derived from Schäfer et al. (2016)[547] and Dray et al. (2018). As well as the pessimistic lens discussed above, we use a central lens which assumes all technology parameters are at central/'most likely' values from available estimates, and an 'optimistic' scenario in which reductions in fuel use from new technologies are at the high end of available estimates, costs are at the low end of available estimates, and the date from which the technology is available is at the early end of available estimates. In all cases we assume consistency with ICAO's CO_2 standard.

Within AIM, measures are adopted based on their cost-effectiveness, using a Net Present Value (NPV) model as described in Dray et al. (2018). This means that high fuel and/or carbon prices can affect which technologies, retrofits and operational strategies are adopted. Because airlines typically use individual aircraft on multiple routes across their networks, technology uptake is assessed at a regional level (e.g. Europe, North America) based on average route-level costs within each region.

The resulting CO_2 per RPK trends depend on a number of further input assumptions. For example, if large-scale supply of cellulosic biomass-derived drop-in aviation fuel is assumed, global CO_2/RPK reductions of on average 2-3% per year could be achievable to 2050. Without large-scale biomass availability, reductions are likely to be 1.5% per year or below (Dray et al., 2018). Given that this study examines CO_2 impacts to a year-2035 timeline, relatively conservative technology assumptions are appropriate. Although

[544] ICAO, 2017. ICAO Council adopts new CO_2 standards for aircraft. https://www.icao.int/newsroom/pages/icao-council-adopts-new-co2-emissions-standard-for-aircraft.aspx

[545] ICCT, 2017. International Civil Aviation Organization's CO_2 standard for new aircraft. https://theicct.org/sites/default/files/publications/Aircraft_CO2_Standard_US_20181002.pdf

[546] Allaire D, Noel G, Willcox K and Cointin R. Uncertainty quantification of an Aviation Environmental Toolsuite. *Reliability Engineering and System Safety*, 2014; **126**:14-24.

[547] Schäfer, A., Evans, A. D., Reynolds, T. and Dray, L. M. Costs of Mitigating CO_2 Emissions from Passenger Aircraft. *Nature Climate Change*, Vol. 6, 2016, pp. 412-417.

Norway has pledged to switch to electric aircraft by 2040 for domestic flights, there is considerable uncertainty as to whether feasible electric aircraft models above air-taxi size will be in use in the fleet before 2050 (e.g. Schäfer et al., 2018[548]). Similarly, although open-rotor engines have reached a ground test stage[549] there is currently no airframe option to which they can be attached, and radical airframe changes such as blended wing body aircraft remain relatively speculative at present (e.g. ATA and Ellondee, 2018[550]). There also remain considerable uncertainties about the extent to which scaling up aviation biofuel production is likely without specific policies in place (e.g. ICCT, 2019[551]; CCC, 2019)[552].

For alternative fuels, each scenario requires assumptions about availability, costs, interactions with different policies and lifecycle emissions. For CORSIA, sustainable aviation fuels can be used to reduce an airline's offsetting requirement. The requirement is reduced proportionately to the reduction in fuel lifecycle emissions based on using the sustainable fuel rather than standard fossil-derived Jet A, using ICAO's own set of emissions factors (ICAO, 2019)[553]. As discussed in Section 2.3.7, the current definition of a CORSIA eligible fuel is rather wide and some fossil-derived aviation fuel may be able to meet it, for example via the use of renewable energy at refineries to reduce emissions associated with the production and distribution of fossil Jet A (though this is at present only a theoretical opportunity). This requirement means that biofuel users still pay carbon costs under CORSIA, just at a reduced rate. For example, use of a biofuel which halved fuel lifecycle emissions in comparison to fossil-derived Jet A would halve CORSIA carbon costs.

In the EU ETS, biofuels have historically been zero-rated provided they meet RED I criteria (e.g. de Jong et al. 2018)[554] – i.e., airlines pay no ETS costs on biomass-derived fuel, provided that it meets EU specifications as discussed in Section 2.3. These specifications are significantly stricter than those used in CORSIA. Additionally, under RED II, non-food biofuels supplied to the aviation sector count towards transport bioenergy use targets using a 1.2 multiplier, i.e. 1 toe of biofuel supplied to aviation counts as 1.2 toe of fuel in terms of meeting bioenergy targets[555]. The overall mandatory target for renewable energy

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548 Schäfer, A., Barrett, S., Doyme, K., Dray, L., Gnadt, A., Self, R., O'Sullivan, A., Synodinos, A. & Torija, A., 2019. Technological, economic and environmental prospects of all-electric aircraft. Nature Energy, 4(2), 160-166.

549 Safran, 2017. Safran celebrates successful start of Open Rotor demonstrator stage. https://www.safran-group.com/media/safran-celebrates-successful-start-open-rotor-demonstrator-tests-new-open-air-test-rig-southern-france-20171003

550 ATA and Ellondee, 2018. Understanding the potential and costs for reducing UK aviation emissions. Report to the Committee on Climate Change and the Department for Transport. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/785685/ata-potential-and-costs-reducting-emissions.pdf

551 ICCT, 2019. Long-term aviation fuel decarbonization: Progress, roadblocks and policy opportunities. https://theicct.org/sites/default/files/publications/Alternative_fuel_aviation_briefing_20190109.pdf

552 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/

553 ICAO, 2019. CORSIA frequently asked questions. https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-FAQs.aspx

554 De Jong, S., van Stralen, J., Londo, M., Hoefnagels, R., Faaij, A. & Junginger, M., 2018. Renewable jet fuel supply scenarios in the European Union in 2021-2030 in the context of proposed biofuel policy and competing biomass demand. Bioenergy, 10, 661-682.

555 EC, 2019. Renewable Energy – Recast to 2030 (RED II) https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii

use in transport in 2030 is 14%, but aviation participation is voluntary and the target is expected to be met primarily via the road and rail sectors. RED II includes a sub-target of 3.6% advanced biofuel use in 2030 which may affect fuels supplied to the aviation sector. Current aviation biofuel use is limited to small-scale schemes at individual airports (e.g. Los Angeles; Bergen; Brisbane; Oslo; Stockholm; IEA, 2019[556]), with total biofuel uptake of less than 0.1% of total aviation fuel consumption. As noted by EEA (2019)[557], although several commercial-scale biofuel production facilities exist in Europe, current European aviation biofuel use is currently 'minimal and is likely to remain limited in the short term.' Limiting factors include the cost relative to fossil-derived Jet A and 'low priority in most national bioenergy policies'. The current potential under existing policies for EU aviation biofuel production is estimated around 2.3 Mt – i.e. around 4% of total EU aviation fuel demand – however, achieving this would require biorefineries to tune processes to increase output of aviation fuel and correspondingly reduce the relative output of biofuels for other sectors. Current hurdles to greater use include feedstock prices (at present 58-69% above fossil-derived Jet A for bio-based aviation fuel from used cooking oil; EEA, 2019), price volatility, and competing demand from the much larger road fuel sector.

Projections of how much biofuel might be in use in aviation up to 2050 vary widely and are dependent on the costs and supply of biomass assumed, as well as the characteristics of and demand from other sectors and policies. Most recent multi-sectoral analyses project relatively low aviation biomass use to 2035. De Jong et al. (2018) project 6-9% of European aviation fuel in 2030 could be derived from biomass, given suitable technology development and policy incentives. ICCT (2019) discuss barriers to sustainable fuel adoption in aviation, noting particularly that larger, more profitable sectors are likely to be more attractive targets for bioenergy companies (in particular, road transport), and projecting biofuel use in global aviation of less than 25% in 2050 even under a high biomass supply scenario. IEA (2019) assume biofuel use in aviation of 19% by 2040 in their Sustainable Development Scenario (SDS). ICCT (2019) also suggest prioritizing longer-term strategies for an aviation transition to sustainable fuel, with priority for road vehicles in the shorter term. Similarly, CCC (2019)[558], in their analysis of how to achieve net zero UK emissions by 2050, suggest that biomass use should be prioritized in applications where carbon capture and storage can also be applied, with only limited use in aviation. Their core year-2050 scenario for UK aviation assumes only 5% biofuel use, with 10% in a 'further ambition' scenario. Air transport is the single largest-emitting UK sector in 2050 under their projections.

An alternative option for low-carbon fuel in aviation is electrofuels (also known as power-to-liquid fuels), i.e. aviation fuel produced by combining hydrogen produced using renewable electricity with carbon monoxide from (ideally direct air capture) CO_2. Given the long timescale of aircraft design and fleet turnover, the largest year-2050 impact is likely to come from drop-in versions of these fuels that can be used in current aircraft. Provided sufficient renewable electricity generation capability is available, fuel lifecycle emissions for this path could be close to zero. This makes electrofuels a potentially important component over the long term in reaching net zero in the aviation sector. In the Paris Agreement-compatible emissions scenarios modelled in support of the EC's 2050 long-term strategy, electrofuels provide up to 34% of aviation fuel use by 2050 (EC,

[556] IEA, 2019. Are aviation biofuels ready for take-off? https://www.iea.org/commentaries/are-aviation-biofuels-ready-for-take-off

[557] EEA, 2019. European Aviation Environmental Report 2019. https://ec.europa.eu/transport/sites/transport/files/2019-aviation-environmental-report.pdf

[558] CCC, 2019. Net Zero: The UK's contribution to stopping global warming. https://www.transportenvironment.org/sites/te/files/WK_2310_2017_INIT_2.pdf

2018)[559]. However, as discussed by Transport & Environment (2018)[560], the projected cost of fuels produced using this process is 3-6 times that of untaxed fossil Jet A; use of electrofuels would likely lead to year-2050 ticket price increases compared to a no-electrofuels baseline of 23-59% for carbon price assumptions of up to €150/tCO_2. Due to these high costs, the current state of electrofuel development is limited, with few demonstrator projects being brought forward (EASA, 2019)[561]. Electrofuels would also have to compete with other sectors for renewable electricity generation capacity. Transport & Environment (2018) project electricity requirements roughly equal to the entire year-2018 European renewable electricity generation capacity, and conclude that it is unlikely that electrofuels can reach cost parity with fossil-derived Jet A even with relatively high levels of carbon pricing, i.e. additional policy could be needed to ensure uptake. Similarly, Brynolf et al. (2018)[562] find projected costs of electrofuels to be consistently at the upper end of or above projected costs for biofuels, and Kieckhäfer et al. (2019)[563] project minimal uptake of electrofuels unless policies specifically aimed at promoting their use are applied. Given these constraints and the current absence of policy initiatives aimed specifically at promoting electrofuel use, we omit electrofuels from the modelling stage. The potential impact of policy changes in this area is discussed in Section 3.2.14.

Based on literature projections, we use the following limits for aviation fuel uptake:

- In the pessimistic technology lens, no aviation biofuel is assumed;
- In the central (nominal) technology lens, an upper limit corresponding to 10% biofuel by 2050 is applied;
- In the optimistic technology lens, an upper limit corresponding to 20% biofuel by 2050 is applied.

These are upper limits on the amount of biofuel that is assumed available to the aviation sector; the modelled amount of uptake beneath this limit depends on the relative costs of biofuel, carbon and fossil Jet A. No additional policy support for aviation biofuel beyond ETS/CORSIA carbon pricing and biofuel exemption policy is assumed, and operators are assumed to use biofuels only if they can reduce total operating costs by doing so. In practice, 0-20% maximum uptake by 2050 leads to uptake of roughly 0-5% by 2030 and 0-10% by 2035, depending on factors such as oil price, carbon price, biofuel characteristics and policy scope. We assume a Fischer-Tropsch fuel from cellulosic biomass (e.g. wood waste) fuel which meets REDII requirements, using the cost curve model used in Dray et al. (2018) to project prices and supply over time. Based on the analysis in Section 2.3.7, we propose a ratio of fuel lifecycle emissions compared to that of Jet A of between 0.15 (pessimistic lens) and 0.1 (optimistic lens), with 0.125 used in the central lens.

For other technology characteristics we consider updates to conventional-technology aircraft, improvements in operations and the option of retrofits, using assumptions used in Dray et al. (2018) for uncertainty ranges in the characteristics of these technologies

[559] EC, 2018. In-depth analysis in support of the Commission communication COM(2018) 773. https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

[560] Transport and Evironment, 2018. Roadmap to Decarbnising European Aviation. https://www.transportenvironment.org/sites/te/files/publications/2018_10_Aviation_decarbonisation_paper_final.pdf

[561] EASA, 2019. Sustainable Aviation Fuels. https://www.easa.europa.eu/eaer/climate-change/sustainable-aviation-fuels

[562] Brynolf, S., Taljegard, M., Grahn, M. & Hansson, J., 2018. Electrofuels for the transport sector: a review of production costs. Renewable and Sustainable Energy Reviews, 81(2), 1887-1905.

[563] Kieckhäfer, K., Quante, G., Müller, C., Spengler, T., Lossau, M. & Jonas, W., 2019. Simulation-based analysis of the Potential of Alternative Fuels towards Reducing CO_2 Emissions from Aviation. Energies, 11(1), 186

and strategies. The corresponding trends in fuel lifecycle CO_2 per RPK broadly correspond to 1.0%, 1.5% (nominal) and 2.2% per year over the 2020-2035 period, although the rate of improvement is not constant but depends on, for example, when new aircraft models become available. Trends by aircraft size class are shown in Figure 21. A discussion of impacts in the case that technological breakthroughs are made beyond those modelled here is given in Section 3.2.14.

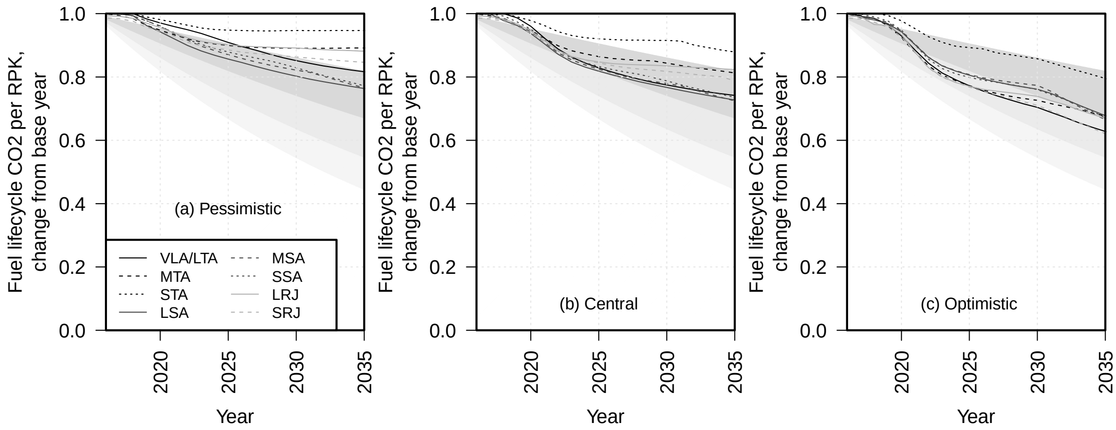

Figure 21. Development of fuel lifecycle RPK/CO_2 by technology lens, under nominal assumptions for other parameters. Note that STA (small twin aisle) aircraft have a slower rate of improvement because the base year fleet is already very fuel-efficient.

Alternative aviation fuels are treated differently in CORSIA and the EU ETS. Because the policy options discussed in Section 3.1.2.1 include different strategies for how the two schemes interact, there is the potential for ambiguities about how alternative fuels are accounted for on routes that are subject to both policies. As discussed above, the EU ETS currently exempts sustainable aviation fuels completely, provided they meet the criteria for sustainability. CORSIA applies much less stringent sustainability criteria, but exempts biofuels only in proportion to the reduction in their fuel lifecycle emissions. In Options 1, 2, 3 and 4, only one type of carbon charge (EU ETS or CORSIA) applies to each individual route. Each scheme can deal with biofuels straightforwardly, and operators can choose whether or not to use alternative fuels on a route based on the carbon charges and exemptions of the policy that applies on the route. In option 6, only one type of carbon charge applies to each individual flight, but there will be routes where both EU/EFTA and non-EU/EFTA carriers operate on which not all carriers will be paying the same carbon costs. In this case, EU/EFTA carriers may have a greater incentive to utilise biofuels on these routes, given suitable supply infrastructure. However, few non-EU/EFTA carriers operate on intra-EU/EFTA routes, so this effect will be limited. For Option 5, depending on the exact details of implementation, the EU ETS and CORSIA may both apply to (portions of) the emissions of a single flight. In this case it would generally be more attractive to an operator who is using biofuels which comply with both schemes to count the biofuels against the EU ETS portion of emissions for that flight, as EU ETS carbon costs are typically higher and the EU ETS biofuel exemption is more generous. Alternatively, if eligibility calculations are based on total reported fuel use for both schemes, it is likely that biofuel use for a given flight will be split between the EU ETS and CORSIA portions of fuel use proportionately. We assume the latter option in the calculations here.

3.1.2.7 Participation

The participation scenarios discussed here refer to participation in CORSIA; the EU ETS participation for the main grid is assumed constant at the current set of EEA countries plus Switzerland and minus the UK (post-2020). As discussed in Section 2.3.1, the set of countries which will participate in CORSIA, particularly in the initial voluntary phase, is still somewhat uncertain. Because CORSIA applies to routes only where both the origin and destination state participate, a country choosing not to participate removes all flights to and from that country from CORSIA scope. At typical projected carbon prices, the within-sector impact of different participation scenarios is likely to be relatively small. However, the removal of an individual large country (e.g. the United States or China) could affect the global CORSIA scope in RTK by over 10% (e.g. ICAO, 2018). This in turn will affect the overall effectiveness of the policy in terms of all-sectors emissions reductions, depending on the extent to which CORSIA offsets are real and additional.

The participation scenarios used here are derived from the analysis carried out in Section 2 (High, Initial Assumed and Low scenarios):

- High participation consists of states 81 States listed by ICAO on its website by July 2019, plus (from 2027) China, India, Brazil, Russia and Vietnam;
- Initial assumed participation (nominal) participation consists of the 81 States listed by ICAO on its website by July 2019 throughout all CORSIA phases;
- Low participation assumes additionally that the United States will not participate in any phase of CORSIA.

3.1.2.8 Assumptions for other sensitivity cases

As discussed above, we carry out additional sensitivity runs for specific cases outside the main grid of model runs.

- Testing the impact of variants of the main six policy options, as discussed in Annex 3. This includes variant versions of the main policies with different treatment of outermost region routes, and consideration of Option 1 including only departing extra-EU/EFTA flights, rather than all extra-EU/EFTA flights, in the EU ETS. Here we test each variant with nominal inputs for all scenario variables against the equivalent main-variant policy. The outcomes of these model runs are reported in Annex 3.
- For higher environmental integrity credits in CORSIA, we use a range of CER prices between CER scenario 1 and EUA base, as discussed in Annex 3.
- For cost pass-through, we run each policy option with 0% and 100% pass-through of carbon costs as well as the nominal assumptions taken from Section 4, with all other scenario assumptions at nominal values. 100% cost pass-through in this case is assumed to mean full pass-through of opportunity costs, for consistency with the full range of values used in the literature. This is discussed in Annex 2.
- For allowance allocation, we run Options 1, 2, 4, 5 and 6 with the following options for changes in auctioning:

  - Status quo: The current legal situation is perpetuated until 2030, i.e. the 15% auctioning share.
  - Immediate phase-out: 100% auctioning from the entry into force of the revision.
  - Swift phase-out: Full auctioning by 2025, starting with an auctioning share of 60% in 2023, and a share of 80% in 2024.
  - Slow phase-out: A linear increase year-by-year to full auctioning by 2030 starting from 20% in 2023.
  - Slow reduction: A linear increase year-by-year starting with an auctioning share of 20% in 2023 and ending at 55% in 2030.

This is discussed in Section 3.2.13.

3.1.2.9 Impact of the COVID-19 pandemic

We have not included the impact of the COVID-19 pandemic in this modelling, because its overall impacts on aviation systems were still developing whilst modelling was ongoing. Multiple short- and longer-term impacts are likely. Initial indications are that global RTK in 2020 will have decreased substantially from year-2019 levels, with IATA projecting that the global aviation industry as a whole will see a net loss of $84 billion[564] (€71 billion as of August 2020), comparable to the impact of the financial crisis on airlines, and reductions in global RPK compared to expected levels of over 50% in 2020 and 32-41% in 2021[565]. These numbers were estimated whilst the crisis was still developing, and are still subject to high levels of uncertainty. Similarly, ICAO[566] (2020) find likely reductions in year-2020 scheduled passenger numbers of 46-62%. For Europe, limited impacts on traffic were observed before March, but weekly air traffic volumes monitored by Eurocontrol (2020)[567] were reduced by 41% and 89% below year-2019 levels in March and April, respectively. In late April, Eurocontrol projected a range of recovery scenarios for 2020 and early 2021, implying year-2020 traffic volumes of between roughly 45-55% of those in 2019[568]. For comparison, SARS, which had a much less widespread impact, led to roughly an 8% reduction in year-2003 RPK in affected regions, arising from disruption lasting for roughly 6 months with peak monthly RPK reduction of 35% and leading to roughly $6bn of lost revenue (ICAO, 2020).

The types of airlines and aircraft flying the routes that remain in operation has also been affected by COVID-19. The pandemic has already resulted in numerous airline bankruptcies (e.g. Virgin Australia, Avianca, Flybe, and LATAM). As yet it is unclear how many of these airlines will disappear permanently, and how many will survive in some form. Historically, routes vacated by collapsed airlines have tended to be rapidly taken on by other similar airlines, at least in a European context (Mayer & Suau-Sanchez, 2019)[569], suggesting that networks and levels of competition are likely to return to pre COVID-19-like situations over the longer term.

The demand reduction led by COVID-19 has also resulted in many airlines scrapping or storing older and/or larger aircraft (e.g. Forbes, 2020)[570]. Storage is a common response to downturns in demand; some of these aircraft will be taken out of storage once demand returns, whilst others will end up permanently retired (e.g. Morrell & Dray, 2009)[571]. Combined with the upcoming end of production for the Airbus A380 and Boeing 747, this is likely to accelerate a global move away from the use of very large and/or quad-engine aircraft. Given that this trend is driven in part by higher fuel costs for these aircraft, it may be partially offset by currently low fuel prices. The impact of a more rapid switch away from very large aircraft than anticipated on CO_2 emissions is relatively small (around a

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564 IATA, 2020. Economic performance of the airline industry. June 2020 Report. https://www.iata.org/en/iata-repository/publications/economic-reports/airline-industry-economic-performance-june-2020-report/

565 IATA, 2020. Covid19: outlook for air travel in the next five years. https://www.iata.org/en/iata-repository/publications/economic-reports/covid-19-outlook-for-air-travel-in-the-next-5-years/

566 ICAO, 2020. Effects of Novel Coronavirus (Covid-19) on Civil Aviation: Economic Impact Analysis. https://www.icao.int/sustainability/Documents/COVID-19/ICAO_Coronavirus_Econ_Impact.pdf

567 Eurocontrol, 2020. Daily Traffic Variation. https://www.eurocontrol.int/Economics/DailyTrafficVariation-States.html

568 Eurocontrol, 2020. Traffic Scenarios. https://www.eurocontrol.int/covid19

569 Meyer, 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.

570 Forbes, 2020. Pandemic plane purge: airlines dump everything from Airbus A380 to Boeing 747. https://www.forbes.com/sites/michaelgoldstein/2020/05/04/pandemic-plane-purge-airlines-ground-or-dump-everything-from-airbus-a380-to-boeing-757/#7604d89e7a19

571 Morrell, P. and 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.

0.3% decrease in global direct aviation CO_2 by 2035 in AIM test runs) under the technology assumptions used here, as lower per-aircraft emissions are balanced out by higher flight frequency.

The overall impact of COVID-19 on aviation in the EU ETS and CORSIA depends on the extent and duration of disruption. In 2019, roughly 48% of European ETS-eligible direct aviation CO_2 emissions were above the reduced-scope EU ETS aviation cap, 44% were covered by freely-allocated EUAAs, and the remaining 8% were covered by auctioned EUAAs[572]. A reduction in intra-European aviation CO_2 of 25% from year-2019 levels would still not take ETS totals below the current cap, but a substantial reduction in the amount that aviation pays to purchase allowances from other sectors would still be likely. If year-2020 intra-European aviation CO_2 is half of year-2019 amounts, emissions will be below the aviation cap and reductions in auctioning revenue will be likely. At a decrease of 60%, intra-EEA aviation CO_2 emissions would be less than the amount of free EUAAs issued, and auctioning revenues would be zero. Because the type of flights flown under COVID-19 disruption, and the individual aircraft used to fly them, differ from typical pre-COVID-19 operations, the decrease in CO_2 corresponding to Eurocontrol's projected 45-55% decrease in traffic volumes is uncertain. However, it looks likely that decreases in CO_2 will be in the range where EUA and potentially EUAA purchases by aviation are strongly reduced for 2020 from year-2019 levels. Similarly, other schemes which rely on air passenger or (to a lesser extent) air freight-generated revenues may have funding shortfalls.

Separately, reductions in oil price will have implications for airline costs and on short-term incentives to invest in fuel-saving technologies (at the time of writing, Brent Crude was below $40/bbl, well outside the range of year-2020 projections). Historically, reductions in oil price have been associated with lower ambition in fuel-saving technology development, for example the shelving of unducted fan engine designs in the late 1980s[573]. Wider impacts on GDP per capita will also feed into demand reduction which may extend into later years. For example, EC (2020)[574] project a year-2020 EU GDP contraction of 7.5% which is only partly offset by a projected rise of 6% in 2021.

COVID-19 has had a similarly unanticipated and significant impact on demand for emissions allowances across all sectors. The Market Stability Reserve (MSR)[575] was set up in 2019 to address the impacts of unanticipated changes in demand for allowances on allowance price. This was a response to the impact of the 2007-08 financial crisis, which led to reductions in CO_2 emissions which were greater than expected. EU ETS emissions were below the overall EU ETS cap from 2009 to 2012 (ETC/CME, 2019)[576], leading to a surplus of emissions allowances and low allowance prices. Unallocated allowances are transferred to the MSR, allowing the supply of allowances for auctioning to be adjusted. From 2023 onwards the number of allowances held in the reserve will be limited to the auction volume of the previous year, and holdings above that amount will lose their validity. The existence of the MSR will limit the amount by which carbon prices fall in

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[572] EU ETS data viewer. https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1

[573] e.g. Flightglobal, 2007. Whatever happened to propfans? https://www.flightglobal.com/whatever-happened-to-propfans/74180.article

[574] EC, 2020. European Economic Forecast, Spring 2020. https://ec.europa.eu/info/sites/info/files/economy-finance/ip125_en.pdf

[575] EC, 2019. Market Stability Reserve. https://ec.europa.eu/clima/policies/ets/reform_en.

[576] ETC/CME, 2019. Trends and projections in the EU ETS in 2019. https://www.eionet.europa.eu/etcs/etc-cme/products/etc-cme-reports/etc-cme-report-3-2019-trends-and-projections-in-the-eu-ets-in-2019.

response to COVID-19. However, a roughly 30 percent fall in the EU ETS carbon prices has still occurred (EEX, 2010)[577].

In neglecting these impacts in the modelling, we effectively assume that severe aviation system disruption will be confined largely to a short time period (1-2 years), with longer-term impacts remaining within the range of scenarios modelled.

A further concern is the impact on the CORSIA baseline. The originally intended CORSIA baseline was to be set using the average of year-2019 and year-2020 CO_2. In June 2020, the ICAO Council decided that during the pilot phase, 2019 emissions shall be used instead of the average between 2019 and 2020 emissions. The impact of using 2019 as the sole baseline year depends on the extent and speed of demand recovery. If demand recovers rapidly (e.g. the 'V'-shaped disruption curve assumed by early assessments of COVID-19-related disruption) then the main impact would be a baseline roughly 1% below the one assumed here, leading to slightly increased demand for offsets but with minimal impacts on airline costs. If demand recovers more slowly (the 'U' or 'L'-shaped disruption scenarios projected by ICAO), then CO_2 may remain below the baseline in 2021 and potentially further, leading to low or zero pilot phase offset requirements. Recently Schneider and Graichen (2020) estimated that "a 2019 baseline would delay mitigation obligations for the industry by several years and most likely waive any offsetting requirements in the pilot phase, and possibly even in the first phase of the scheme"[578].

We do not directly assume any ongoing impacts from the pandemic on global aviation systems. Such impacts could include, for example, a shift towards teleconferencing instead of long-distance travel following the widespread practical deployment of teleconferencing technologies in 2020; ongoing changes in airline networks following airline bankruptcies; extended economic impacts; ticket price and load factor impacts of restrictions on passenger distancing (e.g. requirements for empty middle seats); or delays in new technology investment due to airline capital constraints and low oil prices. However, a full analysis of the ongoing impacts is outside the scope of this report.

3.2 Aviation sector results

This discussion is structured as follows. First, a brief, non-technical summary of overall aviation sector outcomes is given. After this, more detailed outcomes for different aviation sector metrics are discussed in turn. We discuss the geographical and emissions-level coverage of each policy option. After this, we examine the demand for offset credits (in the case of CORSIA) and EU ETS allowances. After this, we examine what impact this has on airline costs and profit margins by geographic scope. Following on from this, we look at the impact on passengers in terms of ticket prices and demand, and the impact on airports within and outside the EU/EFTA region. After this we discuss the wider societal impacts of each policy option.

3.2.1 Summary of Aviation Sector Modelling Findings

Aviation sector modelling comparing the impact on a range of different metrics of the different policy options is discussed in detail in Sections 3.2.2 - 3.2.14. This section briefly summarises the outcomes. A comparison of metrics related to airline costs, demand and global direct (i.e. as emitted from aircraft engines) and net (i.e. adjusted for biofuel use, allowances and offsets) CO_2 is given in Table 17. In summary:

[577] EEX, 2020. Primary Auction Spot Report 2020. https://www.eex.com/en/market-data/environmental-markets/auction-market/european-emission-allowances-auction/european-emission-allowances-auction-download

[578] Lambert Schneider and Jakob Graichen, Should CORSIA be changed due to the COVID-19 crisis?, May 2020

- Option 1 restores the EU ETS for aviation to full scope (i.e. all flights to, from and within the EU/EFTA region, including to and from outermost regions) from 2024. This option is associated with the largest decrease in intra-EU/EFTA and global net aviation CO_2, the largest increase in airline costs and the largest decrease in demand. Demand and cost impacts are still projected to be relatively small; for example, intra-EU/EFTA RTK differs from the lowest airline carbon cost option (option 3) by under 1.5% under nominal scenario conditions. Intra- and extra-EU/EFTA net aviation CO_2 closely follow the EU ETS aviation cap, with a small amount of residual uncertainty arising mainly from biofuel exemptions. Global net aviation CO_2 is projected to continue to rise on average over the time period to 2035 under nominal scenario conditions for option 1 due to growth on non-EU/EFTA, non-CORSIA routes. This option would amount to the EU's non-participation in CORSIA, which runs contrary to the established formal EU position (while noting that the EU has reserved its full policy autonomy by filing differences to the CORSIA SARPs). Moreover, it cannot be excluded that key aviation States that have volunteered to participate would reconsider their decision. If for this reason or another CORSIA would fail, the impact of CORSIA would amount to zero.

- Option 2 keeps the EU ETS for aviation at its current reduced scope (all flights within the EU/EFTA region, excluding those to and from outermost regions). CORSIA is not applied on routes within, to and from the EU/EFTA region. This option is associated with slightly lower increases in intra-EU/EFTA airline costs than option 1, and slightly lower decreases in intra-EU/EFTA demand and emissions. Intra-EU/EFTA net aviation CO_2 emissions decrease to 2035 but are projected to remain at a higher level than in Option 1 (around 4 Mt under nominal scenario conditions by 2035) due mainly to outermost region exemptions. Global net aviation CO_2 is projected to be substantially higher (by 125 Mt in 2035 under nominal scenario conditions) than in option 1, due to the lack of coverage of extra-EU/EFTA flights. This option would amount to the EU's non-participation in CORSIA, which runs contrary to the established formal EU position (while noting that the EU has reserved its full policy autonomy by filing differences to the CORSIA SARPs). Moreover, it cannot be excluded that key aviation States that have volunteered to participate would reconsider their decision. If for this reason or another CORSIA would fail, the impact of CORSIA would amount to zero.

- Option 3 removes aviation completely from the EU ETS. Instead, CORSIA applies to international flights to, from and within the EU/EFTA region. Domestic flights within the EU/EFTA would not be addressed anymore. This option is associated with the biggest global net aviation CO_2 emissions increase, and the smallest impact on demand and airline costs. Under nominal scenario conditions, intra-EU/EFTA year-2035 net aviation CO_2 is projected to be higher than year-2015 values under option 3. Global net aviation CO_2 emissions are projected to be 1.5 times year-2015 values in 2035 under nominal scenario conditions if CORSIA offsets are assumed to be of high quality (as defined in Table 1.4). There is also a risk of even higher net aviation CO_2 emissions in the case that CORSIA offsets are not of high quality.
- Option 4 keeps the EU ETS for aviation at its current reduced scope and applies CORSIA on flights to and from the EU/EFTA region. Outcomes within the aviation sector are broadly similar to option 2, but net global aviation CO_2 is projected to be around 17 Mt lower than option 2 in 2035 under nominal scenario conditions if CORSIA offsets are assumed to be of high quality, due to CORSIA coverage of extra-EU/EFTA flights.
- Option 5 is similar to Option 4, but the EU ETS and CORSIA both apply to routes within the EU/EFTA region. The EU ETS counts only emissions below the CORSIA baseline. Under nominal scenario conditions, outcomes in terms of airline costs, demand and net CO_2 are similar to option 4. Net CO_2 may increase over option 4

values in the case that intra-EU/EFTA demand growth is higher than nominal scenario projections and CORSIA offsets are not of high quality.

- Option 6 is similar to Option 4, but domestic flights and intra-EU/EFTA flights by non-EU/EFTA registered carriers are removed from the EU ETS scope. Under nominal scenario conditions, this option is projected to have broadly similar outcomes to options 4 and 5 because there are relatively few intra-EU flights operated by non-EU carriers. However, net aviation CO_2 is slightly higher than in Options 4 and 5 (by around 3 Mt) due to the exemption of domestic flights.

Table 17. Comparison of estimated airline costs, ticket prices, RTK demand and direct and net aviation CO_2 by policy option. Values in larger font indicate outputs when all uncertain input variables are set to nominal values. Values in brackets indicate ranges due to changes in uncertain input variables. Direct CO_2 includes all CO_2 emitted by aircraft engines. Net CO_2 totals are adjusted to account for offsets, allowances and alternative fuel use, and assume CORSIA offsets are of high quality. EU/EFTA totals include Switzerland and exclude the UK.

Policy option	**Carbon costs as a percentage of airline operating cost, intra-EU/EFTA**		**Carbon costs as a percentage of airline operating cost, extra-EU/EFTA**		**Avg. one-way fare, intra-EU/EFTA, €2018**		**Avg. one-way fare, extra-EU/EFTA, €2018**		**RTK on intra-EU/EFTA routes, billion**	
	2030	**2035**	**2030**	**2035**	**2030**	**2035**	**2030**	**2035**	**2030**	**2035**
Option 1	1.1 (0.9-3.8)	1.4 (1.1-5.7)	2.1 (1.6-7.6)	2.7 (1.9-11.5)	127.0 (115-136)	129.9 (115-141)	343.8 (327-390)	350.2 (328-415)	81.7 (61.3-94.8)	87.8 (63.3-111)
Option 2	1.0 (0.7-3.1)	1.3 (0.8-4.6)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	127.0 (115-136)	129.8 (115-140)	341.0 (324-380)	346.5 (325-399)	81.9 (62.1-95.2)	88.2 (64.6-111)
Option 3	0.006 (0.0-0.3)	0.006 (0.0-0.4)	0.01 (0.0-0.1)	0.01 (0.0-1.3)	126.1 (114-133)	128.5 (113-137)	341.0 (324-380)	346.4 (325-400)	82.4 (63.0-96.0)	89.0 (65.9-113)
Option 4	1.0 (0.7-3.1)	1.3 (0.8-4.6)	0.01 (0.0-0.1)	0.01 (0.0-1.3)	127.0 (115-136)	129.8 (114-140)	341.1 (324-380)	346.5 (325-400)	81.9 (62.1-95.2)	88.2 (64.6-111.6)
Option 5	0.9 (0.7-2.7)	1.1 (0.8-3.6)	0.01 (0.0-0.1)	0.01 (0.0-1.3)	126.9 (115-136)	129.6 (114-140)	341.1 (324-380)	346.5 (325-400)	81.9 (62.0-95.4)	88.3 (64.6-112.0)
Option 6	0.9 (0.6-2.5)	1.1 (0.7-3.7)	0.01 (0.0-0.1)	0.01 (0.0-1.3)	126.8 (115-135)	129.5 (114-140)	341.1 (324-380)	346.5 (325-400)	81.9 (62.2-95.3)	88.3 (64.7-111.8)
Policy option	**RTK on extra-EU/EFTA routes, billion**		**Global direct aviation CO_2 emissions, Mt**		**Global net aviation CO_2 emissions, Mt**		**Intra-EU/EFTA direct aviation CO_2 emissions, Mt**		**Intra-EU/EFTA net aviation CO_2 emissions, Mt**	

	2030	2035	2030	2035	2030	2035	2030	2035	2030	2035
Option 1	289.8 (262-359)	316.8 (283-432)	1135 (926-1334)	1263 (972-1597)	980 (798-1100)	1046 (760-1242)	53.9 (42.2-63.9)	55.1 (41.0-71.2)	27.8 (23.7-29.6)	23.6 (19.0-25.2)
Option 2	293.9 (272-365)	323.0 (298-442)	1138 (931-1339)	1269 (978-1607)	1077 (865-1258)	1171 (839-1482)	54.1 (42.6-64.3)	55.3 (41.5-71.8)	30.6 (28.9-32.7)	27.9 (25.7-31.5)
Option 3	294.0 (272-365)	323.2 (297-442)	1139 (931-1340)	1270 (978-1608)	1094 (883-1250)	1179 (845-1452)	54.4 (43.0-64.8)	55.8 (42.1-72.6)	49.4 (40.4-52.9)	50.8 (37.8-55.8)
Option 4	293.9 (271-365)	323.0 (297-442)	1138 (931-1339)	1269 (978-1607)	1070 (867-1226)	1154 (830-1425)	54.1 (42.6-64.3)	55.3 (41.5-71.8)	30.6 (28.9-32.7)	27.9 (25.7-31.5)
Option 5	293.9 (271-365)	323.0 (297-442)	1138 (931-1339)	1269 (978-1607)	1072 (871-1229)	1155 (833-1429)	54.1 (42.6-64.4)	55.4 (41.5-72.1)	27.8 (23.9-31.6)	26.9 (24.9-32.5)
Option 6	293.9 (271-365)	323.0 (297-442)	1138 (931-1339)	1269 (978-1607)	1073 (868-1232)	1157 (831-1433)	54.1 (42.6-64.4)	55.4 (41.6-72.0)	32.9 (29.5-38.0)	31.1 (26.7-39.2)

Effectiveness refers to how well the alternative options perform against the EU's objectives for reducing emissions from aviation on routes within, to and from EU/EFTA countries. As discussed in Section 2.2, EU objectives for aviation CO_2 are largely defined by aviation's inclusion in the wider EU ETS and by all-sector and transport-wide commitments that include aviation (for example, The European Green deal sets a 90% reduction target for transport emissions in 2050, to which aviation will need to contribute). EU policy does not currently directly address the aviation sector's non-CO_2 climate impacts but Article 30(4) of the European Union Emissions Trading System (EU ETS) Directive requires the European Commission to present an updated analysis of the non-CO_2 effects of aviation which, if relevant, should be accompanied by a proposal on how to best address those effects.[579] This separate study was ongoing at the time of finalising this report. The ratings for this indicator therefore assess the extent to which each policy option is effective at ensuring the aviation sector contributes towards wider CO_2 emissions reduction goals compared to the current policy situation (reduced scope EU ETS, no CORSIA).

Of the different options, Option 1 in associated with the largest decrease in net aviation CO_2 emissions. Option 2 represents a continuation of the current reduced-scope status quo for EU emissions policy. Depending on the assumed quality of carbon credits used for CORSIA compliance, Option 3 represents either a moderate or considerable weakening of EU aviation emissions policy. Option 4 slightly strengthens EU emissions policy via the inclusion of extra-EEA flights in CORSIA and, at nominal scenario demand growth rates, Option 5 has similar outcomes (note, however, that Option 5 is associated with worse CO_2 reduction outcomes than Option 4 at high demand growth if CORSIA offsets are not of

[579] The European Parliament and the Council of the European Union, "Directive (EU) 2018/410 of the European Parliament and of the Council of 14 March 2018 Amending Directive 2003/87/EC to Enhance Cost-Effective Emission Reductions and Low-Carbon Investments, and Decision (EU) 2015/1814," *Official Journal of the European Union*, 2018, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0410&from=DE.

high quality). Option 6 reduces EU ETS coverage, most notably by removing EU domestic flights from scope, but adds CORSIA coverage of intercontinental flights. However, because CO_2 emissions from EU/EFTA domestic flights are likely to continue on a long-term stable or decreasing trend with or without policy, overall outcomes are broadly similar to Options 4 and 5.

Efficiency refers to the balance of costs and benefits of each option. This includes administrative and compliance costs faced by businesses, potential savings in fuel costs, and implications for EU/EFTA State auctioning revenue. Because of Option 1's larger coverage, state auctioning revenues from aviation are higher, but so are airline costs. For Option 3, airline carbon costs are minimal, and EU ETS EUAA state auctioning revenue is eliminated. Options 2, 4, 5 and 6 have similar levels of airline compliance costs and state revenue impact, although options that combine CORSIA and the EU ETS are likely to have higher administrative costs as some airlines would be subject to two regulations, may need to purchase carbon credits and allowances for compliance, and due to the increased complexity of the policy interactions.

Non-financial benefits are largely dominated by climate impacts. Benefits from reducing CO_2 are reflected in the effectiveness criterion, above. Benefits from reducing aviation non-CO_2 climate impacts are greater for options with greater airline costs and hence lower demand, i.e. are greatest in Option 1.

Consistency refers to the extent to which each option contributes to, or potentially conflicts with, the EU's other policy objectives. As discussed in Section 2.2, wider EU climate-related objectives include obligations under the Paris Agreement to pursue 'efforts to limit the temperature increase to 1.5°C above pre-industrial levels', implying global net zero CO_2-levels by 2050; the EU's current NDC target of reducing economy-wide GHG emissions by at least 40% by 2030 compared to year-1990 levels; and the European Green Deal target of 50-55% GHG emission reductions by 2030 compared to year-1990 levels. Consistency with these objectives aligns directly with the 'Effectiveness' criterion discussed above and so the assessment here looks at consistency with other policies only.

The EU's objectives under REDII include 14% of energy consumed by road and rail transport coming from renewable sources by 2030, including 3.5% coming from advanced biofuels. Aviation can opt in to help meet these targets, but this is not obligatory. All other things being equal, policy options associated with higher carbon costs and/or more generous biofuel exemptions will incentivise biofuel use in aviation more and potentially allow for greater aviation opt-in and hence more progress to this goal.

Non-climate related objectives include the Better Regulation agenda, which seeks to ensure open, transparent decision-making with regulatory burdens on businesses, citizens and public administrations kept to a minimum[580]. From this perspective, policy options with limited administrative complexity are preferable. In particular, Option 5 is relatively complex, as both the EU ETS and CORSIA may apply to different components of the emissions from the same flight. Similarly, as discussed in Section 2.3.2.2, ICAO's decision-making with regard to CORSIA is relatively opaque, so options relying more heavily on CORSIA (e.g. Option 3) risk subjecting EU stakeholders to regulations with less transparent decision-making processes.

3.2.2 Coverage by Policy

To aid in visualising the scope of each policy option, Figure 22 shows global flight segments in 2024 by policy eligibility for each of the main policy options, in the 'currently assumed' CORSIA participation case. Traffic and emissions shares between route groups covered by

[580] EC, 2019. Better regulation: why and how. https://ec.europa.eu/info/law/law-making-process/planning-and-proposing-law/better-regulation-why-and-how_en.

the different policies are discussed in Sections 3.2.3-3.2.6. Note that, by 2024, the UK is assumed to be a CORSIA participant but not an EU ETS participant.

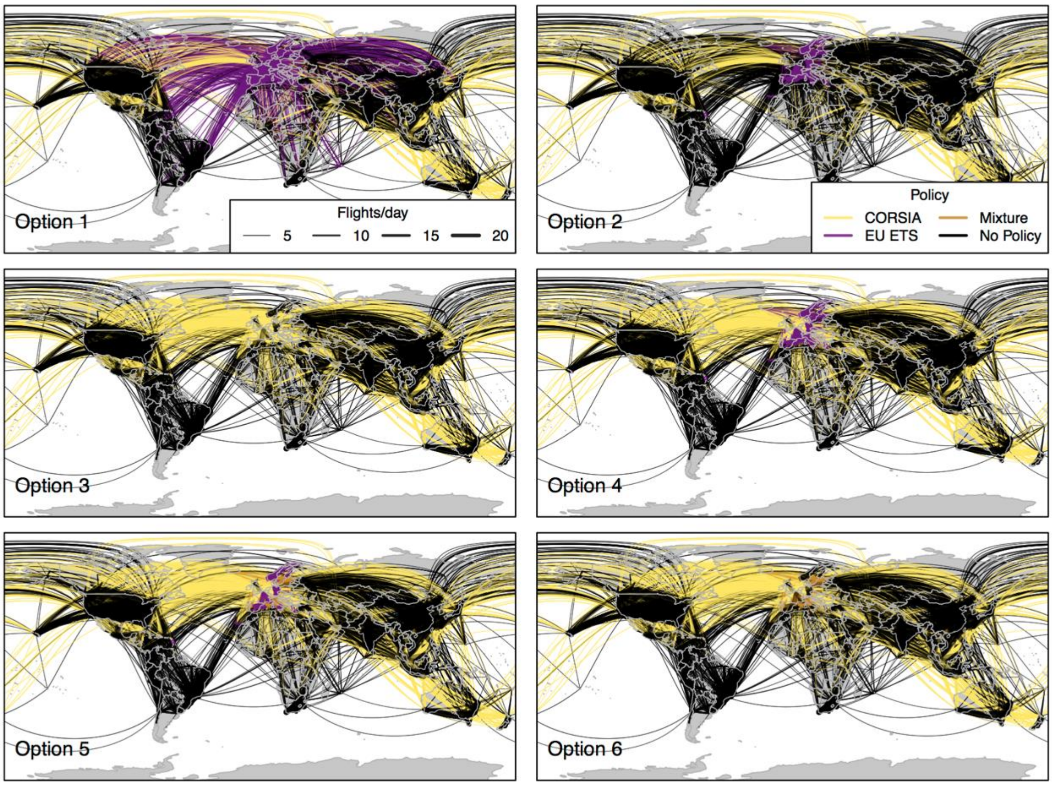

Figure 22. Global flight segments by policy eligibility, 2024, in the 'currently assumed' CORSIA participation case.

On a global basis, the main difference between the different policy options is the treatment of flights to and from the EU/EFTA region, which may be subject to no carbon price (Option 2), a CORSIA-appropriate carbon price (Options 3-6) or an EU ETS-appropriate carbon price (Option 1). As fuel is a larger proportion of operating costs for longer-haul flights, flights to and from the EU/EFTA region are likely to be relatively more impacted by higher carbon prices than those within the region.

Figure 23 shows the corresponding policy eligibility of European flight segments, also in the 'currently assumed' CORSIA participation case. Within Europe, the policy options differ in various aspects, for example whether or not domestic flights are covered; whether or not flights to and from OMRs are covered; whether non-EEA carriers are covered; and whether flights are subject to EU ETS-appropriate carbon prices, CORSIA-appropriate carbon prices, or a mixture of the two.

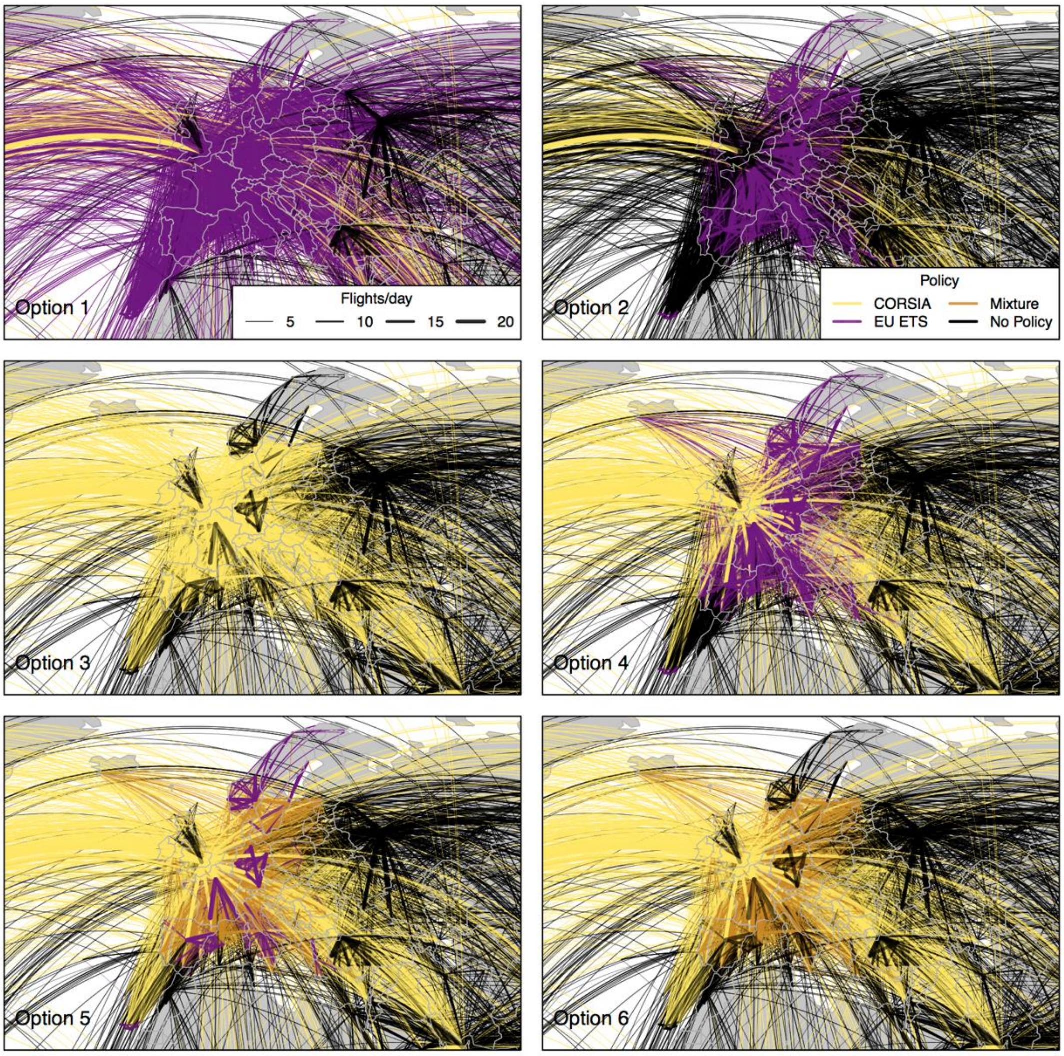

Figure 23. European flight segments by policy eligibility, 2024, in the 'currently assumed' CORSIA participation case.

3.2.3 CORSIA coverage

As discussed in Section 2.3.1, there is a wide variety of estimates for CORSIA's coverage of global international CO_2 emissions. As well as omitting CO_2 from domestic flights (31% of global RTK in 2018; ICAO, 2019[581]), CORSIA only covers emissions from international flights when both origin and destination countries are CORSIA participants. This means that removing a country from CORSIA scope removes both flights to and from that country, so overall coverage decreases rapidly as the number of participating countries decreases. The participation scenarios defined in Section 2.3.1 assess the likelihood of non-EU/EFTA countries participating in CORSIA. Policy options 1-6 (as defined in Section 3.1.2.1) differ as to whether flights to, from and between EU/EFTA countries are covered by CORSIA, the EU ETS or neither policy. Global CORSIA coverage is therefore a function of both the CORSIA participation scenario and the policy option considered. For example, if CORSIA participation follows the Low scenario and flights to and from the EU/EFTA countries are also not included (as in Policy Options 1 and 2) then CORSIA's coverage would not include

[581] ICAO, 2018. Presentation of 2018 Air Transport Statistical Results. https://www.icao.int/annual-report-2018/Pages/the-world-of-air-transport-in-2018-statistical-results.aspx

flights to or from the United States, China, India, the EU/EFTA, Russia or Brazil, leaving less than 20% of global international aviation CO_2 under CORSIA scope.

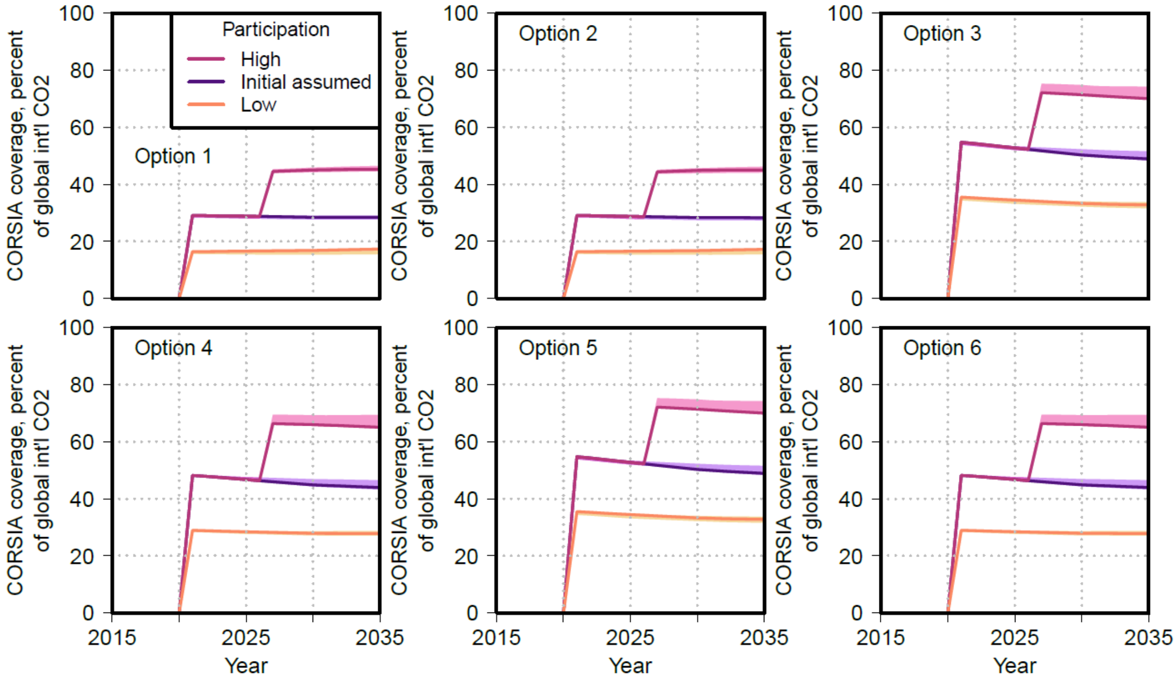

Figure 24. CORSIA coverage of international CO_2 emissions over time, for High, Initial Assumed and Low participation scenarios with all other input values at nominal values (central lines), and background shaded ranges across other values for uncertain variables.

Figure 24 shows CORSIA coverage of international aviation CO_2 to 2035 by policy option and High/Initial Assumed/Low participation scenario. Lines show outcomes with all other scenario input variables set to nominal values. Values for 2025, 2030 and 2035 are also given in Table 18. Small variations between options with similar geographical remits are typically due to demand effects. For example, CORSIA coverage is slightly lower under Policy Option 1 than Policy Option 2, all other input variables being equal, because CO_2 on flights to and from EU/EFTA countries is higher in Option 2, and these flights are outside CORSIA scope under both options. The higher amount of CO_2 emissions from these flights is due to slightly higher demand arising from lower carbon costs). The background shaded ranges show the (smaller) level of variation in CORSIA coverage for each combination of policy option and participation scenario which arises from variation in the other uncertain variables considered (demand growth, oil price, carbon price and technology assumptions). These variations typically relate to the balance of demand growth between different route groups. For example, growth on routes to and from the EEA is relatively higher in the high demand growth scenario, which leads to higher CORSIA coverage in the case that CORSIA applies to those routes (Options 3-6). However, in general, uncertainty in other variables has a much smaller impact on outcomes than CORSIA participation and CORSIA/ETS policy option. Similarly, other factors which act as a proxy for participation (for example, differences in the level of CORSIA enforcement by country) will likely have a larger impact than factors such as oil and carbon prices.

Table 18. CORSIA percentage coverage of international aviation CO_2 emissions in 2025, 2030 and 2035, by participation scenario, with all other input variables set to nominal values. The range of coverage due to variation in other uncertain variables is given in brackets.

Policy option	CORSIA coverage of global international CO_2, Low Participation, %			CORSIA coverage of global international CO_2, Initial Assumed Participation, %			CORSIA coverage of global international CO_2, High Participation, %		
	2025	2030	2035	2025	2030	2035	2025	2030	2035
Option 1	16.6 (15.5-16.6)	16.8 (15.4-16.9)	17.3 (15.5-17.7)	28.9 (28.0-29.1)	28.4 (27.7-29.0)	28.4 (27.6-29.0)	28.9 (28.0-29.1)	45.0 (44.2-45.9)	45.2 (44.6-46.5)
Option 2	16.6 (15.4-16.6)	16.8 (15.4-16.8)	17.2 (15.5-17.4)	28.8 (27.9-29.0)	28.4 (27.4-28.7)	28.3 (27.4-28.7)	28.8 (27.9-29.0)	44.9 (43.9-45.6)	45.0 (44.1-46.2)
Option 3	34.5 (33.2-34.7)	33.3 (32.2-34.0)	32.8 (31.6-33.7)	52.8 (52.0-53.3)	50.3 (49.9-52.3)	48.9 (48.3-51.6)	52.8 (52.0-53.3)	71.4 (71.1-74.8)	70.0 (69.6-74.2)
Option 4	28.4 (27.7-28.6)	27.9 (27.1-28.6)	27.8 (27.1-28.7)	46.7 (46.4-47.6)	44.9 (44.3-46.9)	43.9 (43.2-46.5)	46.7 (46.4-47.6)	66.0 (65.5-69.3)	65.0 (64.6-69.3)
Option 5	34.5 (33.1-34.7)	33.3 (32.2-34.0)	32.8 (31.6-33.7)	52.7 (52.0-53.3)	50.2 (49.9-52.2)	48.9 (48.3-51.5)	52.7 (52.0-53.3)	71.4 (71.1-74.8)	70.0 (69.6-74.2)
Option 6	28.4 (27.7-28.7)	27.9 (27.2-28.6)	27.8 (27.1-28.7)	46.7 (46.4-47.6)	44.9 (44.3-46.9)	43.9 (43.3-46.5)	46.7 (46.4-47.6)	66.0 (66.5-69.2)	65.0 (64.6-69.3)

It should be noted that the values in Table 18 include all emissions under CORSIA remit, including emissions under the CORSIA baseline which are not offset, and biofuel-related direct CO_2 emissions which are exempt. For option 5, they also include international intra-EEA emissions under the CORSIA baseline which are also covered by the EU ETS. Similarly, these values omit CO_2 from domestic flights. The proportion of global aviation CO_2 which is offset under CORSIA is therefore significantly below the proportion of international flights covered, as given here.

3.2.4 EU ETS Coverage

Table 19 shows direct CO_2 emissions under the scope of the EU ETS by each policy option, at nominal values for uncertain input variables (numbers in larger font) and giving the range across all scenarios for uncertain variables (smaller numbers in brackets). For comparison, as discussed in Section 3.1.2.2, the estimated pre-LRF cap values for each policy option are 162.6 Mt for Option 1 (full scope plus Switzerland, minus the UK), 28.4 Mt for Options 2, 4 and 5 (reduced scope plus Switzerland, minus UK) and 21.2 Mt for Option 6 (reduced scope plus Switzerland, minus UK, minus domestic). Under nominal scenario conditions, intra-EU/EFTA RPK grows by a factor of 1.7 over year-2015 levels to 2035 - high enough that direct aviation CO_2 emissions under ETS scope continues to increase, but improvements in technology are sufficient to make that increase relatively slow (typically under a 10% increase in CO_2 between 2025 and 2035). CO_2 emissions remain above the initial cap value before 2.2%/year reduction in all policy options. In Option 5, emissions on intra-EU/EFTA flights are within the scope of the EU ETS up to the CORSIA baseline. This sets an upper limit on emissions under EU ETS scope as demand growth above the CORSIA baseline is covered by CORSIA only. In this case, the only change in ETS-scope CO_2 emissions come from routes where operators are able to reduce their emissions below the CORSIA baseline. As some slow-growing routes are able to do this, CO_2 emissions covered by the EU ETS in Option 5 drops slightly over time.

Table 19. Modelled direct CO_2 on ETS-covered routes, by policy option at nominal values for uncertain input variables (larger text) and range in values due to variation in uncertain input variables (values in brackets), 2015, 2025, 2030 and 2035.

Policy option	Direct CO_2 emissions under the EU ETS scope, Mt, for nominal scenario inputs and uncertainty range			
	2015	2025	2030	2035
Option 1	55	229 (205-269)	245 (212-322)	255 (217-379)
Option 2	55	44 (36-47)	46 (36-54)	46 (34-59)
Option 3	55	0 (0-0)	0 (0-0)	0 (0-0)
Option 4	55	44 (36-47)	46 (36-54)	46 (34-59)
Option 5	55	44 (36-45)	43 (36-45)	43 (34-44)
Option 6	55	36 (29-38)	38 (29-43)	38 (28-47)

At the upper end of the uncertainty range, growth in demand is comparable to industry projections and intra EU/EFTA RPK doubles between 2015 and 2035. In this case, direct CO_2 under the EU ETS scope grows substantially (25-40% between 2025 and 2035 depending on policy, apart from for Option 5). This in turn means that aviation purchases more allowances from other sectors to compensate for the growth in emissions. Because of the substantial tightening of the EU ETS aviation cap over time, none of the combinations of scenario variables result in aviation emissions being under the cap value. For the combination of low demand growth (intra-EU/EFTA demand growing between 2015-2035 by a factor of 1.3), optimistic technology assumptions and high oil and carbon prices, intra-EU/EFTA direct aviation CO_2 declines over time to approximately 35 Mt in 2035. However, this is still over both the year-2035 and pre-LRF caps for aviation on this scope. As all emissions above the cap require the purchase of EUAs from other sectors, if those EUAs are assumed to be completely additional, this means that EU/EFTA net aviation emissions are the same under all combinations of uncertain scenario variables once reductions in other sectors due to aviation-purchased allowances are accounted for.

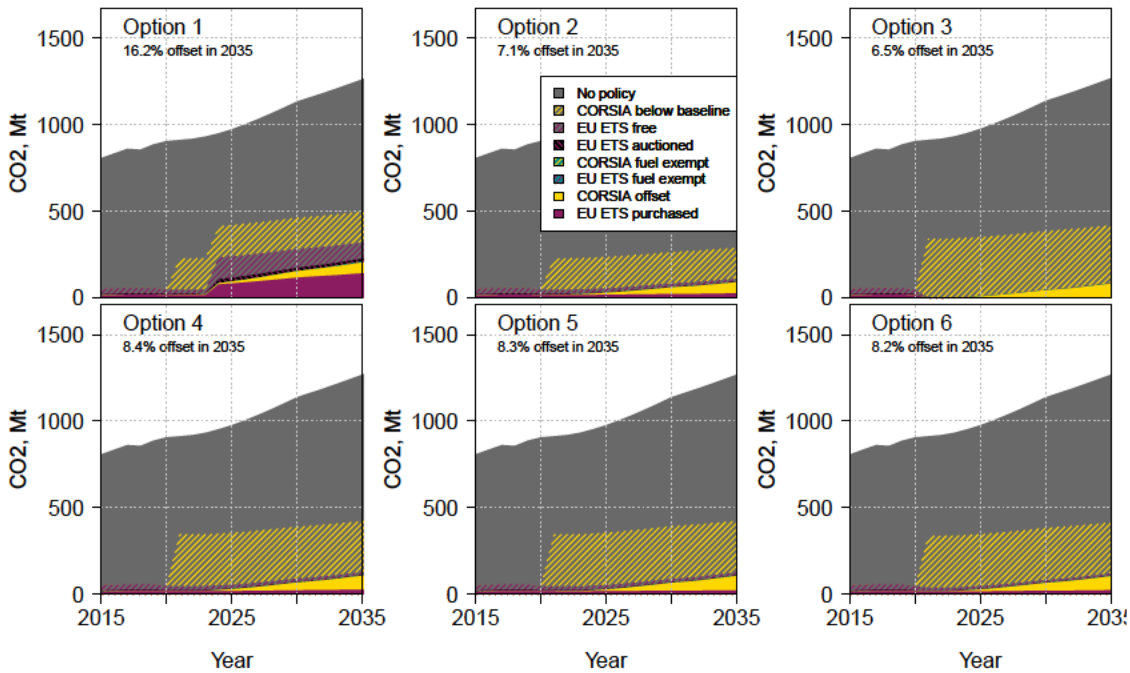

Figure 25. Global aviation CO_2 emission developments to 2035, by type of policy coverage (EU ETS, CORSIA, offset/non-offset, exempt) for all scenario variables at nominal values and Initial Assumed CORSIA participation.

Figure 25 shows the overall amount of global direct CO_2 under the different policy cases and nominal scenario conditions including Initial Assumed participation, including the percentage of global CO_2 subject to either CORSIA offsets or ETS purchase of allowances from other sectors by 2035. Tables of total and offset CO_2 for the EU ETS and CORSIA with uncertainty ranges are also given in Annex 4. Direct CO_2 which is exempt from either the EU ETS or CORSIA because alternative fuels were used (so it is partially offset by negative emissions from fuel production) is included as a separate category. However, alternative fuel use under nominal scenario conditions is small (typically under 5%) to 2035 as carbon prices are not large enough to compensate for greater production costs. If CORSIA offsets are assumed fully additional, the sum of CORSIA offsets and EUA purchases from other sectors represents the total amount of global aviation CO_2 which is offset by reductions in CO_2 in other sectors funded by aviation. In Figure 25, this varies between 16.2% of global direct CO_2 (Option 1) to 6.5% of global CO_2. Note that the totals in Figure 25 include domestic CO_2 as well, i.e. CORSIA percentages do not correspond directly to the international-only totals in Figure 22.

These values are strongly dependent on assumptions about demand growth, CORSIA participation and the extent to which technology can reduce emissions. To illustrate this, we also show CO_2 by policy and offset category in three further cases: nominal scenario conditions and high participation (Figure 26); nominal scenario conditions and low participation (Figure 27), and scenario conditions associated with high emissions growth and high participation (Figure 28). These different assumptions strongly change both the amount of CO_2 offset in 2035, and the balance between CORSIA offsets and the EU ETS allowances purchased from other sectors. If CORSIA participation is high, coverage after the start of the CORSIA mandatory phase in 2027 increases substantially, including fast-growing route groups involving particularly China and India. By 2035, CORSIA offset CO_2 is just under twice as much in the High participation case as in the Initial Assumed participation case, all other things being equal. If participation instead follows the Low scenario, CORSIA may only offset 5% of global aviation CO_2 by 2035 under nominal scenario conditions.

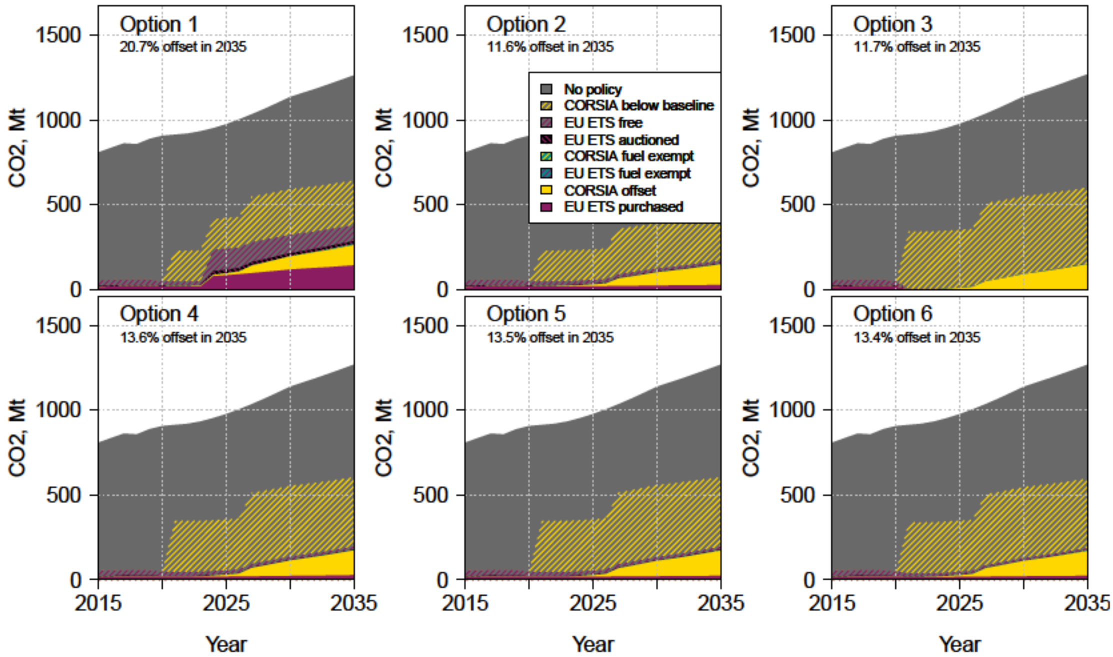

Figure 26. Global aviation CO_2 emission developments to 2035, by type of policy coverage (EU ETS, CORSIA, offset/non-offset, exempt) for all scenario variables at nominal values and High CORSIA participation.

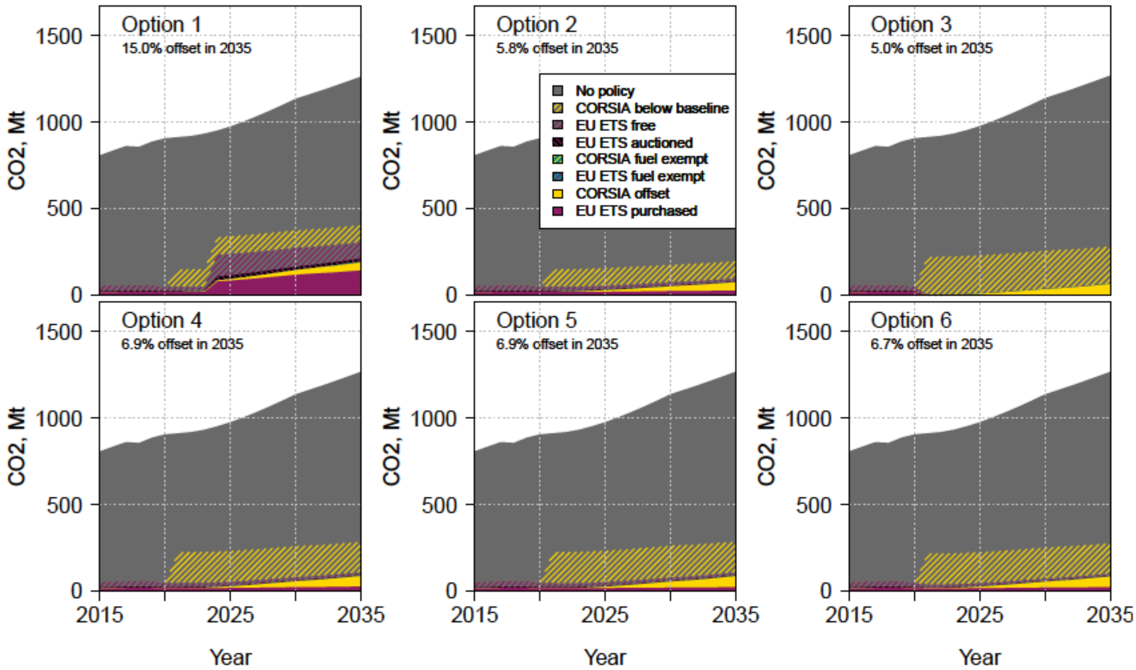

Figure 27. Global aviation CO_2 emission developments to 2035, by type of policy coverage (EU ETS, CORSIA, offset/non-offset, exempt) for all scenario variables at nominal values and Low CORSIA participation.

As well as participation scenario, outcomes are sensitive to assumptions about demand growth rates. This affects comparisons with other projections of CORSIA and EU ETS coverage over time, which typically assume demand growth compatible with ICAO/Airbus/Boeing projections which are higher than the nominal case used here. Figure

28 shows coverage in the case that scenario variables are set values which are likely to result in higher emissions, in particular demand growth rates compatible with Airbus/Boeing projections, and High participation. This represents a plausible upper limit for coverage. In this case, between 17 and 32% of global aviation CO_2 is offset by 2035. Across the full range of values for uncertain variables, emissions either offset through CORSIA or covered by EUAs purchased from other sectors account for between 1.4% (at Low Participation, Low Demand Growth, Optimistic technology assumptions, High oil price, carbon price Scenario 2 and policy option 3) and 32% (at High Participation, High Demand Growth, Pessimistic technology assumptions, Low oil price, carbon price Scenario 1 and policy option 1) of total global aviation CO_2. This large range is due to the sensitivity of offset and EUA demand to growth rates in CO_2, assumed participation and policy option, as discussed further below.

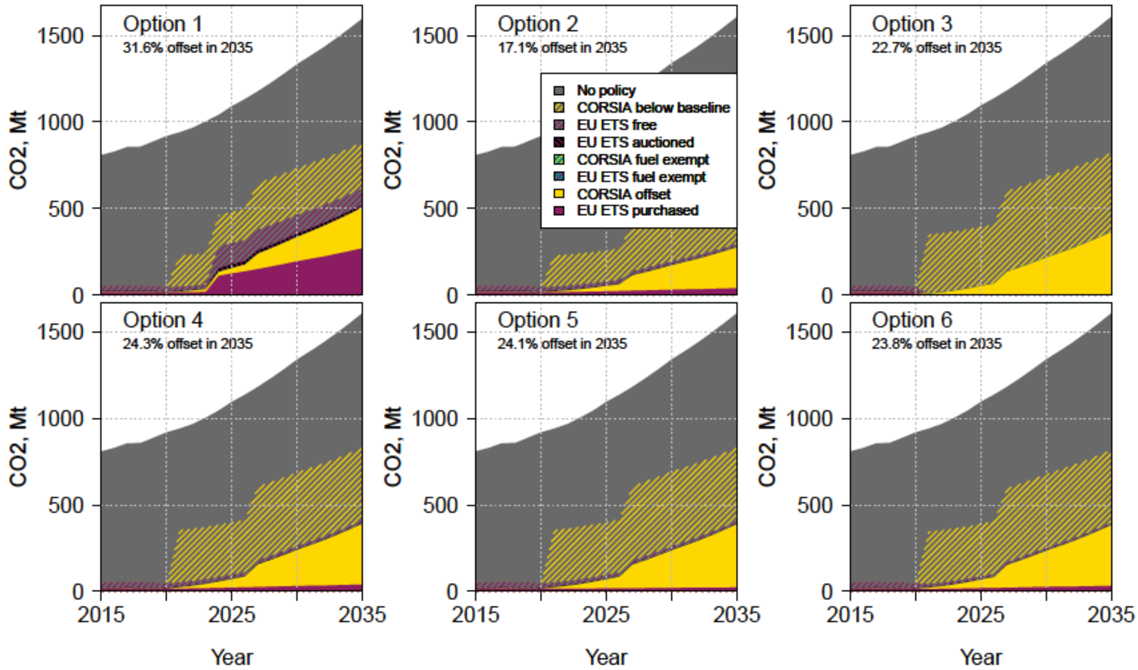

Figure 28. Global aviation CO_2 emission developments to 2035, by type of policy coverage (EU ETS, CORSIA, offset/non-offset, exempt) for scenario values likely to result in high emissions (high demand growth, low oil price, pessimistic technology assumptions) and High CORSIA participation.

These values can be compared with those from Maertens et al. (2019)[582]. Their projections assume similar participation to our High Participation scenario, ICAO growth rates (similar to our High demand growth scenario) and a 1.2%/year increase in fuel efficiency (between our Central and Pessimistic scenarios for technology development). These result in broadly similar year-2035 offset coverage for the policy options they examine which are similar to those examined here. For example, they estimate 20% coverage for CORSIA only by 2035 (compared to 22.7% here) and 23.1% coverage for EU ETS on intra-EEA flights and CORSIA elsewhere (compared to 24.3 % here). The remaining differences between coverage are likely due to their technology scenario having greater yearly improvement in fuel efficiency than the Pessimistic scenario shown in Figure 28.

[582] Maertens, S., Grimme, W., Scheelhaase, J. & Jung, M., 2019. Options to Continue the EU ETS for Aviation in a CORSIA-World. Sustainability, 11, 5703-5722.

3.2.5 Demand for CORSIA Offsets

The demand for CORSIA offsets depends on the extent of CORSIA's route-level coverage, the CORSIA emissions baseline[583], the change in (RTK) demand from baseline levels on those routes, the extent to which direct CO_2 per RTK can be reduced over time, and the amount of alternative fuels in use. Additionally, CORSIA's anticipated move from collective responsibility (each airline offsets an amount of CO_2 corresponding to growth beyond the baseline of the aviation sector as a whole) to individual responsibility (each airline offsets an amount of CO_2 corresponding to growth beyond the baseline of its own emissions) from year 2030 effectively slightly tightens the CORSIA effective cap and slightly increases demand for offsets. This is because operators cannot have a negative offsetting requirement for a compliance period under CORSIA (e.g. ICAO, 2018)[584]. When offsetting requirements are calculated on the basis of whole-sector growth in CO_2 emissions, an airline that manages to reduce its emissions below the baseline contributes towards a slightly smaller offsetting requirement for all airlines. When offsetting requirements are calculated based on individual operator CO_2 emissions growth, an airline which manages to reduce its emissions below the baseline does not need to purchase offsets, but also has no impact on the offsetting requirements for other airlines.

Global offset requirements by CORSIA phase, policy and participation scenario are given in Table 20, and depicted in Figure 29. These estimates do not include the impact of the COVID-19 pandemic and any resulting adjustments to the baseline; a discussion of this is included in Section 3.1.2.10. A few general features are notable. First, because offsets only apply to emissions above the CORSIA baseline, the amount of offsets required is particularly sensitive to emissions growth rates. This means that offset totals vary strongly in response to changes in assumptions about demand growth rates and the capabilities of new technologies. This can be seen by looking at the upper end of the uncertainty range due to variations in uncertain input variables (values in brackets in Table 20; also shown as dashed lines in Figure 29). The upper end of the range for CORSIA offset demand corresponds to input scenario variables set to values that are likely to result in high emissions totals: high demand growth, pessimistic technology assumptions, low oil prices etc. These scenario conditions result in offset requirements which are roughly twice those seen under nominal scenario conditions. This sensitivity also means that offsetting requirements are not necessarily lower in a lower-participation case (at least initially, prior to the introduction of individual airline offsetting requirements). If increasing participation adds in routes where emissions reductions below the baseline can be achieved, for example due to slow-growing demand in combination with the availability of lower-emission aircraft models, offsetting requirements may be initially lower at higher participation.

[583] Due to severe year-2020 COVID-19-related aviation system disruption, the actual CORSIA baseline is uncertain and the methodology used to generate the baseline may be subject to change. At the time of writing this situation was still developing.

[584] ICAO, 2018. Frequently asked questions on CORSIA. https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_FAQs_October%202019_final.pdf (Question 2.20 "If, as a result of the calculation described in questions 2.15 and 2.19, an aeroplane operator's total final offsetting requirements during a compliance period are negative (e.g., the verified emissions reductions claimed by an operator from the use of CORSIA Eligible Fuels are more than its offsetting requirements), the operator has no offsetting requirements for the compliance period. Negative offsetting requirements will not be carried forward to a subsequent three-year compliance period. However, if an operator's offsetting requirements in a given year within a compliance period are negative, the operator reduces its total final offsetting requirement for the three-year compliance period.")

How do these totals compare to other projections? ICAO (2019)[585] projects demand for offsets of 142-174 $MtCO_2$ in 2025, rising to 288-376 $MtCO_2$ in 2030 and 443-596 $MtCO_2$ in 2035, 'to achieve carbon-neutral growth from international aviation'. The low end of these projections are based on a 1.37% improvement in fuel efficiency per year (below IATA goals of 1.5%/year) and 4.3% per year RPK growth, i.e. a broadly similar set of assumptions to the high demand scenario used here with mid-range to pessimistic technology assumptions (therefore close to the upper end of the uncertainty range in Table 20). The offset needs calculated by ICAO are on the basis of all international aviation with no exemptions, i.e. a higher participation scenario than the High participation scenario used here. These projections are therefore well above the projections of offset demand used here, which consider exemptions and non-participation by individual States. If we consider all international aviation in the 'High emissions growth' case, offset demand in 2025, 2030 and 2035 would be 118, 290 and 486 $MtCO_2$ respectively, closely following the ICAO projections[586]. However, because of the sensitivity of offset requirements to emissions growth, offsetting requirements at nominal values of demand growth and the development of technology characteristics are significantly lower. Participation below 100% of international aviation similarly reduces the offset requirement further. If instead demand growth follows the low trajectory identified in our survey of uncertain variables, and technology development follows the optimistic trajectory, then pilot phase CORSIA offset requirements may be close to zero and total second phase offset requirements may be below 100 $MtCO_2$. This corresponds to the lower end of the uncertainty range in Table 20[587].

Table 20. Demand for CORSIA offsets in the pilot, first and second phases (total demand for full period shown), under nominal scenario assumptions (numbers in larger font) and range due to variations in uncertain input variables (numbers in brackets)

Policy option	CORSIA offset demand at Low Participation, million			CORSIA offset demand at Initial Assumed Participation, million			CORSIA offset demand at High Participation, million		
	Pilot	First	Second	Pilot	First	Second	Pilot	First	Second
Nominal scenario assumptions (uncertainty range)									
Option 1	6.6 (0.0-18)	26 (0.7-68)	278 (27-507)	6.5 (0.0-27)	32 (0.7-105)	371 (36-790)	6.5 (0.0-27)	32 (0.7-105)	751 (166-1430)
Option 2	6.6	26	279 (27-508)	6.5	33	373 (37-790)	6.5	33	755

585 ICAO, 2019. ICAO 2019 Environmental Report. https://www.icao.int/environmental-protection/Documents/ICAO-ENV-Report2019-F1-WEB%20(1).pdf; ICAO, 2019. What would be the impact of joining CORSIA? https://www.icao.int/environmental-protection/Pages/A39_CORSIA_FAQ3.aspx

586 The reason for slightly lower offsetting requirements in 2025 than the ICAO scenario range is likely our assumptions about new generation aircraft (e.g. the A320neo, A350 and 777-X) entering the fleet during this time period, which result in a greater initial rate of emissions reduction than assuming a constant fleet-level rate of change in CO_2/RPK; see Section 3.1.2.6.

587 The COVID-19 pandemic strongly increases the likelihood that pilot phase offset requirements will be zero. For example, if the CORSIA baseline is set using year-2019 emissions, IATA's current demand projections (https://www.iata.org/en/iata-repository/publications/economic-reports/covid-19-outlook-for-air-travel-in-the-next-5-years/) are consistent with a close-to-zero offset requirement.

	(0.0-18)	(0.7-69)		(0.0-27)	(0.7-106)		(0.0-27)	(0.7-106)	(167-1430)
Option 3	2.2 (0.0-33)	25 (0.9-124)	360 (39-929)	1.2 (0.0-48)	29 (0.8-182)	463 (51-1370)	1.2 (0.0-48)	29 (0.8-182)	899 (146-2210)
Option 4	4.3 (0.0-30)	28 (0.7-113)	352 (38-844)	2.6 (0.0-45)	31 (0.7-171)	454 (49-1280)	2.6 (0.0-45)	31 (0.7-171)	892 (174-2120)
Option 5	1.6 (0.0-32)	24 (0.9-123)	358 (39-927)	1.1 (0.0-47)	28 (0.8-181)	460 (51-1360)	1.1 (0.0-47)	28 (0.8-181)	896 (145-2210)
Option 6	4.3 (0.0-30)	28 (0.7-113)	352 (38-844)	2.6 (0.0-45)	31 (0.7-171)	454 (49-1280)	2.6 (0.0-45)	31 (0.7-171)	892 (173-2130)

Similarly, Healy (2017)[588] projects total offset demand between 2021 and 2035 of between 1637 and 2732 Mt. These projections are based on the assumption that China participates in CORSIA from 2021. Total offset requirements are close to those in our high emissions growth case, but for nominal scenario assumptions we find offset requirements below the low end of this range.

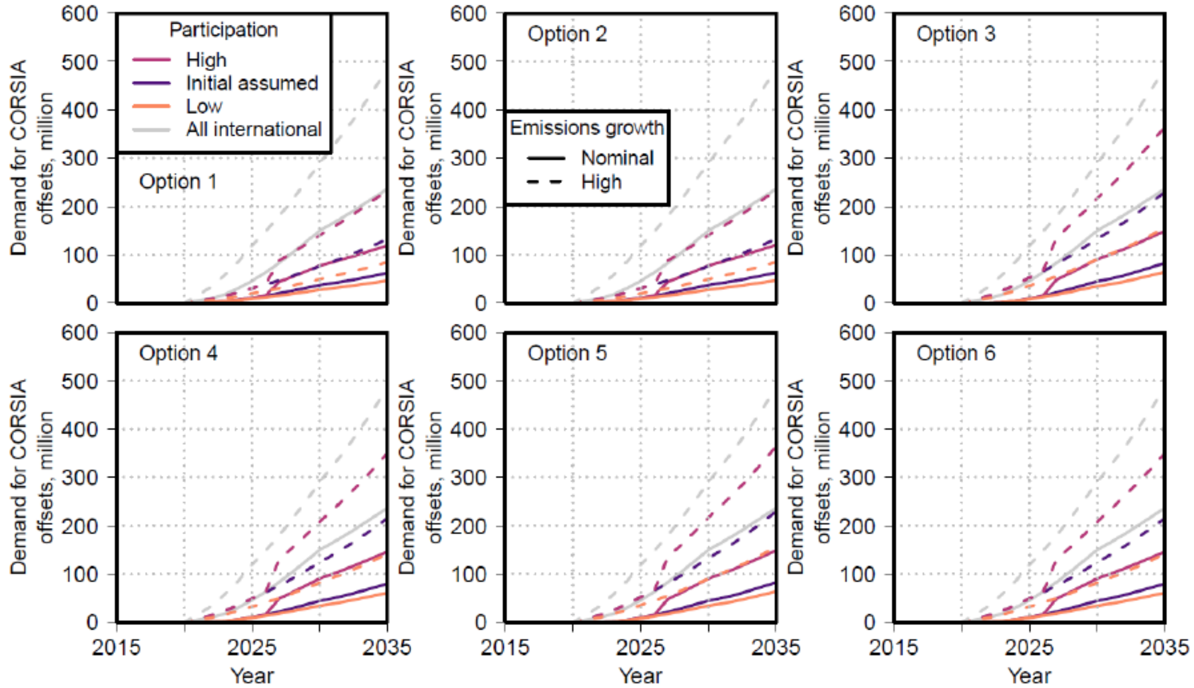

Figure 29. Demand for CORSIA credits by year, policy option and CORSIA participation scenario, for other scenario variables at nominal values (solid lines) and at values at the upper end of the uncertainty range for global CO_2 emissions (dashed lines). One credit is equivalent to one tonne of CO_2.

In conclusion:

- Demand for CORSIA offset credits is uncertain. Under nominal scenario conditions, we project annual offset demand in 2035 of around 370 Mt (in the case that flights to and from EU/EFTA countries are excluded, i.e. policy options 1 and 2) or 450-460 Mt (for the other policy options). However, this number is particularly sensitive

588 Healy, S., 2017. CORSIA: Quantification of the Offset Demand. https://www.carbon-mechanisms.de/fileadmin/media/dokumente/sonstige_downloads/CTI_Workshop_2017/5_Healy_170623_CORSIA_CTI_Presentation.pdf

to assumptions about demand growth, participation and the ability of new technologies to mitigate emissions. Under different assumptions for these inputs, total second phase CORSIA offset demand varies between 30 and 2210 Mt.

- Because removing a state from participation in CORSIA removes all flights to and from that state, relatively small differences in participation can also have a large impact on offset demand. For example, removing the US from CORSIA participation (i.e. moving to the Low Participation Scenario from the Initial Assumed Participation Scenario) reduces total second phase offset demand by around 25% under nominal scenario conditions.
- Typically, literature assessments of offset demand assume high levels of demand growth, limited ability of new technology to mitigate emissions, and high participation. Because offset demand is highly sensitive to these three assumptions, literature assessments of offset demand are typically on the high end of the projections made here.
- The policy option chosen will also have a substantial impact on offset demand as this affects whether flights to, from and within the EU/EFTA region are subject to offsets or not. Under nominal scenario conditions, policy options 1 and 2 are associated with around 20% lower second phase CORSIA offset demand than the other policy options, because they exclude flights to and from EU/EFTA countries from CORSIA scope.

3.2.6 Demand for EU ETS allowances

EU ETS allowances used by aviation may be aviation allowances (EUAAs) or European allowances purchased form other sectors (EUAs). EUAAs cover aviation emissions below aviation's EU ETS cap. This includes both free aviation allowances allocated on the basis of benchmarking (currently 82% plus a 3% new entrants reserve), and allowances that airlines can purchase at auction (currently 15%). This section discusses the case in which the percentage of free and auctioned aviation allowances remains constant at current values to 2035. Section 3.2.13 discusses how these values change under different assumptions about changing auctioning percentages over time. From 2021 onwards, the total amount of EUAAs issued will decrease over time consistently with the LRF applied to all ETS sectors, and the ratio of free to auctioned allowances is a policy decision. Unless aviation emissions fall below the cap, which does not happen in even the low growth, high mitigation scenarios modelled here, the number of EUAAs issued is therefore predictable and does not vary between different scenarios for input variables. EUAs purchased from other sectors cover growth above the EU ETS aviation cap. As with demand for CORSIA offsets, this means that demand for allowances from other sectors is uncertain and varies strongly with assumptions about demand growth rates and technology developments. Whilst aircraft operators were allowed to use international credits to account for up to 1.5% of their verified emissions in Phase III (2013-2020) of the EU ETS, this share falls to zero from Phase IV, and so are omitted from the rest of this discussion. The yearly amount of EUAAs issued, adjusting for international allowances, over the 2016-2018 period was around 38.7 million (EC, 2019)[589], including around 32.3 million freely allocated allowances. EUA purchases by aviation in 2015 were around 19 million, growing to 28 million in 2018 (Eurocontrol, EASA and EEA, 2019; European Environment Agency, 2019)[590]. Compliance with the scheme has been estimated as around 98% in terms of total CO_2 (EC, 2019).

[589] EC, 2019. Report on the functioning of the European carbon market. https://ec.europa.eu/clima/sites/clima/files/ets/docs/com_2018_842_final_en.pdf

[590] Eurocontrol, EASA and EEA, 2019. European Aviation Environmental Report 2019. https://www.eurocontrol.int/publication/european-aviation-environmental-report-2019 .;

The revenues from each type of allowance affect different sectors. Revenue from auctioned EUAAs accrues to EU/EFTA member states[591]. Directive 2003/87/EC specifies the uses to which auctioning revenues should be put, including the intention to use at least 50% of auctioning revenue from EUAs on specific climate and energy activities, and all revenues generated from aviation allowances intended to be used to tackle climate change and to reduce emissions in the aviation sector. Member states report annually on the uses of auctioning revenues from aviation and other sectors. States differ on how auctioning revenue is dealt with in national budgets. In some states, the revenue is earmarked for specific uses; in others, it is pooled into the national budget and redistributed. Transport and Environment (2016)[592] estimate year-2015 EUAA auctioning revenue of €117 million for EU member states. However, this represents two years' worth of auction revenue (2013 and 2014) due to auctioning delays related to the change in EU ETS aviation scope.

Revenue from EUAs purchased from other sectors goes directly to operators in those sectors who have reduced their emissions. These revenues are likely to go in particular to sectors in which more cost-effective emissions mitigation is possible, for example electricity generation.

There is also the possibility that airlines as a whole will have revenue associated with freely allocated allowances, even though aviation emissions remain above the cap for all combinations of model input values. This circumstance would arise if airlines pass the opportunity costs associated with freely allocated allowances through to ticket prices. As discussed in Section 4, assumptions about cost pass-through vary widely. Some past analyses have assumed pass-through of opportunity costs, and we carry out a sensitivity analysis with regard to these assumptions in Annex 4.

Figure 30 shows modelled demand for auctioned EUAAs and EUAs purchased by aviation over time for all uncertain variables set to nominal values (solid lines) and the range of variation in these values due to variation in uncertain input variables (shaded areas)[593]. The impact of COVID-19 on demand in 2020 is not included as this situation was still developing at the time of writing. Step changes in 2020, 2021 and 2024 are related to changes in EU ETS scope and caps due to the addition or removal of particular route groups for each policy option (as discussed in Table 16). The historical data shown is from EEA (2019) and relates to the year of emissions, not the year when sales/auctions took place corresponding to those emissions. Note that Option 1 is plotted with different limits to the other options. Demand for allowances is also given in Table 21 and Table 22.

European Environment Agency, 2019. EU Emissions Trading System Data Viewer. https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1

591 EC, 2017. Analysis on the use of auction revenues by the member states. https://ec.europa.eu/clima/sites/clima/files/ets/auctioning/docs/auction_revenues_report_2017_en.pdf

592 Transport and Environment, 2016. Aviation ETS – Gaining Altitude. https://www.transportenvironment.org/sites/te/files/2016_09_Aviation_ETS_gaining_altitude.pdf

593 It should be noted that our estimates of EUA demand from aviation during the 2016-2018 period are underestimates; this is due to unusually high demand growth rates during this time period which did not follow historical relationships between GDP and population developments and propensity to fly (e.g. 'Demand for air transport continues to outstrip economic growth and defy geopolitical challenges'; RoutesOnline, 2018), in combination with the previously-discussed sensitivity of demand for EUAs with demand growth rates. As discussed by Airbus (2019), in Europe these short-term growth rates were largely driven by low-cost carriers developing new intra-European routes.

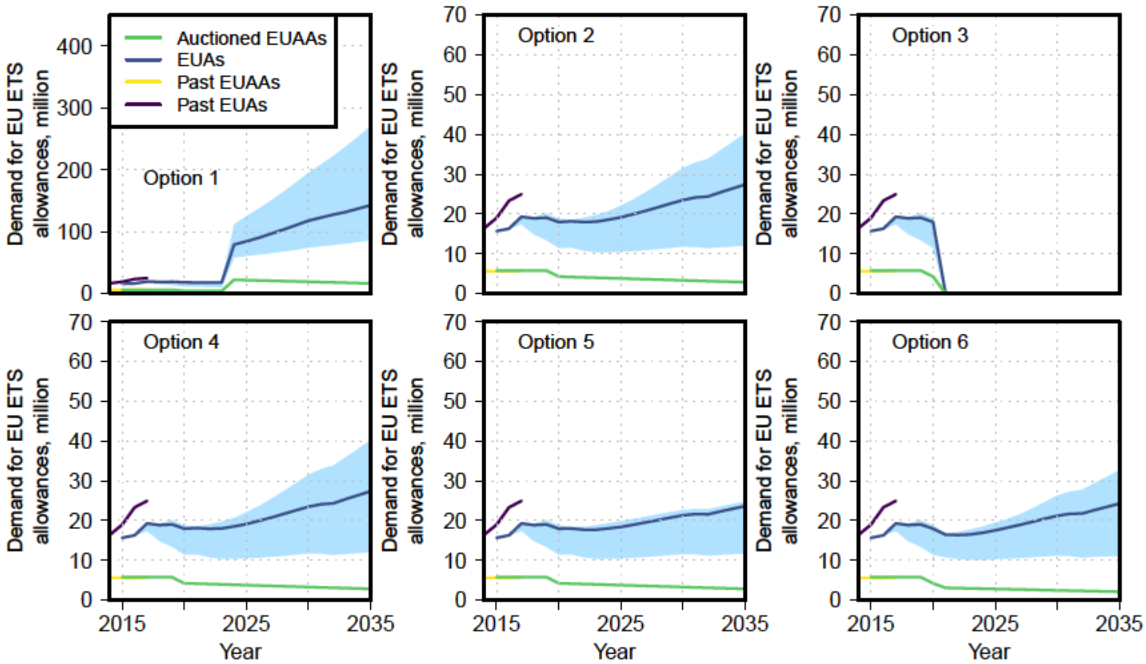

Figure 30. Demand for EUAAs and EUAs purchased by aviation by policy, for uncertain variables set at nominal values (solid lines), and range due to variation in uncertain input values (background shaded area). NB: A different scale has been used for option 1.

As noted above, aviation emissions do not fall below the EU ETS aviation cap under any combination of uncertain variables investigated. In fact, although total intra-EU/EFTA aviation CO_2 falls from current amounts under conditions of low demand growth and optimistic technology assumptions, it does not fall below the initial (pre-LRF) cap in any of the cases examined. This means that demand for auctioned EUAAs depends only on the aviation cap (which depends on the policy scope, cap adjustment methodology per scope, and LRF) and the proportion of EUAAs which are auctioned. In contrast, demand for allowances from other sectors varies substantially depending on both the policy option chosen and emissions growth rates. Several broad points are worth noting:

- Demand from airline operators for EUAs purchased from other sectors is substantially (up to a factor of 8) higher in Option 1 than in the other options. This is due to the much greater geographic scope, the inclusion of longer-haul routes with high growth rates and lower emissions mitigation potential, and the sensitivity of demand for EUAs to emissions growth rates.
- For Options 2, 4, 5 and 6, demand for EUAs does not rise substantially over current levels even under nominal values for uncertain input variables. This is primarily a function of scope change and built-in technological developments. The largest factors affecting the apparent slow rise in demand for EUAs are the removal of the UK from the EU ETS, and emissions reductions from the adoption of current new generation aircraft across the intra-EEA narrow body fleet (e.g. the A320neo), which are similar across all scenarios.
- For Option 5, only emissions up to the CORSIA year 2019-20 baseline are covered. This means that increases in EUA demand are driven only by (LRF) cap reduction as long as total CO_2 stays above the CORSIA baseline. This is why the nominal scenario is close to the upper end of the uncertainty range for EUA demand under this option (with small differences due to some airlines being able to reduce emissions below the CORSIA baseline, and different baseline values). At the low end of the uncertainty range for EUA demand, airlines are more widely able to reduce their emissions below the CORSIA baseline on intra-EU/EFTA routes, leading to an overall reduction in EUA demand over time.

- For Option 6, demand for EUAs is lower than in Options 2 and 4 primarily because domestic flights are excluded. This reduces coverage by roughly 20-28% and accounts for the vast majority of the difference in coverage. Second, intra-EEA flights by non-EU/EFTA carriers are excluded. As discussed in Section 3.2.10, relatively few intra-EU/EFTA flights are operated by non-EU/EFTA airlines. This exclusion reduces coverage by typically under 0.3%.

Figure 31 shows the development of auctioning revenue, and payments to other sectors for EUAs, for these scenarios by policy option over time. Past data shown is from Transport and Environment (2016)[594]; note that these values are affected by time delays between emissions occurring and allowances being purchased, as well as allowance allocation adjustments arising from the initial reduction from full scope (for example, airlines were allowed to surrender year-2013 allowances in 2015). As with Figure 30, note that Option 1 is plotted with different limits. Table 21 summarises projected EUAA demand and revenue by each of these scenarios and policy options, and Table 22 summarises the respective demand for EUAs from each option. Because EUAA demand is consistent between scenarios, uncertainty in auctioning revenues is a function only of uncertainty in carbon prices.

Table 21. Annual demand for auctioned EUAAs from aviation in the EU ETS, and projected revenues, in 2030 and 2035, by policy option at nominal values for uncertain input variables (numbers in larger font) and range due to variations in uncertain input variables (numbers in brackets)

Policy option	Estimated demand for EUAAs, million			Estimated EUAA auction revenue, million €2018		
	2015	2030	2035	2015	2030	2035
Option 1	5.8	19.0 (19.0-19.0)	16.4 (16.4-16.4)	36	575 (575-1534)	650 (650-1906)
Option 2	5.8	3.3 (3.3-3.3)	2.9 (2.9-2.9)	36	100 (100-267)	113 (113-332)
Option 3	5.8	0.0 (0-0)	0.0 (0-0)	36	0.0 (0-0)	0.0 (0-0)
Option 4	5.8	3.3 (3.3-3.3)	2.9 (2.9-2.9)	36	100 (100-267)	113 (113-232)
Option 5	5.8	3.3 (3.3-3.3)	2.9 (2.9-2.9)	36	100 (100-267)	113 (113-232)
Option 6	5.8	2.5 (2.5-2.5)	2.1 (2.1-2.1)	36	75 (75-200)	85 (85-248)

[594] This data is ultimately derived from data on aircraft operator EUA and EUAA purchases on different auction platforms (e.g. EEX, 2020, https://www.eex.com/en/; ICE Futures Europe, 2020, https://www.theice.com/futures-europe)

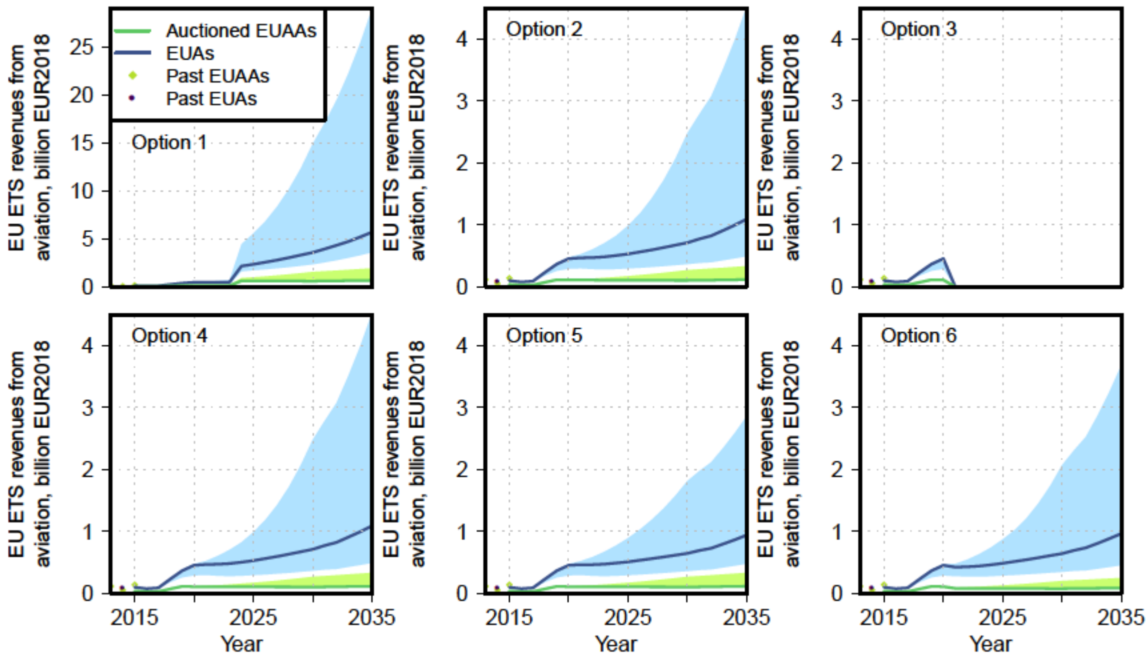

Figure 31. EU ETS auctioning revenue, and revenue to other sectors from aviation purchasing EUAs, by policy, for uncertain variables set at nominal values (solid lines), and range due to variations in uncertain input variables (shaded areas). NB: A different scale has been used for option 1.

Table 22. Annual demand for EUAs from stationary sectors from aviation in the EU ETS, and projected revenues, in 2030 and 2035, by policy option at nominal values for uncertain input variables (numbers in larger font) and range due to variations in uncertain input variables (numbers in brackets). Note that the low and high ends of the EUA demand range and the low and high end of the EUA costs range do not occur in the same model runs.

Policy option	Estimated demand for EUAs by aviation from stationary sectors, million			Estimated amount paid by airlines for EUAs from other sectors, million €2018		
	2015	2030	2035	2015	2030	2035
Option 1	16	118 (74-195)	143 (86-270)	98	3560 (2330-14900)	5680 (3580-28900)
Option 2	16	23 (12-32)	27 (12-40)	98	710 (364-2480)	1090 (492-4530)
Option 3	16	0 (0-0)	0 (0-0)	98	0 (0-0)	0 (0-0)
Option 4	16	23 (12-32)	27 (12-40)	98	710 (364-2480)	1090 (492-4530)
Option 5	16	21 (12-23)	24 (12-25)	98	645 (358-1820)	940 (479-2860)
Option 6	16	21 (11-26)	24 (11-33)	98	642 (346-2070)	966 (455-3690)

Projected revenues by scenario and policy option largely follow the same trends, for the same reasons, as the amounts of allowances previously discussed. The main differences are that allowance prices are assumed to rise over time, leading to corresponding rises in the amount of revenue and higher uncertainty. The upper end of the revenue range corresponds to the higher EUA price trend (IIb) discussed in Section 3.1.2.5. By 2035, this is over twice as high as in the nominal (Base) carbon price case. The full range of EUA payments to other sectors across all uncertain variables is given in Table 22. In general, high EUA payments to other sectors are associated with higher demand growth, lower oil prices, higher EUA prices, more pessimistic technology assumptions and wider policy scope. Low total EUA payments to other sectors arise from lower demand growth, higher oil prices, lower EUA prices, more optimistic technology assumptions and smaller policy scope. Both are largely unaffected by CORSIA participation. The scenarios with the highest demand for EUAs are not the same as those with the highest EUA-related costs, because high carbon price reduces EUA demand. As with demand for allowances, airline costs for purchase of EUAs are also strongly variable with assumptions about demand growth and technology capabilities, as well as assumptions about allowance prices.

3.2.7 Airline Costs

As discussed in the previous section, airline costs related to emissions above a given baseline (EU ETS costs related to CO_2 above the EU ETS aviation cap and CORSIA offset costs related to CO_2 above the CORSIA baseline) are highly uncertain and depend strongly on assumptions about demand growth and technology. Costs related to ETS auctioned allowances are more certain.

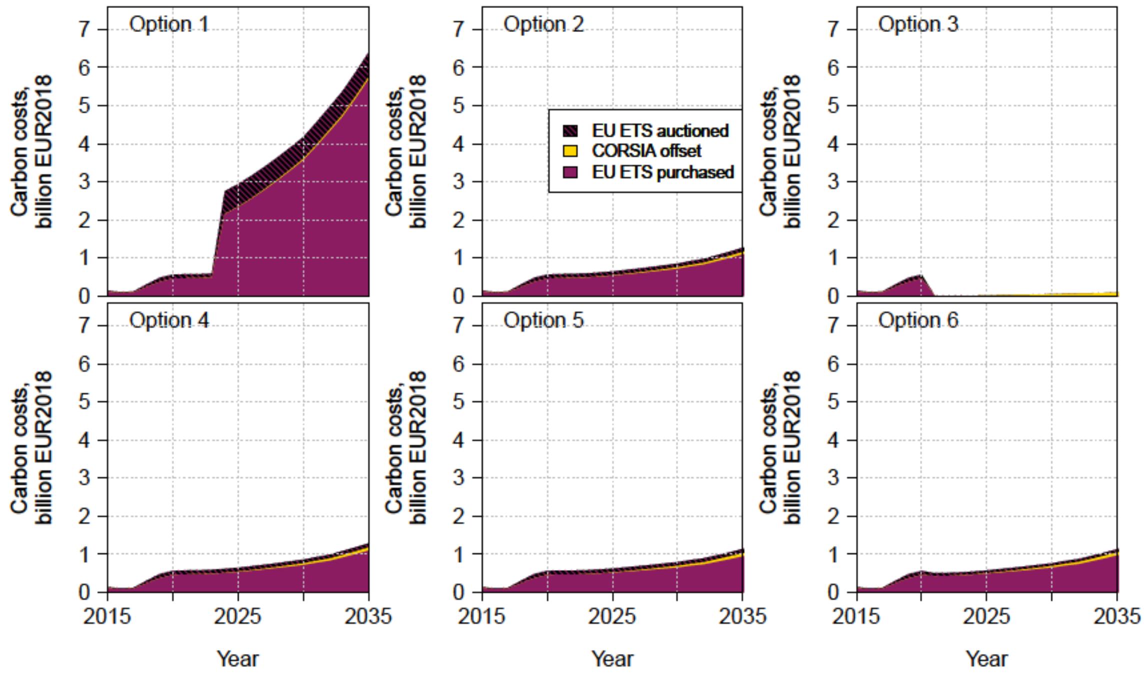

Figure 32. Total global airline carbon costs by policy option, cost type and year, under nominal scenario conditions.

Figure 32 shows the development of total global carbon costs over time under nominal scenario conditions, by policy option. By far the largest component of costs in this case is costs related to the purchase of EUAs from other sectors. This is because EUA prices are much higher than international credit prices.

Although carbon costs are uncertain, they are typically small compared to both other components of airline cost and uncertainties related to other components of airline cost.

EASA (2019)[595] estimate that allowance purchase costs were 0.3% of total intra-EEA airline operating costs in 2017. However, average allowance prices in 2017 were under €6, well below the projected year-2035 values used here of €40-120. Similarly, Transport and Environment (2016) estimate ETS costs per passenger for the reduced scope ETS to have been €0.26-0.76 over the 2013-2015 period. Total year-2015 aviation ETS carbon costs were estimated at €178.5 million[596], excluding international credit costs which will be significantly lower than this. In comparison, fuel costs are typically 20-30% of total airline operating costs and can vary by more than a factor of two between subsequent years. At current levels, carbon costs are generally negligible in comparison to fuel price uncertainty. The relative variation of fuel price with changes in oil and carbon price is shown in Figure 19.

It has been argued (e.g. Ernst & Young and York Aviation, 2007, 2008) that the impact of changes in carbon price on airlines will still be significant if the carbon cost per passenger is a significant fraction of airline profit margins, and airlines are unable to pass this cost on to ticket prices. The operating margin of an airline measures the percentage of airline revenue that remains once operating costs (including fuel, maintenance, crew, landing, enroute, capital and carbon costs) have been subtracted. This differs from an airline's net margin, which accounts for non-operating income and expenses (e.g. income tax) and is usually a smaller (sometimes negative) value. Airline operating margins differ by region, airline type and flight type, and are strongly affected by economic cycles[597]. According to ICAO (2019)[598] and IATA (2019)[599], global airline operating margins have been around 6-8% over the 2015-2018 time period, but were lower over the period following the financial crisis, with negative net result after accounting for non-operating costs in 2009. The *net* margin for global airlines in 2014 was 2.7%, or around $6 (€4.50) per passenger (Warnock-Smith et al., 2017[600]). Ernst & Young and York Aviation (2008)[601] assume an operating profit margin of 4% for network and cargo airlines, 14% for leading low fares airlines, and 2% for other low fares and leisure airlines. Jiang & Hansman (2004) find cyclical behaviour of airline profit margins following a roughly 10-year time period and affected by both exogenous events and endogenous system dynamics (for example, the time lag between ordering aircraft and receiving them). At the low points of this cycle, airlines as a whole typically make losses, as happened in 2009. At a typical intra-EEA ticket price of €150, a 7% operating margin is just over €10. If per-passenger intra-EEA carbon

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[595] EASA, 2019. The EU Emissions Trading System. https://www.easa.europa.eu/eaer/topics/market-based-measures/the-eu-emissions-trading-system

[596] Note that historically ETS costs have been affected by delays in auctioning following the change from full scope and the use of postponed allowances from Phase II, so the costs airlines experienced may not match directly to emissions for a given year.

[597] Jiang, H. & Hansman, R. J., 2004. An analysis of profit cycles in the airline industry. Proceedings of the 6th AIAA ATIO Conference, 25-27 September 2004, Wichita, Kansas. https://arc.aiaa.org/doi/abs/10.2514/6.2006-7732

[598] ICAO, 2019. Presentation of 2018 Air Transport Statistical Results. https://www.icao.int/annual-report-2018/Pages/the-world-of-air-transport-in-2018-statistical-results.aspx

[599] IATA, 2019. Strong Airline Profitability Continues in 2018. https://www.iata.org/en/pressroom/pr/2017-12-05-01/

[600] Warnock-Smith, D., O'Connell, J. & Maleki, M., 2017. An analysis of ongoing trends in airline ancillary revenues. Journal of Air Transport Management, 64(A), 42-54.

[601] Ernst & Young and York Aviation, 2008. Inclusion of Aviation in the EU ETS: Cases for Carbon Leakage. https://www.verifavia.com/bases/ressource_pdf/112/AN-EY-FULL-TEXT-OCT08.pdf.

costs approach this value, and airlines cannot pass those costs onto ticket prices, then airline profitability will decrease significantly.

Figure 33 shows fuel, non-fuel and carbon costs over time for flights between EU ETS-participating countries (excluding the UK and including Switzerland from 2020) in each of the six main policy runs at nominal values for uncertain variables. There are few differences between the policy options under these conditions. The main factors causing costs to change are:

- Changes in oil price (fluctuations pre-2020, and a rising trend thereafter);
- An increasing share of labour costs as GDP per capita rises;
- Changes in average fuel and non-fuel costs related to long-term changes in relative amounts of demand on longer- and shorter-haul flights;
- Moderately reduced maintenance costs from improvements in technology; and
- A reduction in fuel costs per RTK from improvements in technology, applying more strongly when new aircraft models become available.

Compared to these factors, the impact of carbon prices under nominal assumptions for uncertain input variables (orange bands in Figure 33, using nominal ('Base') EUA price assumptions and Sc1 CORSIA eligible credit assumptions) is typically small. In the case where only CORSIA is applied (option 3), intra-EU/EFTA carbon prices remain negligible compared to other airline costs. Fuel and non-fuel costs are also very similar between the policy options. We would expect fuel and non-fuel prices to differ if carbon prices were high enough to change airline (or manufacturer) behaviour around investments in new technology. This effect (the so-called 'Porter hypothesis')[602] could in theory lead to technology-related changes in airline costs and emissions extending well beyond the policy-affected area, as technological innovations driven by carbon costs in one area are employed globally. However, the carbon prices in the base scenario used here are too small to drive large-scale changes in technology adoption. This is in line with the findings of Dray et al. (2018)[603] that most emissions mitigation measures for airlines available now or projected over the near term are either cost-effective at current fuel and carbon prices, or not cost-effective even with substantial rises in carbon price.

[602] Porter, A. & Detampel, M., 1995. Technology opportunities analysis. Technological Foreacsting and Social Change, 49, 237-255.

[603] Dray, L., Schäfer, A. & Al Zayat, K., 2018. The global potential for CO_2 emissions reduction from jet engine passenger aircraft. *Transportation research Record*, 2672(23), 40-51.

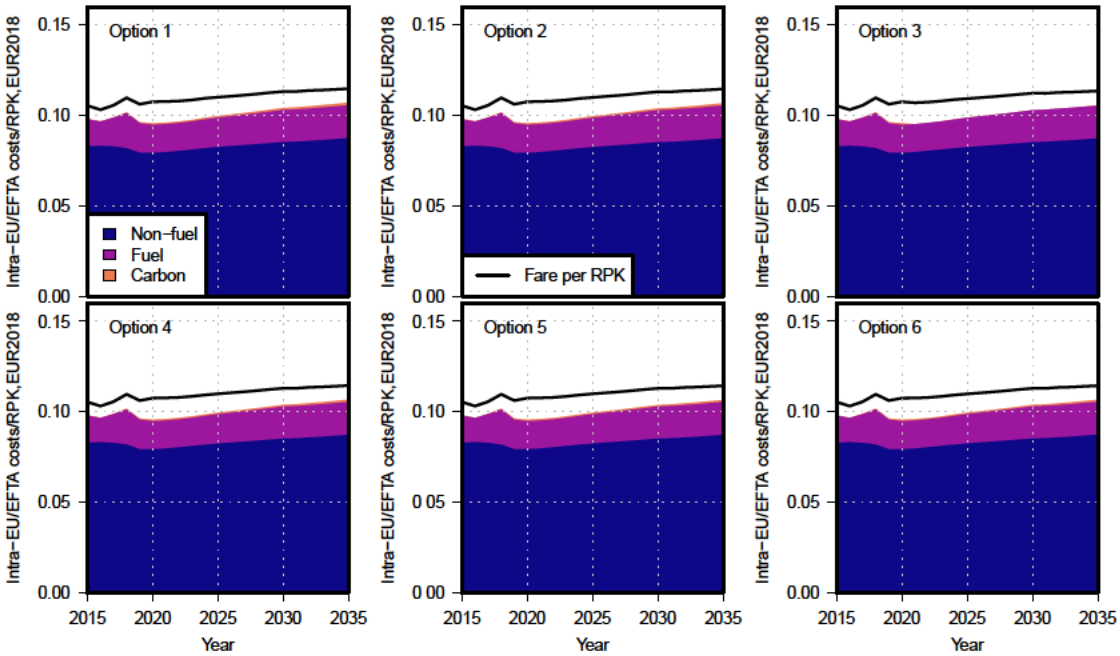

Figure 33. Airline costs per RPK over time for each of the six main policy options at nominal scenario values. Note that the geographic scope plotted changes in 2020.

Figure 33 also shows approximate fare per RPK for intra-EU/EFTA flights under nominal assumptions for uncertain input variables. These numbers should be compared only with caution. Tickets are sold on an origin-destination basis, whereas most costs are incurred on a segment basis, so the mapping between intra-EU/EFTA ticket sales, intra-EU/EFTA segment demand and intra-EU/EFTA costs is not exact. Additionally, fuel, crew and maintenance costs can differ substantially between airlines, depending on their fleet, network, the type of tickets that they sell and their business model. Airlines often hedge fuel costs, meaning that the prices that different airlines pay for fuel at the same time may be different; this has particularly large impacts when oil prices change rapidly. An airline will also typically have multiple revenue sources beyond ticket sales. Many low-cost airlines make losses if only ticket sales are considered, and there is a direct correlation between airlines with high profit margin and those which have high non-ticket revenue (Warnock-Smith et al., 2017). These airlines make up for losses on ticket sales by so-called ancillary revenue sources, including baggage charges, selling food during the flight, tie-ins with travel insurance, car hire and hotel booking via their websites, and website advertising revenue. In 2011, US network carrier ancillary revenue was 3-8% of total revenue (Hao, 2014)[604], but this value can vary strongly between airlines. Passenger airlines also generate revenue by carrying hold cargo. This is typically around 2% of total revenue (Stalnaker et al, 2016)[605]. Ticket prices also include some taxes and charges that do not accrue to airlines, for example the UK's Air Passenger Duty. These different factors broadly cancel out for intra-EU/EFTA flights, leaving the difference between estimated fare per RPK and airline cost per RPK at roughly the expected operating margin of 7% in (IATA, 2019).

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604 Hao, E., 2014. Ancillary Revenues in the Airline Industry: Impacts on Revenue Management and Distribution Systems. MIT Masters' thesis, June 2014.

https://dspace.mit.edu/bitstream/handle/1721.1/89854/890140266-MIT.pdf?sequence=2

605 Stalnaker, T., Usman, K., & Taylor, A., 2016, 2019. Airline Economic Analysis for the Raymond James Global Airline Book. Oliver Wyman, New York.

Carbon prices as a percentage of intra-EU/EFTA projected fuel costs, operating costs and operating margin are shown in Table 23, including ranges due to variation in uncertain input variables. Fuel costs under nominal scenario conditions reflect nominal scenario inputs for oil price. At higher oil prices (the 'high' oil price scenario modelled), carbon costs will typically be a lower fraction of fuel costs; similarly, for the 'low' oil price scenario modelled, carbon costs will be a relatively greater fraction of fuel costs. This is reflected in the uncertainty range shown. Note that the comparison with operating margin is only shown for reference; airlines' operating margin will not decrease by the percentage amount shown because some costs will be passed on to ticket price (typically around 70-80%, as discussed below). Instead these percentages reflect the maximum possible impact on operating margin from the policy in question. In options 1, 2 and 4 the EU ETS is applied broadly as at present for intra-EU/EFTA flights, with greater coverage in option 1 because flights to and from OMRs are included. These options have similar levels of intra-EU/EFTA carbon costs. In option 3, only CORSIA is applied to intra-EU/EFTA flights. As CORSIA has a less stringent baseline, does not cover domestic flights, and is projected to be subject to a much lower carbon price, CORSIA-related costs are almost negligible compared to other sources of airline cost. However, even for Option 1 carbon costs remain negligibly small in comparison to the impact of typical oil price fluctuations. For Option 5, the EU ETS applies to a smaller proportion of intra-EU/EFTA CO_2 (only up to the CORSIA baseline), so the average carbon price experienced by airlines is lower. Similarly, for Option 6 average carbon prices are lower primarily because domestic flights are exempt.

Table 23. Estimated intra-EU/EFTA carbon costs when all scenario variables are at nominal values (numbers in larger font) and range due to variation in uncertain scenario variables (numbers in brackets), as a percentage of fuel costs, total operating costs, and operating margin by policy option, 2015, 2030 and 2035.

Policy option	Carbon costs as % of fuel costs (exc. carbon)			Carbon costs as % of total operating costs			Total carbon costs as % of estimated operating margin if no costs are passed through onto ticket prices[606]		
	2015	2030	2035	2015	2030	2035	2015	2030	2035
Option 1	1.4 (1.4-1.4)	6.4 (4.2-29.1)	8.5 (5.1-48.5)	0.2 (0.2-0.2)	1.1 (0.9-3.8)	1.4 (1.1-5.7)	2.9 (2.9-2.9)	12.5 (8.8-53.0)	20.0 (11.8-152)
Option 2	1.4 (1.4-1.4)	5.6 (3.2-23.3)	7.4 (3.6-37.9)	0.2 (0.2-0.2)	1.0 (0.7-3.1)	1.3 (0.8-4.6)	2.9 (2.9-2.9)	10.9 (6.5-48.0)	17.3 (8.2-128)
Option 3	1.4 (1.4-1.4)	0.03 (0.0-2.0)	0.03 (0.0-3.0)	0.2 (0.2-0.2)	0.006 (0.0-0.3)	0.006 (0.0-0.4)	2.9 (2.9-2.9)	0.06 (0.0-2.4)	0.07 (0.0-4.4)
Option 4	1.4 (1.4-1.4)	5.6 (3.2-23.3)	7.4 (3.6-37.9)	0.2 (0.2-0.2)	1.0 (0.7-3.1)	1.3 (0.8-4.6)	2.9 (2.9-2.9)	10.9 (6.5-48.0)	17.3 (8.2-128)
Option 5	1.4 (1.4-1.4)	5.2 (3.1-20.9)	6.5 (3.6-31.5)	0.2 (0.2-0.2)	0.9 (0.7-2.7)	1.1 (0.8-3.6)	2.9 (2.9-2.9)	10.1 (6.4-45.2)	15.1 (8.0-110)
Option 6	1.4	5.0	6.5	0.2	0.9	1.1	2.9	9.7	15.2

[606] As discussed in the subsequent section, we anticipate around 70-80% of these costs will be passed through onto ticket prices; i.e. non-passed through costs as a percentage of operating margin in 2035 will be 5% or less under nominal scenario conditions and under 40% even at the top of the option 1 uncertainty range.

Policy option	Carbon costs as % of fuel costs (exc. carbon)			Carbon costs as % of total operating costs			Total carbon costs as % of estimated operating margin if no costs are passed through onto ticket prices[606]		
	2015	2030	2035	2015	2030	2035	2015	2030	2035
	(1.4-1.4)	(2.9-19.6)	(3.3-30.9)	(0.2-0.2)	(0.6-2.5)	(0.7-3.7)	(2.9-2.9)	(5.8-42.6)	(7.4-112)

The large uncertainty ranges in Table 23 mainly arise from uncertainty in oil and carbon prices, and from the sensitivity of EUA/offset demand to growth in emissions. Outcomes associated with carbon costs being a high fraction of total costs are: low oil price; high carbon price; and high aviation CO_2 growth (itself associated with high demand growth and pessimistic technology assumptions). At the uppermost end, carbon costs if not passed through would be at a comparable level to operating margin by 2035. However, these conditions only arise for a small, specific set of combinations of uncertain input variables and, as discussed below, in practice aggregate cost pass-through is likely to be 70-80%.

A similar comparison for extra-EU/EFTA flights is shown in Figure 34. Note that fare per RPK is adjusted to account for non-EU/EFTA and intra-EU/EFTA flight legs of extra-EU/EFTA journeys; as with the intra-EU/EFTA fare estimates, these values are approximate and caution should be taken when comparing them. The change in values for 2020 is due to the change in geographic scope (UK removed, Switzerland added; note that the impact of COVID-19 is not modelled as this situation was still developing at the time of writing). Compared to intra-EU/EFTA flights, extra-EU/EFTA flights:

- Are more likely to be long-haul flights performed with twin-aisle aircraft, for which fewer emissions mitigation opportunities exist;
- Typically have a higher percentage of fuel compared to non-fuel costs; and
- Due to greater fuel use and larger variations in coverage, differ more substantially in how they are affected by the different policy options.

Based on US airline international flight data (Stalnaker et al. 2016, 2019), a typical operating margin for intercontinental flights in 2016-17 was around 10-15%, but this value is high compared to typical historical values and is expected to decrease over time.

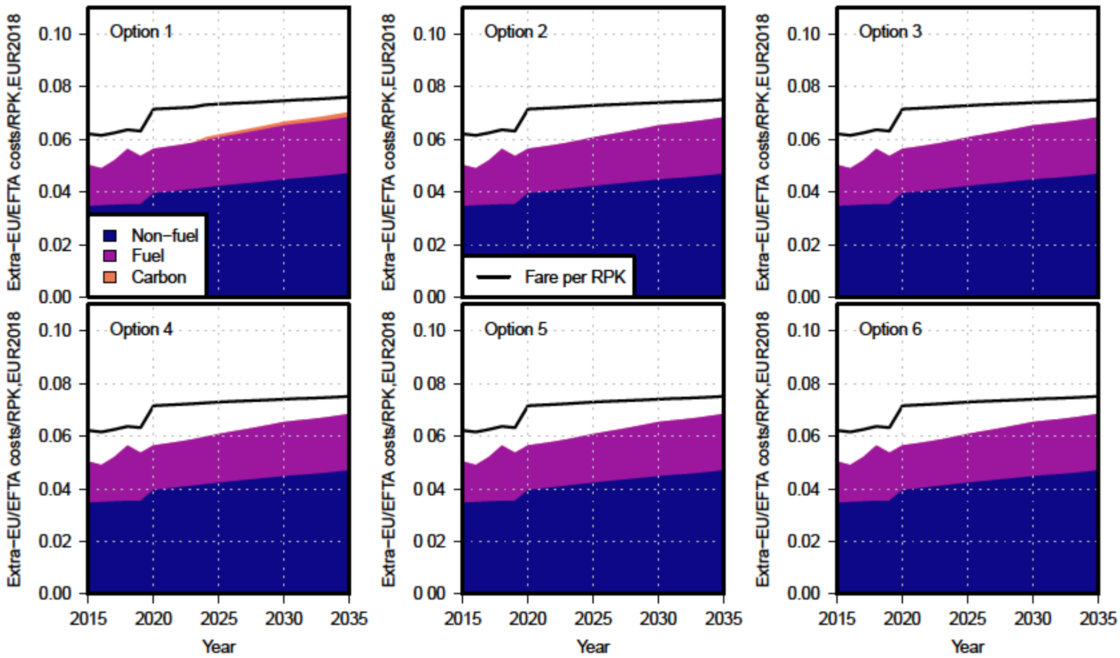

Figure 34. Fuel, non-fuel and carbon costs per RPK for extra-EU/EFTA flights under nominal conditions for uncertain input variables. Note that the geographic scope changes in 2020.

Table 24 shows carbon prices for extra-EU/EFTA flights as a proportion of total fuel costs, operating costs and operating margin (assuming a return to more typical historical values of operating margin over time compared to recent values, and excluding the impact of COVID-19). Under Policy Options 3-6, carbon costs on extra-EU/EFTA flights arise only from CORSIA and are under 0.2% of operating costs to 2035 at nominal values for uncertain scenario variables. In Policy Option 2, no carbon cost at all applies to extra-EU/EFTA flights. Only for Policy Option 1, in which the EU ETS reverts to full scope for aviation, is there a potentially significant impact on extra-EU/EFTA flights. Under nominal values for uncertain scenario variables (including oil price), carbon costs may be up to around 9% of fuel costs by 2035, or 3% of total operating costs. Similarly to intra-EU/EFTA flights, there also exists a set of values for uncertain input variables at which carbon costs are a much higher fraction of operating costs (high carbon price, low oil price, high growth in aviation CO_2) although this is in part because other components of operating cost per RPK are lower rather than because absolute levels of operating cost are higher. As discussed in the next section, if costs are passed through at typical rates per flight segment accounting for constraints related to airport capacity, competition levels and passenger response, it is likely that airline operating margins will be reduced by a much smaller amount (less than 10% at nominal scenario values).

Table 24. Estimated extra-EU/EFTA carbon costs when all scenario variables are at nominal values (numbers in larger font), and range due to variations in uncertain input variables (numbers in brackets) as a percentage of fuel costs, total operating costs, and operating margin by policy option, 2015, 2030 and 2035.

Policy option	**Carbon costs as % of fuel costs**			**Carbon costs as % of total operating costs**			**Carbon costs as % of estimated operating margin if no carbon costs are passed through onto ticket prices[606]**		
	2015	**2030**	**2035**	**2015**	**2030**	**2035**	**2015**	**2030**	**2035**

Option 1	0.0 (0.0-0.0)	6.7 (4.4-30.5)	8.9 (5.4-50.7)	0.0 (0.0-0.0)	2.1 (1.6-7.6)	2.7 (1.9-11.5)	0.0 (0.0-0.0)	17.3 (8.2-101)	33.5 (11.5-176)
Option 2	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.0 (0.0-0.0)
Option 3	0.0 (0.0-0.0)	0.03 (0.0-2.4)	0.04 (0.0-4.9)	0.0 (0.0-0.0)	0.01 (0.0-0.1)	0.01 (0.0-1.3)	0.0 (0.0-0.0)	0.07 (0.0-5.2)	0.11 (0.0-13.5)
Option 4	0.0 (0.0-0.0)	0.03 (0.0-2.4)	0.04 (0.0-5.0)	0.0 (0.0-0.0)	0.01 (0.0-0.1)	0.01 (0.0-1.3)	0.0 (0.0-0.0)	0.08 (0.0-5.5)	0.12 (0.0-13.4)
Option 5	0.0 (0.0-0.0)	0.03 (0.0-2.4)	0.04 (0.0-4.9)	0.0 (0.0-0.0)	0.01 (0.0-0.1)	0.01 (0.0-1.3)	0.0 (0.0-0.0)	0.07 (0.0-5.1)	0.12 (0.0-13.3)
Option 6	0.0 (0.0-0.0)	0.03 (0.0-2.4)	0.04 (0.0-5.0)	0.0 (0.0-0.0)	0.01 (0.0-0.1)	0.01 (0.0-1.3)	0.0 (0.0-0.0)	0.08 (0.0-5.5)	0.12 (0.0-13.4)

These values can also be compared to the estimates of CORSIA impact in ICCT (2017)[607]. ICCT (2017) compare prices for typical CORSIA-covered routes, whereas the analysis here includes the impact of non-participating countries, so our estimates for CORSIA-covered routes are generally lower than theirs. For example, they estimate CORSIA costs of 0.2 - 4.6% of fuel costs in 2035, with the low end corresponding to current CER prices plus a 4% assumed increase per year. However, adjusting for coverage levels our estimates of costs compared to jet fuel costs are similar. Our estimates also align with their general conclusion that the impact of CORSIA is well under that of volatility on jet fuel prices.

3.2.8 Changes in ticket prices

How do these costs impact on ticket prices? As discussed in Section 3.1.1.1, many assumptions have been used in the past about the extent to which airlines pass through costs on to ticket prices. These extend from no (or very limited) cost pass-through, through full pass-through of all incurred costs, to full pass-through including pass-through of opportunity costs from free allowances (i.e., leading to an increase in airline profits). In our main model run grid, we use estimates of cost pass-through generated for this study (discussed in Section 4). We calculate typical pass-through by flight segment based on historical pass-through behaviour by segment type, dividing flight segments into:

- Those involving two, one or no congested airports (see, e.g. Boeing, 2015[608]);
- Monopoly routes, those operated by 2-4 competing carriers, and those operated by 5 or more competing carriers; and
- Short-haul/medium-haul/long-haul/intercontinental segments, as a proxy for typical passenger type.

Each of these segment categories (36 types in total) is associated with a different pass-through rate. The reasoning behind this segmentation, and the estimated rates, are discussed in Section 4.5.[609]

[607] ICCT, 2017. International Civil Aviation Organisation's Carbon Offset and Reduction Scheme for International Aviation (CORSIA). https://theicct.org/sites/default/files/publications/ICAO%20MBM_Policy-Update_13022017_vF.pdf

[608] Boeing, 2015. Boeing Global Airport Congestion Study. http://docplayer.net/34389627-Boeing-global-airport-congestion-study.html

[609] Note that due to the necessary timeframe for carrying out the modelling, the analysis here uses initial estimates of pass-through rates for each route category from Task 3. The final pass-through

In aggregate, across all flight segments modelled, these pass-through assumptions result in:

- Initial average pass-through rates of around 74% for intra-EU/EFTA flights;
- Initial average pass-through rates of around 75-82% for extra-EU/EFTA flights, depending on the type of carbon cost applied[610]; and
- Initial average pass-through rates of around 77% for other routes.

In general, pass-through also varies over time as routes with different pass-through characteristics grow at different rates, and pass-through for each policy option varies depending on which routes the policy applies to. For example, average intra-EU/EFTA pass-through for CORSIA costs in Option 3 is different to that for EU ETS costs in Option 2 because CORSIA does not apply to domestic flights and so covers a relatively smaller range of short-haul flights. Average pass-through for most combinations of policy and broad geographic area decreases slightly over time. For example, intra-EU/EFTA pass-through in Policy Option 1 decreases to 71% by 2035.

The impact of these changes in costs by policy and type of route is shown in Figure 35, for all uncertain scenario variables at nominal values. Grey background ranges show the level of variation across all policies and uncertain variables considered (because the level of variation in fare due to other factors, such as fuel price, demand growth and technology assumptions, is much greater than that due to the different policy option chosen, uncertainty ranges in fares are similar across all policies). Changes in fare over time are driven by similar factors to those driving airline cost changes, but may not track changes in airline cost exactly because pass-through may be different by individual route and by the type of cost that is changing (e.g. Wang et al., 2018)[611]. Fare is also a function of the number of passengers on a given itinerary, which may lead to policy-related second-order fare changes.

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estimates in Task 3 differ slightly from these initial values. An estimate of the impact of these changes is given in Section 4.

[610] Average pass-through across route groups varies slightly between CORSIA and the EU ETS because the distribution of most-affected routes is different, and pass-through is assumed to differ by route.

[611] Wang, B., O'Sullivan, A., Dray, L., Schäfer, A., 2018. Modeling airline cost pass-through within regional aviation markets. Transportation Research Record, 2672(23), 146-157.

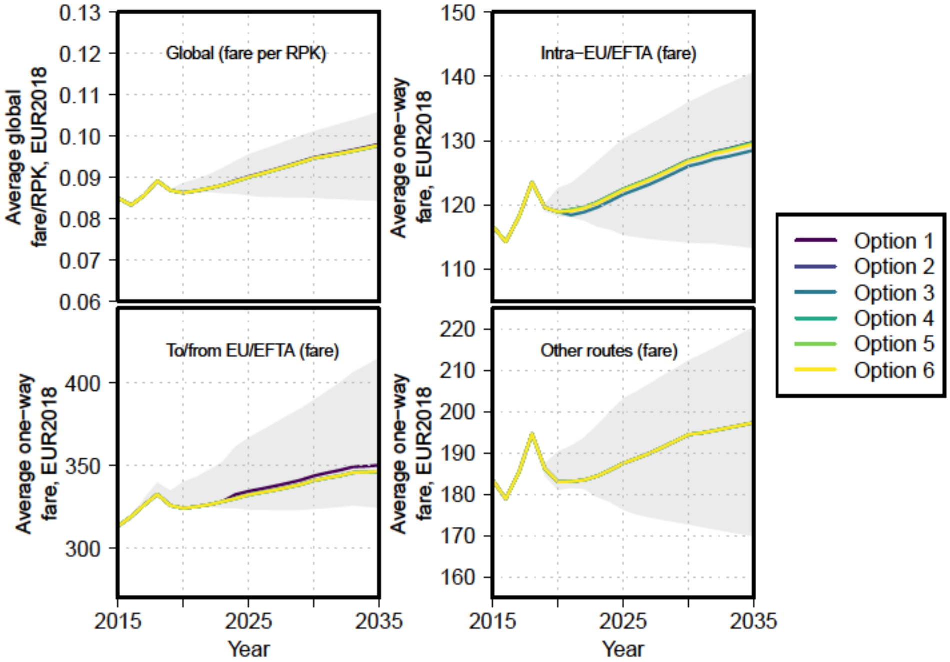

Figure 35. Average fare by main policy option with all uncertain scenario variables at nominal values (solid lines), for intra-EU/EFTA, extra-EU/EFTA and other routes. Background ranges show the range of variation due to changing other uncertain variables.

In general, fare is similar between the different policy options and varies to a much greater extent due to changes in other uncertain variables. For example, average intra-EU/EFTA fare in 2035 varies by around 1% depending on the policy option chosen. Changing other uncertain variables, most notably using the upper or lower oil price trends defined in Section 3.1.2.4, leads to year-2035 fares which are between 7% higher and 12% lower than when all uncertain variables are set to nominal values.

Average fares by policy option and region, for uncertain scenario variables set to nominal values, and uncertainty ranges, are shown in Table 25. Note that fares are charged by itinerary, so fares to or from the EU/EFTA region often include an intra-EU/EFTA flight leg. These itinerary effects can also be observed by comparing extra-EU/EFTA fares between Options 2 and 3. In Option 2, no carbon price applies to extra-EU/EFTA flight segments. In Option 3, the expected CORSIA carbon price (€1/tCO_2 in the nominal scenario) applies to extra-EU/EFTA flight segments. But extra-EU/EFTA fares are slightly higher in Option 2. This is because many extra-EU/EFTA tickets sold include an intra-EU/EFTA flight leg (e.g. New York-Paris-Athens). The intra-EU/EFTA parts of these journeys are subject to an EU ETS-appropriate carbon price which is much higher than the CORSIA carbon price (€30-40 in the nominal scenario by 2030-2035). The net impact is slightly higher extra-EU/EFTA fares for Option 2.

Table 25. Average fare in 2030 and 2035 by region and policy option, for all uncertain scenario values set to nominal values (numbers in larger font), and range across all uncertain variables (numbers in brackets).

Policy option	Avg. one-way fare, intra-EU/EFTA, $€_{2018}$			Avg. one-way fare, extra-EU/EFTA, $€_{2018}$			Avg. one-way fare, other routes, $€_{2018}$		
	2015	2030	2035	2015	2030	2035	2015	2030	2035

Option 1	116.74	127.02 (115-136)	129.82 (115-141)	313.44	343.82 (327-390)	350.23 (328-415)	183.50	194.54 (173-212)	197.43 (170-221)
Option 2	116.74	126.98 (115-136)	129.77 (115-140)	313.44	341.04 (324-380)	346.50 (325-399)	183.50	194.54 (173-212)	197.43 (170-221)
Option 3	116.74	126.06 (114-133)	128.53 (113-137)	313.44	340.96 (324-380)	346.39 (325-400)	183.50	194.54 (173-212)	197.43 (170-221)
Option 4	116.74	126.98 (115-136)	129.77 (114-140)	313.44	341.05 (324-380)	346.52 (325-400)	183.50	194.54 (173-212)	197.43 (170-221)
Option 5	116.74	126.92 (115-136)	129.62 (114-140)	313.44	341.05 (324-380)	346.51 (325-400)	183.50	194.54 (173-212)	197.43 (170-221)
Option 6	116.74	126.79 (115-135)	129.50 (114-140)	313.44	341.05 (324-380)	346.50 (325-400)	183.50	194.54 (173-212)	197.43 (170-221)

In general, fares in 2030 and 2035 vary between policy options by only small absolute amounts. One-way intra-EU/EFTA fares vary by less than €2 between policy options when all uncertain scenario variables are at nominal values. The largest variation is for extra-EU/EFTA fares between Policy Option 1 and the other options in 2035, which is around €3.50 one-way or €7 for a typical round-trip journey. However, this is still only just over 1% of total fare. This level of cost increase is not likely to present a serious barrier to access (beyond those presented by the pre-policy costs of flying in the first place). At the upper end of the uncertainty range average extra-EU/EFTA fares vary between Policy Option and the other policies by up to €16 per one-way journey (up to €32 per round-trip), just under 4% of total fare.

3.2.9 Demand

As discussed above, changes in airline costs due to the different policy options modelled at nominal values for uncertain scenario values lead to variations in fares that are typically under 1.5%. The extent to which this affects RTK depends on the price-sensitivity of passengers and freight shippers in different route groups. However, in common with previous impact assessments of EU ETS aviation-related changes, we predict only small changes in overall demand as a result of these minor fare changes. Table 26 illustrates this by showing intra-EU/EFTA and extra-EU/EFTA RTK for the low, nominal and high demand growth cases, by policy option. Note that the UK is not included in EU/EFTA scope. For comparison, estimated intra- and extra-EU/EFTA RTK in 2015 was around 52 billion and 194 billion respectively. Intra-EU/EFTA RTK varies by only 1.4%, and extra-EU/EFTA RTK by 2.0%, between the highest and lowest carbon price policy options in 2035 when all uncertain scenario variables are set to nominal values.

Table 26. Estimated intra-EU/EFTA and extra-EU/EFTA RTK in 2030 and 2035, by policy and demand growth scenario, with all other uncertain variables set at nominal values (numbers in larger font) and range across variation in other uncertain variables (numbers in brackets).

Policy option	Annual RTK (low demand growth), billion		Annual RTK (nominal demand growth), billion		Annual RTK (high demand growth), billion	
	2030	2035	2030	2035	2030	2035
Intra-EU/EFTA (including OMRs, excluding UK)						
Option 1	65.3 (61.3-69.5)	68.4 (63.3-74.0)	81.7 (76.7-87.0)	87.8 (81.4-95.2)	89.0 (83.5-94.8)	102.5 (94.7-111.0)
Option 2	65.6 (62.1-69.8)	68.8 (64.6-74.4)	81.9 (77.4-87.2)	88.2 (82.5-95.5)	89.5 (84.5-95.2)	103.2 (96.6-111.6)
Option 3	66.0 (63.0-70.3)	69.3 (65.9-75.1)	82.4 (78.6-87.8)	89.0 (84.5-96.5)	90.1 (85.9-96.0)	104.2 (98.9-112.8)
Option 4	65.6 (62.1-69.8)	68.8 (64.6-74.4)	81.9 (77.4-87.2)	88.2 (82.5-95.5)	89.5 (84.5-95.2)	103.2 (96.5-111.6)
Option 5	65.6 (62.0-69.8)	68.8 (64.6-74.4)	81.9 (77.4-87.3)	88.3 (82.7-95.7)	89.6 (84.7-95.4)	103.5 (97.2-112.0)
Option 6	65.6 (62.2-69.9)	68.9 (64.7-74.5)	81.9 (77.5-87.3)	88.3 (82.8-95.6)	89.6 (84.7-95.3)	103.3 (97.0-111.8)
To/from EU/EFTA						
Option 1	275.6 (262-287)	301.6 (283-317)	289.8 (275-303)	316.8 (296-334)	344.3 (327-359)	409.9 (382-432)
Option 2	279.3 (272-292)	307.5 (298-324)	293.9 (285-307)	323.0 (312-341)	349.9 (340-365)	418.7 (406-442)
Option 3	279.4 (272-292)	307.5 (297-324)	294.0 (285-307)	323.2 (312-341)	349.9 (339-365)	419.1 (404-442)
Option 4	279.3 (271-292)	307.4 (297-324)	293.9 (285-307)	323.0 (312-341)	349.9 (339-365)	418.6 (404-442)
Option 5	279.3	307.4	293.9	323.0	349.9	418.7

Policy option	Annual RTK (low demand growth), billion		Annual RTK (nominal demand growth), billion		Annual RTK (high demand growth), billion	
	2030	2035	2030	2035	2030	2035
	(271-292)	(297-324)	(285-307)	(312-341)	(339-365)	(404-442)
Option 6	279.3 (271-292)	307.4 (297-324)	293.9 (285-307)	323.0 (312-341)	349.9 (339-365)	418.6 (404-442)

These variations are mainly the result of passenger response to increases in ticket price as a result of carbon costs, as passenger RTK is by far the largest component of RTK for intra-European flights. Freight RTK varies by up to 3% between the highest and lowest carbon cost policy options for all uncertain scenario variables (including carbon price) set to nominal values. This larger response is mainly due to fuel being a larger proportion of operating costs for freight than for passengers, due to lower freight labour costs. If instead carbon prices follow the high trajectories identified in Section 3.1.2.5, and all other variables are set to nominal values, total intra-EU/EFTA RTK differs by 3.6% between the option with the lowest carbon costs (Option 3) and the option with the highest carbon costs (Option 1).

The impact of uncertainty in demand growth and other variables is shown in Figure 36, Figure 37 and Figure 38 for global, European departing flights and intra-Europe scopes, against other projections and historical data from ICAO, Airbus, Boeing, Eurostat, Eurocontrol, and from the other impact assessments and academic literature discussed in the literature review in Section 3.1.2.3. Note that the lines for different policy options under the same demand growth scenario are typically very close to each other, so the difference between the different policy options is not always visible. Numerical values per policy option are also given in the table below.

Table 27. Estimated global, extra-EU/EFTA and intra-EU/EFTA RPK and FTK by policy option, for all uncertain input variables at nominal values (numbers in larger font) and range due to variation in uncertain input variables (numbers in brackets).

Policy option	Estimated global annual RPK, trillion			Estimated global annual FTK, billion		
	2015	2030	2035	2015	2030	2035
Option 1	6.75	12.53 (10.60-14.27)	14.43 (11.74-17.61)	217	380.7 (296.2-406.4)	450.1 (324.5-489.2)
Option 2	6.75	12.55 (10.66-14.31)	14.47 (11.85-17.67)	217	382.8 (299.7-409.3)	453.1 (330.0-493.8)
Option 3	6.75	12.56 (10.67-14.31)	14.48 (11.87-17.68)	217	382.8 (299.8-409.4)	453.2 (330.0-493.9)
Option 4	6.75	12.55 (10.66-14.31)	14.47 (11.85-17.67)	217	382.8 (299.7-409.3)	453.1 (329.8-493.8)
Option 5	6.75	12.55 (10.66-14.31)	14.47 (11.85-17.68)	217	382.8 (299.7-409.3)	453.1 (329.8-493.8)
Option 6	6.75	12.55 (10.66-14.31)	14.47 (11.84-17.67)	217	382.8 (299.6-409.3)	453.1 (329.7-493.8)

	Estimated extra-EU/EFTA annual RPK, trillion			Estimated extra-EU/EFTA annual FTK, billion		
	2015	2030	2035	2015	2030	2035
Option 1	1.31	1.98 (1.89-2.59)	2.13 (2.02-3.15)	62.3	92.3 (73.7-100.6)	103.8 (77.3-116.3)
Option 2	1.31	2.00 (1.94-2.62)	2.16 (2.11-3.20)	62.3	94.3 (77.4-103.6)	106.8 (83.0-121.2)
Option 3	1.31	2.00 (1.94-2.62)	2.16 (2.10-3.21)	62.3	94.3 (77.4-103.6)	106.8 (82.8-121.2)
Option 4	1.31	2.00 (1.94-2.62)	2.16 (2.10-3.20)	62.3	94.3 (77.4-103.6)	106.8 (82.8-121.2)
Option 5	1.31	2.00 (1.94-2.62)	2.16 (2.10-3.20)	62.3	94.3 (77.4-103.6)	106.8 (82.8-121.2)
Option 6	1.31	2.00 (1.94-2.62)	2.16 (2.10-3.20)	62.3	94.3 (77.3-103.6)	106.8 (82.7-121.2)
	Estimated intra-EU/EFTA annual RPK, trillion			**Estimated intra-EU/EFTA annual FTK, billion**		
	2015	**2030**	**2035**	**2015**	**2030**	**2035**
Option 1	0.49	0.78 (0.58-0.90)	0.84 (0.60-1.05)	2.86	3.44 (2.87-4.79)	3.65 (2.91-5.60)
Option 2	0.49	0.78 (0.59-0.90)	0.85 (0.62-1.06)	2.86	3.45 (2.92-4.83)	3.67 (2.99-5.67)
Option 3	0.49	0.79 (0.60-0.91)	0.85 (0.63-1.07)	2.86	3.52 (3.03-4.97)	3.77 (3.14-5.89)
Option 4	0.49	0.78 (0.59-0.90)	0.85 (0.62-1.06)	2.86	3.45 (2.92-4.83)	3.67 (2.99-5.67)
Option 5	0.49	0.78 (0.59-0.91)	0.85 (0.62-1.06)	2.86	3.46 (2.92-4.87)	3.68 (2.99-5.76)
Option 6	0.49	0.78 (0.59-0.90)	0.85 (0.62-1.06)	2.86	3.47 (2.95-4.87)	3.69 (3.03-5.74)

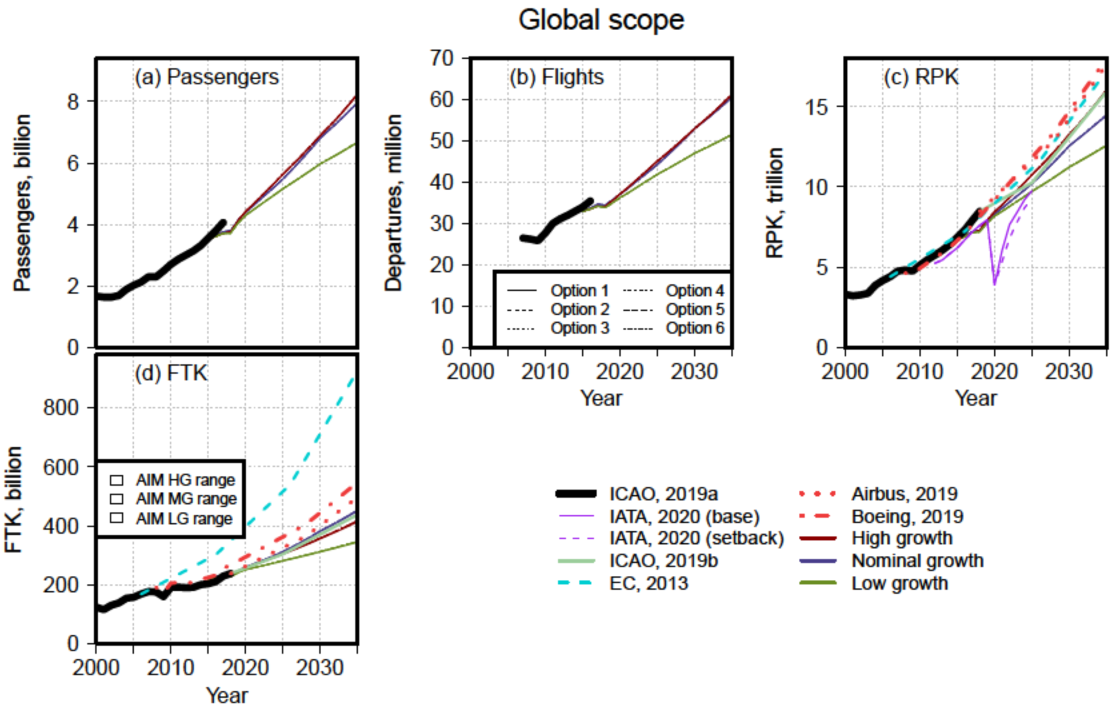

Figure 36. Global demand metrics (passengers, flights, RPK, FTK and direct CO_2) showing uncertainty ranges in outputs by demand growth scenario and main policy option.

As discussed in Section 3.1.2.3, there is no single commonly-defined metric for intra-European and extra-European aviation demand growth. Different studies report different metrics, on different geographic scopes, with different components of aviation included or excluded. In particular, the alternative projections shown in Figure 37 and Figure 38 are based on multiple different definitions of Europe, as well as numerous other differences in what is included or excluded. Because of these scope differences, alternative projections are included only for comparison of growth rates. The AIM projections shown for passengers cover departing passengers on a segment basis (so, e.g., a passenger flying from Paris to Oslo to Bergen would add two to passenger totals). Flights include freighter and non-scheduled flights but exclude military. FTK includes hold freight and freight on freighter aircraft. All European AIM totals shown totals are based on the EU/EFTA region (i.e. totals are shown for the same geographic area, including Switzerland, Iceland, Norway, Croatia and other EU countries, but not the UK, for the whole 2015-2035 period).

For Figure 36, Figure 37 and Figure 38, lines for each policy option in combination with central, high and low demand growth scenarios are shown, with all other uncertain variables at nominal values. The background ranges shown for central, high and low demand growth scenarios indicate the combined impact on demand of variation in the other uncertain variables considered (oil price, carbon price, CORSIA participation, capabilities of new technology). Note that these ranges sometimes overlap. In the case of global demand metrics, the difference between the individual policy options is typically small compared to the impact of changes in other uncertain variables (this means that individual policy lines in these figures are hard to distinguish from each other; the reader is referred to the associated tables for differences between policy options). For all geographic scopes, uncertainty in demand growth typically has the largest impact on year-2035 passenger and freight traffic, uncertainty due to other uncertain variables (in aggregate) is also significant, and demand variation due to EU ETS/CORSIA policy options is very small compared to the overall uncertainty range. For example, the different demand growth scenarios result in intra-EU/EFTA RTK that is around 50% different by 2035. The different policy options (at nominal values for carbon price) result in around a

1.4% difference in intra-EU/EFTA RTK by 2035 (if carbon prices follow the higher trajectories identified in Section 3.1.2.5, this difference is around 3.6%).

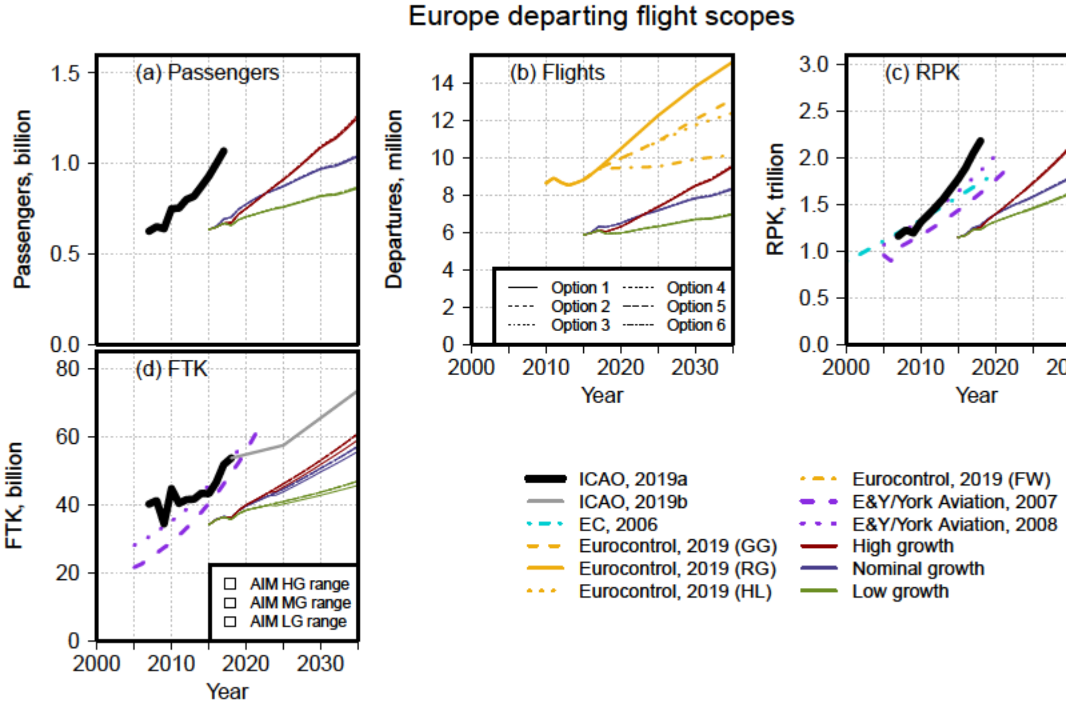

Figure 37. Demand metrics (passengers, flights, RPK, FTK and direct CO_2) on an EU/EFTA departing flights scope, showing uncertainty ranges in outputs by demand growth scenario and main policy option. Note that alternative projections use multiple different definitions of 'Europe' and are included for comparisons of growth rate only. The AIM numbers shown exclude the UK throughout the plotted time period.

Similarly to global demand metrics, variation in intra-EU/EFTA and extra-EU/EFTA demand metrics due to the different policy options is sufficiently small that the different lines for different policy options are often not distinguishable in Figure 37 and Figure 38.

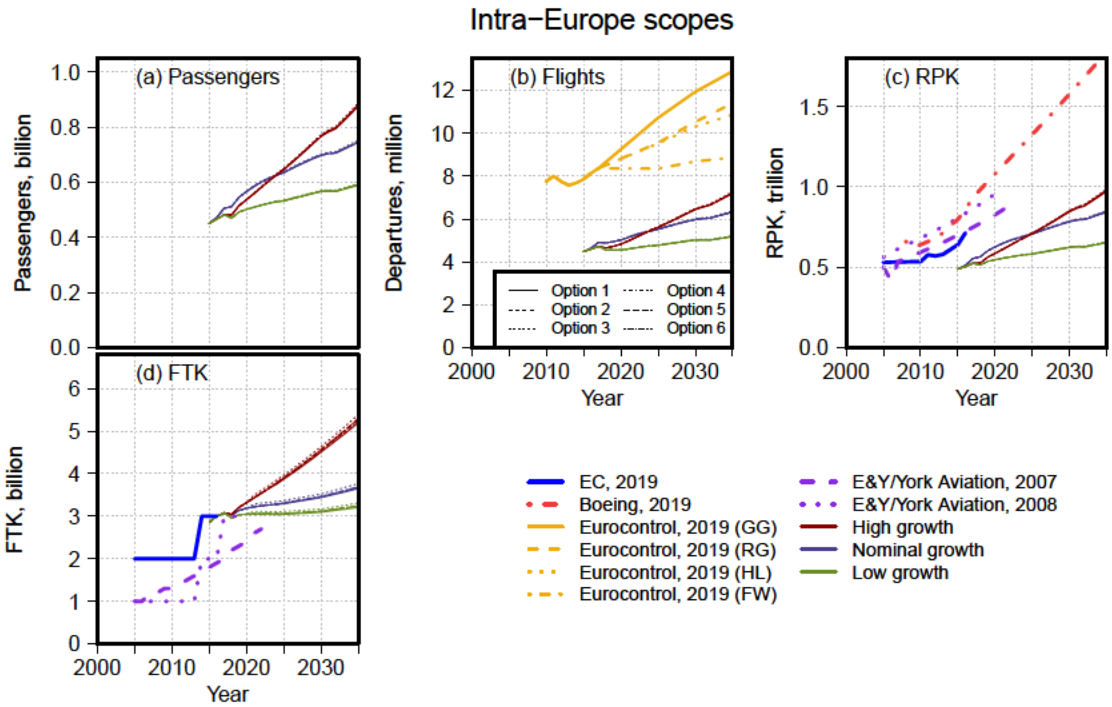

Figure 38. Demand metrics (passengers, flights, RPK, FTK and direct CO_2) on an intra-Europe scope, showing uncertainty ranges in outputs by demand growth scenario and main policy option. Note that alternative projections use multiple different definitions of 'Europe' and are included for comparisons of growth rate only. The AIM numbers shown exclude the UK throughout the plotted time period.

The nominal-case demand comparisons given above assume base case carbon prices. However, even if carbon prices follow the higher trends identified as part of the uncertainty range analysis (EUA price trajectory IIb and CORSIA eligible emissions unit price trajectory 2), intra-EU/EFTA RTK differs by only 3.6% in 2035 between the policy options with the greatest and least impact on demand, and extra-EU/EFTA RTK by a maximum of 5.1% Totals by policy option in 2030 and 2035 directly comparing the impact of different carbon price assumptions, with all other scenario input variables set to nominal values, are shown below. This amount of variation remains small compared to uncertainty in other factors.

Table 28. Direct comparison of intra-EU/EFTA and extra-EU/EFTA RTK at different carbon price assumptions, under nominal scenario inputs for all other uncertain variables, by policy option.

Policy option	Intra-EU/EFTA annual RTK				Extra-EU/EFTA annual RTK			
	Nominal scenario inputs		Nominal scenario inputs + higher carbon price		Nominal scenario inputs		Nominal scenario inputs + higher carbon price	
	2030	2035	2030	2035	2030	2035	2030	2035
Option 1	81.7	87.8	80.4	85.8	289.8	316.8	283.1	306.5
Option 2	81.9	88.2	81.0	86.8	293.9	323.0	293.8	322.6
Option 3	82.4	89.0	82.4	88.9	294.0	323.2	293.7	322.6

Option 4	81.9	88.2	81.0	86.8	293.9	323.0	293.5	322.1
Option 5	81.9	88.3	81.0	87.0	293.9	323.0	293.5	322.1
Option 6	81.9	88.3	81.1	87.0	293.9	323.0	293.5	322.1

Taken in combination, these outcomes agree with the conclusion of previous impact assessments that only limited impacts on demand from any of the possible policy options is likely from the levels of carbon price anticipated to 2035.

3.2.10 Net aviation CO_2 emissions and climate impact

The comparisons of aviation CO_2 in the previous sections consider only direct CO_2 emitted from aircraft engines. However, the final climate impact of the different policy options will differ from this for several reasons:

- Depending on the policy applied and the effectiveness of different types of emissions allowances and/or offsets, emissions reductions will occur in other sectors;
- Some of the direct CO_2 emitted is associated with reductions in fuel lifecycle CO_2 via the use of biofuels;
- Aviation has non-CO_2 climate impacts associated with, e.g. contrails, aircraft-induced cirrus cloud and NOx emitted at altitude; and
- There may be a CO_2 rebound effect as passengers who would have spent money on aviation instead spend money elsewhere (for example, using money not spent on aviation on home improvements), resulting in an increase in CO_2 from other sectors.

This section discusses the first three areas mentioned above. Rebound-type effects in other sectors are covered by use of AIM outputs as input to the E3ME model, as discussed below. Note that the impact of COVID-19 is not considered in this section, as the situation was still developing at the time the modelling took place. See Section 3.1.2.9 for a discussion of how this may impact outcomes.

Global and European net CO_2 emissions are summarised in Table 29 for different levels of CORSIA offset quality. Direct CO_2 totals shown include all CO_2 directly released from aircraft and do not adjust for the lower fuel lifecycle emissions of biofuels, offsets, or reductions in emissions from other sectors from aviation purchase of EUAs. Net CO_2 emission totals at 0% CORSIA offset additionality are adjusted for biofuel lifecycle emissions and for EUA purchases, but not for CORSIA offsets. These are the outcomes likely if CORSIA offsets are not additional, are double-counted, are temporary in scope or otherwise do not represent real long-term reductions in CO_2 emissions. Net CO_2 emission totals at 100% CORSIA offset additionality also take into account the purchase of CORSIA offsets and assume that all offsets are of high quality. Note that the UK is not included in EU/EFTA totals.

Figure 39 shows global (international plus domestic) CO_2 emissions by policy option and demand growth scenario as absolute direct CO_2 emission totals (black lines); CO_2 emission totals adjusted for biofuel use[612] (cyan lines); CO_2 emission totals adjusted for both biofuel use and emissions reductions in other (EU/EFTA) sectors via purchase of EUAs (maroon lines); and CO_2 emission totals adjusted for biofuel use, EUA purchases and CORSIA offsets

[612] Biofuel CO_2 accounting differs depending on which sector the fuel lifecycle emissions are allocated to. For these figures, biofuel direct CO_2 (i.e. the CO_2 emitted from combustion in aircraft engines, which for drop-in biofuels is similar to that of fossil Jet A) is adjusted by the ratio of the fuel's lifecycle emissions to those of fossil Jet A.

(orange lines). For CORSIA offsets, we show two cases: one in which offsets are of high quality (solid orange lines) and one in which (arbitrarily) only half of offsets result in additional reductions in CO_2 emissions(dashed orange lines). Lower-quality offsets with even lower additionality than this would fall closer to the maroon lines covering ETS allowance purchase-type offset CO_2 only. These lines are for all other scenario variables at nominal values, including only limited use of biofuels by 2035. Background ranges show the level of variation in outcomes based on changes in these variables (i.e. oil price, carbon price, technology assumptions and CORSIA participation level).

Table 29. Year-2030 and 2035 net aviation CO_2 after offsets and EU ETS allowances are subtracted, for different levels of CORSIA offset additionality. Central values shown are for all scenario variables at nominal values, including demand growth.

Policy option	Direct annual CO_2 emissions, Mt		Net annual CO_2 emissions, Mt (0% additional CORSIA offsets)		Net annual CO_2 emissions, Mt (100% additional CORSIA offsets)	
	2030	2035	2030	2035	2030	2035
Global						
Option 1	1135 (926-1334)	1263 (972-1597)	1018 (811-1149)	1108 (798-1326)	980 (798-1100)	1046 (760-1242)
Option 2	1138 (931-1339)	1269 (978-1607)	1115 (877-1308)	1234 (878-1566)	1077 (865-1258)	1171 (839-1482)
Option 3	1139 (931-1340)	1270 (978-1608)	1139 (890-1340)	1262 (890-1608)	1094 (883-1250)	1179 (845-1452)
Option 4	1138 (931-1339)	1269 (978-1607)	1115 (877-1307)	1234 (878-1566)	1070 (867-1226)	1154 (830-1425)
Option 5	1138 (931-1339)	1269 (978-1607)	1117 (877-1319)	1238 (878-1584)	1072 (871-1229)	1155 (833-1429)
Option 6	1138 (931-1339)	1269 (978-1607)	1117 (878-1313)	1237 (879-1574)	1073 (868-1232)	1157 (831-1433)
Extra-Europe (to/from EU/EFTA, excluding UK, including OMRs)						
Option 1	191 (169-258)	200 (176-308)	99 (97-103)	86 (84-91)	99 (97-103)	86 (84-91)
Option 2	193 (173-263)	205 (181-317)	193 (166-263)	204 (165-317)	193 (166-263)	204 (165-317)
Option 3	193 (173-263)	205 (181-317)	193 (166-263)	204 (165-317)	179 (160-231)	185 (155-261)
Option 4	193 (173-263)	205 (181-317)	193 (166-263)	204 (165-317)	177 (158-229)	184 (154-259)
Option 5	193 (173-263)	205 (181-317)	193 (166-263)	204 (165-317)	179 (160-231)	185 (155-260)
Option 6	193 (173-263)	205 (181-317)	193 (165-263)	204 (165-317)	177 (159-229)	184 (154-259)
Intra-Europe (EU/EFTA, excluding UK, including OMRs)						
Option 1	53.9 (42.2-63.9)	55.1 (41.0-71.2)	27.8 (23.7-29.6)	23.6 (19.0-25.2)	27.8 (23.7-29.6)	23.6 (19.0-25.2)
Option 2	54.1 (42.6-64.3)	55.3 (41.5-71.8)	30.6 (28.9-32.7)	27.9 (25.7-31.5)	30.6 (28.9-32.7)	27.9 (25.7-31.5)
Option 3	54.4 (43.0-64.8)	55.8 (42.1-72.6)	54.4 (41.1-64.8)	55.8 (38.3-72.6)	49.4 (40.4-52.9)	50.8 (37.8-55.8)
Option 4	54.1 (42.6-64.3)	55.3 (41.5-71.8)	30.6 (28.9-32.7)	27.9 (25.7-31.5)	30.6 (28.9-32.7)	27.9 (25.7-31.5)
Option 5	54.1 (42.6-64.4)	55.4 (41.5-72.1)	32.8 (29.0-44.0)	31.7 (26.0-49.0)	27.8 (23.9-31.6)	26.9 (24.9-32.5)
Option 6	54.1 (42.6-64.4)	55.4 (41.6-72.0)	32.9 (29.5-38.0)	31.1 (26.7-39.2)	32.9 (29.5-38.0)	31.1 (26.7-39.2)

There is significant overlap in these totals arising from the impact of different assumptions about uncertain input variables on output CO_2 emissions. For example, the Pessimistic technology scenario assumes aviation biofuel use remains negligible to 2035. In this case, biofuel-adjusted totals are the same as absolute direct CO_2 emission totals. Figure 40 shows the same comparison for intra-EU/EFTA CO_2 (a geographic scope of EU27 + Switzerland, Norway and Iceland is shown; note that although the EU ETS applies to all of these countries at some point between 2015 and 2035, Switzerland does not participate before 2020 and UK contributions pre-2020 are not shown). Note that the comparison in these figures does not link offset effectiveness and carbon price (i.e., it is likely that more effective CORSIA offsets will be associated with a higher CORSIA carbon price). Black lines in these figures show direct CO_2 emissions under nominal scenario conditions. Cyan lines show totals adjusted for biofuel lifecycle emissions. Maroon lines show totals after adjusting for EU ETS allowances purchased from other sectors, and solid orange lines in these show the nominal scenario case net aviation CO_2 emissions to 2035 in the case that CORSIA offsets are of high quality.

By 2035, global net aviation CO_2 emissions after adjusting for offsets and allowances vary significantly. In the case that CORSIA is applied globally, demand growth follows trends similar to Airbus and Boeing projections, aviation is removed from the EU ETS and the majority of CORSIA credits are low-quality, aviation could account for up to 1600 Mt CO_2 emissions even after offset-related reductions are subtracted - roughly a doubling from year-2015 levels. Conversely, in the low emissions growth cases considered here there remains the possibility that global aviation emissions will be able to adhere to the CORSIA ambition of "carbon-neutral growth" from 2020 once offsets are accounted for. However, this "carbon-neutral growth" only occurs for a very specific set of input assumptions, including high CORSIA participation, low demand growth, high quality CORSIA offsets, high oil prices and optimistic assumptions about technology. In particular, because CORSIA covers less than 80% of international aviation CO_2 emissions even at high participation, "carbon-neutral growth" in aviation requires other sources of emissions mitigation beyond CORSIA to achieve. For example, in most scenarios where "carbon-neutral growth" from 2020 is achieved, EU ETS emissions reductions (and the EU ETS's greater level of ambition emission reduction level) help cover this gap. In the case of Policy Option 3, where the EU ETS is not applied after 2020, "carbon-neutral growth" is still achievable in the specific case that high oil prices and optimistic technology assumptions prompt use of biofuels on non-CORSIA routes (provided CORSIA participation is high, all offsets are additional, and demand growth is low). These scenarios, however, represent the very edges of the uncertainty range. If, instead, uncertain variables are set to nominal values, "carbon-neutral growth" from 2020 is not achieved in any scenario.

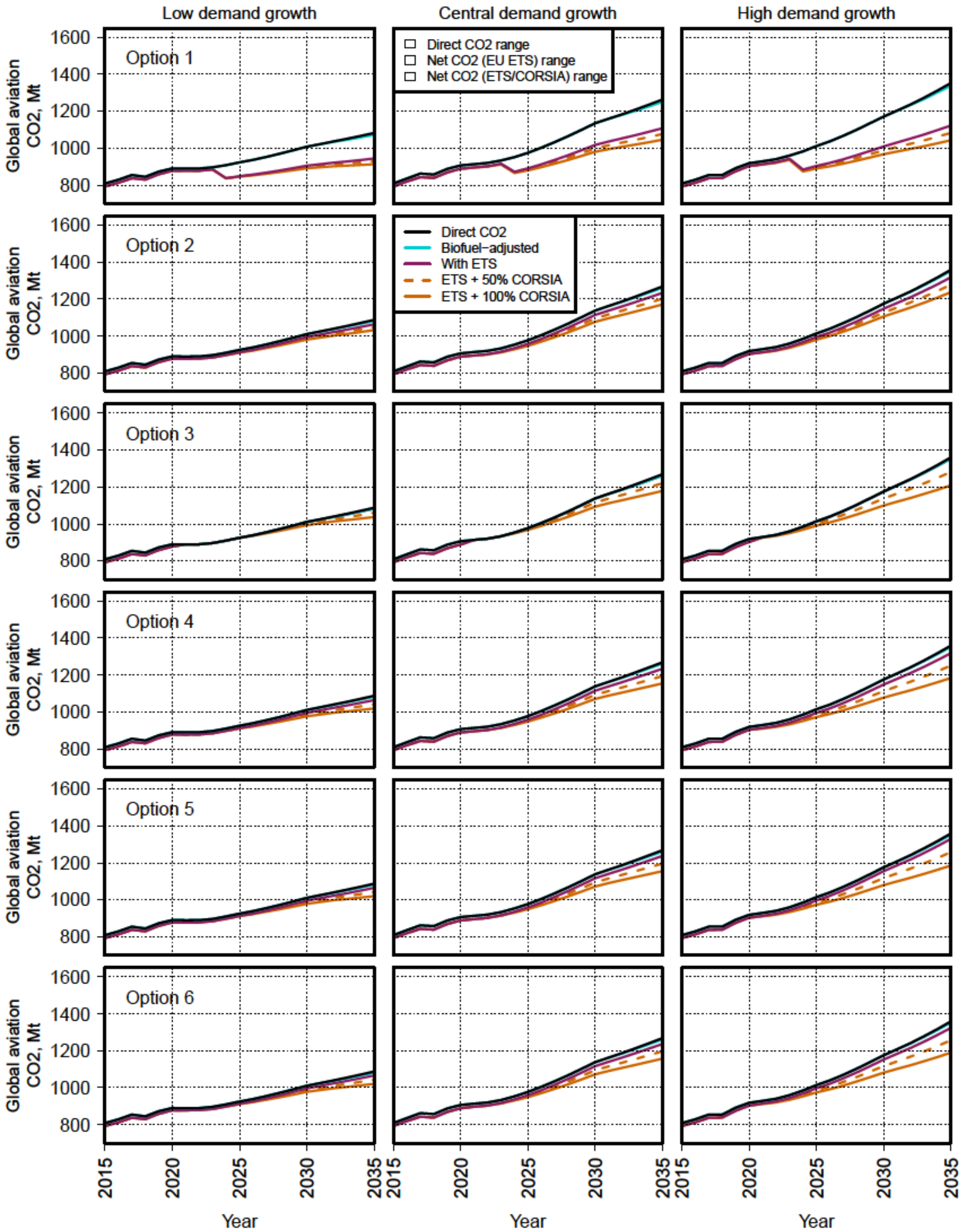

Figure 39. Global net aviation CO_2 emissions by policy option and demand growth scenario, including the impact of EUAs purchased from other sectors and CORSIA offsets at different levels of effectiveness. Background ranges show variation across all combinations of uncertain variables.

These scenarios also differ in the location of emissions reductions, which may in turn interact with national and regional targets. Emissions reductions associated with the purchase of EU ETS allowances by aircraft operators will occur in European countries under the remit of the EU ETS. The location of emissions reductions via CORSIA offsets will depend on the offset supplier, as discussed in Section 2.3.4. Recent CDM international credits have tended to result in emissions reductions in China, with India and Brazil also responsible for significant amounts of CDM credits. American Carbon Registry and Climate Action Reserve credits have typically resulted in US emissions reductions (e.g. American Carbon Registry, 2020)[613]; China GHG Voluntary Emission Reduction Programme credits focus on Chinese emissions reductions; and Gold Standard and VCS projects have also tended to focus on China, India and US emissions reductions[614].

"Carbon-neutral growth" from 2020 is itself a modest goal compared to those being set (and achieved) in some ground-based sectors such as power generation, and reflects the relative difficulty of aviation emissions reductions. Global aviation emitted around 510 Mt CO_2 in 1990 (IEA, 2018)[615]. "Carbon-neutral growth" from 2020 still represents over a 70% increase from year-1990 aviation CO_2 levels. As discussed in Section 2.2, the Paris agreement, in aiming for a global temperature increase of below 1.5°C, implies a global net-zero target by 2050. The long timescales associated with aviation technology development and fleet turnover imply that reaching net zero in aviation would be extremely challenging if "carbon-neutral growth" is maintained to 2035, unless rapid deployment of zero-carbon fuels (with associated limitations on infrastructure, supply and costs as discussed in Section 3.1.2.6) could be deployed. These global outcomes are therefore likely only compatible with the Paris agreement in the case that other sectors can reduce their emissions below zero to a large enough extent that they compensate for aviation's likely net positive CO_2 emissions in 2050 (beyond the emissions reductions in other sectors already accounted for in the projections above).

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613 American Carbon Registry, 2020. Projects Report. https://acr2.apx.com/myModule/rpt/myrpt.asp?r=111; Climate Action Reserve, 2020. Projects Report. https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=111

614 Hamrick, K., Gallant, M., Donofrio, S., Thiel, A. and Yoshimoto, E., 2018. Voluntary Carbon Market Insights: 2018 outlook and first-quarter trends. https://vdocuments.mx/document/voluntary-carbon-markets-insights-forest-trends-2018-09-10-voluntary-carbon.html

615 IEA, 2018. World Energy Balances 2018. https://webstore.iea.org/world-energy-balances-2018-overview

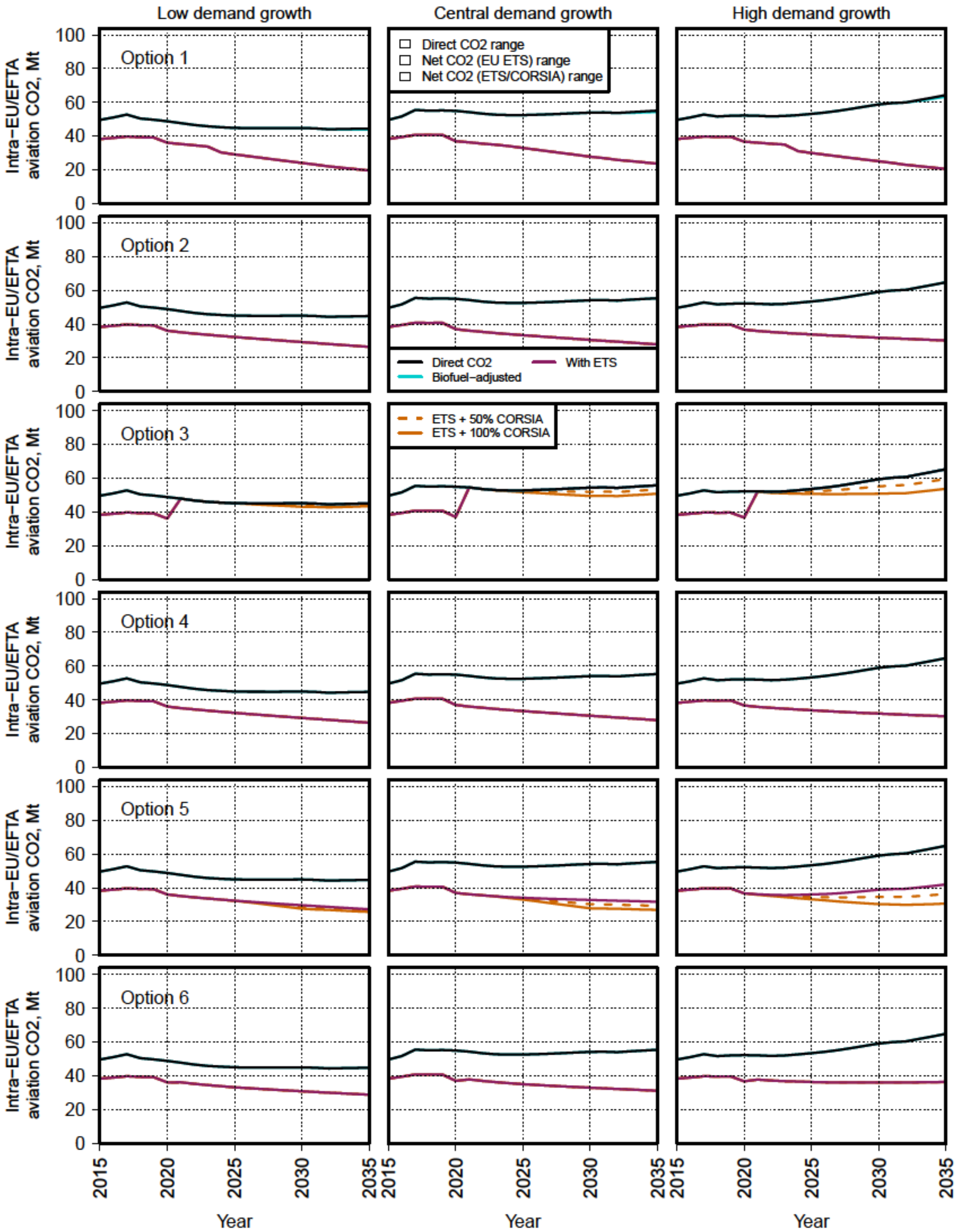

Figure 40. Intra-European (EU27 + Norway, Switzerland, Iceland, not including the UK) net aviation CO_2 emissions by policy option and demand growth scenario, including the impact of EUAs purchased from other sectors and CORSIA offsets at different levels of effectiveness. Background ranges show variation across all combinations of uncertain variables.

The intra-Europe (EU/EFTA, including OMRs but excluding the UK) CO_2 totals shown in Figure 40 demonstrate a larger impact of mitigation measures and offsets. This arises both from greater route-level policy coverage and from typically lower demand growth rates. The larger coverage level also decreases the amount of uncertainty associated with

European net aviation CO_2 emissions. In Option 1, where the EU ETS applies to almost all intra-EU/EFTA flights, net CO_2 emissions remain close to the EU ETS cap throughout. Intra-EU/EFTA totals remain greater than the intra-EU/EFTA EU ETS cap, and uncertainty in outcomes is nonzero, because:

- In Option 6, domestic aviation (and intra-EU/EFTA flights by non-EU/EFTA carriers) is excluded from EU ETS scope;
- In Options 2-6, flights to and from outermost regions are excluded from EU ETS scope;
- In Options 3 and 5 there is substantial coverage of intra-EU/EFTA flights by CORSIA, which exempts domestic flights from scope;
- In Option 1, the EU ETS cap is set on a full scope basis, so there is a small effect on intra-EU/EFTA net CO_2 arising from different balances of pre-2024 demand growth between intra-EU/EFTA and extra-EU/EFTA routes between scenarios;
- For all options, fuel lifecycle emissions associated with the use of biofuels under the EU ETS are not covered (as biofuels are fully exempt but have non-zero CO_2 emissions on a fuel lifecycle basis).

Because the EU ETS cap decreases over time, the relative proportion of total net CO_2 contributed by route groups that are not covered increases over time. If the EU ETS is applied, but CO_2 from route groups or fuel types that are excluded grows faster than the EU ETS aviation cap decreases, then increases in net aviation CO_2 are still possible.

The different levels of uncertainty in outputs per policy reflect the sources of uncertainty discussed above. For example, Option 1 has the highest level of intra-European EU ETS coverage, including both domestic flights, flights to and from outermost regions, and flights between the UK and the EU/EFTA area. The remaining small level of uncertainty arises from biofuel fuel lifecycle emissions. In general, however, EU goals for aviation CO_2 are determined through the EU ETS aviation cap, and so net CO_2 outcomes are consistent with EU ETS goals to the extent that the sector's full emissions are covered by each option. Uncertainty in the quality of CORSIA offsets remains important for Options 3 and 5, but has only a small impact on the other policy options. In the case that Option 3 is chosen and offsets are of low quality, net intra-EU/EFTA aviation CO_2 is likely to increase (by up to around a doubling in 2035 from year-2015 values). Option 3 with the lower of the two offset price trends considered and low-quality offsets is also very close to the case than neither the EU ETS or CORSIA apply to aviation at all. How do these totals interact with aviation's non-CO_2 climate impacts? As discussed by Lee et al. (2009)[616], aviation affects radiative forcing via multiple channels beyond CO_2 emissions, including NOx emissions at altitude via their effect on tropospheric O_3, soot/sulphate aerosols, persistent contrails and aircraft-induced cirrus cloud. Of these, NOx combines both warming and cooling impacts (positively via increases in tropospheric O_3, cooling via reductions in ambient CH_4); sulphate emissions have a cooling impact; soot emissions have a warming impact; and contrails and aviation-induced cirrus have a net warming impact (Dessens et al., 2014)[617]. The magnitude of these impacts is more uncertain than that of CO_2, and the timescales on which they operate are substantially different, making relative impacts dependent both in the metric chosen for comparison and the timescale of comparison. Aviation's total climate impact has been estimated as a factor of 1.7-5.1 above that of CO_2 alone, depending on the assessment timescale (e.g. Macintosh and Wallace, 2009)[618]. As CO_2

[616] Lee, D.S., Fahey, D., Forster, P., Newton, P., Wit, R., Lim, L., Owen, B. and Sausen, R., 2009. Aviation and global climate change in the 21st century. Atmospheric Environment 43, 3520-3537.

[617] Dessens, O., Köhler, M., Rogers, H., Jones, R. and Pyle, J., 2014. Aviation and climate change. Transport Policy, 34, 14-20.

[618] Macintosh, A. and Wallace, L., 2009. International aviation emissions to 2025: Can emissions be stabilised without restricting demand? Energy Policy, 37(1), 264-273.

has the climate impacts of longest duration, CO_2 is a larger fraction of total impacts for longer assessment timescales; for example, at a typical assessment timeframe of 100 years total aviation climate impacts are likely to be closer to a factor of 2 above CO_2 impacts rather than a factor of 5. Neither the EU ETS nor CORSIA address aviation non-CO_2 impacts. Flights whose emissions have been offset, and flights which are exempt from carbon costs via use of biofuels, will both still continue to have non-CO_2 impacts that are similar to those they would have had in the absence of CORSIA or the EU ETS (e.g. Krammer et al., 2013[619]). In general, these studies suggest that, without additional policy, aviation's global climate impact will likely continue to grow over the time horizon of this study, even if the EU ETS and CORSIA are successful in their goals. A reduction in aviation non-CO_2 impacts would require mitigation measures and policy instruments aimed specifically at non-CO_2.

Because a parallel project is currently assessing aviation non-CO_2 as mandated per Article 30 of the EU ETS Directive, the reader is referred to that study for further discussion of the interaction of aviation non-CO_2 impacts with policy.

3.2.11 Impacts on Airline and Airport Competition

The policy-related increases in airline costs examined in this report are likely to affect different airlines and different airports to different extents. This arises both of different policies applying to different routes, and also because longer-haul and shorter-haul routes may be differently affected by the same policy. This in turn may affect the competition between those airlines and airports. In this section, we discuss potential impacts on airline and airport competitiveness. These may include:

- In Option 6, EU/EFTA-registered and non-EU/EFTA registered airlines will pay different carbon costs whilst operating on the same (direct) routes;
- Where effective carbon prices are different for different route groups, airlines which mainly operate on routes with higher carbon prices will have higher total carbon costs (i.e., they will not be able to cross-subsidise from unaffected routes, and may also experience capital constraints that affect their investment decisions);
- Decreases in demand at more-affected airports may affect airport revenue and in turn the ability of those airports to provide connecting schedules and invest in facilities attractive to passengers;
- For multi-segment journeys, itineraries which have lower carbon costs may have a competitive advantage, affecting both airlines and (hub) airports;
- Carbon costs may affect competition between airlines and ground modes, either for individual routes or as part of multi-segment journeys (for example the itinerary New York-London + train London-Paris, versus a New York-Paris direct flight);
- Airlines might choose to move their hub operations to airports associated with lower costs;
- Over the longer term, decisions about the establishment of new airlines and decisions by airline groups about where to invest may prioritise regions with lower carbon costs;
- Tourist destinations which are associated with higher carbon costs and ticket prices may lose market share to those which are not so affected, affecting airports and airlines operating to those destinations;
- Even if policies are applied equally across all routes, competitive distortion may still arise if those policies are not enforced equally across all routes;
- If auctioning costs are fed back into European aviation-related R&D, this may lead to benefits for European airlines and airports (depending on where the results of that R&D are deployed).

[619] Krammer, P., Dray, L., and K Köhler, M., 2013. Climate-neutrality versus carbon-neutrality for aviation biofuel policy. Transportation Research Part D, 23, 64-72.

These areas are discussed individually below. Impacts across the whole aviation sector (in terms of operating costs, ticket prices, and demand) are discussed in Sections 3.2.7, 3.2.8, and 3.2.9.

The most notable potential source of competitive distortion between airlines applies in policy option 6. For the other policy options, all airlines operating on the same flight segment will have broadly similar carbon costs (with small variations depending on the technology and size distribution of the fleet they use on that route). In Option 6, airlines operating on the same flight segment may have substantially different carbon costs. If all scenario variables are set to nominal values, the difference between total operating costs between EU/EFTA-registered and non EU/EFTA-registered airlines on a typical intra-EU/EFTA segment would be around 1% (with a range of around 0.7-3.3% across uncertain scenario variables). Unequal carbon costs between different airlines may also affect the extent to which these costs can be passed through. At an operating margin of 7% (as discussed in Section 3.2.7), a 1-3% difference in operating costs that cannot be passed through may put affected airlines at a significant disadvantage. However, this disparity will apply only on a limited number of routes, because relatively few non-EU/EFTA airlines operate on intra-EU/EFTA routes. In the simulations carried out here, typically 0.2% of intra-EU/EFTA RPK is by non-EU/EFTA airlines. This low fraction arises from legal restrictions and logistical constraints about which airlines can fly between which countries. The rights of airlines to fly between given pairs of states are governed by bilateral air transport agreements between those states. Flights between two states by airlines which are not registered in either state are known as fifth freedom flights (if they are additional hops on the end of a flight originating in the carrier's own state) or seventh freedom flights (if there is no stop at all in the carrier's own state) and are relatively rare[620]. Intra-EU/EFTA flights flown by non-EU/EFTA carriers are almost exclusively additional 'hops' on the end of long-haul extra-EU/EFTA flights (for example, Ethiopian's flight ET713/712 Dublin-Madrid-Addis Ababa). The right to operate this type of flight may be conferred by open skies agreements; for example, the EU-US open skies agreement conferred the right for US airlines to operate an intra-EU flight if it acted as a continuation of a flight originating in the US. If future European aviation includes wider open skies agreements incorporating more countries with seventh freedom rights, it is possible that the proportion of non-EU/EFTA carrier flights within the EU/EFTA will increase in future. However, at present the impact of excluding non-EU/EFTA carriers from EU ETS scope in Option 6 is minimal in comparison to the impact of excluding domestic flights. Additionally, with the UK leaving the EU it is possible that flights by UK-registered airlines might operate within EU/EFTA countries, depending on the eventual operating rights that are negotiated between the UK and other countries. However, in practice UK-based airlines with significant numbers of intra-EU/EFTA flights have already responded to uncertainty surrounding the UK's exit from the EU by setting up European subsidiaries registered in European countries, and transferring the necessary fleet to those subsidiaries to carry on operations (e.g. Easyjet Europe, registered in Austria). Conversely, non-UK registered airlines hoping to operate from the UK to other non-EU/EFTA countries have set up UK subsidiaries (e.g. Norwegian Air UK). One further risk with Option 6 is that, if carbon prices become sufficiently high, airlines in multinational airline groups that include EU/EFTA and non-EU/EFTA members may seek to operate the same flights with their non-EU/EFTA members instead. Similarly, airlines might consider setting up non-EU/EFTA subsidiaries in adjacent countries if the rights were available to operate flights from them. However, this relies on suitable rights being available and (in the case of new subsidiaries) incurs significant costs.

[620] European Parliamentary Research Service, 2016. Briefing: EU External Aviation Policy. https://www.europarl.europa.eu/RegData/etudes/BRIE/2016/582021/EPRS_BRI(2016)582021_EN.pdf

A more general competition-based risk with policies that apply to only a given set of routes is that airlines which operate mainly on affected routes have a higher cost burden than those which only operate a small proportion of flights on those routes. This may affect their ability to cross-subsidise services on affected routes. For example, a US airline operating transatlantic flights might have an advantage over a European airline, because the European airline's total carbon costs were higher. This effect is discussed in CE Delft (2005)[621], CE Delft and MVA (2007)[622], and Scheelhaase & Grimme (2007)[623]. The extent to which airlines cross-subsidise, and the extent to which cross-subsidisation can cause competitive distortion, is relatively uncertain. Scheelhaase & Grimme (2007) find scope for competitive distortion in the case that full cross-subsidisation is assumed. CE Delft (2005) and CE Delft and MVA (2007) argue, however, that cross-subsidisation should be minimal if airlines are assumed to be profit-maximising, as fares on each route should be set at a profit-optimal level for that route and cross-subsidising will reduce overall profits. Faber and Brinke (2007)[624] argue that, because airlines compete on a city-pair level, and all routes are affected roughly equally on this level, the risk of competitive distortion on this basis is small. As noted by CE Delft (2005), airlines that have less fuel-efficient fleets will also suffer higher carbon costs. However, it is arguable as to whether this should be counted as a competitive distortion, as encouraging improvements in fuel efficiency would be a positive policy outcome.

Another risk of competitive distortion applies to competition between airports (both between EU/EFTA and non-EU/EFTA airports, and between different EU/EFTA airports that are affected to different extents). The largest risk of competitive distortion here is between EU/EFTA airports and major non-EU/EFTA airports that are close enough to the edge of the policy area to provide an alternative. This also applies to airlines that operate using these airports as hubs. To illustrate the airport-level impacts of policies, we consider two specific examples where competitive distortion is possible:

- The London airport system (Heathrow, Gatwick, Stansted, Luton and City airports) in comparison to the Paris airport system (Charles de Gaulle and Orly) and Amsterdam Schiphol airport, and
- The Istanbul airport system (Istanbul and Sabiha Gökçen airports) in comparison to Athens International airport.

Typically, each airport will be affected differently based on the policy scope, the airlines operating out of that airport (e.g. full service vs. low-cost), the balance of routes (long-haul vs. short-haul) and regional growth rates in demand. Because airports derive the majority of their revenue from passenger spending (non-aeronautical revenue, e.g. Yokomi et al. 2017[625]) and a more limited share from landing costs (aeronautical revenue), we compare totals in terms of million passenger movements per annum (mppa). Because different regions have different underlying assumed rates of economic growth, it is not

[621] CE Delft, 2005. Giving wings to emissions trading: Inclusion of aviation under the European emissions trading scheme (ETS): design and impacts. https://www.cedelft.eu/en/publications/334/giving-wings-to-emission-trading, Delft, 2005.

[622] CE Delft and MVA (2007). Implications of EU Emission Trading Scheme for Competition Between EU and Non-EU Airlines. CE Delft, Delft.

[623] Scheelhaase, J. & Grimme, W., 2007. Emissions trading for international aviation– an estimation of the economic impact on selected European airlines. Journal of Air Transport Management, 13(5), 253-263.

[624] Faber, J. & Brinke, L., 2011. The inclusion of aviation in the EU Emissions Trading System. ICTSD Programme on Trade and Environment, Issue Paper No. 5. ICTSD, Geneva.

[625] Yokomi, M., Wheat, P. & Mizutani, J., 2017. The impact of low cost carriers in non-aeronautical revenues in airport: An empirical study of UK airports. Journal of Air Transport Management, 64(A), 77-85.

possible to directly compare growth rates per airport region. However, we can compare how airport regions respond to different policies. For the London airport system, the policy option with the greatest impact is option 1. Compared to option 1, demand in mppa is 0.54% higher in options 2 and 4, 0.55% higher in options 3 and 6, and 0.53% higher in option 5. In comparison, changing policy option changes demand at Paris and Amsterdam airports by between 1.0 and 1.4%, with the option with the largest impact being option 1 and that with the least option 3. Similarly, option 1 leads to around 0.45% lower demand at Istanbul airports than the other options; for Athens, the difference in demand by 2035 between options 1 and 3 is around 1.2%.

These levels of impact on individual EU/EFTA airports are broadly consistent with total intra-EU/EFTA demand impacts, discussed in Section 3.2.9. These outputs are generally consistent with the analysis in ATA and Clarity (2018)[626] and Dray and Doyme (2019); they suggest that the net impact of applying carbon prices within a given geographical region on areas outside that region is a *decrease* in demand (due to connecting passengers originating in the affected region choosing not to fly) rather than a leakage-associated increase (due to transfer passengers choosing to hub through unaffected airports). Therefore, we would anticipate that policies associated with higher intra-EU/EFTA carbon costs will reduce demand at both EU/EFTA and non-EU/EFTA airports close to the EU/EFTA, but that the EU/EFTA airports will be marginally more affected (by around 0.5% in terms of total demand, which is significantly under one year’s typical total projected growth for these airport systems).

The possibility of competitive distortion between air and ground modes, or policy-induced mode shift affecting airline competition, is discussed in ATA and Ellondee (2018). This may be in the form of mode shift for the whole journey (e.g train rather than flight from Paris to Rome) or only part (e.g. a flight from New York to Paris, followed by train from Paris to Rome, rather than a direct flight from New York to Rome or a connecting itinerary from New York to Rome stopping in Paris). As discussed by Behrens and Pels (2012)[627], the main alternative mode to air for passengers is high-speed rail (HSR), but this typically only acts as a substitute where a suitable line is available and total journey time is under around 200 minutes. Many routes for which this is the case already have high HSR mode share and the impact of a small change in air ticket prices on air-rail competition is likely to be small. Similarly, increased provision of night trains has been suggested as a way of increasing mode shift from air but existing competition with overnight coach services, high costs per passenger and low capacity limit the amount of mode shift practically achievable in this way (European Parliament, 2017)[628].

Longer-term competitive impacts could be associated with airlines moving their hub operations to less-affected airports, and airline or airline group decisions about where to invest focussing on regions with lower operating costs. As discussed in Section 3.1.1.1, changing networks, and in particular changing hub location, is associated with significant costs. Based on the literature discussed in Section 3.1.1.1, the carbon prices assessed here are unlikely to have a significant impact on passenger airline hub choice. Freight

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[626] 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

[627] 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.

[628] European Parliament, 2017. Passenger night trains in Europe: the end of the line? https://www.europarl.europa.eu/RegData/etudes/STUD/2017/601977/IPOL_STU(2017)601977_EN.pdf

airlines are typically more willing to change hub location (e.g. Gardiner et al., 2005[629]; 43% those surveyed had moved a cargo service in the past two years and 47% of those who had moved did so partly due to cost reductions available elsewhere). However, freight operators who move operations primarily do so between airports in the same catchment area (e.g. Yuen et al. 2017[630]). Because all policy options examined here have similar impact across a given catchment area, this suggests that there will be limited impact on freight hubbing. The impact of individual airlines relocating between regions is dismissed as unlikely by Ernst and Young & York Aviation (2008) due to bilateral air service agreements and ownership regulations. In the case of airline groups which include members from affected and non-affected countries, and/or airlines which share (part-) ownership (e.g. Delta and Virgin) there is a potential risk of long-term investment targeting non-EU/EFTA routes or even the abandonment of EU/EFTA routes in the case that the typical rate of return on affected routes falls below acceptable values. However, as discussed above and in Sections 3.1.1.1 and 3.2.6, the carbon prices here are typically not enough to lead to network change and changes in operating costs are typically well below those due to normal fluctuations in fuel price.

A further source of potential distortion is changes in flight destination. In particular, tourist destinations which are associated with higher carbon costs and ticket prices may lose market share to those which are not so affected, affecting airports and airlines operating to those destinations. However, historically tourism demand has been relatively insensitive to cost changes. Although destination choice can vary between years, typically it is influenced by hard to measure factors such as destination image and destination loyalty (e.g. Chi & Qu, 2008[631]). UNWTO (2006)[632] find only 'limited' impact of tourism demand due to oil price shocks, primarily because oil price-linked changes in air fare were only a small fraction (<5%, judged 'insufficient to alter consumer behaviour') of total holiday cost in the data they examined. Given that even the highest carbon price examined here would have a smaller impact than the changes in oil price examined by UNWTO (2006), it is unlikely that the choice of EU ETS/CORSIA policy would substantially alter tourism destination choice. Similarly, Mayor & Tol (2007)[633] assess the impact of UK Air Passenger Duty (APD) on tourism destination choice and project only a 1.2% reduction in tourism demand to the UK at considerably higher per-passenger ticket price increases than those projected in this report. EC (2009)[634] examine how European tourists responded to recession; whilst these responses are a result of a decrease in disposable income rather than an increase in price, they provide an indication of possible responses to increased flight costs. The surveyed tourists prioritised shorter trips (25%) and cheaper accommodation (19%) as ways of cutting back on holiday budgets, with 16% prioritising

[629] Gardiner, J., Ison, S. and Humphreys, I., 2005a. Factors influenceing airlines' choice of airport: an international study. Journal of Air Transport Management, 11(6), 393-399; Gardiner, J., Ison, S. and Humphreys, I., 2005b. Freight choice operators' choice of airport: a three-stage process. Transport Reviews, 25(1), 85-102.

[630] Yuen, A., Zhang, A., Van Hui, Y., Leung, L. and Fung, M., 2017. Is developing air cargo airports in the hinterland the way of the future? Journal of Air Transport Management, 61, 15-25.

[631] 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.

[632] UNWTO, 2006. The impact of rising oil prices on international tourism. https://www.e-unwto.org/doi/pdf/10.18111/9789284410521

[633] Mayor, K. & Tol, R. The impact of the UK aviation tax on carbon dioxide emissions and passenger numbers. Transport Policy, 14(6), 507-513.

[634] EC, 2009. Europeans and Tourism – Autumn 2009 analytical report. https://ec.europa.eu/commfrontoffice/publicopinion/flash/fl_281_en.pdf

holidays closer to home, 13% taking fewer holidays, and 6% opting for a cheaper means of transport. This suggests that mode switch and changes in destination choice may occur, but are likely small impacts at projected carbon costs, as also projected in previous EU ETS impact assessments; however, tourists reducing their spend on accommodation may still have an impact on tourist destinations.

Another source of potential distortion arises where competing airlines are in theory subject to the same policy, but that policy is enforced to different extents. Aviation has been in the EU ETS since 2012, and current compliance with the scheme has been estimated at around 98% in terms of total CO_2 (EC, 2018). As noted by EC (2019)[635], '*Non-compliant operators* [for 2018] *are typically small or ceased operating in 2018*'. This suggests that compliance and enforcement differences are of limited impact for EU ETS carbon costs. For CORSIA, different levels of enforcement by different states could in theory be a source of competitive distortion; however, because CORSIA effective carbon prices are expected to be much lower than EU ETS effective carbon prices, the impact of this is likely to be minimal.

Finally, possibilities exist for policy impacts that provide competitive advantages to European airlines. If EU ETS revenues are invested into aerospace R&D, European airlines, airports and manufacturers may benefit from the results. ATI (2018)[636] assess typical R&D costs for different types of aerospace technology, noting: *"Clean-sheet aircraft programmes typically cost between $10 and $15 billion* [€9-14 billion]*, whereas variants and new engine adaptation cost between $1 and $5 billion* [€0.9-4.6 billion]*.".* For uncertain variables set to nominal values and no change in auctioning percentage, yearly auction revenues are projected to be €0.7 billion (Option 1), €0.12-0.16 billion (Options 2, 4, 5, 6) or €0 (Option 3; Section 3.2.6) – i.e., likely insufficient to wholly fund development of a completely new aircraft, but comparable (on a yearly basis) to the capital cost of, e.g. implementing A-CDM across 30 or more airports (Eurocontrol, 2008[637]; A-CDM implementation costs estimated at €4 million/airport). Competitive advantages are likely to accrue to EU/EFTA airports and airlines only if the R&D outcomes are used in an EU/EFTA-specific context (e.g. the development of operational procedures to implement at EU/EFTA airports, rather than technology which can be implemented globally. However, given typically long timescales for aviation technology development and deployment[638], it is likely most funding of aviation technology development over the 2020-2035 timescale will lead to mitigation (and competition) impacts after 2035.

3.2.12 Aviation Externalities

Although the policies examined in this report primarily target direct CO_2 emissions, other aviation externalities will be affected via changes in operations and technology. Aviation externalities which are not CO_2-related include airport-area noise, pollution and health impacts from emissions of NO_2/NOx and particulates, non-CO_2 climate impacts including contrails and aircraft-induced cirrus cloud, externalities associated with fuel production and transportation, and water quality issues from airport runoff. EC (2019)[639] give

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[635] EC, 2019. Emissions Trading: emissions have decreased by 3.9% in 2018. https://ec.europa.eu/clima/news/emissions-trading-emissions-have-decreased-39-2018_en

[636] ATI, 2018. The evolving aerospace R&D landscape. https://www.ati.org.uk/media/5fqj5bne/insight_10-the-evolving-aerospace-rd-landscape.pdf

[637] Eurocontrol, 2008. Airport CDM cost benefit analysis. https://www.eurocontrol.int/eec/gallery/content/public/document/eec/report/2005/027_Airport_CDM_CBA_2005.pdf

[638] Dray, 2014. Time constants in aviation infrastructure. Transport Policy, 34, 29-35.

[639] EC, 2019. Handbook on the external costs of transport. https://ec.europa.eu/transport/sites/transport/files/studies/internalisation-handbook-isbn-978-92-

guidance for assessing costs associated with these externalities and for other externalities related to transport, such as those related to accidents, congestion and habitat damage. Although only passenger aviation is considered, the broad impacts of freighter aircraft are likely to be similar as freighter aircraft models are usually either based on specific passenger aircraft models or directly converted from them. We calculate aviation externality costs using the suggested approach in EC (2019), based on the number of passengers and LTO cycles for European airports and modelled NOx and PM2.5 totals. For the scenarios examined here, the appropriate methodology is to use marginal costs, i.e. the additional externality-related costs of adding some amount of extra aviation activity above existing levels. In many cases (e.g. accident costs, air pollution, climate change-related costs) these are close to or identical to non-marginal costs. For example, for air pollution, dose-response relationships and the relationship of other sources of air pollution damage to pollution level are typically linear (EC, 2019). This is not the case for noise: adding additional noise to an already noisy situation is typically less damaging than adding noise to a previously quiet situation, so marginal noise costs are typically below absolute average noise costs. Where a range of values is given, this range is used to inform the upper and lower end of the uncertainty range estimated.

In general, total externality costs are the same or similar across the different policy options unless the impact of CO_2 reductions outside the aviation sector is included (which, depending on the emission-reducing sector, may be associated with other changes in externalities associated with that sector). For example, for accidents, EC (2019) calculate typical costs based on dividing total costs by performance data (passengers, tonnes carried, passenger-km or LTO cycles), using an EASA-derived accident rate per movement. Estimated average accident-related cost per landing and takeoff (LTO) cycle is around €22.95. The different CORSIA and ETS-related options affect accident costs only via different numbers of takeoffs and landings. If all scenario values are set at nominal values, the largest difference between policy options in global number of flights is between Option 1 and Option 3, at around 120,000 flights by 2035. Option 3 in this case would have average global accident-related costs (assuming costs are equal in all countries with a Europe-appropriate Value of Statistical Life) of around €3 million more than Option 1 in 2035.

For congestion, EC (2019) do not give aviation-related estimates. Congestion and disruption can be significant sources of costs for airlines and passengers, particularly within Europe where regulations mandate varying levels of passenger support for a given level of delay (e.g. Cook et al., 2012)[640]. These costs are non-linear with delay amount, with overnight delays for which airlines are required to provide hotel accommodation and refunds the most costly. However, the amount of delay cost is strongly linked both to decisions about airport capacity and to disruptive events within the aviation system which can be difficult to predict. Because there is little information on capacity decisions over the timescale of the simulations carried out here, we assume that sufficient capacity will be available to keep delays at current levels[641], implying that per-passenger delay costs will remain roughly constant.

Table 30 shows typical values for the metrics used to calculate externality costs, on an EU/EFTA basis. In general, non-CO_2 externalities are also related to the level of demand (via passenger and aircraft movements and/or fuel use), and are lower in lower-demand scenarios. NOx and PM2.5 are calculated directly in AIM. Although AIM produces output

79-96917-1.pdfhttps://op.europa.eu/en/publication-detail/-/publication/9781f65f-8448-11ea-bf12-01aa75ed71a1

[640] Cook, A., Tanner, G. & Lawes, A., 2012. The hidden cost of airline unpunctuality. Journal of Transport Economics and Policy. 46(2), 157-173.

[641] In some cases, this may involve increased usage of secondary airports in multi-airport systems.

noise energy metrics, because EC (2019) does not provide externality costs on this basis, we use the number of LTO cycles over time to estimate noise-related costs. This effectively assumes that noise costs per LTO remain roughly constant to 2035[642]. Habitat destruction costs are estimated as a function of total passenger numbers, and accident costs are estimated as a function of the number of LTO cycles. Because of trade-offs between engine fuel use, noise and NOx, NOx emissions indices (i.e., the amount emitted for a given amount of fuel burnt) have tended to remain broadly constant or increase over time, with reductions in NOx coming primarily from decreases in absolute fuel use (e.g. Faber at al., 2008)[643]. PM2.5 emissions are modelled a function of, and reflect trends in, engine pressure ratio. Externality totals are also a function of fleet composition, which is itself a function of rates of demand growth over the past 30 or more years. In the case that demand growth is higher, the regional aircraft fleet is typically younger, as a higher proportion of the fleet will have been bought more recently.

Table 30. Metrics used to calculate annual externalities (passenger and flight movements, local NOx and local PM2.5), 2030 and 2035. Numbers in larger font show values at nominal inputs for uncertain scenario variables. Numbers in brackets show the range due to variation in uncertain scenario variables.

Policy option	EU/EFTA airport passenger movements, Mppa		EU/EFTA airport LTO cycles, million		EU/EFTA airport local NOx, thousand tonnes		EU/EFTA airport local PM2.5, tonnes	
	2030	2035	2030	2035	2030	2035	2030	2035
Option 1	1930 (1540-2310)	2070 (1600-2710)	7.79 (6.18-9.09)	8.28 (6.36-10.3)	54.8 (42.9-75.9)	56.5 (43.1-88.7)	307 (236-425)	279 (206-434)
Option 2	1940 (1560-2320)	2080 (1630-2720)	7.81 (6.25-9.13)	8.31 (6.47-10.4)	55.1 (43.4-76.7)	57.1 (43.9-90.0)	308 (239-429)	284 (208-605)
Option 3	1950 (1570-2330)	2100 (1660-2740)	7.85 (6.32-9.18)	8.37 (6.57-10.5)	55.4 (43.7-77.1)	57.5 (44.3-90.8)	310 (240-432)	287 (211-444)
Option 4	1940 (1560-2320)	2080 (1630-2720)	7.81 (6.24-9.13)	8.31 (6.47-10.4)	55.1 (43.4-76.6)	57.1 (43.9-90.0)	309 (239-429)	285 (210-484)
Option 5	1940 (1560-2320)	2080 (1630-2730)	7.81 (6.24-9.14)	8.32 (6.47-10.4)	55.2 (43.4-76.8)	57.2 (43.9-90.3)	309 (238-549)	284 (210-445)
Option 6	1940 (1560-2320)	2080 (1640-2730)	7.82 (6.26-9.14)	8.32 (6.50-10.4)	55.2 (43.5-76.8)	57.2 (44.0-90.3)	309 (239-580)	284 (256-561)

Figure 41 shows the corresponding development of externality costs for European (EU/EFTA) airports to 2035, excluding climate costs. These values are similar to those estimated for the European aviation system in EC (2019) and remain at similar levels to 2035. This reflects typically lower externality impacts per flight, but a greater number of

642 Although we project noise energy per LTO to decrease to 2035, the relationship of this to noise annoyance, health impacts and costs is more complex; uncertainty in noise impacts is covered in the range of total costs shown via a range of noise cost per LTO estimates.

643 Faber ,J., et al. ,2008. Lower NOx at higher altitudes. https://ec.europa.eu/transport/sites/transport/files/modes/air/studies/doc/environment/oct_2008_nox_final_report.pdf

flights. In the high demand growth case demand growth is faster than typical externality reductions per flight, leading to a substantial increase in total externality costs to 2035.

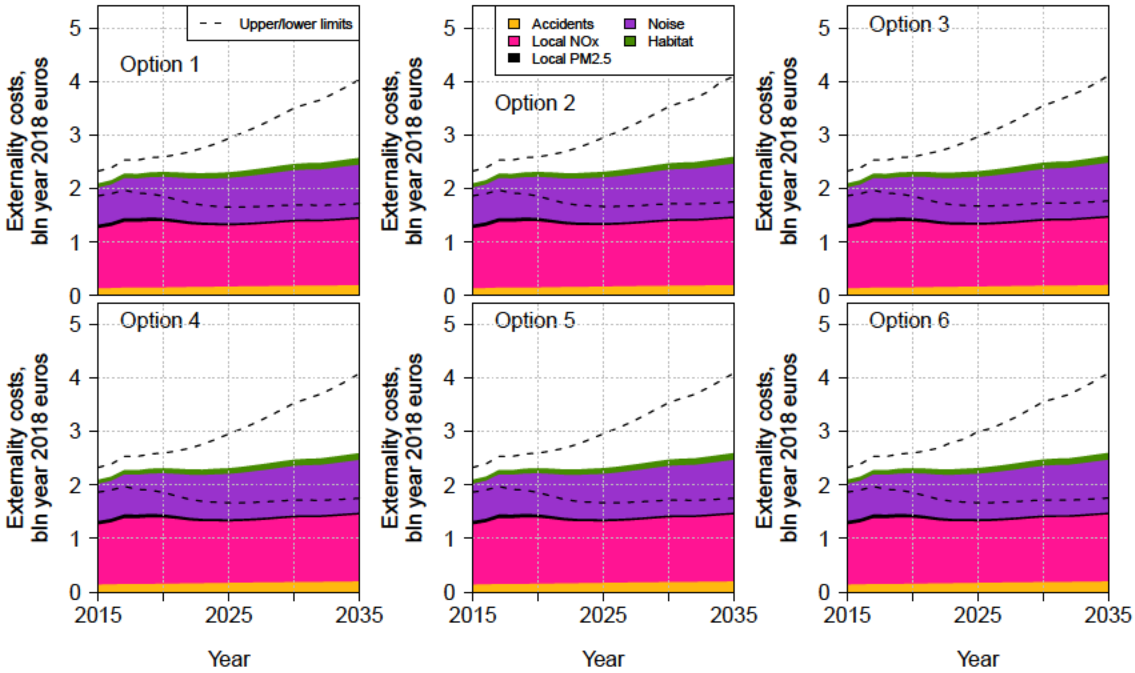

Figure 41. Estimated externality costs from European airports (EU/EFTA) by policy option and externality type, excluding climate impacts.

As discussed in EC (2019), however, for aviation climate-related externality costs dominate cost totals. Figure 42 shows aviation externality costs over time, including climate costs. Although non-climate costs are also plotted, they are not visible on the scale needed to cover the uncertainty range in climate costs. These totals assume an effective uplift factor of 2 for non-CO_2 climate impacts. Because CO_2 reductions in other sectors may be associated with their own (uncertain) changes in other externalities, only within-sector costs are shown. Similarly, costs associated with the fuel lifecycle are omitted. EC (2019) recommend the use of a higher externality cost for CO_2 emissions after 2030, shown as a step change in Figure 42.

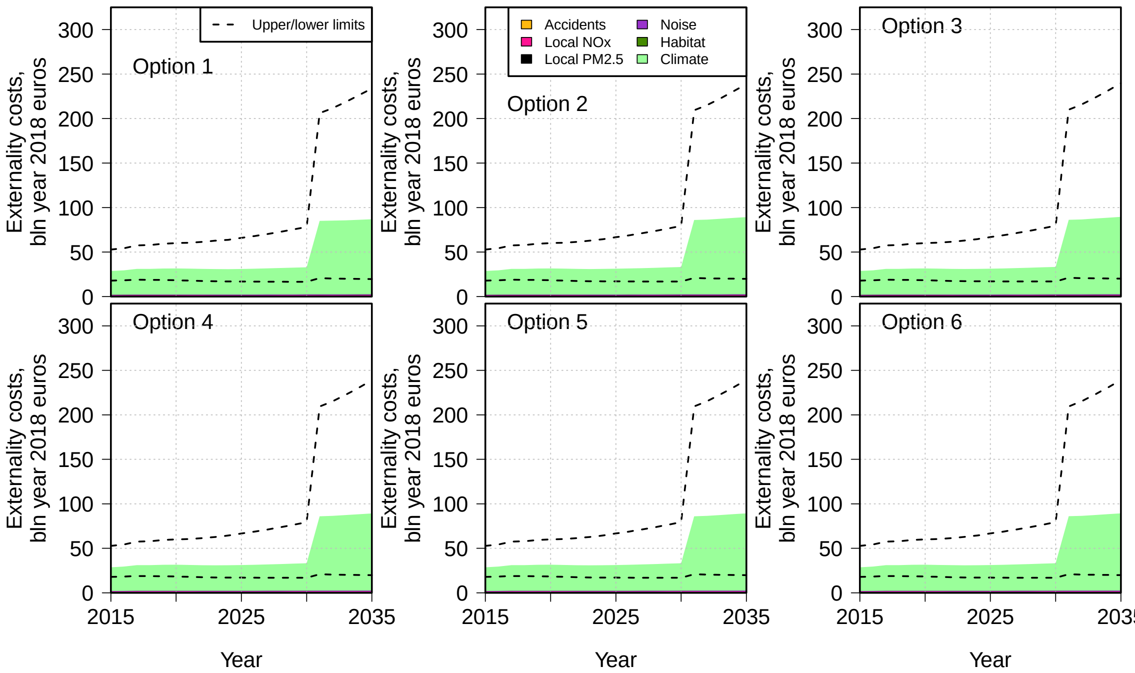

Figure 42. Estimated externality costs from European airports (EU/EFTA) by policy option and externality type, including climate impacts. Note different recommended per-kg costs for CO_2 before and after 2030.

Total estimated externality costs by policy option are shown in Table 31. Climate costs are direct costs, i.e. arising from CO_2 emitted in flight and not accounting for reductions in CO_2 in other sectors. If climate-related costs are not considered, the differences in externality cost between different policy options are small and arise almost entirely from differences in demand between the different scenarios. For example, NOx-related costs are lowest for Policy Option 1 because the number of flights in Policy Option 1 is lowest. Similarly, if climate-related costs are considered, Policy Option 1 has the lowest externality cost because within-sector CO_2 is lower that for the other options. Because climate costs dominate over all other sources of externality cost combined for aviation, if CO_2 reductions in other sectors are considered then the policy with the lowest externality costs is straightforwardly the lowest net-CO_2 option, as discussed in Section 3.2.10.

Table 31. Total estimated EU/EFTA aviation externality costs by category, 2021-2035. Numbers in larger text give values at nominal values for all uncertain scenario variables. Numbers in brackets give the range of variation across different values for uncertain scenario variables.

Policy option	Accident costs, billion €2018	NOx costs, billion €2018	PM2.5 costs, billion €2018	Noise costs, billion €2018	Habitat destr'n costs, billion €2018	Climate costs, billion €2018	Total, billion €2018
Option 1	2.579 (2.084-2.925)	17.27 (13.85-22.60)	0.616 (0.489-0.801)	12.98 (6.991-19.62)	1.688 (1.366-1.946)	693.4 (238.9-1685)	728.5 (263.7-1733)
Option 2	2.586 (2.102-2.935)	17.37 (13.98-22.80)	0.617 (0.493-0.876)	13.02 (7.051-19.70)	1.693 (1.381-1.954)	703.1 (241.3-1710)	738.4 (266.3-1758)
Option 3	2.600 (2.121-2.952)	17.45 (14.06-22.94)	0.621 (0.496-0.831)	13.09 (7.117-19.81)	1.701 (1.393-1.965)	704.9 (242.7-1715)	740.4 (267.9-1764)
Option 4	2.586 (2.101-2.935)	17.37 (13.98-22.81)	0.617 (0.493-0.820)	13.02 (7.050-19.70)	1.693 (1.381-1.954)	703.1 (241.3-1710)	738.3 (266.3-1758)
Option 5	2.587 (2.101-2.938)	17.38 (13.98-22.84)	0.617 (0.493-0.806)	13.02 (7.050-19.72)	1.694 (1.381-1.956)	703.2 (241.3-1712)	738.5 (266.3-1760)
Option 6	2.590 (2.106-2.940)	17.39 (14.00-22.84)	0.618 (0.493-0.907)	13.03 (7.067-19.73)	1.695 (1.384-1.957)	703.3 (241.4-1711)	738.6 (266.5-1759)

3.2.13 Impacts of Changes in Auctioning

Currently, 15% of aviation allowances (EUAAs) are auctioned and 85% are supplied free of charge (82% via benchmarking, and 3% as a new entrants' reserve). Because aviation emissions exceed the EU ETS aviation cap, airline operators also pay for EUAs from other sectors. In practice, this currently means that around 45% of allowances used by aviation are free allowances (EU ETS data viewer, 2020). Free allocation is intended for use in sectors where carbon leakage may occur (EC, 2019)[644]. Carbon leakage is the increase of CO_2 emissions outside a given policy area when a policy is applied, and is usually expressed in percentage terms. For example, in the case of 100% leakage the increase in emissions outside the policy area would be exactly equal to the decrease in emissions in the policy area, leading to no overall global change in CO_2. The intention of free allocation is to prevent emitters avoiding carbon costs by moving the location of emissions outside the policy area (e.g. relocating a factory outside the EEA). For aviation, leakage might occur via airline decisions (e.g. choosing to develop non policy-affected routes) or passenger decisions (e.g. choosing an itinerary that hubs via a non-policy-affected country), with the balance of the two depending on rates of cost pass-through. Most sectors in which free allocation is used are undergoing a gradual transition towards greater auctioning percentages. For example, free allocation is planned to decrease to 30% in 2020 from an initial 80% for manufacturing industry. An additional concern for aviation is that airline profit margins are often small, and sufficiently large carbon prices could put EEA airlines

[644] EC, 2019. Free allocation. https://ec.europa.eu/clima/policies/ets/allowances_en.

at a competitive disadvantage in geographic contexts where they are competing with unaffected airlines.

The extent to which aviation is subject to carbon leakage is uncertain, and likely depends on the geographic extent of the policy area and the type of policy applied. Ernst and Young & York Aviation (2008) discussed a number of case studies where leakage was likely to occur, but did not quantify system-wide impacts. Dray & Doyme (2019)[645] model global-level carbon leakage of different UK-specific policy types, including carbon pricing. If leakage is defined as any change in emissions outside a given policy area, then they find that leakage due to carbon pricing is often negative, i.e. emissions both inside and outside the policy area decrease. This arises from the combination of two main competing effects:

- Passengers who are on a stopping itinerary who could hub via an airport in the policy area choose instead to hub via a (cheaper) airport outside the policy area, leading to an increase in emissions outside the policy area (this is the main leakage mechanism discussed in Ernst & Young and York Aviation (2008)).
- Passengers who are travelling to or from the policy area on a stopping itinerary may decide not to travel due to increased costs, reducing emissions both inside and outside the policy area (for example, a passenger choosing not to fly Paris-Dubai-Sydney will reduce emissions on both the Paris-Dubai and Dubai-Sydney legs). This leads to negative leakage.

The relative magnitude of these impacts will depend on the price sensitivity of passengers as well as parameters related to passenger choice of itinerary. However, for the specific case of UK policies discussed in Dray & Doyme (2019) the negative leakage component typically exceeds the positive leakage component for most combinations of parameters. Because the positive components of aviation leakage are typically smaller for policies with a larger geographic extent (as fewer alternative non-policy hubs are available which do not involve a large detour), significant positive leakage is unlikely from greater auctioning percentages. The main risk of this type of leakage comes from the assumed omission of the UK from policy scope. This is because London Heathrow is one of a number of competing, geographically close hub airports for intercontinental flights transferring to an intra-Europe flight leg. However, the UK has recently adopted a 2050 net zero CO_2 target (BEIS, 2019)[646] assumes substantial carbon prices in its own aviation forecasts (DfT, 2017)[647] and already applies air passenger duty (at standard rate) of £26-176 (€29-196) per flight[648]. This suggests that additional changes in UK aviation policy would be required to make the UK a significant leakage risk for changes in EU ETS auctioning. Numerical estimates of leakage are discussed later on in this section.

In this report, we test five options for changing the auctioning percentage to 2030. These options are:

0) Status quo: The current legal situation is perpetuated until 2030, i.e. a 15% auctioning share.

1) Immediate phase-out: 100% auctioning from the entry into force of the revision.
2) Swift phase-out: Full auctioning by 2025, starting with an auctioning share of 60% in 2023, and a share of 80% in 2024.
3) Slow phase-out: A linear increase year-by-year to full auctioning by 2030 starting from 20% in 2023.

[645] Dray, L. & Doyme, K., 2019. Carbon Leakage in Aviation Policy. Climate Policy, 19, 1284-1296.

[646] BEIS, 2019. UK becomes first major economy to pass net zero emissions law.

[647] DfT, 2017. UK aviation forecasts 2017. https://www.gov.uk/government/publications/uk-aviation-forecasts-2017

[648] HM Revenue and Customs, 2019. Rates for air passenger duty. https://www.gov.uk/guidance/rates-and-allowances-for-air-passenger-duty

4) Slow reduction: A linear increase year-by-year starting with an auctioning share of 20% in 2023 and ending at 55% in 2030

For the 2030-2035 period we assume for each of the cases above that the auctioning share remains constant at its year-2030 value (so, for example, in the Slow Reduction case the auctioning share remains at 55% between 2030 and 2035). These options are evaluated by policy option with all uncertain inputs set to nominal values separately from the main grid of models. However, information from the main grid of model can be used to infer uncertainty levels in the modelling outputs. In particular, as all combinations of parameters in the main grid still result in CO_2 remaining above the EU ETS aviation cap, auctioning revenues are likely to be predictable and consistent across all combinations of uncertain variables other than carbon price. Figure 43 shows the number of allowances by type (free, auctioned EUAAs and EUAs purchased by aviation from other sectors) over time for each combination of ETS/CORSIA policy option and auctioning percentage option. Note that the panels for Option 1 (top row) are plotted with different limits to those for the other options. The number of free and auctioned allowances (left-hand and central panels) depend only on policy decisions such as the EU ETS aviation scope and cap, LRF and auctioning percentage over time. These totals may be different if different decisions are made about these policies, but are unlikely to vary significantly in response to changes in uncertain variables. The number of EUAs purchased from other sectors (right-hand panels in Figure 43) is broadly consistent between the scenarios shown because all are run with uncertain scenario variables set to nominal values. However, as discussed in Section 3.2.6, the amount of EUAs purchased by aviation can vary significantly based particularly on uncertainty related to future demand growth and aircraft technology. The uncertainty range for EUA demand from aviation for these scenarios is expected to be similar to that for the main grid of model runs. The small differences in EUA demand between the different auctioning options shown in Figure 43 arise from differences in small demand due to greater or smaller carbon costs. This demand response in percentage terms is likely to be smaller for higher baseline demand growth scenarios, because the relative growth in carbon price from changing auctioning percentages will be less.

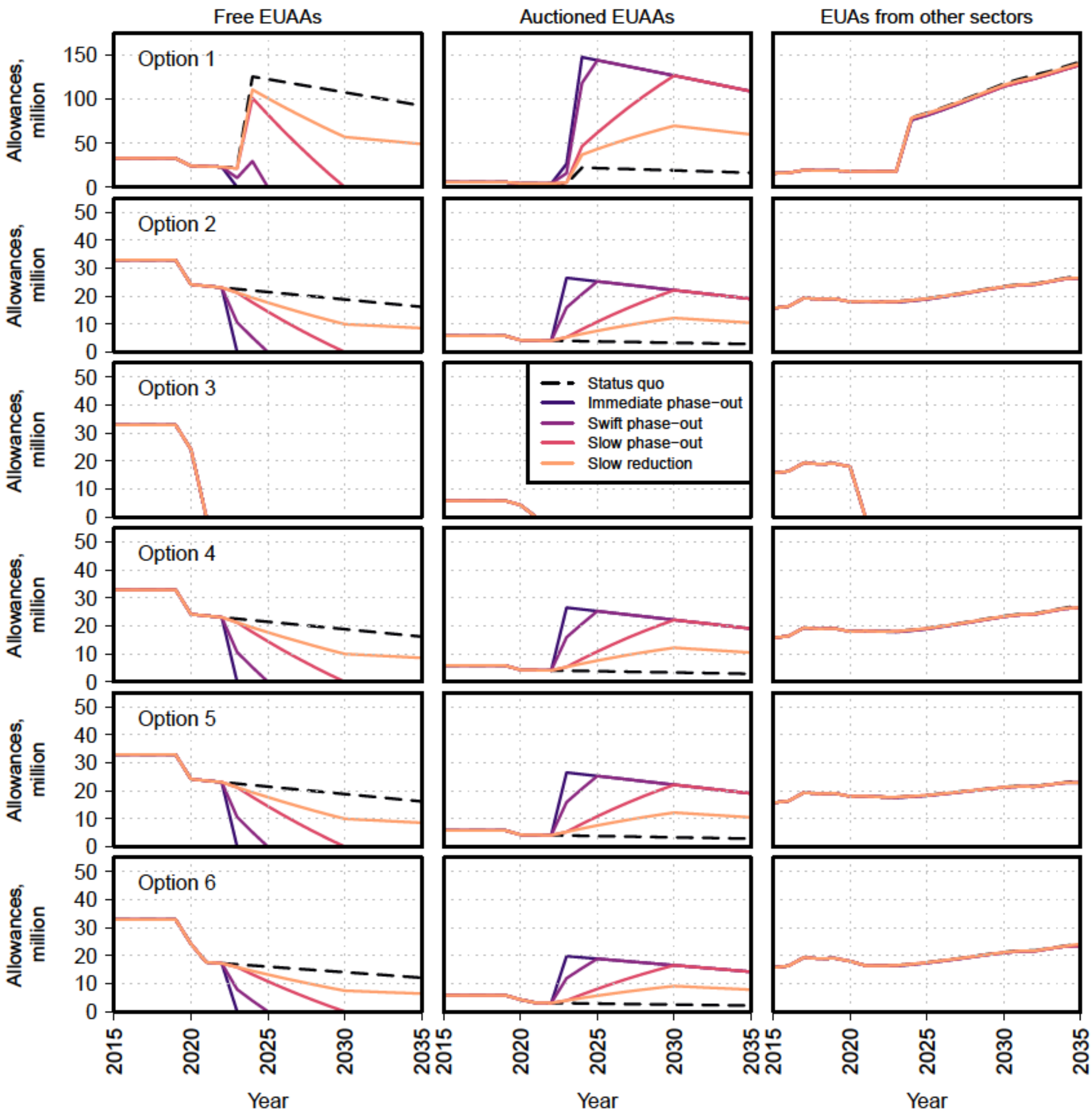

Figure 43. Free and auctioned EUAAs and EUAs purchased from other sectors, for the six different policy options and five different options for auctioning percentage over time, with uncertain scenario variables at nominal values. A different scale has been used for Option 1.

Figure 44 shows total global EUAA auctioning revenue, airline costs for EUA purchase from other sectors, and (for comparison) CORSIA offset costs over time, by main policy option and auctioning option. All uncertain variables are set to nominal values, including carbon price. Note that the top panels (Option 1) use a different limit to the lower panels. For the higher carbon price scenario, we would expect EUAA auction revenues to scale straightforwardly with carbon price. For EUA purchase costs and CORSIA offset costs, we would expect totals to approximately scale with carbon price, but with an additional small reduction in demand at higher carbon price due to higher ticket prices. Table 32 shows the corresponding total year 2023-2030 projected aviation auctioning revenue per combination of policies as well as the projected amount paid by aviation for allowances from other sectors.

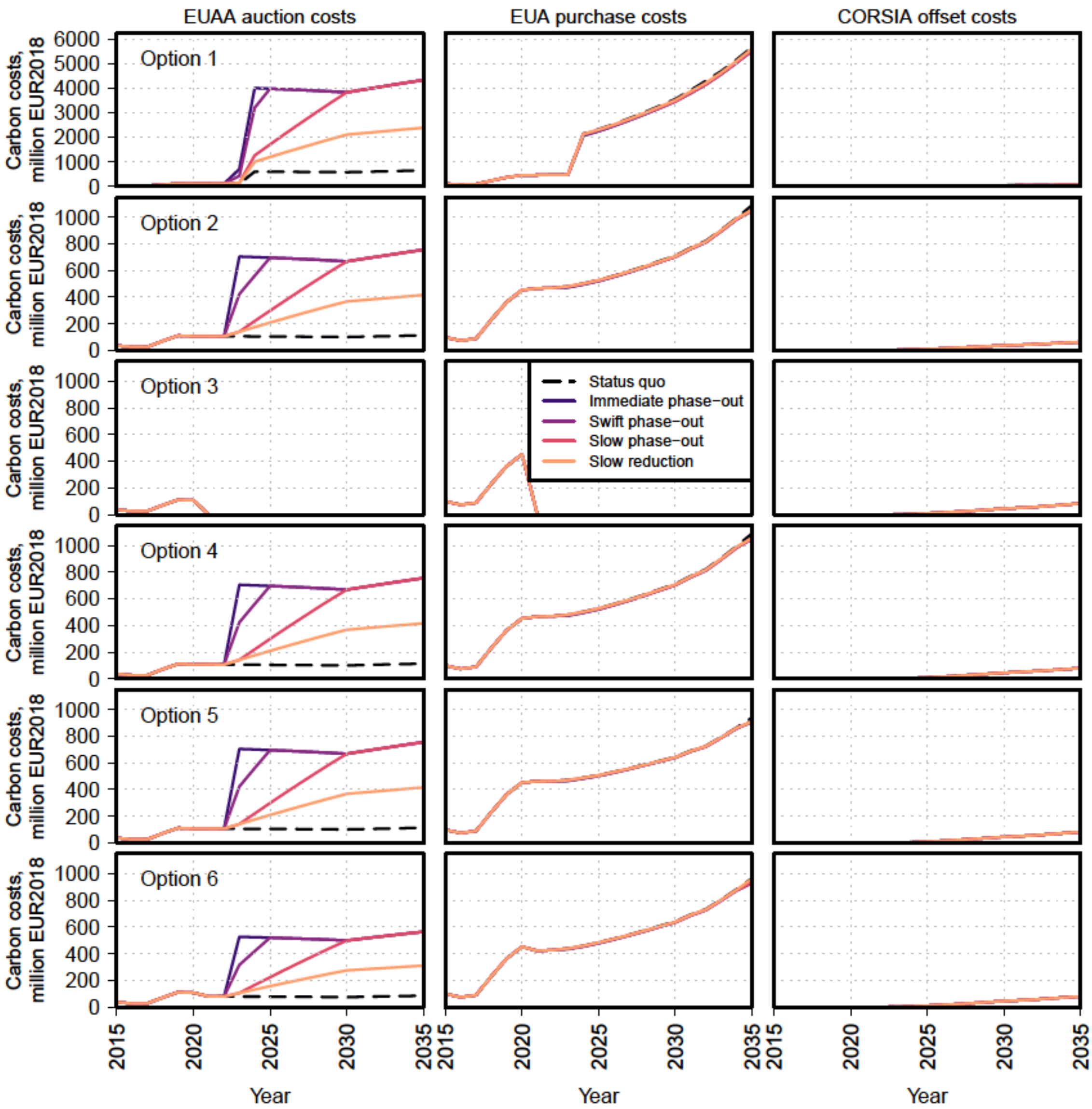

Figure 44. Global auctioned EUAA costs, costs from EUAs purchased from other sectors, and CORSIA costs, for the six different policy options and five different options for auctioning percentage over time, with uncertain scenario variables at nominal values. A different scale has been used for Option 1.

With scenario variables set to nominal values, aviation auctioning costs to airlines vary substantially depending on the auctioning option chosen, ranging from nearly €30 billion over the 2023-2030 period in the case of an immediate phase-out of auctioning and full scope EU ETS, to €0 in the case that only CORSIA is applied. Typically, global EU ETS-related airline costs exceed CORSIA-related costs unless the EU ETS for aviation is stopped completely (Option 3). This is because EUA prices are assumed to be significantly higher than eligible unit prices for CORSIA under nominal scenario values. By far the largest total global airline carbon costs are incurred in Policy Option 1, which includes flights to and from the EU/EFTA region within the EU ETS scope. Additionally, carbon costs per passenger are also substantially greater in Option 1, because a greater proportion of the costs associated with extra-EEA flights is fuel costs (as discussed in Section 3.2.6). The speed of the phase-out strongly affects EUAA auctioning revenue over the 2023-2030 time period, with an immediate phase-out being associated with 50% more total revenue than a slow phase-out. In contrast, aviation demand for EUAs is only weakly affected by the chosen auctioning option chosen, with typically only 1-3% difference in total year 2023-

2030 EUA demand between the status quo and immediate phase-out options. This reflects relatively small impacts on overall demand. A much larger impact on EUA requirements is expected in the case that baseline demand growth is faster or slower than in the central demand scenario, or technology developments are faster or slower than in the central technology scenario, as discussed in Section 3.2.6.

Table 32. Total year 2023-2030 auctioning revenue and amount paid by aviation to other sectors for EUAs, by ETS/CORSIA policy and auctioning option, with all other scenario variables set to nominal values.

	Status quo	Immediate phase-out	Swift phase-out	Slow phase-out	Slow reduction
Total EUAA auctioning revenue 2023-2030, million €2018					
Option 1	4230	28200	27100	18100	11100
Option 2	826	5510	5080	3280	2050
Option 3	0	0	0	0	0
Option 4	826	5510	5080	3280	2050
Option 5	826	5510	5080	3280	2050
Option 6	617	4110	3800	2450	1530
Total amount paid for EUAs from other sectors, 2023-2030, million €2018					
Option 1	20100	19600	19600	19800	20000
Option 2	4680	4620	4620	4650	4670
Option 3	0	0	0	0	0
Option 4	4680	4620	4620	4650	4670
Option 5	4410	4370	4370	4390	4400
Option 6	4260	4220	4230	4240	4250

Impacts on airline cost per RPK, ticket prices and demand (in RPK) by route group are shown in Figure 45, and totals by policy for intra-EU/EFTA scope are summarised in Table 33. For Figure 45, for clarity only policy options 1, 2 and 3 are shown, as outcomes for options 4, 5 and 6 are close to those in option 2. As discussed above, the main factors affecting the development of airline costs and fares over time are: changes in fuel prices; increased labour costs as GDP per capita increases; changes in maintenance and fuel costs arising from the adoption of new technologies; changes in average costs of all types arising from changes in the average routes flown (for example, a general trend towards longer-haul flights); and carbon costs. Of these, typically the greatest source of short-term variability is fuel price. In the most extreme carbon price case (extra-EU/EFTA flights with immediate phase-out of auctioning combined with Option 1), carbon costs in 2024 add around 4% to total operating cost per RPK compared to a situation where no carbon price is applied to these routes, increasing to just under 5% by 2035. This is about twice the impact, in terms of total costs, of applying the same policy option without any changes in auctioning, but is still well below the impact of recent fluctuations in oil price. We project that around 75% of this cost will be passed through, given the characteristics of the routes operated in terms of competition, airport congestion and passenger demand sensitivity. As discussed in Section 3.2.6, recent (2015-2018) intercontinental airline operating margins have been large, often in excess of 10%, though it is unclear if they will return to these values after the COVID-19 pandemic. Historical operating margins have typically been below this and are occasionally negative. Full auctioning of allowances on extra-EU/EFTA routes is likely to result a reduction in profits on these routes. If starting from a baseline of year 2015-2018 operating margins, full auctioning of allowances on extra-EU/EFTA routes would reduce margins to a level more typical of shorter-haul flights.

The proportional impact of auctioning changes depends on overall emissions growth rates. In the case that demand growth is faster than the nominal scenario used here, or CO_2 mitigation options are fewer, emissions under the EU ETS aviation cap would be responsible for a smaller fraction of overall aviation CO_2. Changing auctioning percentages in this case would result in a lower relative increase in costs and hence a lower relative impact on airline profits, fares and demand.

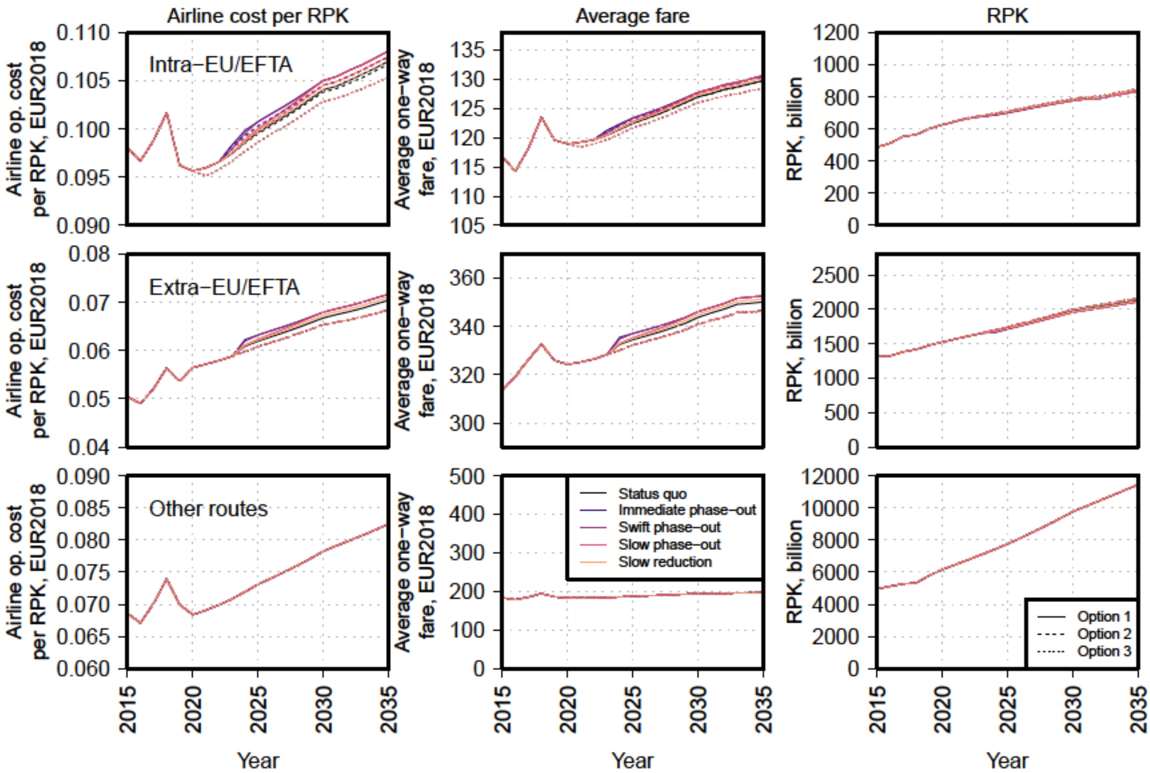

Figure 45. Airline cost per RPK, average one-way ticket price and RPK by combination of CORSIA/ETS and auctioning policy option, for all uncertain scenario variables set to nominal values and intra-EU/EFTA, extra-EU/EFTA and other route scopes. Only policy options 1, 2 and 3 are plotted as outcomes for options 4, 5 and 6 are close to option 2.

Table 33. Year-2030 impact on one-way intra-EU/EFTA ticket prices and intra-EU/EFTA RPK by combination of CORSIA/ETS policy and auctioning option, with uncertain scenario variables set to nominal values.

	Status quo	Immediate phase-out	Swift phase-out	Slow phase-out	Slow reduction
Intra-EU/EFTA average one-way ticket price, year 2030, €2018					
Option 1	127.0	127.8	127.8	127.8	127.4
Option 2	127.0	127.7	127.7	127.7	127.3
Option 3	126.0	126.0	126.0	126.0	126.0
Option 4	127.0	127.7	127.7	127.7	127.3
Option 5	127.0	127.6	127.6	127.6	127.2
Option 6	126.8	127.2	127.2	127.2	127.0
Intra-EU/EFTA RPK, year 2030, billion					
Option 1	782	776	776	776	779
Option 2	784	781	781	781	783
Option 3	789	789	789	789	789
Option 4	784	781	781	781	783
Option 5	785	781	781	781	783
Option 6	785	782	782	782	783

As AIM models passenger itinerary choice and airline frequency choice per route, we can also check whether carbon leakage due to these effects has occurred. For example, non-EU/EFTA routes are treated equally in Option 3 and in Option 1 with immediate phase-out of free alliances; both are subject to CORSIA only. Changes in emissions on these routes due to changes in carbon costs on EEA routes reflects various different leakage mechanisms, for example:

- Multi-segment passengers whose origin or destination is in an EU/EFTA country choosing not to fly, reducing emissions on both the EU/EFTA and non-EU/EFTA segments in their journey (negative leakage);
- Passengers whose origin or destination is in an EU/EFTA country choosing to route via a non-EU/EFTA hub airport (if a suitable hub is available), moving some of the emissions associated with their journey outside the policy scope (positive leakage);
- Multi-segment passengers travelling between non-EU/EFTA countries choosing to hub via a non-EU/EFTA country (if a suitable hub is available; positive leakage);

- Airlines investing in new technologies to reduce their carbon costs and using those technologies across their whole route network, including non-EU/EFTA routes.

Comparing Option 3 and Option 1 with immediate phase-out of free allowances in 2035, we find that non-EU/EFTA routes in Option 3 have higher CO_2 by around 0.9 Mt, i.e. leakage from these sources is overall negative. In comparison, direct aviation CO_2 on flights to, from and within the EU/EFTA region reduces by around 9 Mt, and 133 Mt of aviation CO_2 is offset by emissions reductions in other ETS sectors. Similarly, comparing Option 4 with immediate phase-out of free allowances with Option 3 allows assessment of ETS aviation leakage in the case that the EU ETS does not cover extra-EU/EFTA routes. In this case we also see negative leakage, with around 0.6 Mt reduction in direct CO_2 in 2035 on non-ETS routes in Option 4 with immediate phase-out. The other policy and phase-out options typically have smaller differences in carbon costs between adjacent regions, so should have smaller leakage effects. In all cases the dominant source of leakage appears to be the first effect discussed above, i.e. negative leakage from passengers on multi-segment journeys starting or ending in the policy area who choose not to fly. As discussed in Dray & Doyme (2019), the size of this effect is dependent on assumptions about passenger price sensitivity, but it still occurs across a wide range of assumptions about price sensitivity.

In general, these results suggest there is a low risk of (positive) carbon leakage when switching to a higher auctioning percentage, and that changes in cost associated with auctioning changes are still well within the range of cost variability due to fluctuations in fuel price. However, airline profits might be impacted but impacts on passengers are likely to be limited. As discussed in section 3.2.7 and as noted in previous impact assessments it is unlikely that there would be significant impacts on access to mobility for outermost regions.

The areas discussed above are not the only potential sources of leakage. If passengers choose not to fly because of increased carbon costs, they may choose to spend the money they would have spent on flying on something else with associated carbon emissions. If those emissions are within the EU, they are likely to be covered either by the EU ETS or the Effort-Sharing Resolution[649]. If these emissions are outside the EU, however, they may count as leakage. Similarly, if reduced demand for fossil fuels from aviation affects fuel prices, leading to increased demand for fossil fuels from other sectors, leakage may occur. These sources of leakage are covered by the E3ME modelling discussed below.

3.2.14 Impact of disruptive events and initiatives and investments that go beyond evolutionary/marginal advancements

As discussed in Section 3.1.2.9, these projections omit several factors that may influence future aviation CO_2. We do not model the impact of the COVID-19 pandemic (as this report was produced whilst the situation was still developing). Similarly, it is likely that over the time period to 2035 there will be other unanticipated events that affect the aviation system, and the distribution and amount of demand, to a greater or lesser extent. Historically, the impact of disruptive events on aviation growth has typically been short-term (e.g. 9/11 or the financial crisis), though impact on underlying demand drivers may have a longer timescale. In some cases, shocks may also lead to technological developments. For example, open rotor engine designs were explored in the 1980s due to high oil prices (e.g. the General Electric GE36) but abandoned once oil prices had decreased, and are only now being re-explored. Similarly, use of sugar cane ethanol as a fuel in Brazil, and large-scale development of the Fischer-Tropsch process in South Africa, was motivated in part by high oil prices and oil embargoes in the 1970s.

[649] EC, 2019. Effort-sharing resolution. https://ec.europa.eu/clima/policies/effort_en. This establishes binding annual greenhouse gas targets for EU member states to 2030. However, these targets are less strict than those for EU ETS sectors.

We also do not model changes in policy aimed at influencing aircraft technology, operations or fuel use. On a year-2035 timeframe, the impact of the development of completely new aircraft technologies is likely to be small. As discussed in Section 3.1.2.6, new technology developments are subject to long timeframes. Even if the next generation of new aircraft beyond that represented by the A320neo involves radical changes in technology, the typical 15-20 year gap between aircraft generations combined with fleet turnover means that these aircraft will have relatively limited impact on the fleet before 2035. Although electric aircraft could strongly reduce emissions per substitutable flight (assuming suitable carbon intensity of electricity generation), current battery energy densities are only sufficient to allow substitution of very short-haul flights with small aircraft.

Two potential exceptions which could have a shorter-timescale impact not examined in the main set of projections are the large-scale deployment of biofuels or electrofuels; and radical changes in operations. Biofuels are already in (limited) use in commercial aviation and, although it is most likely that use will remain limited over the short term (as discussed in Section 3.1.2.6) and that biomass will primarily be used in other sectors, greater use is possible. Widespread use of electrofuels would likely require significant reductions in projected cost. In this study, we assume limited availability of drop-in aviation biofuels (up to around 10% of aviation fuel use by 2035 in the optimistic technology scenario) and no significant use of electrofuels to 2035. For biofuels, the consequence of year-2035 uptake being much higher than projected would likely mean that CO_2 under both CORSIA and the EU ETS would be closer than expected to their baseline/cap values, strongly reducing the amount that aviation pays to other sectors for offsets and/or allowances but probably not affecting auctioning revenue significantly. The same is true for significant use of electrofuels. Biofuels or electrofuels would need to account for around 70% of intra-EEA aviation fuel under nominal scenario conditions in 2035 for biofuel exemptions to cause aviation CO_2 to fall below the (post-LRF) ETS aviation cap (around 63 - 80 % across different scenarios for uncertain variables). At biofuel use of less than this threshold, aviation's spending on EUAs (and therefore carbon costs) would reduce broadly proportionally to the amount of biofuel used, but EUAA auction costs and revenues would remain unchanged. In general, calculations of optimal biomass use suggest that biomass use in aviation supplies less climate benefit than is available from using biomass in some other sectors where carbon capture and storage is available (e.g. CCC, 2018)[650]. If aviation uses biomass instead of another EU ETS sector (e.g. power generation), either that other sector must find alternative and potentially more expensive options to reduce its CO_2 emissions, or the net impact on European CO_2 emissions will be small.

The projections made in this report include the impact of likely improvements in operational efficiency (e.g. those examined in Marais et al., 2011; these address developments such as more direct flight routing and continuous descent approaches which are already underway via programmes such as SESAR)[651]. Larger reductions in emissions from operational changes are in theory possible if flights are more closely matched to the design range of each aircraft, including the use of multi-hop flights for long-haul trips (e.g. Poll, 2011)[652]. Changing operations in this way could in theory reduce operations for some individual flights by up to 45%, provided aircraft optimised for each stage length were used and short-haul typical seating densities were applied. However, on a global scale the

[650] CCC, 2019. Net Zero: The UK's contribution to stopping global warming. https://www.transportenvironment.org/sites/te/files/WK_2310_2017_INIT_2.pdf

[651] Marais, K., Reynolds, T., Uday, P., Lovegren, J., Dumont, J.-M. and Hansman, R. J., 2011. Evaluation of potential near-term operational changes to mitigate environmental impacts of aviation. Journal of Aerospace Engineering, 227(8), 1277-1299.

[652] Poll, I., 2011. On the effect of stage length on the efficiency of air transport. The Aeronautical Journal, 115(1167), 273-283.

likely impact of flight staging is likely closer to 1-6%, with benefits on the longest-haul routes. Implementing operations fully optimised for fuel use would imply significant changes in aircraft networks and in aircraft requirements by airline, and is unlikely over the short term. Similarly, particularly short-haul flights are subject to large ATM-related inefficiencies (around 20% on a global level; Poll, 2018)[653]. These inefficiencies arise from a range of different sources, including weather avoidance, restricted airspace, operational constraints and congested airports[654]. Some relate to safety requirements and cannot be easily reduced, whilst others are already being addressed by large-scale programmes such as SESAR. Operational CO_2 mitigation strategies beyond those typically anticipated would likely require additional policy support (for example, incentives to better match aircraft types and flight frequencies to CO_2-optimum values for a given flight segment). The general impact of operational improvements beyond those typically anticipated would likely be a U-shaped curve in fuel efficiency improvements with flight distance, with the greatest benefits coming from very short haul and ultra long-haul; in particular, emissions from domestic flights, which are typically shorter-distance, would likely decrease more than those for intra-EU/EFTA international flights. However, the size of the decrease in fuel use in this case would be much less than that anticipated for widespread biofuel use and would likely not, for example, bring aviation CO_2 below the EU ETS aviation cap.

3.2.15 Analysis of legal aspects of each option

The 2017 Impact assessment already looked at legal considerations which remains valid. In this section we have looked more closely at the six options.

Table 34. Option 1: EU ETS full legal scope (i.e. all flights to, from and within the EU/EFTA region) from 2024

Scope	
EU/ETS	**CORSIA**
Flights to, from, within EU/EFTA, including domestic (from 2024)	Int’l flights between participating non-EU/EFTA countries; to/from EU/EFTA not covered

Such option would avoid the chance of overlap between the two instruments as their scopes of application would be distinct. Airlines, whether European or non-European, will be required to apply the same mechanism when operating the same flights, which shall avoid any distortion of competition.

In 2018, the EU Member States notified ICAO that certain differences exist between Directive 2003/87/EC and CORSIA[655]. The EU ETS Directive applies irrespective of the nationality of the aeroplane operator and in principle covers flights which depart from or arrive in an aerodrome situated in the territory of a Member State to which the Treaty

[653] Poll, I., 2018. On the relationship between non-optimum operations and fuel requirement for large civil transport aircraft, with reference to environmental impact and contrail avoidance strategy. The Aeronautical Journal, 122(1258), 1827-1870.

[654] EEA, EASA and Eurocontrol, 2019. European Aviation Environmental Report, 2019, https://ec.europa.eu/transport/sites/transport/files/2019-aviation-environmental-report.pdf

[655] Council Decision (EU) 2018/2027 of 29 November 2018 on the position to be taken on behalf of the European Union within the International Civil Aviation Organization in respect of the First Edition of the International Standards and Recommended Practices on Environmental Protection — Carbon Offsetting and Reduction Scheme for International Aviation, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32018D2027

applies. These differences limit the scope of CORSIA application to be in accordance with whatever amendments are made to the EU ETS Directive.

Only if the EU ETS Directive were amended to allow distortion of competition would European airlines and non-European airlines apply different systems while they operate the same route.

This option would amount to the EU's non-participation in CORSIA, which runs contrary to the established formal EU position (while noting that the EU has reserved its full policy autonomy by filing differences to the CORSIA SARPs). Moreover, it cannot be excluded that key aviation States that have volunteered to participate would reconsider their decision. If for this reason or another CORSIA would fail, the impact of CORSIA would amount to zero

Table 35. Option 2: Intra EU/EFTA only (all flight within the EU/EFTA region, excluding those to and from the outermost regions)

SCOPE	
EU/ETS	**CORSIA**
Flights within EU/EFTA, including domestic	Int'l flights between participating non-EU/EFTA countries; to/from EU/EFTA not covered

Such option would avoid the chance of overlap between the implementation of the two instruments as their scopes of application would be distinct. Airlines, whether European or non-European, will be required to apply the same mechanism when operating the same flights, which shall avoid any distortion of competition.

In such option however, flights to and from the EU/EFTA are not covered, nor by the EU/ETS directive, nor by CORSIA. This would leave some flights not being covered by any system of greenhouse gas emissions system.

This option would amount to the EU's non-participation in CORSIA, which runs contrary to the established formal EU position (while noting that the EU has reserved its full policy autonomy by filing differences to the CORSIA SARPs). Moreover, it cannot be excluded that key aviation States that have volunteered to participate would reconsider their decision. If for this reason or another CORSIA would fail, the impact of CORSIA would amount to zero

Table 36. Option 3: CORSIA only (removing aviation completely from the EU ETS. Instead, CORSIA applies to international flights to, from and within the EU/EFTA region)

SCOPE	
EU/ETS	**CORSIA**
No flights	All int'l and intra-EU/EFTA (non-domestic) flights (excluding to/from CORSIA non-participating States)

Without considering domestic flights, this option will avoid the chance of overlap in relation to implementation for flights between EU/EFTA Member States as these flights would be covered by CORSIA. Domestic flights within the EU/EFTA would not be addressed anymore.

Table 37. Option 4: ETS-CORSIA clean cut (keeping the EU ETS for aviation at its current reduced scope but applies CORSIA on int'l flights to and from the EU/EFTA region)

SCOPE	
EU/ETS	**CORSIA**
Flights within EU/EFTA, including domestic	Int'l flights (excluding to/from CORSIA non-participating States), intra-EU/EFTA excluded

Such option would avoid the chance of overlap between implementation of the two instruments as their scopes of application would be distinct. Compared to option 2, all flights are covered by one of the two mechanisms. Airlines, whether European or non-European, will be required to apply the same mechanism when operating the same flights, which shall avoid any distortion of competition.

Table 38. Option 5: ETS-CORSIA "mix" (keeping the EU ETS for aviation at its current reduced scope but the EU ETS and CORSIA both apply to routes within the EU/EFTA regions. The EU/ETS counts only emissions below the CORSIA baseline)

SCOPE	
EU/ETS	**CORSIA**
EU/EFTA domestic flights, Intra-EU/EFTA flights up to CORSIA baseline	All int'l flights and intra EU/EFTA (non domestic) flights (excluding to/from CORSIA non-participating States)

Such option would avoid overlap between implementation of the two instruments as their scopes of application would be distinct.

Airlines, whether European or non-European, will be required to apply the same mechanism when operating the same flights, which shall avoid any distortion of competition. In practice however, this system is more likely to constitute an additional charge imposed on European airlines as they are more likely to operate domestic flights and intra-European flights than non-European airlines.

Table 39. Option 6: ETS-CORSIA "mix" according to licence of aircraft operators (similar to option 4, but domestic flights and inter EU/EFTA flights by non EU/EFTA registered carriers are removed from EU/ETS scope)

SCOPE	
EU/ETS	**CORSIA**
Flights within EU/EFTA, excluding domestic, if operator licence issued by an EU/EFTA state	Int'l flights to and from EU/EFTA. Flights within EU/EFTA where operator license issued by a non-EU/EFTA state

Without prejudice to issues of equal treatment, such option would avoid overlap between implementation of the two instruments as their scopes of application would be distinct.

However, it is noted that this option would create distortion of competition when comes to comparing flights operated by European and non-European airlines on the same route within the EU/EFTA: European ones would be required to apply the EU ETS while non-European airlines wouldapply CORSIA.

This unequal treatment could be highly problematic. In its opinion on the Air Transport Association of America and Others case, the Advocate General Kokott recalled that " (…) In EU law, according to settled case-law, the principle of non-discrimination requires that comparable situations must not be treated differently and that different situations must not be treated in the same way, unless such treatment is objectively justified"[656].

3.3 Socioeconomic impacts of the scenarios

We used the macro-econometric model E3ME[657] to assess the socioeconomic impacts of the different policy scenarios considered. E3ME operates at national level and distinguishes each of the 27 Member States plus other ETS partners individually, and in total covers 61 countries and areas globally. Below we set out how the outputs of the AIM aviation sector model were fed into E3ME; the impacts at the national level, and then estimates of regional socioeconomic impacts.

It is important to note that the scope of the macroeconomic modelling was limited to understanding two specific phenomena; first, how changing demand for air transport and air transport fuels affects the European economies, through direct effects, but also indirect (through supply chains to these sectors) and induced effects (through changes in wages, leading to further changes in consumption and therefore further multiplier effects), and second, through the recycling of ETS revenues, which essentially increases government revenues from air transport and uses the revenues either to increase government expenditure or to reduce the incidence of other taxes across the economy. The analysis here does not seek to assess the resultant changes in national and regional connectivity in the scenarios, and how these might be expected to affect national/regional competitiveness and agglomeration effects.

3.3.1 E3ME modelling methodology

3.3.1.1 Overview of the E3ME model

The global macro-econometric model E3ME was used to estimate the wider social and economic impacts outside of the aviation sector for the main EU ETS-CORSIA policy options. E3ME is a computer-based model that captures interlinkages between the economic, environmental and energy systems, often used for evaluating the impact of policy shocks through scenario-based analysis. Its broad structure, and the linkages between these systems, is set out in Figure 46 below. A more detailed description of the model is included in the Annex.

[656] Opinion of Advocate General Kokott delivered on 6 October 2011 (1) Case C-366/10, §196.

[657] See www.e3me.com. More detail on the model is provided in the Annex.

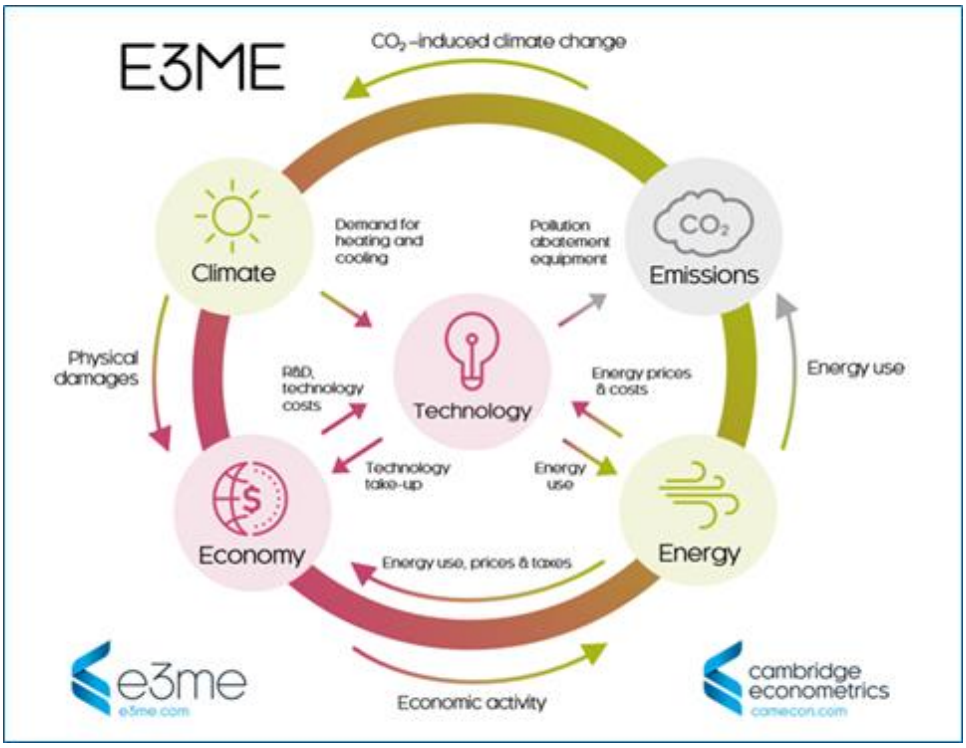

Figure 46. The structure of E3ME

3.3.1.2 Modelling assumptions

The policy options were developed on top of the E3ME baseline calibrated to the IMF and DG EcFin's Ageing report[658] socio-economic assumptions for European Member States. At the EU aggregate level, these baseline projections were sufficiently aligned with the projections used in the AIM baseline for the modelling period.

For each policy option, a set of AIM outputs were used as inputs to the E3ME modelling:

- Absolute levels of expenditure on air transport, split into household and business expenditure using historical data in E3ME
- Absolute demand for fuels (including jet fuels, biofuels and electricity) by the air transport sector
- Auctioning revenues from the part of the EU ETS associated with aviation in each scenario

These inputs, available by country in AIM, were aggregated to E3ME's regional classification (for some non-EU countries, where the model groups countries in some cases) and converted to the appropriate currency and unit used by E3ME.

In addition, global crude oil price and EU ETS price projections, consistent with the central view implemented in AIM, were incorporated and held constant across all policy options.

Although the modelling captured the impact of both the EU ETS and CORSIA on aviation demand, it did not attempt to quantify the potential macroeconomic impacts of the revenue recycling of projected demand for CORSIA offsets, due to the complexity of determining how this may be reinvested by firms providing the offsets in practice. For example, such investments in environmental projects and low-carbon technology developments are likely to result in more positive economic impacts in those sectors and their supply chains than would be captured by this modelling exercise, if such investment is additional to what would have otherwise taken place (i.e. there is no crowding out).

[658] https://ec.europa.eu/info/sites/info/files/economy-finance/ip079_en.pdf

Nevertheless, this addition is likely to be limited, because the amount of CORSIA offsets is expected to be relatively small compared to revenues from the EU ETS in all except Option 3 (where all flights are to be regulated by CORSIA from 2021). In all scenarios except Option 3, the EEA purchases of CORSIA offsets are only a modest proportion of total costs (i.e. they are dwarfed by ETS revenues), and EEA CORSIA offset purchases are no more than 22% of global CORSIA offsets across the scenarios.

Table 40 shows the projected cumulative amount of EU ETS revenues and CORSIA offsets between 2020 and 2035, under each policy option.

Table 40. EU ETS revenues and CORSIA offsets accumulated over 2020-35

	EU ETS revenues (trillion euros, current prices)	Global CORSIA offsets (trillion euros, current prices)	EEA CORSIA offsets (trillion euros, current prices)	EEA CORSIA offsets (% of global total)
Option 1	220,004	1,840	87	5%
Option 2	37,792	1,849	89	5%
Option 3	0	2,379	517	22%
Option 4	37,792	2,312	415	18%
Option 5	32,263	2,366	508	21%
Option 6	32,892	2,312	415	18%

Source: AIM

3.3.1.3 Modelling changes in demand for air transport and transport fuels

AIM outputs for expenditure on air transport from the central policy options were modelled in E3ME as exogenous changes to household consumption and intermediate demand (other sectors' purchases of intermediate inputs) of air transport, respectively. The split between the two was based upon the historical shares of aviation demand by households and businesses respectively.

Similarly, fuel demand results generated from AIM were implemented as exogenous changes to demand for those fuels from the air transport sector. The economic relationships that characterise the potential impacts of these shocks in E3ME are shown in Figure 47 below.

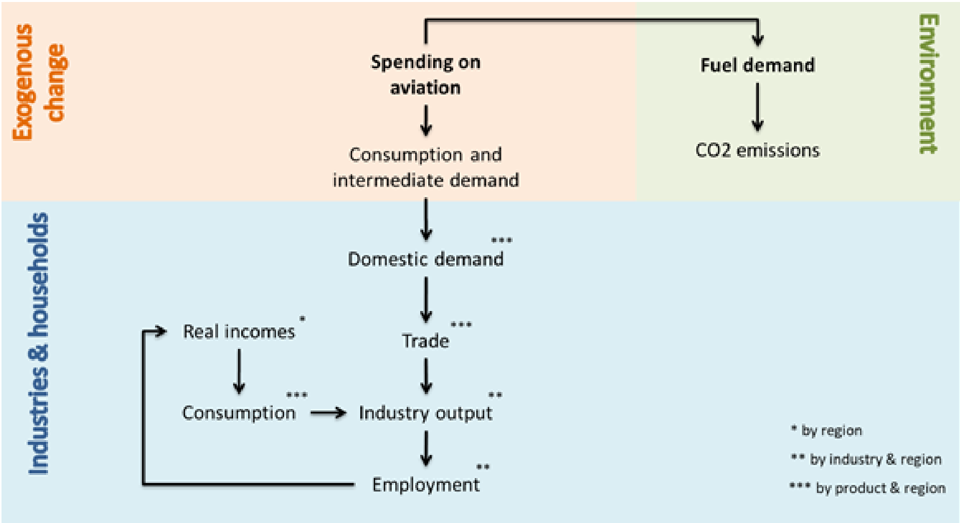

Figure 47. Impact of a change in demand for aviation

First, changes in expenditure are expected to lead to a direct impact on domestic demand for air transport by households and firms. Secondary impacts are then generated through multiplier effects in the supply chain and changes in demand for trade, affecting the level of economic activity (captured by gross output) in the rest of the economy. This ultimately leads to a change in demand for inputs to production including labour. As a result, an impact on employment is to be anticipated, followed by impacts on household incomes and total consumption. Because of the model dynamics, this is likely to lead to further feedbacks to total demand over time.

In addition, the modelling assumed that changes in demand for air transport alter household consumption patterns, such that any proportion of household income which is not spent on air transport would be spent on other goods and services, rather than saved.

The impact on the energy sector and the environment reflects the economic impacts described above, as well as exogenous changes in energy demand. For example, if the AIM modelling suggests a policy option would lead to a lower level of demand for air transport with a shift towards low-carbon fuels by flight operators, the E3ME modelling is likely to show a negative impact on the air transport and fossil fuel sectors, in contrast with positive impacts in the rest of the economy.

3.3.1.4 Recycling of carbon revenues

For all policy options, it was assumed that the amount of auction revenues collected from the EU ETS would have implications for the government's budget balance. A common recycling option in E3ME, which was adopted for the modelling of the main policy options, is to use the revenues (in equal proportions) to reduce direct and indirect tax rates (including income tax, employers' social security contributions and VAT).

This is expected to lead to positive macroeconomic impacts in most sectors, because lower tax rates would be reflected in lower costs for industries and lower prices for consumers, leading to an increase in total demand and real incomes (see Figure 48), as well as reducing the tax burden on consumers directly, and therefore increasing household expenditure.

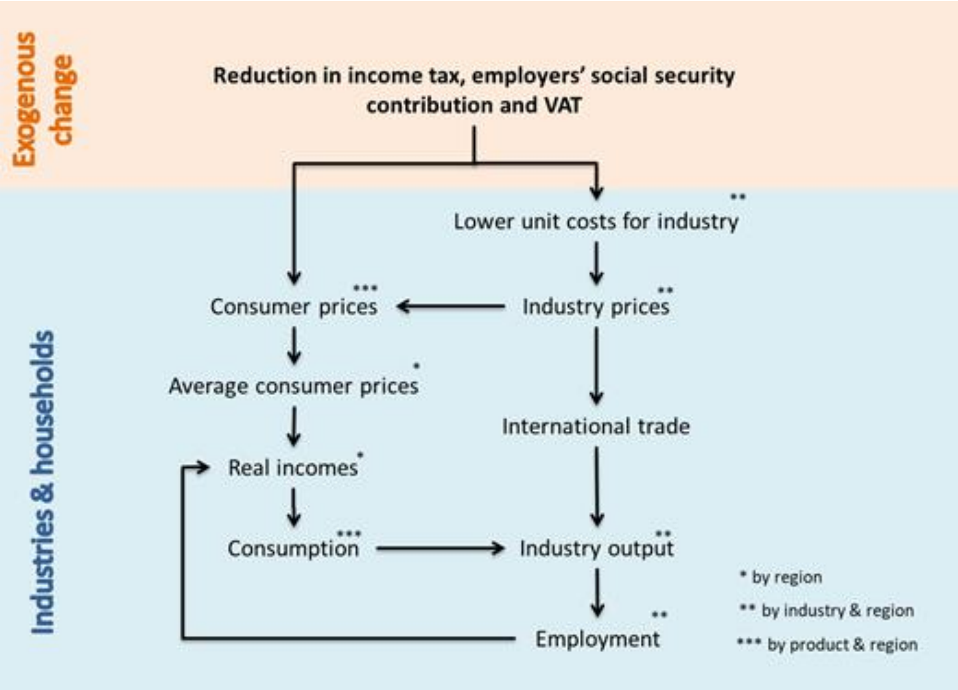

Figure 48. Impact of revenue recycling

3.3.2 National results

3.3.2.1 Overview of the EU

The E3ME modelling suggests that, of the policy options explored, when taking into account the effect of revenue recycling, extending the EU ETS to cover all flights (Option 1) would have the greatest positive impact on EU27 employment and GVA. The full-scope CORSIA scheme (Option 3) is associated with the weakest macroeconomic outcomes, while the other options with a mix of CORSIA and ETS scopes are expected to have broadly similar intermediate outcomes. However, the variation in expected macroeconomic effects between policy options is small. For example, aggregate EU27 employment is projected to be just over 50,000 workers higher by 2035 in Option 1 than Option 3 (a difference of around 0.02%), as shown in Table 41 below.

In the tables that follow, the different options are compared to the scenario which had the weakest macroeconomic outcomes in each case. This should not be interpreted as representing a baseline case, but it simply provides a frame through which the results can be interpreted. As outlined above, in all cases the differences in macroeconomic impacts are, at the EU level, marginal.

Table 41. Differences from option 3 by 2035 in EU27+UK for GVA and employment, with revenue recycling

	GVA				**Employment**			
	Levels in 2020 (€2010bn)	**Levels in 2035 (€2010bn)**	**Differ-ence by 2035 (€2010bn)**	**% differ-ence by 2035**	**Levels in 2020 (000 work-ers)**	**Levels in 2035 (000 work-ers)**	**Differ-ence by 2035 (work-ers)**	**% differ-ence by 2035**
Option 1	11,354	13,968	6.2	0.04 %	203,162	201,079	52,700	0.03%

	GVA				Employment			
Option 2	11,354	13,963	1.2	0.01 %	203,162	201,038	11,800	0.01%
Option 3	11,354	13,962	-	-	203,162	201,026	-	-
Option 4	11,354	13,963	1.2	0.01 %	203,162	201,038	11,900	0.01%
Option 5	11,354	13,963	1.1	0.01 %	203,162	201,037	10,500	0.01%
Option 6	11,354	13,963	1.1	0.01 %	203,162	201,037	10,400	0.01%

Source: E3ME.

Most of the projected macroeconomic impact of each option can be attributed to the influence of recycled EU ETS revenues, rather than changes in demand for fuels and air transport which are not expected to vary substantially between options (according to the AIM modelling). In other words, options with more positive economic outcomes are generally those with a larger volume of projected revenues from the EU ETS (see Table 40 and Table 41).

Without the recycling of government revenues (see Table 42), there are weaker macroeconomic outcomes than in the case of revenue recycling for all options. The full-scope CORSIA scheme (Option 3) is still expected to deliver the weakest outcome for GVA, which reflects the impact on the aviation sector and associated impacts on its supply chain. However, the variation between policy options for employment is negligible and subject to a statistical margin of error so no meaningful conclusion can be drawn about relativity.

Table 42. Differences from option 3 by 2035 in EU27 for GVA and employment, without revenue recycling

	GVA				Employment			
	Levels in 2020 (€2010bn)	**Levels in 2035 (€2010bn)**	**Differ-ence by 2035 (€2010bn)**	**% differ-ence by 2035**	**Levels in 2020 (000 work-ers)**	**Levels in 2035 (000 work-ers)**	**Differ-ence by 2035 (work-ers)**	**% differ-ence by 2035**
Option 1	11,354	13,963	0.7	0.00 %	203,162	201,026	-	-
Option 2	11,354	13,962	0.1	0.00 %	203,162	201,027	400	0.00%
Option 3	11,354	13,962	-	-	203,162	201,027	700	0.00%
Option 4	11,354	13,962	0.1	0.00 %	203,162	201,027	400	0.00%

	GVA				**Employment**			
Option 5	11,354	13,962	0.1	0.00 %	203,162	201,027	500	0.00%
Option 6	11,354	13,962	0.1	0.00 %	203,162	201,027	500	0.00%

Source: E3ME.

3.3.2.2 Sectoral distribution

The recycling of the EU ETS revenues via payroll tax reductions is expected to generate macroeconomic benefits via two channels. The first channel is through a price effect, whereby these tax reductions reduce businesses' unit production costs, allowing them to offer products at lower prices. The second channel is through an income effect, which occurs as employees see wages increase due to capturing some of the gains from falling production costs, and as a smaller proportion of this income is subject to direct taxation. Together, these effects translate into an increase in consumer spending, which accounts for much of the projected differences in output impacts (measured by GVA) across the policy options.

As a result, the economic impacts are projected to be widely distributed across all sectors of the economy (see Table 43). Consumer and professional services, including retail, hospitality, financial and legal services, are amongst the greatest beneficiaries. The projected distribution of economic benefits across sectors is similar in all the policy options explored, with each sector benefiting the most in Option 1, as compared to the weakest economic outturn observed under Option 3.

In E3ME, the determination of employment in each sector follows a wage bargaining model where demand for the sector's output and average wages are typically the main drivers. Therefore, outcomes for employment in the air transport industry closely reflect the assumptions for aviation demand (based on the outputs from the AIM modelling).

At the EU aggregate level, this is projected to be lowest in Option 1 while at a similar and slightly higher level for all other options. The impact on air transport GVA, however, is more in line with the whole economy impact with Option 1 expected to generate the most positive outcome and Option 3 the least positive. Because GVA is derived as the difference between output and intermediate demand, it takes into account not only sector-specific effects (as employment does) but also linkages with other sectors which make up a much larger share of the economy. The difference in impact on GVA and employment implies that where taxation and regulation result in lower demand for air transport, workers are likely to take a hit while airline operators have more options to maintain profits such as cutting back on intermediate purchases and investment.

In addition, the differences relative to Option 3 are expected to be moderate for Industry (which includes mining, manufacturing and utilities sectors), even when there are positive feedbacks from revenue recycling. This is due to two factors: that directly impact these sectors in opposite directions changes in demand for air transport (which purchase intermediate inputs from those sectors) and associated changes in demand for jet fuels (which particularly impacts the activity of gas extractors and distributors).

Table 43. Differences from option 3 by 2035 for GVA and employment, by broad sector, for the EU27, with revenue recycling

NACE code	Sector description	Option 1	Option 2	Option 4	Option 5	Option 6
GVA						
A	Agriculture	0.06%	0.01%	0.01%	0.01%	0.01%
B-E	Industry	0.02%	0.01%	0.01%	0.00%	0.00%
F	Construction	0.02%	0.00%	0.00%	0.00%	0.00%
G-I	Wholesale, retail, transport, hospitality	0.09%	0.02%	0.02%	0.01%	0.01%
H51	Air transport	2.16%	0.26%	0.27%	0.24%	0.24%
J	Information and communication	0.05%	0.01%	0.01%	0.01%	0.01%
K	Financial	0.06%	0.01%	0.01%	0.01%	0.01%
L	Real estate	0.03%	0.01%	0.01%	0.01%	0.00%
M-N	Professional services	0.06%	0.01%	0.01%	0.01%	0.01%
O-Q	Public sector	0.02%	0.00%	0.00%	0.00%	0.00%
R-U	Arts and entertainment	0.06%	0.01%	0.01%	0.01%	0.01%
Employment						
A	Agriculture	0.01%	0.00%	0.00%	0.00%	0.00%
B-E	Industry	0.02%	0.00%	0.00%	0.00%	0.00%
F	Construction	0.03%	0.01%	0.01%	0.01%	0.01%
G-I	Wholesale, retail, transport, hospitality	0.04%	0.01%	0.01%	0.01%	0.01%
H51	Air transport	-0.13%	-0.03%	-0.03%	-0.03%	-0.03%
J	Information and communication	0.03%	0.01%	0.01%	0.00%	0.01%
K	Financial	0.02%	0.00%	0.00%	0.00%	0.00%
L	Real estate	0.01%	0.00%	0.00%	0.00%	0.00%

NACE code	Sector description	Option 1	Option 2	Option 4	Option 5	Option 6
M-N	Professional services	0.04%	0.01%	0.01%	0.01%	0.01%
O-Q	Public sector	0.02%	0.00%	0.00%	0.00%	0.00%
R-U	Arts and entertainment	0.03%	0.01%	0.01%	0.00%	0.00%

Source: E3ME

3.3.2.3 Geographical distribution

Figure 49 shows the range of macroeconomic impacts (the relative difference between options with the strongest and weakest macroeconomic outcomes, Option 1 and Option 3, respectively) for all current EU Member States under the assumption that government revenues are recycled. This range was observed to be generally widest where the projected EU ETS revenues is largest relative to GDP. These examples include Cyprus, Malta and the Netherlands. The result for Spain, meanwhile, can also be explained by the extent of spare capacity in the economy, in the form of high levels of unemployment, which means a reduction in payroll taxes is expected to result in larger multiplier effects.

In addition, there is a variation in the range of GVA and employment impacts across countries. Spain, Malta, Cyprus, Luxembourg and Croatia are expected to see a large proportion of additional demand (generated from revenue recycling) reflected in increased demand for labour, which is demonstrated by the employment differences being similar to the GVA differences. In contrast, Bulgaria and Belgium are projected to see employment impacts that are noticeably smaller (in relative terms) than GVA impacts. This pattern implies that more value added is to be distributed to firms in the form of profits than to workers through an increase in employment and wages in these countries. This variation is mainly determined by differences in the responsiveness of employment to changes in output (captured by econometrically estimated coefficients in E3ME), particularly in sectors that are major employers such as construction, retail and public services.

A comparison of economic outcomes between each of the other policy options and Option 3 shows broadly similar trends, and therefore conclusions.

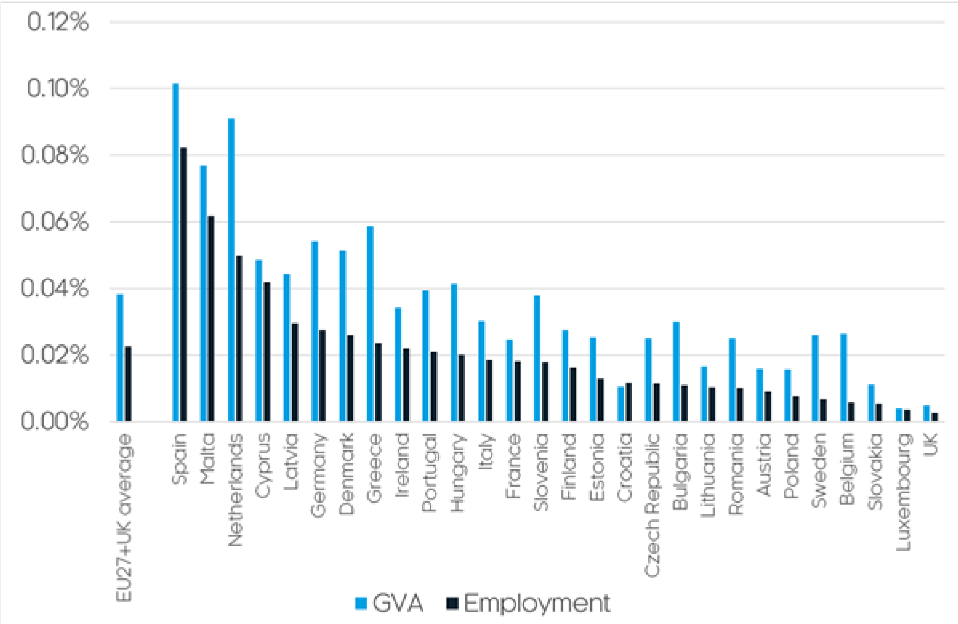

Figure 49. Differences in GVA and employment by 2035 between Options 1 and 3, by country

Without the effect of revenue recycling, the outcomes for individual Member States are much more uniform across policy options. For the majority of Member States, GVA is still expected to be highest under Option 1 and lowest under Option 3, as in the recycling case, with the widest ranges (in relative terms) observed in Netherlands, Greece and Hungary.

The exceptions are Austria and Cyprus where the opposite is observed, namely that Option 1 is associated with the weakest GVA outcomes and Option 3 the strongest, with all other options around the middle of the range. This is in line with the magnitude of assumed changes in demand from the AIM modelling. For air transport, there is a high share of intermediate demand coming from within the sector in Austria and a large contribution to total output in Cyprus, both suggesting that its impact is more strongly reflected in the economy-wide impact.

For employment, the only noticeable impacts are for Austria, which are very similar to GVA impacts in relative terms (the difference between Option 3 and Option 1 being 0.013% by 2035).

3.4 Impacts on Outermost Regions

There are nine areas classified as EU outermost regions: Martinique, Mayotte, Guadeloupe, French Guiana, Réunion, Saint-Martin, Madeira, the Azores, and the Canary Islands. These regions have special status in relation to aviation policy due to their remoteness and constrained development potential. For instance, unemployment is often higher than in other EU regions, and per-capita GDP lower (€8,000-15,000 per year, compared to more typical EU values of €15,000-30,000 per year; ESPON, 2013)[659]. There are substantial differences within this group with regard to the type and number of flights to, from and within each region. For example, Mayotte and French Guiana have relatively little aviation activity, the bulk of which is domestic (the main commercial airport in French Guiana, Cayenne – Félix Eboué (CAY) handles only around 1,000 passengers per day; Sabre, 2017). The collectivity of Saint-Martin forms part of the divided island of Saint Martin. Although Saint-Martin has its own airport (Grand Case-Espérance, SFG), it is used primarily for local short-haul flights. The main international airport for flights to and from Saint-Martin is Princess Juliana International Airport (SXM) in the neighbouring territory of Sint Maarten, which is not classed as an outermost region. In general, most flights to outermost regions are either domestic (e.g. Guadeloupe - Paris) or local short-haul flights with small aircraft, with the exception of the Canary Islands. Given this, it is likely that differences in how flights to and from outermost regions are handled will impact mainly on the Canary Islands, as shown in the figure below. In particular, flights between the UK and the Canary Islands represent approximately 20% of total outermost region-related RPK.

[659] ET2050, 2013. Territorial Scenarios and Visions for Europe (ET2050). Outermost regions report.
http://www.et2050.eu/TechNotes/ET2050_DiscNote16_OutermostRegions_v(27_02_12).pd

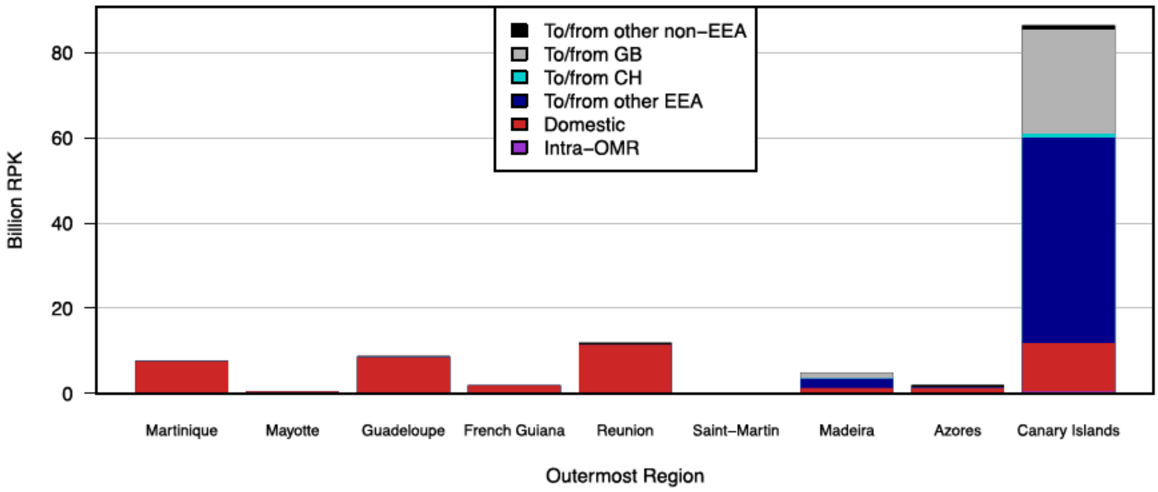

Figure 50. RPK on routes to and from the different EU Outermost Regions in 2015, by route group, from the Sabre (2017) database of passenger movements.

Currently flights to and from outermost regions are exempt from EU ETS carbon costs until the end of 2023, as with the scope derogation regarding third country flights. Broadly, the six main policy options are likely to affect the outermost regions as follows:

Option 1 – EU ETS full legal scope: includes EU/EFTA flights to/from and within the outermost regions, as well as flights between outermost regions and non-EU/EFTA destinations. This option would lead to EU ETS carbon costs for nearly all outermost region arriving and departing flights.

Option 2 – intra-EU/EFTA only: this would continue the current situation (flights within a given outermost region included in the EU ETS, flights to and from outermost regions to both EU/EFTA and non-EU/EFTA destinations excluded). There would also be no change of status for UK-Canary Islands or Switzerland-Canary Islands flights.

Option 3 – CORSIA only: Flights between outermost regions and international destinations participating in CORSIA would be included (at CORSIA-appropriate carbon prices), but domestic flights, including flights within a given outermost region, would be excluded. As shown in above, the majority of RPKs to and from OMRs other than Madeira and the Canary Islands are domestic. Because CORSIA carbon prices are projected to be low, and only apply to emissions above the CORSIA baseline, this option is likely to have only limited impacts. Additionally, few Central and South American nations are likely to be CORSIA participants, so short and medium-haul flights for EU outermost regions in this region are unlikely to be covered.

Option 4 – ETS/CORSIA clean cut: This option would be broadly similar to Option 2, but non-EU/EFTA non-domestic flights to and from outermost regions would be covered under CORSIA. Thus e.g. flights from the UK to the Canary Islands would have a small extra carbon cost.

Option 5 – ETS/CORSIA mix: This would have a similar impact to Option 4.

Option 6 – ETS/CORSIA mix according to license of aircraft operators: Because this option does not include domestic flights under the EU ETS remit, flights within each given OMR would be exempt. Otherwise this option would be similar to Options 4 and 5.

Transport accessibility issues affecting the outermost regions are summarised in Pickup & Mantero (2018)[660]. Changes in the cost of flying or the frequency of available flights can

[660] Pickup, L. & Mantero, C., 2018. Final report on transport accessibility for the EU outermost regions.

affect the access by outermost region residents to education, training, goods and services to a much greater extent than for other, less-isolated regions. For outermost regions other than the Canary Islands, access costs to national capital cities as a fraction of the local minimum wage are 2-3 times greater than they are in other insular European regions (ESPON, 2013). This means that the same level of cost increase in ticket prices for outermost region routes as for other routes can represent a significantly higher cost burden for residents of these regions. In turn, this may affect the economic development of these regions. A particular challenge noted by Pickup & Mantero (2018) is the low level of competition on most air services to outermost regions, which tends to result in relatively high air fares. Flights to and from some of the outermost regions (e.g. Guadeloupe, Reunion and the Azores) are subject to user-based subsidies to allow greater access to transport to, e.g., residents or students. Additionally, many flights within outermost regions that have been deemed socially necessary are operated under Public Service Obligations (PSOs). This includes flights between the Canary Islands and between individual islands in the Azores, as well as flights between Portugal and the Azores, and Paris and the French outermost regions (Merkert & O'Fee 2013)[661]. These flights may remain excluded from the EU ETS due to their PSO status even if the general exclusion of routes to and from outermost regions is lifted. It is likely, therefore, that the main impact of changes to the EU ETS will be on flights to and from the Canary Islands and, to a lesser extent, flights to and from Madeira. However, many international flights to and from OMRs are considered experimental, are not subsidised, and may be abandoned after a short period of operation (e.g. Schade et al. 2013)[662].

Within the aviation sector, the impact on outermost regions of changing ETS eligibility are likely to consist of changes to air fares and flight frequency. Longer-term impacts might include decreases in the number of carriers operating on non-PSO routes if carbon costs substantially affect the operating margin on outermost region-associated routes.

Changing flight costs and frequency may also affect the attractiveness of the outermost regions as tourist destinations. The outermost regions differ significantly in regard to what percentage of air passengers are residents, and what percentage tourists. The Canary Islands and Madeira have well-developed tourism sectors. For example, 12% of Canary Islands residents are employed in the tourism sector, and 10% of the population of Madeira, compared to typical EU values of 1-6%; both regions have over 100 hotel beds per 1,000 inhabitants, and around one third of the Gross Regional Product of the Canary Islands is estimated to come from tourism (Schade et al. 2013). The other outermost regions had between 5 and 36 hotel beds per 1,000 inhabitants in 2011, similar to national averages. Reducing flights by tourists will have an impact on local economies, as discussed in the E3ME modelling section below. Reducing flights by residents will impact on residents' access to employment, education and other opportunities. This in turn may act to limit the economic development of these regions, although schemes exist to offset some of these difficulties, for example promotion of telemedicine in the Canary Islands.

Changing flight costs and frequency may also affect air freight to the outermost regions. However, impacts on overall freight volume are likely to be limited, as the outermost regions depend primarily on shipping for the transport of goods (Pickup & Mantero, 2018). For example, in 2015 the Canary Islands received 25.5 million tonnes of freight by sea but only 40,000 tonnes by air.

Because of their remote locations, flights to and from outermost regions are typically long-haul flights for which fuel is a relatively high percentage of total costs. Airline cost and

[661] Merkert, R., & O'Fee, B., 2013. Efficient procurement of public air services – lessons learned from European transport authorities' perspectives. Transport Policy, 29, 118-125.

[662] Schade, W., Mieja-Dorantes, L., Rothengatter, W., Meyer-Rühle, O., Drewitz, M., Auf der Maur, A., 2013. The orientations and policies of interurban transport in the outermost regions. https://op.europa.eu/en/publication-detail/-/publication/c44dc25f-6935-471f-b0cc-904a8d276b9f

ticket price impacts for applying carbon prices on these flights are similar to those for applying carbon prices on extra-EU/EFTA flights, and typically exceed impacts for intra-EU/EFTA flights, as discussed in Section 3.2.8. Estimated airline cost impacts, as a fraction of total operating costs, and changes in flight frequency, are given in the table below. Note that the upper end of the uncertainty range for carbon costs as a percentage of operating cost arises in cases where other sources of operating cost are low (e.g., low oil price), rather than particularly high total operating cost.

We estimate cost pass-through for these routes to be around 74-77%, based on the analysis in Section 4, which is similar to the level of pass-through on extra-EU/EFTA routes. Fares to or from OMRs often include an EU ETS-eligible flight leg even if flights to or from OMRs are excluded from EU ETS scope (for example, a fare for Bergen-Oslo-Tenerife counts as a fare to or from an OMR, but the Bergen-Oslo leg is EU ETS-eligible under most policy options and this will affect total trip costs and the decision about whether or not to travel). OMRs typically have limited connectivity, meaning that a high percentage of destinations may only be reachable from OMRs via a multi-segment journey. This means that policy options which exclude direct flights to and from OMRs will still have an impact on average ticket price to and from OMRs. Modelled average one-way fares for routes to, from and within the outermost regions by policy option are shown below.

Table 44. Projected carbon costs and numbers of flights on routes to and from outermost regions, 2030 and 2035. Numbers in larger font show outcomes when all uncertain variables are at nominal values. Numbers in brackets show range across all values for uncertain input variables.

Policy option	Projected carbon costs as a percentage of total segment operating cost on routes to/from/within outermost regions		Projected number of flights to/from/within outermost regions, thousand	
	2030	2035	2030	2035
Option 1	1.74 (1.39-6.21)	2.25 (1.64-9.27)	422 (323-493)	470 (344-585)
Option 2	0.07 (0.05-0.24)	0.09 (0.05-0.34)	426 (332-499)	476 (357-593)
Option 3	0.003 (0.001-0.132)	0.006 (0.001-0.46)	427 (333-499)	477 (358-595)
Option 4	0.07 (0.05-0.37)	0.09 (0.05-0.58)	426 (332-499)	476 (357-593)
Option 5	0.07 (0.05-0.48)	0.08 (0.05-0.69)	426 (332-499)	476 (357-594)
Option 6	0.004 (0.001-0.132)	0.004 (0.002-0.24)	427 (333-499)	477 (358-595)

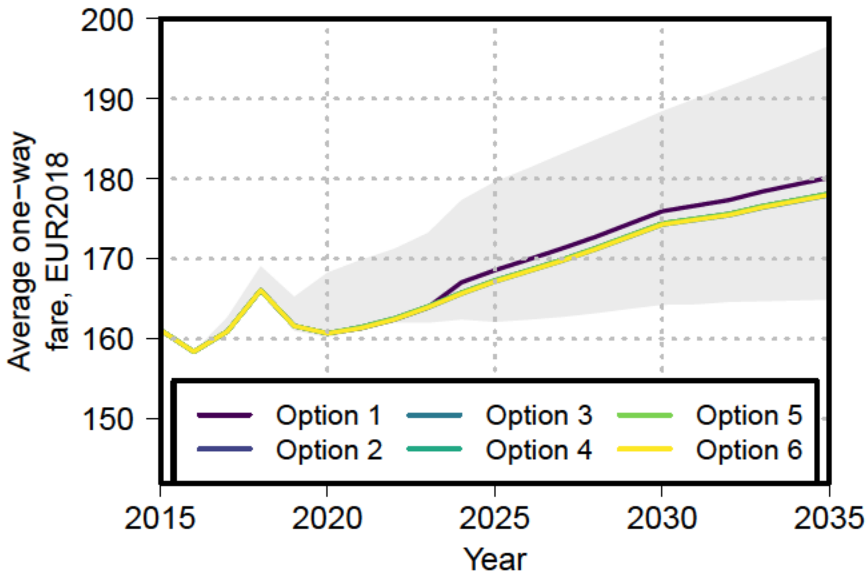

Figure 51. Average one-way fare on routes to, from and within EU outermost regions, by policy option at nominal values for uncertain input variables (solid lines). Grey shaded areas show the range of uncertainty across all uncertain variables.

Modelled impacts on fares are shown in the table below. Because OMRs are typically geographically distant from mainland Europe, the impact of applying the EU ETS to flights to and from OMRs in Option 1 is similar to that of applying the EU ETS to extra-EU/EFTA flights, i.e., around €2.20 per one way flight or 1.2% of ticket price at nominal values for uncertain variables. At the upper end of the uncertainty range impacts could be up to 4.8% of ticket price (€9 per one way flight). The differences between policy options 2-6 are under €0.50 per ticket throughout. These levels of change in ticket price are small compared to variations arising from changes in other variables, most notably fluctuations in fuel price.

Table 45. Average one-way fare for routes to/from/within EU outermost regions by policy option, 2015, 2030 and 2035, for all uncertain variables set to nominal values (numbers in larger font) and range due to variation in uncertain input variables (numbers in brackets).

Policy option	Avg. one-way fare, to/from/within OMRs, €2018		
	2015	2030	2035
Option 1	161.11	175.94 (166-188)	180.16 (167-197)
Option 2	161.11	174.43 (164-184)	178.18 (165-189)
Option 3	161.11	174.27 (164-183)	177.96 (165-188)
Option 4	161.11	174.43 (164-184)	178.18 (165-189)
Option 5	161.11	174.43 (164-184)	178.18 (165-189)
Option 6	161.11	174.28 (164-183)	177.99 (165-188)

For Options 2-6, these differences in fare result in only small differences (0.1% or less) in passenger and freight RTK demand to, from and within OMRs. However, passenger RTK is up to 1.8% lower and freight RTK is up to 3.4% lower when routes to and from OMRs are included in EU ETS scope (i.e., Option 1). Flight frequencies show a similar level of decrease. By 2035, Option 1 is associated with around 1.5% fewer flights to outermost regions than the other policy options (under nominal scenario conditions) or up to 4% fewer flights (in the case of carbon price scenario 2).

Changes in auctioning, as discussed in Section 3.2.13, are also likely to have impacts on the outermost regions. This mainly affects policy option 1, due to EU ETS exemptions for flights to and from outermost regions in the other policy options (though there is still a small impact via the coverage of flights within each outermost region). Applying option 1 with immediate phase-out of auctioning results in an increase in operating costs per RPK for flights operating to/from or within OMRs in 2024 of around 4%. This would have a substantial impact on airline profits if not passed on, as many airlines have operating margins of around 4%. In practice, the use of pass-through estimates from Section 4 implies that ticket prices will increase by around 2% in response, driven in part by large numbers of price-sensitive leisure passengers. Depending on the current operating margins of airlines running flights to and from the outermost regions, this may still represent a reduction of profits on these routes of between a half and a third[663]. Although this is still comparable to historical year-on-year fluctuations in airline profit margins, reduced profitability on these routes raises the risk that operators may decide to withdraw service on routes that are not supported by other means (e.g., PSOs). The other phase-out auctioning strategies in combination with Option 1 take effect more gradually, but have similar impact by 2030. Impacts on passengers are likely to be limited, with cost increases for Option 1 with full auctioning of around €3 per one-way flight and demand reductions of 2-3% compared to scenarios where no carbon price applies to flights to and from OMRs.

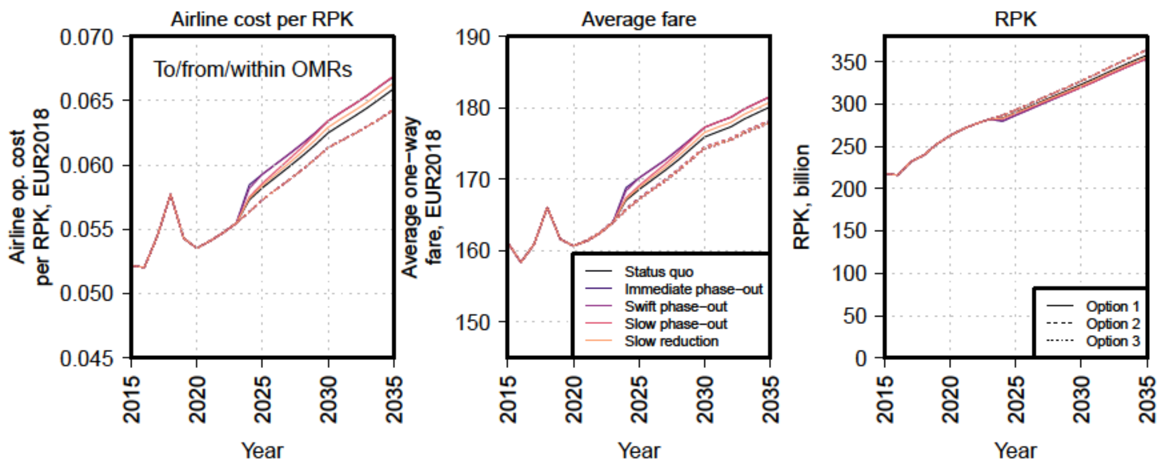

Figure 52. Impacts on airline cost per RPK, average fare, and RPK travelled, for routes to, from and within OMRs, by policy option and future allowance auctioning option at nominal values for uncertain input variables.

The projected impacts on flights to, from and within the outermost regions in terms of airline cost per RPK, average fare, and RPK travelled, by policy option and future allowance auctioning option are shown above, for all uncertain input variables set to nominal values. Only policy options 1-3 are shown, as outcomes for options 4-6 are very similar to option

663 It should be noted that some flights to and from outermost regions are run as Public Service Obligations (PSOs) with subsidy from regional budgets (EC, 2018, Final Report on Transport Accessibility for the EU Outermost Regions, https://ec.europa.eu/regional_policy/sources/policy/themes/outermost-regions/pdf/transport_report_en.pdf).

2. These further demonstrate that the impact on OMRs of changes in auctioning are minimal for policy options 2-6, but may be significant for policy option 1.

Socioeconomic impacts

The socioeconomic impacts of policy options on the outermost regions in our analysis take two forms; first, we present an assessment of the social impacts through qualitative analysis, presented directly below. We then present wider economic impacts modelled using the macroeconomic model E3ME.

The analysis presented above shows that under Options 2-6, increases in one-way flight tickets to the OMRs are around €0.50 per ticket. Under Option 1, in the central case the increase is €2.20 per ticket, and at the upper end of the uncertainty range up to €9 per ticket (a 4.8% increase in the ticket price). The social impact of these price changes should be considered for two separate markets; passenger and freight. For passengers, the major impacts are on tourism and family visits; for freight, the potential impact of higher transportation costs for consumer goods delivered via aviation.

Nearly all OMRs rely on tourism as their main form of economic activity apart from French Guiana, Martinique and Mayotte who have nascent tourism industries (Hammoud et al. n.d.). An increase of up to 4.8% will only impact the most price sensitive of holiday makers but is unlikely to deter the majority. This is because the proportion of spending for flights out of the total average holiday cost will increase by only 1%. In addition to price, holiday makers also consider non-price factors, such as travel time and destination climate. Therefore, despite the price changes, it is likely that those destinations closer to mainland Europe will continue to receive tourists, as there aren’t alternatives within the same vicinity (e.g. Canary Islands, Madeira) with shared characteristics. But those OMRs, further away (e.g. Saint Martin), may lose out, since there are a greater amount of alternative destinations with similar travel times such as Maldives or West Indies, which will be comparatively cheaper if the same price effects don’t apply.

However, if impacts were to be more pronounced, the largest impact is likely to be in the tourism industry as overseas tourists will look to other destination resorts or domestic holidays. This would have strong implications for most of the OMRs who depend financially on tourism (Hammoud et al. n.d.; Ángel and Hernández 2004). According to the Multi-Regional Input-Output tables from ESPON[664], tourists (including those from elsewhere in the Member State) spent €5 billion euros on hotels, restaurants, and transportation in the Canary Islands in 2010, equivalent to 27% of the total domestic household expenditure.

Returning expatriates, or those visiting friends and family, are likely to be less price sensitive to this scale of change. In fact, this group are more affected by seasonal variation in the ticket’s prices as the available user-subsidy is fixed (Mantero, n.d.). They are more likely to travel home during peak season where ticket prices can increase by 350%.

The social impact through the increase imported goods is limited, primarily because air-freighted goods are a minor share of total imports; in 2015 goods which arrived by air were less than 1% of total imports for all OMRs (Mantero, n.d.). Furthermore, the majority of goods which are transported by air are luxury items (e.g. cut flowers and designer dresses) as Cafaro (2012) illustrates. Assuming that this is true for the OMRs as well, the social impact of increased prices, even if more severe than our analysis suggests, would have minor impacts on the majority of households in the OMRs.

Outside of luxury items, the products which rely on air transportation are those which require rapid transit; fish, but also medicines, biological materials, tissue samples and living organisms for both medical and research needs (Cafaro 2012). It is therefore likely that the price of medicines would increase. In addition, the economies of Canary Islands and Martinique would be particularly affected since part of their economic activity relies

[664] PBL EUREGIO database (2000-2010)

on biological research institutions (Hammoud et al. n.d.), which depend on the delivery of biological materials etc. In a case that is more extreme than Option 1, this could harm the ability for these islands to do effective research, potentially putting jobs and economic activity at risk.

The wider economic impact of policy options on the outermost regions was modelled using the macroeconomic model E3ME. The main body of the report describes the E3ME modelling that was done for the six options, and the outcomes at the Member State and European level. Furthermore, Annex 9 describes the E3ME model in more detail, and sets out how subnational impacts were estimated.

The OMR are located across eight NUTS2 regions. These include one Spanish region, five French regions, and two Portuguese regions. The eight regions and their corresponding NUTS classification code are summarised in Table 46. Note that the ninth outermost region, Saint Martin, is part of the NUTS2 region of Guadeloupe. In accordance with the Member State results, this section presents results in each Option in levels and as relative differences from the option with the weakest macroeconomic outcomes, Option 3. In this section results for the scenario variants which include the effects of revenue recycling are presented. Results for the scenario variants without revenue recycling are not presented because the differences are very small at the national level and equally small at the subnational level. Therefore, adding these results to this analysis would not add much insight.

Table 46. EU27+UK outermost regions (NUTS 2)

Member State	**NUTS 2 Code**	**Region**
Spain	ES70	Canarias
France	FRY1	Guadeloupe
	FRY2	Martinique
	FRY3	French Guiana
	FRY4	La Réunion
	FRY5	Mayotte
Portugal	PT20	Região Autónoma dos Açores
	PT30	Região Autónoma da Madeira

Table 47 present E3ME total GVA results in levels and Table 48 presents E3ME total GVA results relative to Option 3 results. Table 47 indicates that in terms of total GVA, the eight outermost regions can expect negligible improvement in both 2025 and 2035 when comparing all other options to Option 3. In fact, the largest 2035 improvement when compared to Option 3 is in Canarias (ES70) under Option 1, a difference of 0.10%, equivalent to an absolute difference of €57.2 million. Out of all outermost regions, the Canarias have the largest economy in terms of GVA in both 2025 and 2035. In fact, in terms of absolute changes, ES70 shows the largest increases in total GVA under all options when compared to Option 3. However, the results in relative differences indicate that, in terms of total GVA, no substantive changes are expected in any of the outermost regions when comparing any of the design options to Option 3.

Similar conclusions are drawn when analysing 2035 results at the sectoral level (proposed in Annex 5). All changes are positive but very close to zero. Across all four economic sectors, the largest 2035 improvement is observed in ES70 under Option 1. Under Option 1, ES70 NACE A-E (Agriculture & Industry) GVA improves by 0.10%, NACE F-I (Construction, Whole, Transport and Accommodation & Food Services) GVA improves by 0.15%, NACE J-N (Financial & Business Services) GVA improves by 0.08%, and NACE O-U (Non-Market Services) GVA improves by 0.06% when compared to Option 3. These improvements are very minor and none of the outermost regions can expect any substantive changes to their sectoral GVA under any of the proposed options.

Table 47. Outermost regions' total GVA in levels (€2010 mn), with revenue recycling

	Option 1	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Option 6**
GVA levels by 2025						
ES70	44,541.3	44,535.8	44,532.2	44,535.8	44,535.8	44,535.3
FRY1	9,892.5	9,891.9	9,891.8	9,891.9	9,891.9	9,891.9
FRY2	9,262.4	9,261.9	9,261.8	9,261.9	9,261.9	9,261.9
FRY3	4,666.1	4,665.8	4,665.8	4,665.8	4,665.8	4,665.8
FRY4	19,021.8	19,020.8	19,020.5	19,020.7	19,020.7	19,020.7
FRY5	2,530.2	2,530.1	2,530.1	2,530.1	2,530.1	2,530.1
PT20	3,848.6	3,848.2	3,848.1	3,848.2	3,848.2	3,848.2
PT30	4,588.7	4,588.1	4,588.0	4,588.1	4,588.1	4,588.1
GVA levels by 2035						
ES70	52,813.6	52,770.7	52,756.5	52,770.8	52,769.8	52,768.6
FRY1	11,176.2	11,173.9	11,173.5	11,173.9	11,173.8	11,173.8
FRY2	10,473.8	10,471.7	10,471.4	10,471.7	10,471.7	10,471.6
FRY3	5,266.5	5,265.4	5,265.3	5,265.4	5,265.4	5,265.4
FRY4	21,487.2	21,483.0	21,482.4	21,483.0	21,482.9	21,482.8
FRY5	2,819.1	2,818.7	2,818.6	2,818.7	2,818.7	2,818.7
PT20	4,299.4	4,298.0	4,297.7	4,298.0	4,298.0	4,298.0
PT30	5,189.6	5,187.7	5,187.3	5,187.7	5,187.7	5,187.7

Source: E3ME.

Table 48. Differences in outermost regions' total GVA compared to Option 3, with revenue recycling

	Option 1	Option 2	Option 4	Option 5	Option 6
GVA % difference by 2025					
ES70	0.02%	0.01%	0.01%	0.01%	0.01%
FRY1	0.01%	0.00%	0.00%	0.00%	0.00%
FRY2	0.01%	0.00%	0.00%	0.00%	0.00%
FRY3	0.01%	0.00%	0.00%	0.00%	0.00%
FRY4	0.01%	0.00%	0.00%	0.00%	0.00%
FRY5	0.01%	0.00%	0.00%	0.00%	0.00%
PT20	0.01%	0.00%	0.00%	0.00%	0.00%
PT30	0.01%	0.00%	0.00%	0.00%	0.00%
GVA % difference by 2035					
ES70	0.11%	0.03%	0.03%	0.03%	0.02%
FRY1	0.02%	0.00%	0.00%	0.00%	0.00%
FRY2	0.02%	0.00%	0.00%	0.00%	0.00%
FRY3	0.02%	0.00%	0.00%	0.00%	0.00%
FRY4	0.02%	0.00%	0.00%	0.00%	0.00%
FRY5	0.02%	0.00%	0.00%	0.00%	0.00%
PT20	0.04%	0.01%	0.01%	0.01%	0.01%
PT30	0.04%	0.01%	0.01%	0.01%	0.01%

Source: E3ME.

Table 49 present E3ME total employment results in levels and Table 50 presents E3ME total employment results relative to Option 3 results. Table 49 indicates that the eight Outermost Regions can expect small employment improvements in both 2025 and 2035 when comparing other options to Option 3. As with the GVA results, the largest 2035 improvement when compared to Option 3 is exhibited in ES70 under design Option 1. ES70 shows an increase in 780 jobs in the Canarias, equivalent to a 0.09% increase compared to Option 3. Therefore, these results show that, in terms of total employment, no major changes are expected in any of the outermost regions.

Sectoral employment results show that all changes are positive and close to zero. For all four economic sectors, the largest 2035 improvement is observed in ES70 under Option 1. Under Option 1, ES70 NACE A-E employment improves by 0.06%, NACE F-I employment improves by 0.10%, NACE J-N employment improves by 0.12%, and NACE O-U employment improves by 0.04% when compared to Option 3. These improvements are small in magnitude and, therefore, as in the case of sectoral GVA, none of the outermost regions can expect any significant changes to their sectoral employment under any of the proposed options.

Table 49. Outermost regions' total employment in levels (000 workers), with revenue recycling

	Option 1	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Option 6**
Employment levels by 2025						
ES70	875.8	875.8	875.7	875.8	875.8	875.8
FRY1	135.1	135.1	135.1	135.1	135.1	135.1
FRY2	138.2	138.1	138.1	138.1	138.1	138.1
FRY3	72.8	72.8	72.8	72.8	72.8	72.8
FRY4	292.0	291.9	291.9	291.9	291.9	291.9
FRY5	42.4	42.4	42.4	42.4	42.4	42.4
PT20	115.4	115.4	115.4	115.4	115.4	115.4
PT30	124.5	124.5	124.5	124.5	124.5	124.5
Employment levels by 2035						
ES70	904.1	903.6	903.4	903.6	903.6	903.5
FRY1	137.4	137.4	137.4	137.4	137.4	137.4
FRY2	139.9	139.8	139.8	139.8	139.8	139.8
FRY3	73.6	73.6	73.6	73.6	73.6	73.6
FRY4	295.3	295.3	295.3	295.3	295.3	295.3
FRY5	42.7	42.7	42.7	42.7	42.7	42.7
PT20	112.3	112.3	112.3	112.3	112.3	112.3
PT30	121.9	121.9	121.9	121.9	121.9	121.9

Source: E3ME.

Table 50. Differences in outermost regions' total employment compared to Option 3, with revenue recycling

	Option 1	Option 2	Option 4	Option 5	Option 6
Employment % difference by 2025					
ES70	0.01%	0.01%	0.01%	0.01%	0.01%
FRY1	0.01%	0.00%	0.00%	0.00%	0.00%
FRY2	0.01%	0.00%	0.00%	0.00%	0.00%
FRY3	0.01%	0.00%	0.00%	0.00%	0.00%
FRY4	0.01%	0.00%	0.00%	0.00%	0.00%
FRY5	0.01%	0.00%	0.00%	0.00%	0.00%
PT20	0.01%	0.00%	0.00%	0.00%	0.00%
PT30	0.01%	0.00%	0.00%	0.00%	0.00%
Employment % difference by 2035					
ES70	0.09%	0.02%	0.02%	0.02%	0.02%
FRY1	0.02%	0.00%	0.00%	0.00%	0.00%
FRY2	0.02%	0.00%	0.00%	0.00%	0.00%
FRY3	0.02%	0.00%	0.00%	0.00%	0.00%
FRY4	0.02%	0.00%	0.00%	0.00%	0.00%
FRY5	0.02%	0.00%	0.00%	0.00%	0.00%
PT20	0.02%	0.00%	0.00%	0.00%	0.00%
PT30	0.02%	0.00%	0.00%	0.00%	0.00%

Source: E3ME.

3.4.1 Conclusions

The overall macroeconomic impacts of the different central policy options considered, when evaluated through impacts on the aviation sector, fuel supply sectors, and through linked supply chains and associated multiplier effects, are relatively small; less than 0.05% in terms of both value added and employment in all cases at the EU27 level. The impacts are similarly small in the outermost regions, once a regionalisation method is applied to convert MS impacts from E3ME into NUTS2-level effects; differences are always smaller than 0.1% between any of the policy options.

However, it is important to note that this presents only a partial analysis of the expected effects; as the aviation modelling shows, there are changes in flight frequency and capacity as a result of different policies, and these will affect the connectivity between regions and countries. Although modelling such effects is beyond the scope of this analysis, it is reasonable to expect that such impacts may be more substantial, in macroeconomic terms, than the changes felt through the aviation sector and associated supply changes.

4 Cost pass-through study per Art. 3d of the ETS Directive

The EU ETS Directive Art. 3d(2) requires that the Commission shall undertake a study on the ability of the aviation sector to pass on costs resulting from CO_2 emissions to its customers, in relation to the EU ETS and to the global market-based measure developed by ICAO (CORSIA).

This section of the report details the method and results of this cost pass-through study, starting with a literature review to consolidate and assess a comprehensive range of ex-ante and ex-post studies on cost pass-through in aviation and other industries. This includes a review of the auctioning percentages in other industries, and how this compares to aviation.

The second part of this study assesses quantitatively the ability of the aviation industry to pass through the cost of required emission units.

4.1 Cost Pass-through theory

'Cost pass-through' describes the change in the price of a products or service following a change in the cost of production as defined by RBB Economics[665]. Cost pass through is typically described as the percentage of the input cost change that is passed through to customers – so for example, in a 100% cost pass-through scenario every €1 increase in the price of inputs is passed through as a €1 increase in the price seen by the customer. Cost pass-through is typically between 0% to 100%, and only in exceptional cases will be outside this range.

A specific cost pass-through will depend on firm-specific and industry-wide factors. Industry-wide factors concern the ability of firms to pass-through a common cost change affecting all players in an industry. Firm-specific factors consider the ability of one firm to pass-through a cost change affecting only the firm in question.

Theoretical analyses of cost pass-through usually assume perfect markets to simplify the analysis. This assumes markets are entirely efficient, with equal access to information from all market participants, rational actors and no transaction costs. Under these assumptions, the key factor determining the cost pass-through is the elasticity of demand relative to supply, with a highly elastic demand and a less elastic supply leading to lower levels of cost pass-through, all else being equal. However, these assumptions of perfect markets rarely hold in practice, and in the same report RBB Economics highlights the range in cost pass-through possible, even for extreme cases of monopoly and perfect competition (2014). Across these market structures a number of additional driving factors have been suggested to increase cost pass-through, including convex inverse-demand, increases in marginal cost as input costs increase and the level of competition in the market[666]. Figure 53 shows the different demand profiles. With a convex profile, demand becomes inelastic as the price increases, also called "convex to the origin".

[665] RBB Economics, 2014. Cost pass-through: theory, measurement, and potential policy implications A Report prepared for the Office of Fair Trading.

[666] CE Delft and Oeko-Institut, 2015. Ex-post investigation of cost pass-through in the EU ETS. An analysis for six sectors.

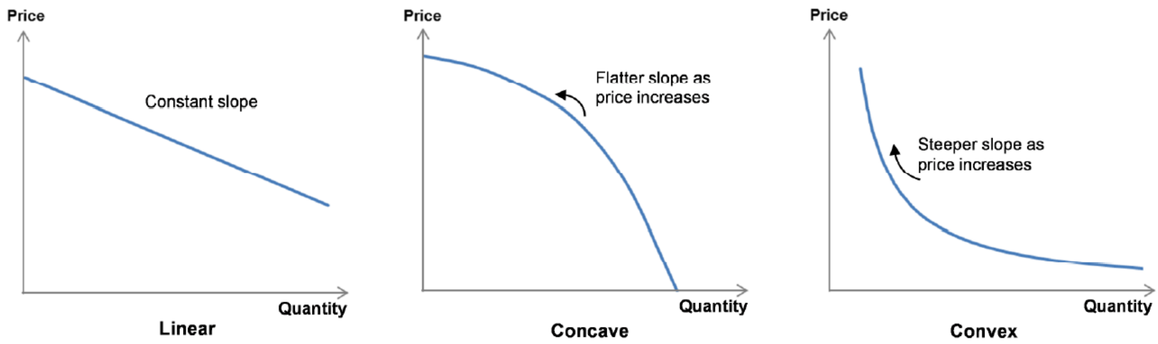

Figure 53. Demand profiles (source: RBB Economics, 2014)

According to RBB Economics report, following an industry-wide shock with homogeneous products, in the case of firms competing in price for a single product, the more competitive the market, the greater probability that costs are passed through to consumers.

4.2 Air Transport Industry & Carbon Emissions

In the air transport industry, the estimated ability of airlines to pass-through cost changes varies significantly. As airlines' pricing decisions generally aim at profit maximisation, prices should in theory match the marginal cost of production under the perfect competitive aviation market assumption. This would mean that all operating cost (and therefore cost changes impacting all competitors equally) are fully passed to passengers through the ticket price.

However, in real market conditions, many factors are impacting airlines' pricing decisions, which deviates from the perfect competition assumption. These factors include the following:

- Market conditions based on infrastructure and airline network constraints, slot shortage and allocation
- Variations in the price elasticity of demand, which can be segmented along multiple dimensions, but often includes length of haul and/or leisure and business travellers
- Level of competition, determined by the number of airlines flying on a specific route, frequency of flights
- Product differentiation, including seat pitch, catering, loyalty scheme
- Imperfect information
- Barriers to entry such as high capital costs, slot constraints making it challenging for young players in the industry

Airline Business Model

Not all airlines behave the same way to costs variation. Due to the complexity of the ticket pricing process, fares depend more on market factors rather than business model. Therefore, we will use different aspects found to be relevant on the route level to analyse airlines' cost pass-through abilities.

Anger & Köhler[667] assessed the assumptions used in the literature and found cost pass-through ranging from 0% to 100%, illustrating the complexity of determining the isolated cost changes impact on price movements.

In the context of this study, we focus on the operating costs and policy options related to EU-ETS and CORSIA, holding other costs constant in principle. We define cost pass-through as the ability to pass on the costs of required allowances to cover the carbon

[667] Anger, A., & Köhler, J., 2010. Including aviation emissions in the EU ETS: much ado about nothing? A review. Transport Policy, 17, 38-46.

emissions or offsetting requirements, which includes the following, as defined by Bloomberg New Finance report in 2011[668]:

- *Out-of-pocket costs:* those required by airlines to pay for the emissions deficit by acquiring EU ETS allowances or CORSIA Eligible Emissions Units,
- *Opportunity costs*: foregone earnings that could have been made, had the airline not made the flight and sold the allowances.

4.3 Literature review

4.3.1 Articles analysed

We analysed the articles (listed below) covering a variety of ex-ante and ex-post studies in both the industrial and aviation sectors, regarding the carbon emissions scheme cost pass-through.

Table 51. Summary of ex-ante and ex-post studies on cost pass-through assessed

ID	Title	Authors	Date published	Study type
1	Assessment of the Financial Impact on Airlines of Integration into the EU Greenhouse Gas Emissions Trading Scheme	Oxera	2003	Ex-ante
2	Economic consideration of extending the EU ETS to include aviation. A report prepared for the European Low Fares Airline Association (ELFAA).	Frontier Economics	2006	Ex-ante
3	CO_2 Cost Pass Through and Windfall Profits in the Power Sector	Sijm, Neuhoff & Chen	2006	Ex-post
4	Estimating Air Travel Demand Elasticities: Final Report. Prepared for IATA	Intervistas	2007	Ex-post
5	Air travel demand estimates. In: Lee, D. (Ed.), The Economics of Airline Institutions, Operations and Marketing. Elsevier, Amsterdam.	Gillen, Morrison, Stewart	2007	
6	The impact of the UK aviation tax on carbon dioxide emissions and visitor numbers	Mayor & Tol	2007	Ex-ante
7	A Study to Estimate Ticket Price Changes for Aviation in the EU ETS: A report for Defra and DfT. Vivid Economics	Vivid Economics	2008	Ex-ante
8	Inclusion of aviation in the EU ETS: Cases for carbon leakage	Ernst & Young and York Aviation	2008	Ex-ante
9	The impact of power market structure on the pass-through of CO_2 emissions trading costs to electricity prices	Sijm et al.	2009	Ex-post

[668] Bloomberg NEF, 2011. Including aviation in the EU ETS - the burning question.

ID	Title	Authors	Date published	Study type
10	Including aviation emissions in the EU ETS: much ado about nothing? A review	Anger & Köhler	2010	Ex-post
11	Including aviation in the European emissions trading scheme: Impacts on the industry, CO_2 emissions and macroeconomic activity in the EU	Annela Anger	2010	Ex-ante
12	Assessment of the economic impact of market-based measures. Prepared for the Expert Group on Market-based Measures, International Maritime Organization.	Vivid Economics	2010	Ex-post
13	Bloomberg - Including aviation in the EU ETS – the burning question	Guy Turner	2011	Ex-ante
14	The inclusion of aviation in the EU Emissions Trading System. ICTSD Programme on Trade and Environment, Issue Paper No. 5. ICTSD, Geneva.	Faber & Brinke	2011	Ex-ante
15	Does EU ETS instigate Air Cargo network reconfiguration? A model-based analysis	Ulrich Derigs, Stefan Illing	2012	Ex-ante
16	The impact of the European Union Emissions Trading Scheme on US aviation	Robert Malina et al.	2012	Ex-ante
17	Aviation and the EU ETS What happened in 2012 during 'Stop the Clock'?	Sandbag	2013	Ex-post
18	Study on the Impacts of the EU ETS on China's Passenger Airlines. Northeast University of Finance and Economics	Wang	2013	
19	Carbon leakage prospects under Phase III of the EU ETS and beyond	Vivid Economics	2014	Ex-ante
20	Cost pass-through: theory, measurement, and potential policy implications A Report prepared for the Office of Fair Trading	RBB Economics	2014	Ex-post
21	Ex-post investigation of cost pass-through in the EU ETS - An analysis for six sectors	CE Delft and Oeko-Institut	2015	Ex-post
22	2015 Impact Assessment ETS Review (and findings and cited literature therein)	-	2015	Ex-post
23	Exploring the EU ETS beyond 2020: A first assessment of the EU Commission's proposal for Phase IV of the EU ETS (2021-2030)	I4CE, Enerdata, IFPen	2015	Ex-ante

ID	Title	Authors	Date published	Study type
24	The EU Emission Trading Schemes' effects on the competitive situation within national and international aviation	INFRAS, CE Delft & TAKS	2016	Ex-post
25	Will airline efficiency be affected by "Carbon Neutral Growth from 2020 strategy? Evidences from 29 international airlines	Qiang Cui, Ye Li	2017	Ex-ante
26	Exploring the impacts of EU ETS on the pollution abatement cost of European airlines: an application of Network Environmental Production Function	Qiang Cui, Ye Li, Yi-Ming Wei	2017	Ex-post
27	The carbon leakage and competitiveness impacts of carbon abatement policy in aviation	Dray et al.	2018	Ex-ante

Among the articles listed above, most studies analyse the EU ETS impact on airlines' financial performance. However, carbon emissions cost pass-through is mostly used as an assumption rather than the main purpose of the study, based on different factors including market conditions, specific airline and other industries feedback. The conclusion from these articles are drawn in the following section.

4.3.2 Main findings from Literature Review

The analysis of the above literature indicates that the following factors have a significant impact on carbon emissions cost pass-through:

1. Market Condition
2. Market Infrastructure
3. Demand elasticities
4. Exposure to international trade
5. Carbon costs distribution

Depending on the industry, these factors may have interdependences.

Market Condition

Market conditions refer to the degree of competition in the markets, or trade intensities of the players that operate in these markets.

The air transport industry is marked by an intense degree of competition among airlines in many markets and routes around the world. Although this might seem counter intuitive, this competition is a factor that could enhance the ability of airlines to pass-through an additional cost. According to Ernst & Young and York Aviation[669], on routes connecting uncongested airports, the carbon cost pass-through would be 50%, 70% or 90% when the route is served by one, three or nine airlines respectively.

[669] Ernst & Young and York Aviation, 2008. Inclusion of Aviation in the EU ETS: Cases for Carbon Leakage York Aviation.

Similar results were found in CE Delft and Oeko-Institut[670], report for several industries. The cement industry has relatively low competition from non-EU countries which are not subjected to carbon emissions costs. Their study revealed that indicative cost pass-through rates in the cement market are below 50% in some countries like Germany (40%) or France (20%). The three possible explanations are:

1. The oligopolistic characteristic of the cement market aims to lower prices to increase profitability. According to Sijm et al. (2009)[671], oligopolistic market's ability to pass-through costs depends on pricing strategy and utilization rate. The higher capacity utilization is, the bigger cost pass-through will be.
2. Price variables: the mix of contract and spot prices can limit the ability of passing-through the carbon prices.
3. EU ETS threshold rules, pushing the industry to maintain certain levels of production to keep free carbon allowances and therefore having a downward pressure on pricing in order to maintain market share. This impacts the ability of cement producers to pass-through the cost of carbon emissions.

The cement industry example supports the theory stating that cost pass-through is higher in a competitive environment. Surprisingly, the theory was not supported by the refinery industry, especially in the diesel and petrol sector. In their report, CE Delft and Oeko-Institut found cost pass-through rate above 100% for diesel and 80-100% for petrol, whereas high operating margins in diesel markets suggest the sector is less competitive than the petrol market.

Despite the different examples for and against the theory, CE Delft and Oeko-Institut concluded in their report that the more firms operate in a market (i.e. the more competitive is the market), the higher the cost pass-through.

Market Infrastructure

In the context of this study, market infrastructure can be defined by the level of airports congestion in the air transport industry. Historic growth in the airline industry has not always been match by adequate growth in airport infrastructure, for example due to geographic, financial and environmental constraints. As a result, some airports operate at capacity, particularly at peak times. This has been analysed in an Oxera analysis carried out in 2003[672], which investigated the ability of airlines to pass-through the cost of carbon emissions trading depending on factors such as airports congestion. Oxera defined two categories of airports:

- Uncongested airports: the allowance/credit price is passed through to passengers in the ticket price, resulting in a loss of profit margin and volume,
- Congested airports: the costs are not passed through in the ticket price, avoiding volume loss, but resulting in higher loss of profit margin.

The two following figures (Figure 54 and Figure 55) illustrate supply and demand dynamics at the different types of airport. The vertical supply curves S0 and S1 are the inelastic curves of seats supply at a specific airport, limited by its capacity. D represents the demand at the specific airport and the horizontal supply curves illustrate the seat capacity provided by the airline under different price conditions P0 and P1. The latter curves are

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[670] CE Delft and Oeko-Institut, 2015. Ex-post investigation of cost pass-through in the EU ETS. An analysis for six sectors.

[671] Sijm et al. (2009), J. Slijm, Y. Chen, F. Hobbs, The impact of power market structure on the pass-through of CO_2 emissions trading costs to electricity prices – A theoretical approach Paper: presented at the 17th Annual Conference of the European Association of Environmental and Resource Economics (EAERE), Amsterdam, June 24-27, 2009.

[672]Oxford Economic Research Associates, 2003 - Assessment of the Financial Impact on Airlines of Integration into the EU Greenhouse Gas Emission Trading Scheme.

horizontal as it is assumed that the marginal cost of offering extra airline seats is the same as the average cost of offering extra airline seats.

At uncongested airports, the demand does not exceed the maximum capacity supply curve of the airport. As a result, if additional costs, such as the EU ETS carbon costs are passed through, then the price increases, and there's an uplift along Line D, resulting in decreased demand. If market participants choose not to pass-through the increased cost, then in a competitive market where the price (p0) does not allow excess profits they would incur a loss and be forced to exit the market in the long-term. If they passed-through more than the increase, then their higher price would limit demand for their outputs, reducing their share of the market.

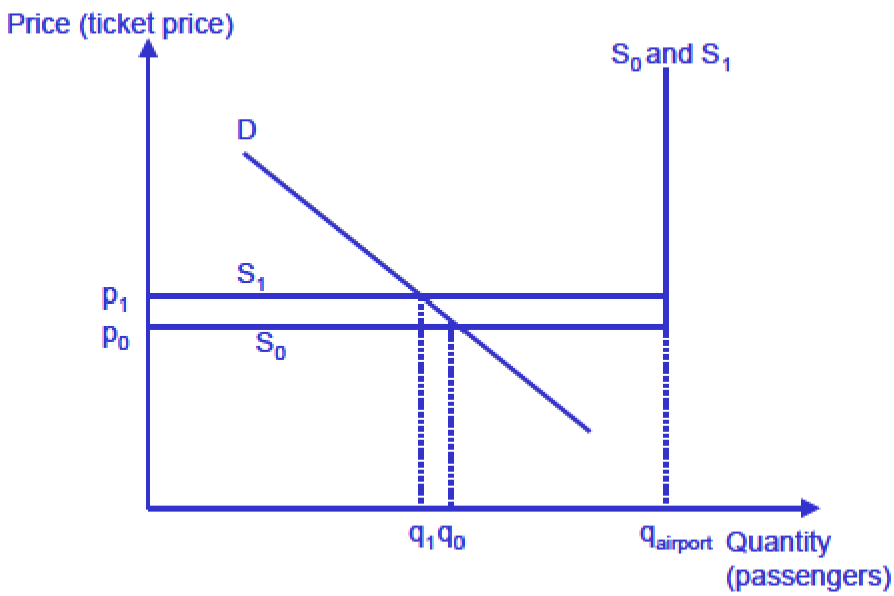

Figure 54. Demand and supply at uncongested airports (source: Oxera, 2003)

In contrast, at congested airports, airlines operate at maximum capacity and therefore establishing ticket fares at the demand clearance pricing point, above the supply curve, as shown in the figure below. This point is selected as the price at which demand matches the available capacity, and consequently is typically well above the cost of inputs, allowing market participants to earn excessive profits. Increasing the ticket price above this point would reduce demand below the available capacity, so increases in costs tend to be absorbed (reducing airline profitability) rather than passed through.

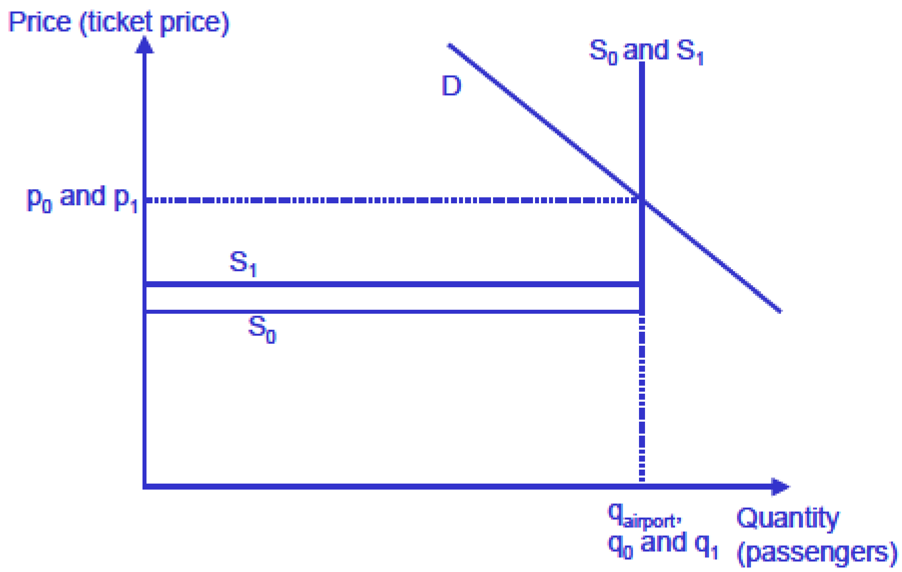

Figure 55. Demand and supply at congested airports (source: Oxera, 2003)

Oxera assumed that the proportion of flights from and to congested airports in the European Union represented 25%, with no cost pass-through possible at these airports.

A study from Mott MacDonald, cited in Ernst & Young and York Aviation[673], segmented traffic going through congested airports by airline business model. For network airlines, traffic from congested airport would increase from 30% in 2005 to 50% in 2025. In contrast, 100% of operations is considered to be to and from uncongested airports for low fares airlines. The latter might be less true today with many prominent low-cost airlines such as Ryanair and easyJet operating from major congested hubs such as Dublin and Gatwick airports respectively.

Quiang Cui, Ye Li and Yi-Ming Wei[674] investigate the impacts of the EU ETS on the pollution abatement costs of European airlines. In their study, they assume that the European airlines would not pass-through the cost of carbon emissions based on a study carried out by Wang in 2013[675]. Wang study analyses the cost pass-through of Chinese airlines and conclude that due to the highly competitive environment as well as the substantial congestion of airports, the pass-through rate should be less than 12%. They postulate that for slot-constrained European airports, the cost pass-through rate would be low as demand condition and airport capacity would drive pass-through strategy instead of operating costs.

Demand elasticity

Demand elasticity refers to the degree to which supply or demand of a product responds to a change in price. If the demand elasticity of a product is zero (i.e. rigid demand) then

[673] Ernst & Young and York Aviation, 2008. Inclusion of Aviation in the EU ETS: Cases for Carbon Leakage York Aviation.

[674] Quiang Cui, Ye Li, Yi-Ming Wei, 2017. Exploring the impacts of EU ETS on the pollution abatement costs of

European airlines: An application of Network Environmental Production Function. Transport Policy, 60, 131-142.

[675] Wang, J., 2013. Study on the Impacts of the EU ETS on China's Passenger Airlines. Northeast University of Finance and Economics (in Chinese).

price changes would not affect demand and additional CO_2 costs can be passed through with no risk of a firm losing market share. Conversely, if the price elasticity is high, a small change in price would cause substantial changes in demand or supply.

Anger (2010)[676] analysed the impact of including aviation in EU ETS on the global industry, CO_2 emissions and macroeconomic activity in the EU. The particularity of this study is that Annela Anger uses the E3ME simulation model which can simulate the interactions between air transport and 41 other industrial sectors in a particular region instead of isolating the aviation sector. This type of model allows feedbacks between sectors in response to a particular policy imposed on one or several industries. The E3ME model used in the study assumes 100% cost pass-through and the study argues that the small impact on demand for air transport that they observe are attributable to the counter effect of increasing consumer income and to feedbacks from other industrial sectors in the model. Namely, the decrease in economic activity in the aviation sector is partly offset by increased income generated from substitute activities. The assumption on cost pass-through is based on various studies that demonstrate that the income elasticities of demand are estimated to be between 1 and 2, whereas the price elasticities of demand for airline services has a wide range of estimates from 0 to -3.2 (Gillen et al., 2007[677]; Intervistas 2007[678]). Hence income elasticities would outweigh the negative effects of price elasticities in most of the case. In addition, this assumption is also emphasised by studies (Vivid, 2008[679]; Mayor & Tol, 2007[680]) showing that the possibility of passing 100% of the cost is likely to happen due to demand being inelastic. Therefore, the potential decrease in economic activity in the air transport sector is likely to be offset by increased income generated from other industries.

According to Frontier Economics analysis (2006)[681], there are only two situations in which an increase in marginal costs leads to complete pass through of costs in higher prices:

1. Supply of aviation services is perfectly elastic (horizontal supply curve as used by Oxera, 2003) or,
2. Demand for aviation is perfectly inelastic (vertical demand curve)

These two situations are theoretical and neither of these scenarios reflect the real aviation environment. Demand for aviation services is clearly not insensitive to price, while the supply would only be perfectly elastic under specific conditions mentioned in the Market Infrastructure section, which are not plausible in real market conditions.

In practice, both demand and supply of aviation services are price sensitive. According to Frontier Economics, an increase in marginal costs will not be fully passed on in higher prices.

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676 Annela Anger, 2010. Including aviation in the European emissions trading scheme: Impacts on the industry, CO_2 emissions and macroeconomic activity in the EU. Journal of Air Transport Management, 16, 100-105.

677 Gillen, D., Morrison, W.G., Stewart, Chr, 2007. Air travel demand estimates. In: Lee, D. (Ed.), The Economics of Airline Institutions, Operations and Marketing. Elsevier, Amsterdam.

678 Intervistas, 2007. Estimating Air Travel Demand Elasticities: Final Report. Prepared for IATA.

679 Vivid, 2008. A Study to Estimate Ticket Price Changes for Aviation in the EU ETS: A report for Defra and DfT. Vivid Economics.

680 Mayor, K., Tol, R.S.J., 2007. The impact of the UK aviation tax on carbon dioxide emissions and visitor numbers. Transport Policy 14, 507–513.

681 Frontier Economics, 2006. Economic consideration of extending the EU ETS to include aviation. A report prepared for the European Low Fares Airline Association (ELFAA).

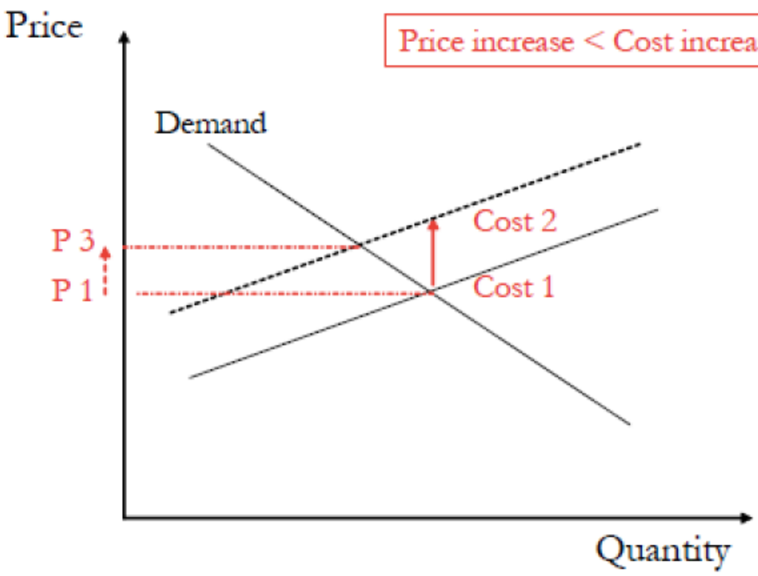

Figure 56. Elastic Demand and Supply (source: Frontier Economics, 2006)

When demand and supply are price elastic full cost pass through cannot be achieved as shown by Figure 56.

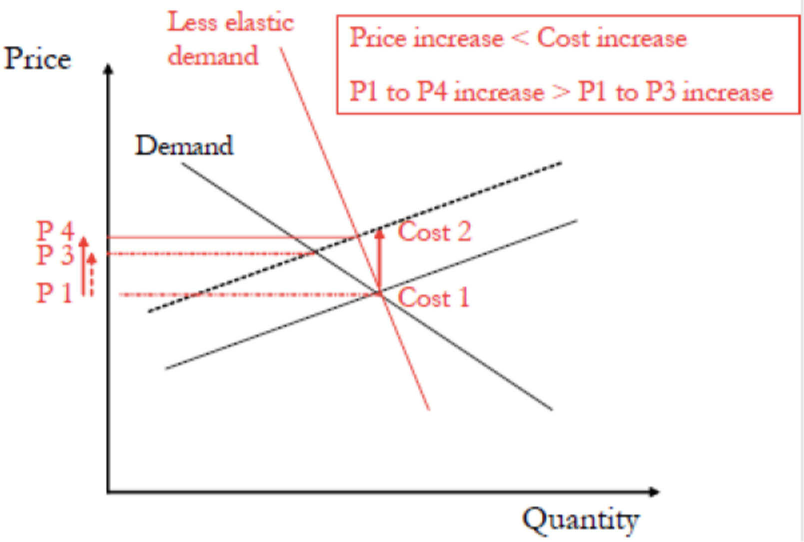

Figure 57. Less Elastic Demand vs Supply (source: Frontier Economics, 2006)

Figure 57 shows that a less elastic demand leads to a higher cost pass-through in higher prices.

Ernst & Young and York Aviation[682] described the shape of the demand curve as one of the main important factors when analysing cost pass-through in the aviation sector. The cost pass-through rate is lower when the price elasticity increases because of higher ticket prices, that is to say if the demand-curve is concave.

[682] Ernst & Young and York Aviation, 2008. Inclusion of Aviation in the EU ETS: Cases for Carbon Leakage York Aviation.

The refinery sector defined above covers different types of refined products including petrol, diesel and gasoline. Cost pass-through will vary depending on the type of refined product. According to CE Delft and Oeko Institute (2015), Diesel has a higher potential for carbon cost pass-through compared to gasoline due to its lower price elasticity. This could be affected by other assumptions deviating from the Perfect Competition market and from different pricing strategies. Cost pass-through rate is also affected by geographies with different rates across EU Member States.

In the maritime sector, Vivid Economics[683] demonstrated that higher price elasticity leads to lower cost pass-through. Crude oil shipping has high level of cost pass-through – over 100% cost pass-through for South Korea which is heavily relying on sea-borne transport – compared to approximately 50% for apparel and furniture shipping, which are by nature more price elastic.

Exposure to international trade

Exposure to international trade also influences the ability of a firm to pass through additional carbon costs. If the exposure of a firm to international trade is low, higher product prices due to passing through additional costs may not impact the competitiveness of the firm.

According to Vivid Economics (2014)[684], the aluminium sector is associated with low levels of cost pass-through, absorbing more than 80% of the carbon prices, as the commodity is traded on a global market and there is sufficient global capacity, the EU supplying only 8% of global output. In contrast, the EU is a major exporter of malt with very low imports and the absence of non-EU competition. This combination allows malt producers to fully pass-through the cost of carbon.

The cement industry, facing low competition from non-EU producers, has a high propensity to pass-through carbon costs in certain regions (90-100% in Poland and Czech Republic) according to CE Delft and Oeko-Institut (2015). However, exposure to international trade is one factors among many, as demonstrated to the low rate of cost pass-through in the Western Europe cement industry.

The steel industry shows a low cost pass through as EU firms compete with foreign firms that have not been impacted by the increases in prices. Steel demand peaked before the financial crisis in 2009 and has significantly dropped after that without any growth regain to pre-crisis levels. This characteristic combined with intense competition in Asia leads to a limited capacity to pass-through carbon costs as steelmakers try to sustain market share by keeping prices low.

The broader study carried out by CE Delft and Oeko-Institut (2015) shows that higher trade intensity coincides with a limited ability to pass-through costs and lower trade intensity might enable higher cost pass-through. However, the difficulty is to determine how trade intensities influence the level of cost pass-through.

Regarding the air transport industry, in the EU ETS scheme, the scope of the charge application was reduced from all the departures and arrivals from EU airports to intra-EEA routes only. Therefore, the impact of international trade for EU airlines is limited as any EU or non-EU airline operating a given route will be subjected to the same rules (i.e. EU ETS charges incurred on intra-EEA and exempted extra-EEA routes). However, at a network level, airlines operating intra-EEA routes will incur higher costs compared to

[683] Vivid Economics, 2010. Assessment of the economic impact of market-based measures. Prepared for the Expert Group on Market-based Measures, International Maritime Organization.

[684] Vivid Economics, 2014. Carbon leakage prospects under Phase III of the EU ETS and beyond. Report prepared for the UK Department of Energy & Climate Change.

airlines operating extra-EEA routes exclusively. Airlines operating a mixed network can therefore disadvantage the overall company's cost base and profitability.

Sandbag Aviation (2012)[685] report points out the disproportionate distribution of free allocations to EU airlines, being too generous to airlines travelling long haul which can then get windfall profits for passing the opportunity cost of free allowances on to the consumer. On the other end, as a short-haul airline, Ryanair with 84% of its emissions subject to the EU ETS, complains that due to the EU's decision to suspend the operation of the ETS on flights to/from non-EU countries, legacy carriers present an unfair advantage as on average only 50% of their emissions are subject to the EU ETS[686].

Carbon costs distribution

Depending on the scope and structure of carbon costs, airlines are likely to be impacted to varying degrees relative to each other. The relative difference in the charge is likely to influence the cost-pass through, linking to the concepts above and references in other studies. When modelling airline competition, we have found that unequal carbon costs for competing airlines on a route tends to lead to lower average pass-through for the most affected airlines and/or profit increases for the less-affected airlines. In order to operate a specific flight, airlines need to cover their effective running costs. Therefore, the airline operating with the most advantageous cost function (i.e. lower carbon charges) can derive higher profits[687]. In the same way, carbon policies applied unilaterally to one region only will increase costs for companies operating in that region whilst those operating outside region won't face these costs. Inequality in carbon distribution is defined in different ways, as demonstrated by Fabre and Brinke[688] in a study on the impact of unilateral carbon price policies on the aviation industry in 2011. They analysed three different arguments on a possible distortion of competition between EU airlines and non-EU airlines:

1. Cross-subsidisation effect: EU airlines with a larger proportion of flights falling under the scope of the EU ETS policy will have limited opportunities to cross-subsidise affected routes from profits on unaffected routes.
2. Volume effect: the greater the network subject to the EU ETS the bigger the cost burden for airlines (e.g. As a short-haul airline operating almost entirely within the EU, 84% of Ryanair's emissions are subject to the EU ETS. This is a much higher proportion than legacy carriers[689]).
3. Hub effect: airlines operating hubs within EU will face higher costs than those with hubs outside the EU, potentially shifting markets if cost is passed through to ticket price.

Dray et al. (2018)[690] analysed the change in demand following policies implementation such as carbon charges in a specific area, the UK. They demonstrated that an increase in carbon price applied to all UK departing flight would result in a reduction in UK O&D passengers and in some cases changes in itinerary choice for international-international transfer passengers.

Auctioning and allocation options: Ryanair Case Study

685 Sandbag, 2012. Aviation and the EU ETS: What happened in 2012 during the 'Stop the Clock'?

686 Ryanair Holdings PLC Annual Report, 2019.

687 INFRAS, CE Delft & TAKS, 2016. The EU Emission Trading Schemes' effects on the competitive situation within national and international aviation.

688 Faber, J. & Brinke, L., 2011. The inclusion of aviation in the EU Emissions Trading System. ICTSD Programme on Trade and Environment, Issue Paper No. 5. ICTSD, Geneva.

689 Ryanair Holdings PLC Annual Report, 2019.

690 Lynnette Dray, David Hart, Andreas Schäfer and Roger Gardner, 2018. The Carbon Leakage and Competitiveness Impacts of Carbon Abatement Policy in Aviation. Report to the Department for Transport.

According to European Commission's latest assessment regarding auctioning and free allocation, alternative policy options to modulate the share of free allocation are to be addressed. The current situation is a *de jure* 85% free allocation. In the future, the European Commission explores the following options:

0. **Status quo**: The current legal situation is perpetuated until 2030, i.e. the 15% auctioning share.
1. **Immediate phase-out**: 100% auctioning from the entry into force of the revision.
2. **Swift phase-out**: Full auctioning by 2025, starting with an auctioning share of 60% in 2023, and a share of 80% in 2024.
3. **Slow phase-out:** A linear increase year-by-year to full auctioning by 2030 staring from 20% in 2023.
4. **Slow reduction**: A linear increase year-by-year starting with an auctioning share of 20% in 2023 and ending at 55% in 2030.

The five different policy options will have different impact on airlines' profitability. In this section, we choose to analyse their impact on Ryanair's results for several reasons:

- In their 2019 fiscal year, Ryanair reported the environmental charges they paid related to the EU ETS scheme
- Over the same year, 84% of its network's emissions was subject to EU ETS charges

In fiscal year 2019, Ryanair paid approximately €115M EU ETS charges, flying 142M passengers for an average fare of €37. This translates to an average EU ETS charge of €0.81 per passenger, or 2.2% of the ticket fare. Ryanair earn an additional €17 per passenger in ancillary revenues (e.g. baggage fees, seat allocation, etc), which further reduces the share of the ETS charge to 1.5% of a typical total flight cost including ancillary charges.

In the *de facto* situation, Ryanair reported 10,452,411 verified emissions in EU ETL for a free allocation amounted to 4,610,591, leading to a 44% of free emissions allowances[691]. Over the next decade, the policy chosen could impact ticket fares in different ways as shown by Figure 58 (increasing per-tonne costs at the 1.8% Base rate provided by DG CLIMA, and varying share of auctioning).

691 https://ec.europa.eu/clima/ets/ohaDetails.do?languageCode=en&action=all&accountID=106071

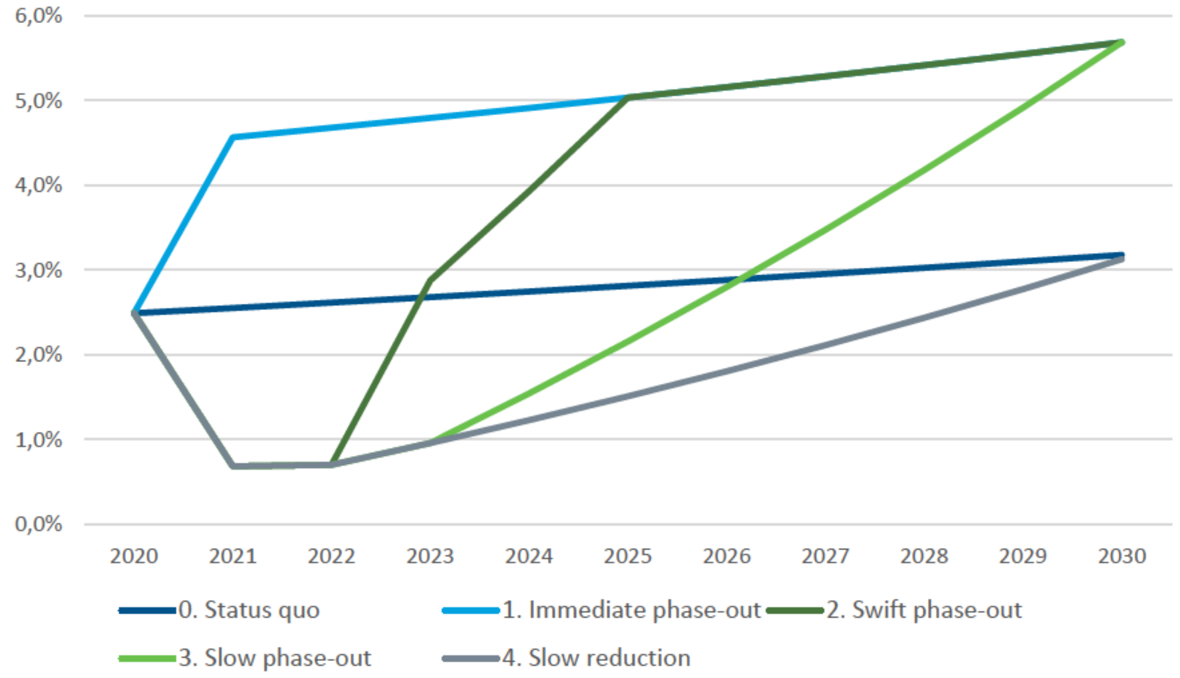

Figure 58. Estimated Ryaniair's EU ETS charge as a portion of ticket price (source: ICF projections)

To estimate projections of EU ETS charges over the next decades, forecasts of EU ETS payments by the airline, growth of passengers and average ticket fares were produced based on historical figures. The slightly declining trend in average ticket fares over the years exacerbates the increasing portion of emissions charges. Base case scenario was used for EUA prices growth, at a 1.8% yearly rate between 2020 and 2030.

Despite EU ETS charges increasing to approximately 6% of ticket price in 2030 in the highest cost scenario, these increases remain relatively small in absolute euro terms charged to passengers as shown by Figure 59. EU ETS charges per ticket will remain between €0.2 and €2 between 2021 and 2030.

From the airline perspective, they will either pass-through this cost and raise their ticket price by 6% or absorb the cost and significantly increase the operating costs. Historically, airlines have rarely been able to achieve high levels of profitability, and a sustained increase in costs without a commensurate increase in revenues would lead in most cases to bankruptcy.

On the other hand, from the passenger perspective, an additional €2 on the ticket fare may not represent a significant increase on the overall cost of the trip, which is likely to also include ancillary expenses of over €17 on average[692], transport to and from the airport, the cost of the stay at destination and meals. According to Eurostat, the average

[692] Average Ancillary Revenue per Passenger Booked = €17.14. Ryanair Holdings PLC Annual Report, FY 2019.

tourism trip of Europeans in the EU cost €336 for the accommodation only[693]. The additional ticket charge would therefore likely represent less than 0.9%[694] of the trip cost.

In past studies ICF has analysed the impact of government taxes or airport charges on air fares. Ticket pricing is a complex process influenced by numerous factors and prices can be extremely volatile. Seat prices can vary significantly depending on when the ticket is booked, time of travel, remaining seats on sale and the levels of competition on the route. As a result, the level of carbon charges per passenger pales in comparison to typical variations in tickets prices, which can vary drastically for essentially the same product, sometimes by €100s[695].

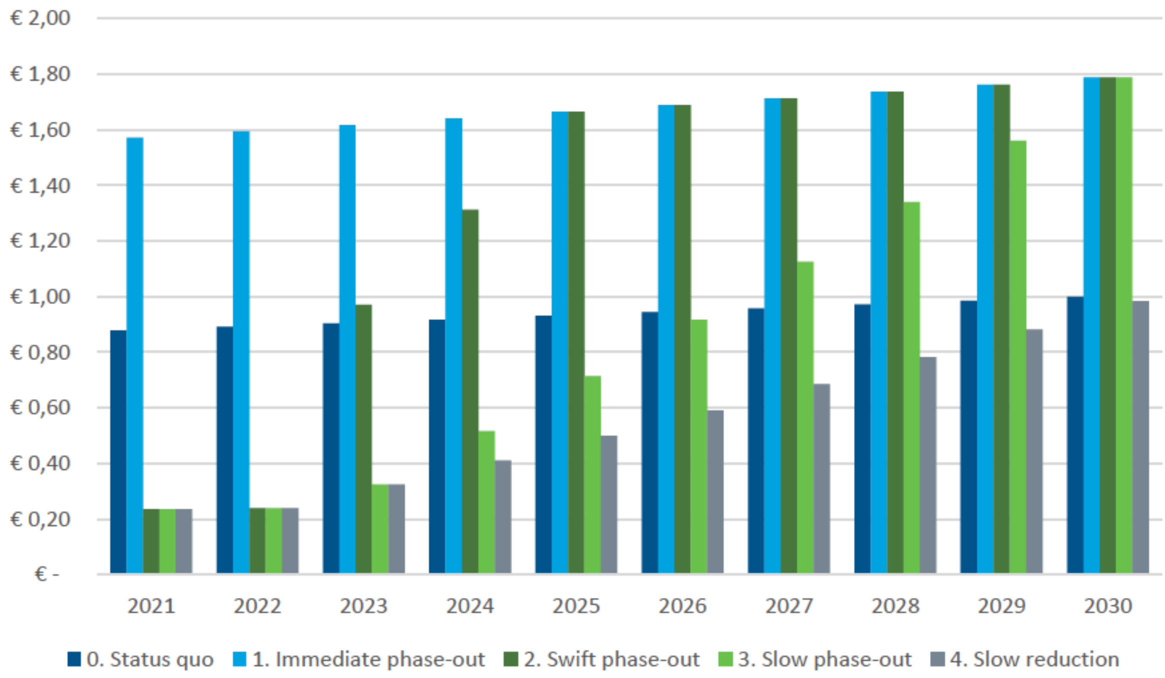

Figure 59. Illustrative policy option impact on Ryanair individual ticket fares (source: ICF projections based on Ryanair FY 2019 reported EU ETS costs) #

Impact of free allocation

In the EU ETS, free allocation of allowances is intended for sectors where carbon leakage may occur. As regards aviation, the 2006 Impact Assessment considered that the cost of participating in the scheme can be passed to the customers. However it was decided to use free allocation for aviation. As of 2020, aviation gets approximately 45% of free allowances.[696] The impact of auctioning and free allocations will vary depending on the auctioning policies and ETS/CORSIA mix scenarios retained among those described by the European Commission. The immediate phase-out of free allowance allocation could cost airlines nearly €30 billion over the 2023-2030 period under full EU ETS scope, whereas applying the CORSIA scheme only could cost €0 as demonstrated in Section 3.2.13.

693 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Tourism_trips_of_Europeans

694 €4 / €458 = 0.9%. Note: €4 is the charge on a return trip, €458 is the cost of the trip (assuming €336 for the accommodation, €37 ticket fare per leg, €34 ancillary expenses, and the additional €4 charges).

695 https://www.icf.com/insights/transportation/identifying-the-drivers-of-air-fares, page 30

696 https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1

As the EUA prices are substantially higher than eligible unit prices for CORSIA, airlines will have greater challenges to pass-through the cost of carbon charges under the EU ETS scheme, compared to CORSIA. Furthermore, if aviation remains part of the ETS, with free allowances removed, the demand for EUAs will increase significantly, driving prices upwards which will further affect airlines' ability to pass-through the cost of carbon charges.

Comparison with the Rail and Power sectors

Concerning rail transport, more than 9.6 billion passengers travelled on national railway networks in the EU, in 2017, compared to 1 billion of air transport passengers.[697] Rail is not included in the EU ETS as a standalone sector but indirectly through the use of electricity for the electrified railways. According to the Community of European Railway and Infrastructure Companies (CER)[698], 80% of the rail passengers transported in the EU are using electrified railways which are subject to EU ETS. Following the same source, the rail sector spent €110m of ETS charges in 2015 and will spend €370 annually between 2020 and 2030. Thanks to an extrapolation, the rail sector spent approx. €214m in 2017 for its carbon emissions, for 7.68b passengers transported on the electrified infrastructure, or 3 cents per passenger. This figure is ten times lower than best case scenario of Ryanair's case study. Therefore, this suggests the rail sector can pass-through carbon charges more easily than the aviation sector.

In the power sector, the 2009 review of the EU ETS decided that full auctioning should be the rule from 2013 onwards, taking into account its ability to pass on the increased cost of CO_2. In this sector different players are affected in different ways due to the diversity of power generation technologies producing varying amounts of carbon emissions. In their research[699], Sijm et al. looked at how the spot power price can be explained by a change in the price of a CO_2 allowance on the EUA market. They found that power producers pass on the opportunity costs of freely allocated emission allowances on the price of electricity. However, the increase in CO_2 costs per MWh over the years is not entirely passed through with rates varying between 60% and 100% for wholesale power markets in Germany and the Netherlands.

Competitiveness between different transport modes

Transport represents almost a quarter of Europe's greenhouse gas emissions and is the main cause of air pollution in cities. The transport emission are still growing contrary to other sectors such as industries or agriculture. Within this sector, road transport is by far the biggest emitter accounting for more than 70% of all GHG emissions from transport in 2017, followed by aviation and shipping both at 13%.[700]

Europe's ambition is to become climate neutral by 2050. According to the European Green Deal communication, in order to achieve this objective a 90% reduction in transport emission is needed by 2050.

Travelling by rail is between three and ten times less CO_2-intensive compared with road or air transport. Rail's share of transport energy consumption is less than 2%, despite a market share of over 8.5%.[701] Despite being the smallest polluter, rail transport is indirectly included in the EU ETS and is thus disadvantaged in a modal split over non-

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697 https://ec.europa.eu/eurostat/statistics-explained/index.php/Passenger_transport_statistics#Rail_passengers

698 https://www.cer.be/sites/default/files/publication/CER%20Factsheet_EU%20ETS%20Reform_Sept%202016.pdf

699 Sijm, Neuhoff & Chen, 2006. CO2 Cost Pass Through and Windfall Profits in the Power Sector.

700 https://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2019_en

701 https://uic.org/sustainable-development/energy-and-co2-emissions/

electrically-powered transport. According to the CER, the rail sector pays 100% of its emissions emanating from electricity production, which amounted to €110m in 2015, compared to aviation where free allowances are still distributed and road transport which is out of the EU ETS.

Maritime transport emits around 940m tons of CO_2 annually and is responsible for 2.5% of global greenhouse gas emissions. Shipping emissions represented around 13% of EU GHG emissions from the transport sector in 2017. Since 2018, the maritime sector is subject to CO_2 emissions monitoring and reporting obligations. In its Communication on the European Green Deal, the Commission announced that it will propose to extend European emissions trading to the maritime sector.

Road transport, like maritime, remains excluded from the EU ETS despite being the most polluting mode of transportation. In 2015, the sector represented 20% of European GHG emissions and more than 70% of European transport emissions. There have been many discussions and reports from the European Commission to include road transportation in the EU ETS. However, some studies demonstrate that including road transport in the EU ETS could disturb effort-sharing between sectors and EUA prices.[702]

Competition within the aviation sector can be distorted under different EU ETS/CORSIA combined options. As described in Section 3.2.11, option 6 is the biggest source of competitive distortion as different airlines operating the same flight segment would have substantially different carbon costs. Other options will apply broadly the same level of carbon charges for all airlines operating the same flight segment, leading to minimal competition distortion within the industry.

Competitiveness of the aviation sector with other transport sectors will heavily depend on the combined options. As described earlier, depending on the option pushed forward by the European Commission, carbon charges could cost airlines from €0 (CORSIA only) to €30 billion (EU ETS full scope) as emission caps and carbon unit price are different in the two schemes. Ryanair’s case study showed per passenger carbon cost between €0.2 and €2, or between ten and a hundred times higher than per passenger train carbon charge. This may affect travel purchasing decisions. However, the main factor playing in favour of aviation is the ticket price differences and the ease of access to remote or geographically constrained locations where train or road access are difficult or impossible.

Finally, this issue is part of a broader discussion on the internalisation of external costs[703] and current tax exemptions including for aviation and maritime fuels[704].

4.4 Findings summary

Figure 59 below summarises the literature review and the different carbon cost pass-through rates identified in the reports analysed. There is a wide range of cost pass-through rates both within the aviation sector and in other sectors, depending on several factors summarized in Table 52 below.

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[702] Institute for Climate Economics, Enerdata and IFPen, 2015. Exploring the EU ETS beyond 2020: A first assessment of the EU Commission’s proposal for Phase IV of the EU ETS (2021-2030)

[703] In-Depth analysis in support of the Commission Communication COM(2018) 773, A Clean Planet for all, page 110

[704] European Green Deal communication, page 10

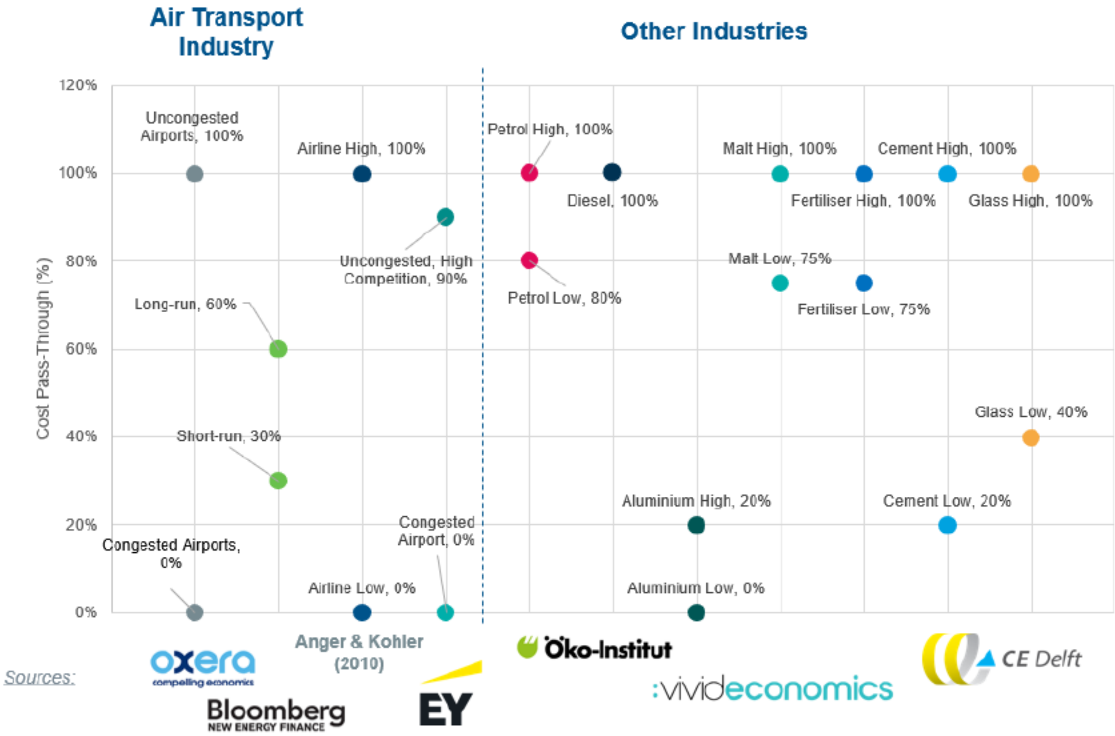


Figure 60. Cost pass-through rates summary (source: ICF)

Table 52. Findings from Literature Review: Factors impacting cost pass-through

Factors influencing cost pass-through	Impact
Market Condition	High competition = High cost pass-through
Market Infrastructure	High congestion = Low cost pass-through
Demand Elasticity	High elasticity = Low cost pass-through
Exposure to international trade	High exposure = Low cost pass-through
Carbon costs distribution	Unequal distribution = Low cost pass-through

In the following section, ICF will build on these literature findings, as well as data and analysis specific to aviation carbon costs, to inform the appropriate rate of cost pass through for the key dimensions of the European airline and route landscape.

4.5 Quantitative assessment of cost pass-through for airlines

Koopmans & Lieshout (2016)[705] highlighted the lack of empirical research with respect to the pass-through of airline cost changes, due to the difficulty in obtaining and analysing detailed ticket fare data and the need to control for many factors such as competition, airport capacity and hedging for fuel. In this section we analyse fares' movements in different configurations including the previous ones mentioned by Koopmans & Lieshout.

In the previous section, we identified five factors affecting the ability of airlines to pass-through additional costs such as the carbon charges under the EU ETS to ticket fares. Among these five, three main factors were selected for this quantitative assessment both for their relevance and data availability:

1. Airport congestion,
2. Competition intensity,
3. Demand elasticity.

Airline fare setting is a complex and dynamic process, varying by carrier, route and time. It lies at the heart of an airline's commercial strategy as it aims to maximise the return on its assets employed, namely its aircraft and its people. However, in this section, we analyse how increases in airline costs are passed through to the ticket fares, depending on these three factors identified above. The analysis will look at how variation of costs can be passed-through at a route level, depending on the characteristics of each route in the European Economic Area (EEA).

The following process is used to determine airlines' cost pass-through on a specific type of route (Figure 61).

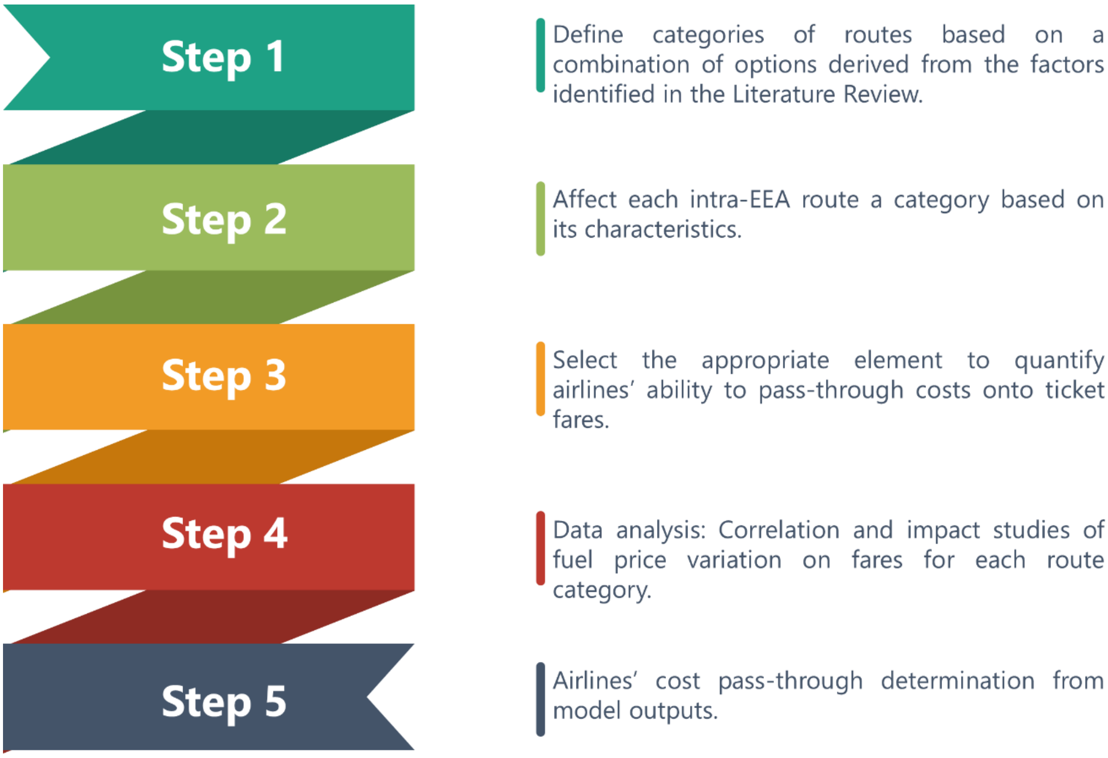


Figure 61. Airline cost pass-through determination (source: ICF)

It is to be noted that this study will focus the analysis on what we defined as the *out-of-pocket costs,* which are the actual costs incurred by the airlines. The opportunity costs

[705] Koopmans, C. & Lieshout, R., 2016. Airline cost changes: To what extent are they passed through to the passenger? Journal of Air Transport Management, 53, 1-11.

created by the free allowances distributed to airlines are harder to quantify due to the limited data available for the analysis and are therefore not included in the cost pass-through defined for this study. Each step is further described below.

4.5.1 Step 1: Define route categories

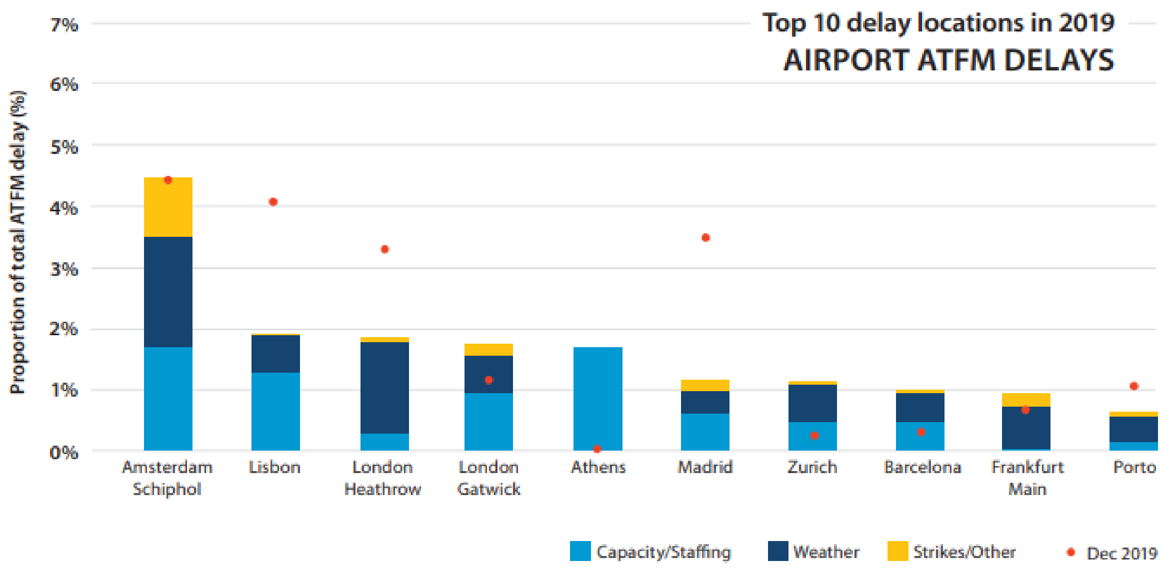
Based on the three factors identified in the literature review, we define route categories based on the different options each of the three factors could take, leading to 27 different combinations of options, described below.

Level of congestion

The level of congestion at a specific airport for a given period of time is defined by Eurocontrol (2018)[706] as the ratio between the traffic demand and the available capacity. In their 2018 analysis, Eurocontrol observed that six airports were operating at 80% or more of capacity during six consecutive hours or more, and this is to climb to 16 congested airports by 2040. Mayer and Sinai[707] demonstrated that two different types of congestion, network benefits from hubbing and congestion externalities, have the potential to cause delays at airport, with the former leading to higher level of delays.

In our analysis, we define congested airports as the top ten airports with the most delayed traffic, measured by Eurocontrol (Figure 62). Therefore, each intra-EEA route can be defined by one of the three-following options:

- Congested airport to Congested airport (C & C),
- Congested airport to Uncongested airport (C & UC),
- Uncongested to Uncongested airport (UC & UC).



[706] Eurocontrol, 2018. European Aviation in 2040: Challenges of growth.

[707] Mayer, C., & Sinai, T., 2003. Network Effects, Congestion Externalities, and Air Traffic Delays: Or Why Not All Delays Are Evil. American Economic Review, 93 (4), 1194-1215.

Figure 62. Airport delays (source: Eurocontrol, 2019)

Level of competition

In this analysis, we used the number of airlines operating between two points as a proxy to determine the competitive intensity on each route. As for airport congestion, we defined three different options at the route level for competition:

- Low: one or two airlines operate on the route.
- Medium: between three and four airlines operate on the route.
- High: five airlines or more operate on the route.

For the purpose of the analysis, airlines operating in the same group are assumed to be only one airline as the competitiveness among groups is supposed to be limited (e.g. British Airways and Iberia as part of IAG).

Some examples of route competition categorisation below:

- Low: London Heathrow – Malta Internal Airport has historically been operated by only one airline, Air Malta.
- Medium: Stockholm Arlanda – Helsinki Airport has had three airlines operating over the past few years (SAS, Finnair and Norwegian).
- High: Dusseldorf International Airport – Heraklion International Airport route is operated by six airlines (Lufthansa, Aegean, Condor, TUI, SunExpress Deutschland and Lauda).

Demand Elasticity

In economics, elasticity measures the response or sensitivity of one economic variable to the change in another economic variable. Elasticities are a useful concept as they allow decision makers insight into the impact of different economic actions. A common elasticity concept is demand elasticity. This measures the change in quantify demanded of a particular good or service as result of changes to other economic variables, such as the price of the that good or service, the price of competing or complimentary goods/services, income levels, taxes, etc.

The previous section showed the importance of demand elasticity in the determination of cost pass-through. Intervistas[708] explored many ways to analyse demand elasticity in the air transportation industry. One of them is the route distance (trip length). The intuition behind the use of distance as an explanatory variable resides in its ability to address value of travel time savings and availability of substitutes, with the rationale that as haul length increases, other modes of transport become less viable to circumvent obstacles that may arise such as oceans, poor terrain, unfriendly states, etc.

In its research, Intervistas found that length of haul has a statistically significant result and that the fare elasticities on short-haul routes are generally higher than on long-haul routes, reflecting the opportunity for inter-modal substitution on short-haul routes (e.g. to rail or car).

Other researches have shown that route distance between two airports have some effect on the fare elasticities, as the one conducted by Gillen et al. in 2002, Figure 63.

[708] Intervistas, 2007. Estimating Air Travel Demand Elasticities. Prepared for IATA.

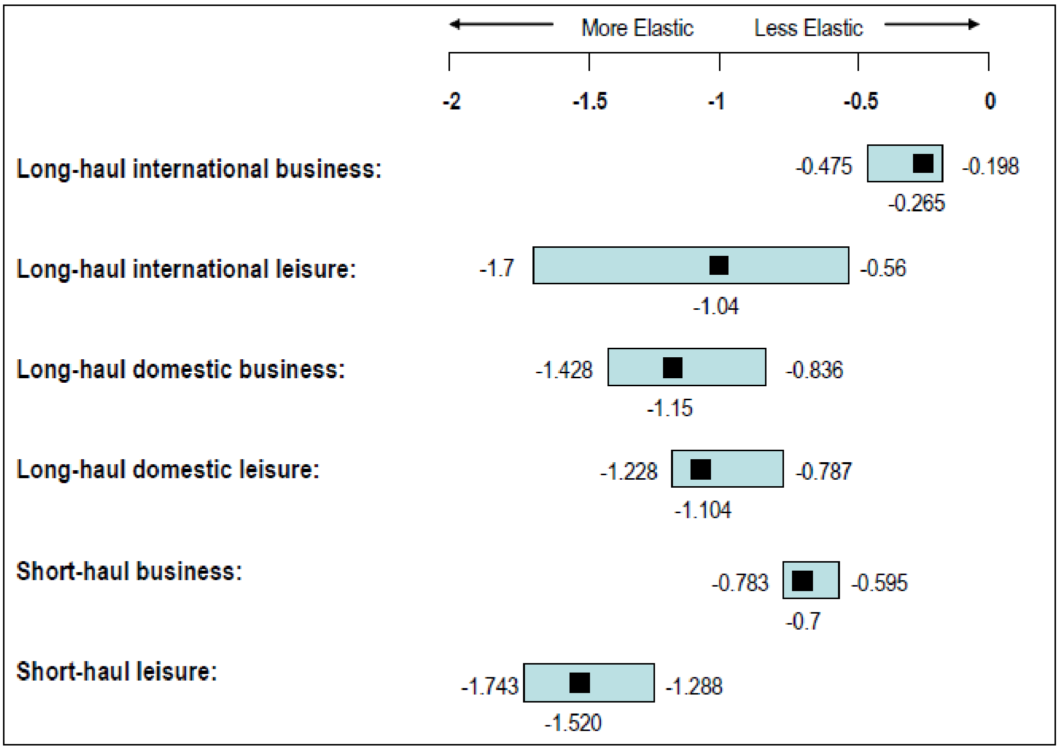


Figure 63. Own-price elasticities of demand (source: Gillen et al., 2002[709])

In light of these studies, route distance was used as a proxy for demand elasticity between two airports on each route to analyse how it affects cost pass-through opportunities. Three different distance options for each route within EEA were defined, to form three groups with similar numbers of routes:

- Short distance: routes below 650 km
- Medium distance: routes between 650 km and 1250 km
- Long distance: above 1250 km

4.5.2 Step 2: Route categorisation

From the three factors defined previously and the three different options per factor, 27 combinations are defined, leading to a categorisation for every intra-EEA route within a specific group, as shown below.

Data was extracted from OAG database for each individual route in order to assign them to one of the 27 categories (Figure 64), based on characteristics described in previous steps.

[709] Gillen D., Morrison W.G., and Stewart C., 2002. Air Travel Demand Elasticities: Concepts, Issues and Measurement.

Inputs			
Category	Congestion	Competition	Route Distance
1	C & C	1+	Short
2	C & C	1+	Medium
3	C & C	1+	Long
4	C & C	3+	Short
5	C & C	3+	Medium
6	C & C	3+	Long
7	C & C	5+	Short
8	C & C	5+	Medium
9	C & C	5+	Long
10	C & UC	1+	Short
11	C & UC	1+	Medium
12	C & UC	1+	Long
13	C & UC	3+	Short
14	C & UC	3+	Medium
15	C & UC	3+	Long
16	C & UC	5+	Short
17	C & UC	5+	Medium
18	C & UC	5+	Long
19	UC & UC	1+	Short
20	UC & UC	1+	Medium
21	UC & UC	1+	Long
22	UC & UC	3+	Short
23	UC & UC	3+	Medium
24	UC & UC	3+	Long
25	UC & UC	5+	Short
26	UC & UC	5+	Medium
27	UC & UC	5+	Long

Figure 64. Route categories (source: ICF)

Analysis of movements within a specific group, described in section 4.5.4 below, will enable the isolation and assessment of certain factors' impact on airlines' ability to pass-through additional costs.

4.5.3 Step 3: Selection of fuel for the analysis

The aim of the analysis is to assess the airlines' potential to pass-through carbon charges. In our analysis we will analyse the impact of fuel price fluctuations on ticket fares as a proxy to identify how airlines respond to variations of costs.

We chose to study the fuel price fluctuations as fuel has represented an average of 26.7% of airlines' total costs over the last ten years and changes in the cost are relatively transparent and impact all operators to some degree (Figure 65). As a significant portion of expenses, it is easier to statistically analyse how airlines try to adapt to changes in fuel costs, depending on the characteristics of the routes analysed, as defined above.

For each route category, our analysis will first measure the correlation between fuel prices and airlines fares, assess the amplitude of changes of the two variables and will estimate the derived cost pass-through of airlines.

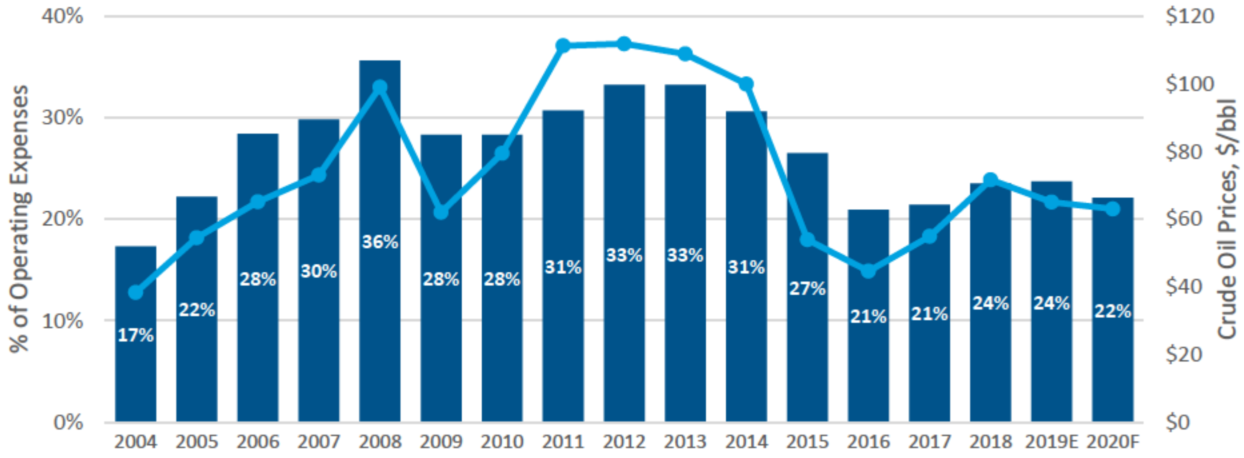


Figure 65. Fuel cost as a percentage of airline operating expenses, crude oil price (source: IATA Airline Industry Economic Report, December 2019)

Carbon emissions charges under the EU ETS certainly don't have the same impact as fuel cost due to the proportion of these charges relative to total airlines' cost and several other factors such as its relative stability compared to fuel prices volatility. However, fuel by its nature and importance in airlines' expenses is believed to be a relevant case study for this cost pass-through analysis.

4.5.4 Step 4: Data analysis

We used fuel price as a proxy for estimating the airlines' capacity to pass carbon emission charges through to ticket prices. To this end, we used historical fuel price data from the US Energy Information Administration and cross-correlated it with historical ticket price data from IATA PaxIS. The fuel price (see Figure 66) is given as monthly data points in USD per gallon, and the ticket prices for each category are given as the monthly average price across all fare classes per route. Figure 66 shows the average ticket price of all routes in a sample category (Category 15), along with the median price.

The raw data used in the analysis is noisy, and the ticket prices exhibit strong seasonality (see Figure 66 (a) and (c)). To remove this noise from the data, we decomposed it to trend, seasonality and noise using moving averages, and used the trend of the fuel price and the median ticket price to carry out the analysis. Figure 66 (a) and (c) show the trend, and the raw data for the fuel and ticket prices for Category 15, respectively.

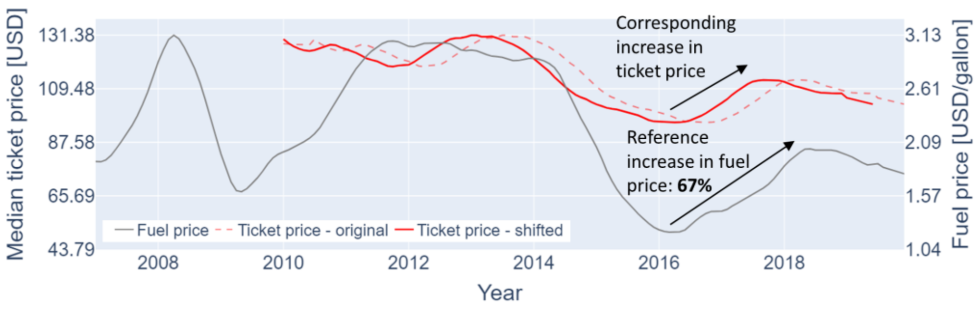
Furthermore, we assumed that the airlines would respond to the increase in fuel price with a delay. Due to developments in the aviation sector, such as changes to fuel hedging strategies and price evolution prediction capabilities, we assumed that the time-lag at which the airlines respond to the changes in fuel price has not been constant over the years. Therefore, for the cross-correlation, we chose the period starting from 2010 as the reference period, as it contains a well-defined plateau from October 2011 to April 2014, followed by a decline until April 2016 and a peak around June 2018 (see the trend line of fuel price in Figure 66 (a) and (d)).

From this reference period, we chose the increase in fuel price between 2016 and 2018 as the reference cost increase to be passed on to the ticket prices (see Figure 66(d)). This peak amounts to 67% increase in fuel price and it was used in this analysis to find the maximum correlation with each route category fares variation and their corresponding increase in ticket prices.

Historic fuel price. Raw data in dashed and trend line in solid.

All routes in Category 15 (coloured lines) and their median (in black).

The raw median ticket price for Category 15 (dashed) and the trend line (solid).



The reference increase in fuel price (in grey) and cross-correlated ticket price (original in dashed and at maximum correlation with 6 months shift in solid).

Figure 66. Data used in the cost pass-through analysis.

In order to find the increase in ticket price that corresponds to the 67% increase in fuel price, we cross-correlated the ticket price with the fuel price, allowing for a time-lag from one to 12 months in the response of the ticket price increase (i.e., the ticket price was shifted backwards up to 12 months to find the maximum correlation). The 12-month assumption is used to capture the effects of both fuel hedging strategies and advance bookings. An example of this is shown in Figure 66 (d), illustrating the fuel price in grey, the un-shifted (original) ticket price in dashed red and the ticket price shifted by six months (the lag at maximum correlation) in red for Category 15. The increase in ticket price corresponding to the increased fuel cost was determined as the difference (in percentage) between the 'valley' and the 'peak', as seen in Figure 66 (d).

After finding the maximum correlation and the increase in ticket price, the cost pass-through was quantified as follows:

$$\text{Cost pass-through} = \frac{\%\text{increase in ticket price}}{\%\text{fuel of ticket price x }\%\text{increased fuel cost}}$$

where the numerator is the increase in ticket price and the denominator is the proportion of fuel cost in the ticket price, multiplied by the increased fuel cost (i.e., the proportion of fuel in the ticket price if all other ticket pricing costs remain constant). The cost pass-through was thus defined as the ratio of increase in the ticket price to the proportion of fuel in the ticket after the increased fuel price.

To understand the percentage of fuel costs in the ticket price, the fixed costs had to be identified and excluded. This includes costs such as aircraft ownership or lease fees, airport landing and ground handling costs and staff wages. While many of these will vary between airlines – for example depending on contracts and business model – there is generally limited variation over a given route between given airports. Firstly, this is because airlines design route structures that tend to overlap with other airlines operating similar business models. For example, low cost carriers fly extensive networks within Europe, but very few transatlantic routes. Secondly, many airlines have little bargaining power outside their key bases and will incur similar fixed costs between similar airports. For example, the landing fees at a given airport will generally be similar, as will the ground handling cost. As a result of these dynamics, in this analysis we believe it is justified to identify the fixed costs as function of the route length. We calculated this by calculating the non-fuel costs as a percentage of revenue for a range of airlines, including Ryanair, easyJet, Wizz, Aurigny and Norwegian. These percentages were then regressed against each airline's average sector length. This regression showed a strong negative relationship, with an R-squared over 0.57 and gave the fuel price proportions shown in the following table.

Table 53. The proportion of fuel cost in ticket the price before and after fuel price increase for different flight distances.[710]

Distance	%fuel of ticket price	%fuel of ticket price x %increased fuel cost
Short	12%	20.1%
Medium	21%	35.1%
Long	35%	58.5%

[710] These figures were updated with more accurate fuel cost data points. Consequently, the modifications change the cost pass-through, which latest figures are shown in Table 4.4 below. On average, new cost pass-through figures are 10% below figures provided to Task 2 analysis. The impact on Task 2 analysis is limited as demonstrated in Annex sensitivity analysis, where a 0% cost pass-through assumption would result in an aggregate 1% lower operating margin for airlines and +0.9% RTK.

Regarding the cross-correlation analysis performed on each route category, some did not have enough routes to reliably determine the cost pass-through, due to data availability and variability in data quality. To address these issues, some route categories were manually adjusted to find the increase in fuel price that corresponds to the increased fuel cost.

Finally, to obtain estimates for categories with insufficient data, and to remove outliers from the analysis, we performed a regression analysis on the cost pass-through values obtained with the cross-correlation. We used linear regression with the level of congestion (C & C, C & UC and UC & UC), level of competition (1+, 3+ and 5+ flights per route) and flight distance (short, medium, long) as the inputs to the regression analysis.

4.5.5 Step 5: Fuel cost pass-through values

The results of the regression analysis are summarised in Table 54 and the final cost pass-through values from the regression for each category are given in Table 55. Figure 67 shows the average cost pass-through for each factor of the route categorisation (competition, congestion and distance).

Table 54. Coefficients of regression analysis for cost pass-through.

	Coefficients	Standard error
Intercept	0.51	0.129
Congestion	0.09	0.040
Competition	0.17	0.048
Distance	-0.20	0.038
Mean absolute error		0.100

Table 55. Results of the fuel cost pass-through analysis.

Category	Congestion	Competition	Distance	Pass-through
1	C & C	1+	Short	55%
2	C & C	1+	Medium	35%
3	C & C	1+	Long	15%
4	C & C	3+	Short	75%
5	C & C	3+	Medium	55%
6	C & C	3+	Long	35%
7	C & C	5+	Short	90%

8	C & C	5+	Medium	70%
9	C & C	5+	Long	50%
10	C & UC	1+	Short	65%
11	C & UC	1+	Medium	45%
12	C & UC	1+	Long	25%
13	C & UC	3+	Short	85%
14	C & UC	3+	Medium	65%
15	C & UC	3+	Long	45%
16	C & UC	5+	Short	100%
17	C & UC	5+	Medium	80%
18	C & UC	5+	Long	60%
19	UC & UC	1+	Short	75%
20	UC & UC	1+	Medium	55%
21	UC & UC	1+	Long	35%
22	UC & UC	3+	Short	90%
23	UC & UC	3+	Medium	70%
24	UC & UC	3+	Long	50%
25	UC & UC	5+	Short	100%
26	UC & UC	5+	Medium	90%
27	UC & UC	5+	Long	70%

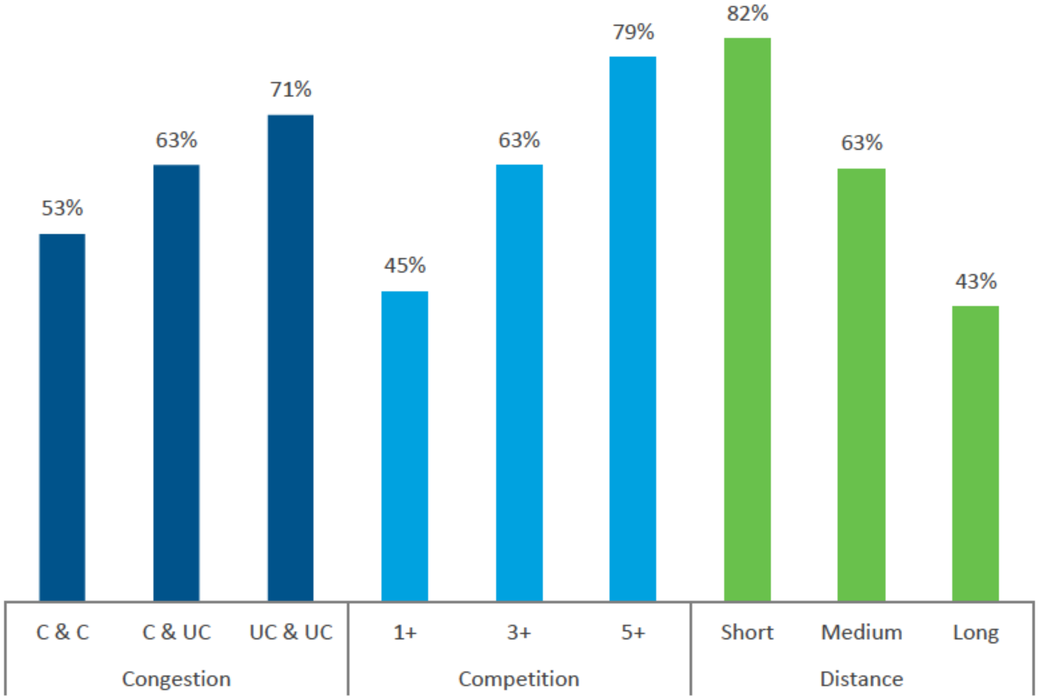


Figure 67. Average cost pass-through for each factor of the route categorization (source: ICF)

The analysis presented here was carried out on routes within the EEA. We believe cost pass-through behaviour of the aviation market in Europe are fairly representative of global airline behaviour. Airports and routes operated around the world all present varying degrees of congestion and competition, and prices are likely to be driven by the same underlying economic rational. Therefore, we believe it is reasonable to extrapolate the values in Figure 67 to other intracontinental flights. However, many international flights are far longer that those we analysed, so should be accommodated for separately.

Cost pass-through for long-haul flights

The pricing of long-haul flights is considered less elastic as demonstrated by Gillen et al. (2002) and would therefore present a cost pass-through rate in the upper range**.** 80% is the rate used by Dray et al. (2018)[711] for freight, which is roughly in the middle of the range of their literature values. Based on this, we assumed a cost pass-through of 80% for competitive long-haul flights between congested airports and applied the coefficients from Table 54 to obtain the cost pass-through values for routes on all congestion and competition levels. The cost pass-through values for long-haul flights are given in Table 56.

[711] Lynnette Dray, David Hart, Andreas Schäfer and Roger Gardner, 2018. The Carbon Leakage and Competitiveness Impacts of Carbon Abatement Policy in Aviation. Report to the Department for Transport.

Table 56. Cost pass-through estimations for long haul flights.

	Congestion			
Competition		**C &C**	**C & UC**	**UC & UC**
	1+	45%	55%	60%
	3+	65%	70%	80%
	5+	80%	90%	95%

4.5.6 Discussion and limitations

These results predominately align with theoretical expectations. In this section we evaluate the alignment of each factor against the expectations from theory.

To review the theory for congested airports, we would expect to see higher rates of cost pass through for uncongested airports, and lower rates at congested airports. As detailed in the Market infrastructure section, this is because congested airports are expected to drive pricing to the demand clearance level and consequently absorb rather than pass through any increases in input costs. By contrast, airlines operating at uncongested airports are more likely set prices to ensure supply matches demand and would therefore increase prices in alignment with increases in industry-wide cost changes. This dynamic is confirmed in our analysis, which demonstrates higher pass-through rates at the more congested airports. The key shortfall of this is the difficulty in defining congestion at airports, which would significantly vary by time of day.

The theory for competition also aligns with the results of this analysis. If an airline has a monopoly over a route, then there is more flexibility to set the ticket prices to match the demand to the capacity the airline provides – and hence higher input costs would not necessarily be passed through to the customer. This would not hold for competitive routes, where airlines are already maximising profits by pricing tickets at marginal costs. Hence in the long run higher or lower input costs would be passed through to customers in order to survive in this market.

It's interesting to note that this coefficient had the highest standard error. We hypothesise that this is due to competitive dynamics. While it is extremely hard to add capacity at a congested airport, it is generally easier to redeploy capacity between routes. As a result, if an airline is thought to be making excessive profits on a route then other airlines would be likely to start flying it too, which might explain the lower explanatory power of the competition factor. Multiple airlines flying routes may also be misleading to the strength of competition, as factors such as the time of departure and arrival, loyalty schemes and passenger preference may allow individual airlines to set higher ticket prices.

The distance coefficient encapsulates a few different factors. The shortest flights would be the most substitutable with other forms of traffic, particularly the 4.2 million Km of rail across Europe. This should increase the competition within routes of this length and limit excess profits, forcing market participants to pass through any increases in costs. This is seen in the analysis, with high cost pass-through over the shortest flights. We hypothesised that over longer routes the lower elasticities would allow greater costs to be passed through, as demand would be less sensitive to the increases in cost. However, the results of the analysis suggest this is not the case for this dataset, with other effects dominating. Potentially the relatively short length of all routes in the analysis is greatly reducing the impact of the pricing elasticity. This analysis referred to routes over 1,272 Km as 'long' but these are relatively short compared to true intercontinental routes – for example LHR – JFK is over 5,600Km. As the short routes are also dominated by fixed costs (rather than fuel costs), the increase in fuel cost is reflected as a relatively small increase in the ticket price, which in turn is lower over short routes and therefore a smaller proportion of passenger’s income. This may mean that airlines are more able to pass-through the costs over short routes, as it translates to relatively small absolute increases for passengers. Finally, there are likely correlations between flight distance and other factors, such as airline business model, premium demand and passenger profiles.

The analysis conducted here can present some potential limitations:

Data limitations on ticket fares

Ticket fares data are extracted from IATA’s Passenger Intelligence Services (PaxIS) module. PaxIS reports ticket information from more than 400 airlines and carriers. However, PaxIS does not capture all carriers’ ticket price data and relies on estimates. The reliability of these estimates has not been tested by ICF but remains the most accurate and widely available data source for global ticket fares.

Airline may not behave the same way to an increase in carbon charges, compared to fuel costs

On one hand, fuel costs represent a large portion of airlines’ costs and may be more easily passed onto passenger ticket fares where airlines would otherwise make a potential loss, following significant increase in fuel price. On the other hand, predictability of carbon charges through policy implementation can also help airlines and operators manage the anticipated carbon charges and better price their tickets in consequence.

Airlines price air fares according to market fundamentals

Numerous case studies demonstrate that the price of a seat can vary significantly depending on when the ticket is booked, time of travel and the levels of competition on the route. These variations in price are primarily driven by short run demand and supply factors, not the long run cost of operating the flight. Therefore, the adjustment of airlines’ ticket pricing to a change in cost may only be observable over a longer term.

4.5.7 Cost pass-through modelling

In Task 3, a literature review was conducted to research the factors influencing cost pass-through in aviation and other industries. Once the factors were identified, a quantitative analysis was conducted to understand the ability of airlines to pass-through cost changes to passenger ticket fares. Fuel, representing a large and volatile proportion of airlines’ cost structure, was used as a proxy to define the amplitude of cost pass-through possible under various situations, distributed across 27 categories for intra-EEA routes.

The outputs of this analysis were used as inputs to the AIM model of Task 2. The cost pass-through figures were used together with other variables such as airlines’ behaviour and passenger demand on specific flight segments. The AIM model produced refined cost pass-through figures which were cross-checked and validated.

The process followed is illustrated in Figure 68.

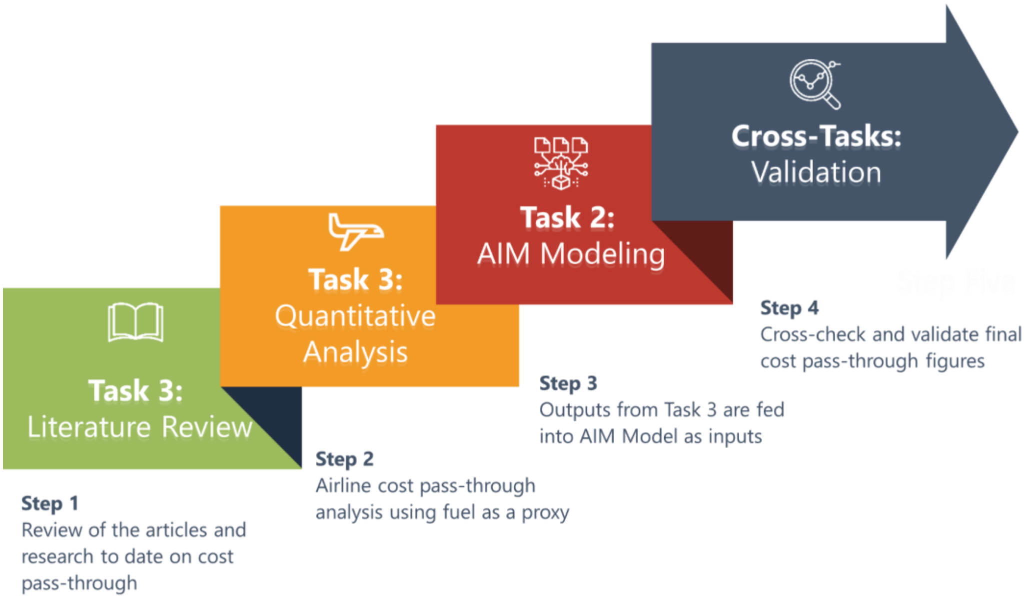


Figure 68. Cost pass-through analysis process

4.5.8 Conclusion

As shown in the literature review, there is significant variation in the potential for airlines to pass-through costs to customers. We identified three key factors:

1. Level of congestion at the origin and destination airports
2. Level of competition over the route
3. Length of route

These factors were used in an analysis of the percentage of fuel cost variations that were passed through to passengers in the form of ticket prices. The results from this are shown across the 27 combinations in Figure 67, and demonstrated that for these parameters the fuel cost pass-through ranged from 15% on long range routes connecting two congested airports with low competition, to 100% on short haul routes connecting two uncongested airports with high competition.

Carbon charges are likely to account for a smaller portion of cost compared to fuel, representing between 0.2% and 1.3% of total operating costs. Its magnitude at the passenger level will be limited to an upper range of €2 on intra-continental routes as demonstrated in section 4.3. These two results illustrate the potential for airlines to pass-through additional regulatory costs emanating from their emissions.

In aggregate, the pass-through estimations resulting from Task 2 modelling are:

- Initial average pass-through rates of around 74% for intra-EEA flights;
- Initial average pass-through rates of around 75-82% for extra-EEA flights, depending on the type of carbon cost applied;
- Initial average pass-through rates of around 77% for other routes; and
- Initial average pass-through rates on routes to and from EU outermost regions of 74-77%, depending on the type of carbon cost applied.

The results above demonstrate that many airlines will pass on the majority of the additional carbon costs to passengers, manifesting as higher air fares. This increase is likely to be small compared to the total expenditure of a holiday or business trip, and if applied on an industry level is likely to have a low impact on aggregate demand, although it may impact the market share of the airlines depending on their comparative ability to accommodate such a cost increase.

From the airlines' perspective, the costs represent a significant gross expenditure, even if the net expenditure may be lower due to the cost-pass through potential described in this analysis. For example, Ryanair paid €115 million in 2019 for its EU ETS charges, even after receiving 44% of free allowances.

On an aggregate basis, a cost pass-through range from 0% to 100% would affect airlines' operating margin from -1pt to +1pt (i.e. a 7% total operating margin would decrease to 6% in case of 0% cost pass-through, and increase to 8% in case of 100% cost pass-through), as demonstrated in the Annex.

In conclusion, this analysis suggests that on average airlines are able to pass-through a significant percentage of industry-level cost increases to passengers. However, the dynamics are complicated, and the capacity of airlines to pass through the costs will significantly vary between routes, with up a 100% variation. Individual airlines will consequently be affected differently, which will introduce comparative advantages and disadvantages between market participants.

4.6 Qualitative impacts on airline behaviour and new entrants

4.6.1 Impact on airline behaviour and network planning

This section discusses airline network planning and how these decisions could be influenced by the cost burdens imposed by the EU ETS and CORSIA.

Network planners are responsible for deciding which routes to fly, which aircraft to deploy on these routes and how often and at what times to fly the routes. In effect they are working to optimise the utilisation of the airline's fleet in the near term, while contributing to the long-term fleet decisions that will determine the future network. As discussed in sections 3.2.9 & 3.2.11, the EU ETS / CORSIA cost impacts will impact both the overall quantum of demand and have the potential to introduce competitive distortions. These factors can influence airline decision making in a number of ways, which we will discuss further below.

The means by which these additional costs could influence network development can broadly be categorised under the following three categories:

1. Generally higher costs will increase the revenue-threshold for route viability
2. Uneven allocation of costs could result in competitive advantages / disadvantages for specific airlines on specific routes
3. Uneven geographical participation in the schemes could result in airlines orienting networks towards lower cost destinations

Network planners assess route viability in different ways depending on the decision timeframe. In the short-term, when the airline's fleet is relatively fixed, route viability requires that the operation of the route generates more revenue than the marginal costs of flying the aircraft (rather than not flying it). This is typically referred to as route contribution. In the longer term, network planners consider the route profitability inclusive of aircraft ownership and fixed costs to determine whether the route is sustainable.

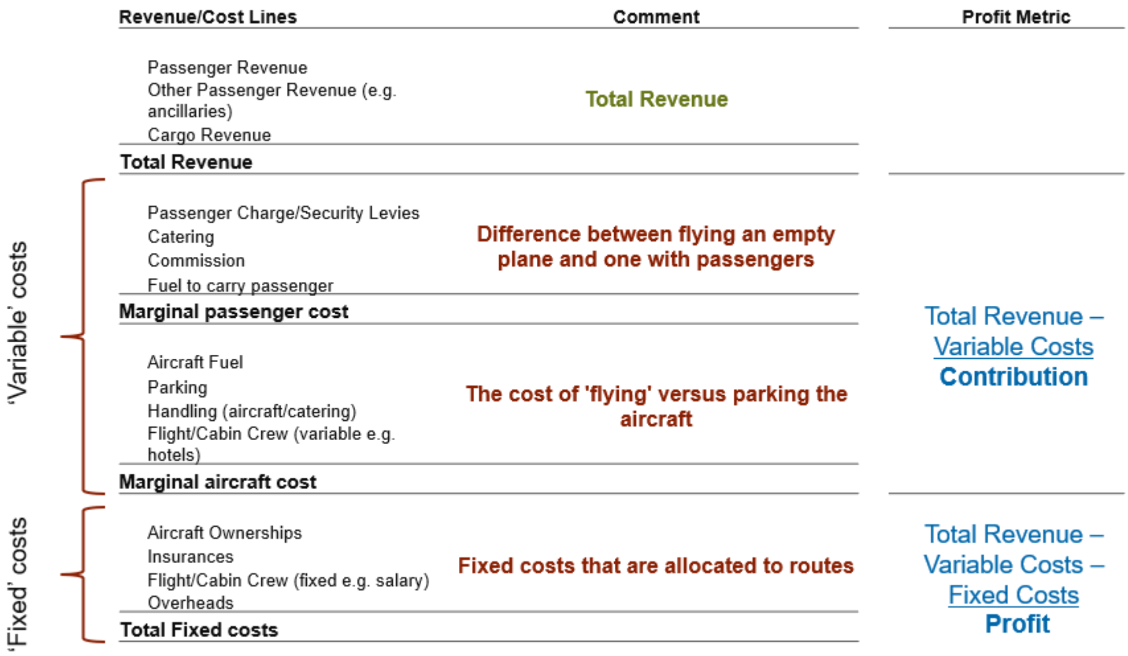


Figure 69. Airline route profitability schematic (illustrative)

In the case of both EU ETS and CORSIA, the associated costs are theoretically marginal aircraft costs since they are directly related to the amount of flying. However in practice, the complexity of the CORSIA scheme in particular (whereby the actual costs depend both on the airline network capacity (rather than individual route) and on sectoral growth, that is largely outside of the individual airline's control) will likely lead it to be accounted for as a 'fixed cost'. Regardless, the higher costs could potentially lead to marginal routes becoming un-sustainable, and over time lead to fewer 'thin' routes opening. There are, however, reasons to believe this will be a relatively small impact: firstly, the cost impacts are small – estimated at typically below 5% of total operating costs in Section 3.2.7 – and secondly, as discussed above, it is expected that much of this additional cost will be able to be passed on to customers. In particular, in the assessment of new routes these cost levels will be considerably lower than the uncertainty ranges around other revenues (fares and load factors) and costs (e.g. fuel prices) factors, and so are unlikely to greatly influence these decisions.

Aviation is a competitive environment, and a large part of the role of a network planner in assessing route performance is determining what market share the individual airline can expect. There are numerous factors that influence an airline's market share, including brand awareness, corporate accounts, loyalty schemes and schedule, but price is a major consideration. On a competitive route, an airline with lower costs will accrue a competitive advantage by passing this on to consumers in the form of lower fares. In the most part, carbon costs are borne equally by all operators on a given route. The main exception is policy Option 6 where non-EU/EFTA airlines operating intra-European routes will be exempt from EU ETS costs, however as discussed in section 3.2.1 this equates to only a very small fraction of intra-European capacity. Moreover, the lack of scale and brand awareness of these airlines will often nullify the marginal cost advantage. Potentially a greater factor is that at a network level, airlines with less exposure to carbon-cost incurring markets would enjoy a lower overall cost base than other airlines, which could translate to a price advantage even on routes that incur carbon costs. For example, an airline from a state not participating in CORSIA would have a lower overall carbon cost than an airline based in a participating state. On a route between these two countries, the airline from a non-participating state could in theory utilise this cost advantage to cross-subsidise the route and offer lower prices. However, in reality, the carbon costs would typically be negligible compared to differences in other cost factors which can vary significantly between different geographies. This is particularly true if considering a developed, participating state, and a developing, non-participating state where labour costs will be significantly lower in the developing country.

Similarly, competitive advantages could exist on intra-EU markets where airlines with a significant share of their capacity deployed on long haul markets (outside of the EU ETS scope) would have a lower overall ETS cost exposure compared to an airline with only intra-EU operations. This cost advantage could allow the less-exposed airline to cross-subsidise its intra-European operations, by, for example, not passing on EU ETS costs to its customers, and absorbing these costs at the network level. In practice however, airlines will typically allocate costs as far as is possible to routes according to how they are incurred. Cross-subsidising also results in a sub-optimal pricing on the (arguably more important) long haul routes as discussed in Section 3.2.11. Probably a more significant impact is that which already occurs today – European carriers with full networks (both short and long haul operations) are typically hub carriers, and they can support below-cost fares on their short-haul operations because of the network contribution of passengers connecting onto long-haul flights. Even in this instance, due to the high costs of operating from primary airports, maintaining diverse fleets and global outstations and the complexities of hub operations, this form of cross-subsidisation only mitigates some of the cost advantages enjoyed by the low cost carriers that now dominate short-haul routes in Europe.

Finally, the fact that different destinations will have different exposure to the EU ETS and CORSIA schemes could influence how airlines evolve and grow their networks, potentially favouring lower cost destinations. When evaluating new route options, network planners will typically draw up a short list based predominantly on market and strategic factors (e.g. market size, business travel, airline presence in the country, levels of competition, compatibility with network strategy, fleet capability). Route profitability studies will be conducted based on anticipated market shares, average fares and predicted operating costs. Finally, decisions will be made based on a combination of strategic, operational and profit considerations. It is conceivable that carbon costs could play a deciding role, but in practice it is likely to be a relatively small factor. Where it could play a more influential role is when there are two similar very options with different carbon cost profiles. For the most part, the markets in and out of scope of EU ETS are different enough that other factors will dominate. However, under the policy scenario in which extra-EU/EFTA routes are excluded, European territories and countries that would fall out of scope such as the Canary Islands, the UK and Turkey (plus to a lesser extent North African holiday destinations) could gain an advantage that could play a role in decision-making. It is however debatable whether the relatively small cost impact would have enough influence to counter the additional costs of flying to Turkey rather than Greece for example.

4.6.2 Impact on new entrants

This section investigates the incentives that CORSIA creates for new entrants to the airline market. Two elements of CORSIA have the potential to create these incentives: firstly, the initial exemption for new entrants and secondly the use of the growth factor(s) in calculation of offsetting requirements.

New entrants are exempt from the offsetting obligations of CORSIA for the first three years of operation, or until the aircraft operator's annual emissions exceed 0.1% of total 2020 emissions from the international aviation sector. When an operator meets the first of these conditions their emissions are subject to the offsetting requirements if it operates on the routes covered by CORSIA. Consequently, a new entrant operating routes covered by CORSIA would have a very slight cost advantage compared to incumbents until it met one of these two thresholds.

The use of the growth factor(s) in the CO_2 offsetting requirements should also be considered. Over the first 9 years of CORSIA (2021 through 2029) a pure-sectoral growth factor is used to multiply each operators' annual emissions to calculate their CO_2 offset requirements (as per SARPs section 3.2.2). Later phases of CORSIA do gradually move to include the individual operator's emissions growth factor, initially at least 20% from 2030-2032 and at least 70% over the remaining years. The specified percentage will be determined by the ICAO Assembly in 2028. However, the focus on sectoral growth over individual growth should allow new entrants to grow and compete without incurring an excessive offsetting burden. As an example, a recent entrant with a 0.2% share of total 2020 emissions (and therefore included within CORSIA) could double in size and only add 0.2% to the sectoral growth factor (assuming all else equal). At the other extreme, if a larger carrier with a greater market share were to grow by a similar amount the impact to the sectoral growth factor would be proportionately larger and therefore the offsetting obligation for all airlines would rise. However, this effect is almost certain to be negligible in the initial years, and as the individual airline's growth factor becomes more important in the formula in later years this will act as a stronger headwind to rapidly growing smaller airlines.

To summarise these effects, the exemption for new entrants will convey a very slight cost advantage to the new entrants, and the focus on sectoral growth factor will allow them to grow and compete without incurring excessive CO_2 offsetting costs. In later years, the increased weighting on the individual operators' growth factor will disproportionately impact new entrants which are more likely to need to grow to effectively compete with incumbent airlines.

The impact of these effects will be minimal. As shown in section 2.3.6 the offsetting cost is expected to represent between 0.2% and 1.3% of total operating costs. The exemption from these costs for new start-ups is a useful but very minor advantage when compared to the challenge of competing with incumbents, which have significant other cost advantages though the scale of their operations, as well as potential advantages through brand recognition, contracts, slot rights and innumerable other facets of the operation. Clearly this cost advantage is only relevant over routes covered by CORSIA, which is likely to only be a portion of a new operator's network.

The decisions made by a new entrant to take advantage of this are likely to significantly vary on a case-by-case basis. If operating on a route with a high cost-pass through, manifesting as a higher ticket price, a new entrant that does not incur these costs may choose to comparatively discount tickets to stimulate sales, or increase revenue by the equivalent of passing through the cost – although as above the existence of this cost differential is likely to be minimal due to significant cost differentials in other areas. If the route has a low cost-pass through, then management have fewer options and the avoidance of CORSIA costs would primarily support lower costs and comparatively higher margins. As new entrants are rarely able to win in direct competition with incumbents, they often fly routes with less competition. As shown in section 4.5.6, this may lead them to operate routes with a relatively low cost pass-through percentage, supporting a theory that the avoidance of CORSIA related costs would support the margins of new entrants rather than lower costs for consumers. This may be mitigated somewhat by the challenge for new entrants to obtain slots at congested airports, preventing them from operating routes with the lowest cost-pass through potential.

The EU ETS Directive provides for year 2010 CO_2 tonne kilometre data to set the benchmark upon which free allocation is calculated. The Article 3f of the EU ETS Directive allows new operators who commence flight activity after 2010 or operators who experience a growth in tonne-kilometre activity in excess of 93.8% between 2010 and 2014 to apply for free allowances from the Special Reserve[712]. Beyond this date, the legislation does not foresee further possibility for free allocation. The aviation ETS review in 2017 extended

[712] Article 3f of the EU ETS Directive

the current regime through to 2023 (in the context of considerations to implement CORSIA through the EU ETS). The corresponding FAQ explained that "*the allocation from the special reserve is a one off allocation based on 2014 activity. No new allocation will take place before the next review of the legislation*"[713]. Therefore, airlines which entered the market after 2014 are not entitled to any free allowances and would have to buy allowances to cover 100% of their emissions. The current method of free allocation seems detrimental to new entrants and fast growers operators. As shown in the figure below[714], on average, operators entitled to Special Reserve allowances (green) seem to obtain a smaller share of free allowances (37%) than the other operators (55% in blue) in 2015 and that gap tends to increase with the time.

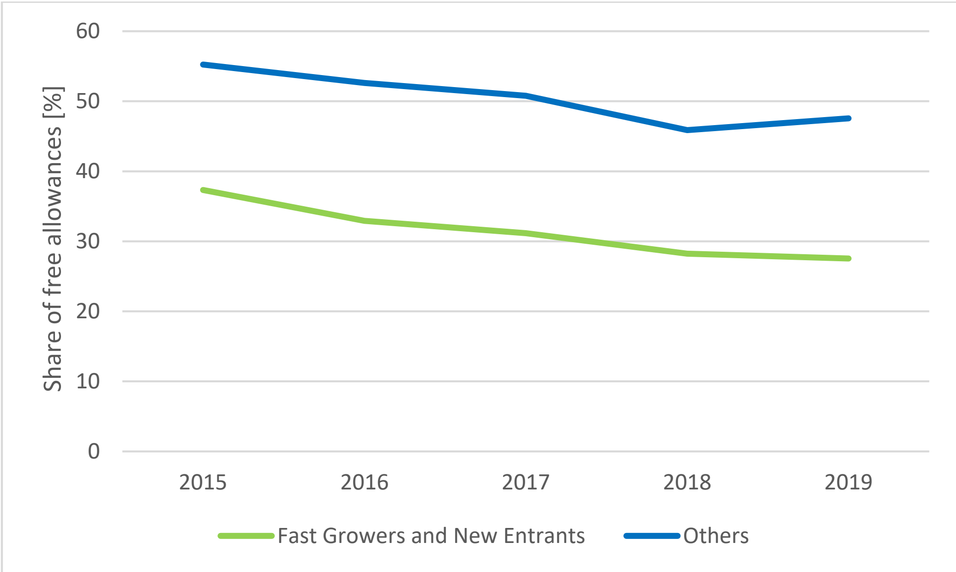


Figure 70. Share of free allowances between fast grower operators and new entrants, and other operators

4.7 Section Summary

As shown in the literature review, there is significant variation in the potential for airlines to pass-through costs to customers. We identified three key factors:

1. Level of congestion at the origin and destination airports
2. Level of competition over the route
3. Length of route

These factors were used in an analysis of the percentage of fuel cost variations that were passed through to passengers in the form of ticket prices. The results from this are shown across the 27 combinations in Figure 67, and demonstrated that for these parameters the fuel cost pass-through ranged from 15% on long range routes connecting two congested airports with low competition, to 100% on short haul routes connecting two uncongested airports with high competition.

Carbon charges are likely to account for a smaller portion of cost compared to fuel, representing between 0.2% and 1.3% of total operating costs. Its magnitude at the passenger level will be limited to an upper range of €2 on intra-continental routes as demonstrated in section 4.3. These two results illustrate the potential for airlines to pass-through additional regulatory costs emanating from their emissions.

[713] https://ec.europa.eu/clima/ets/ohaDetails.do?accountID=116541&action=all&languageCode=en

[714] Based on EUTL data

In aggregate, the pass-through estimations resulting from Task 2 modelling are:

- Initial average pass-through rates of around 74% for intra-EU/EFTA flights;
- Initial average pass-through rates of around 75-82% for extra-EU/EFTA flights, depending on the type of carbon cost applied;
- Initial average pass-through rates of around 77% for other routes; and
- Initial average pass-through rates on routes to and from EU outermost regions of 74-77%, depending on the type of carbon cost applied.

The results above demonstrate that many airlines will pass on the majority of the additional carbon costs to passengers, manifesting as higher air fares. This increase is likely to be small compared to the total expenditure of a holiday or business trip, and if applied on an industry level is likely to have a low impact on aggregate demand, although it may impact the market share of the airlines depending on their comparative ability to accommodate such a cost increase.

From the airlines' perspective, the costs represent a significant gross expenditure, even if the net expenditure may be lower due to the cost-pass through potential described in this analysis. For example, Ryanair paid €115 million in 2019 for its EU ETS charges, even after receiving 44% of free allowances.

On an aggregate basis, a cost pass-through range from 0% to 100% would affect airlines' operating margin from -1pt to +1pt (i.e. a 7% total operating margin would decrease to 6% in case of 0% cost pass-through, and increase to 8% in case of 100% cost pass-through), as demonstrated in the Annex.

In conclusion, this analysis suggests that on average airlines are able to pass-through a significant percentage of industry-level cost increases to passengers. However, the dynamics are complicated, and the capacity of airlines to pass through the costs will significantly vary between routes, with up a 100% variation. Individual airlines will consequently be affected differently, which will introduce comparative advantages and disadvantages between market participants.

Annex 1: States that responded to State Letter ENV 6/1-16/87 on intention to participate in CORSIA

Table 57. Summary of state-level intention to participate in CORSIA

State	Date of response to SL ENV 6/1-16/87
Australia	27 September 2016
Canada	16 September 2016
Costa Rica	10 October 2016
Czechia	27 September 2016
Germany	20 September 2016
Italy	23 September 2016
Jamaica	29 June 2017
Japan	20 September 2016
Kenya	16 September 2016
Malaysia	16 September 2016
New Zealand	23 September 2016
Republic of Korea	23 September 2016
Switzerland	16 September 2016
United Arab Emirates	22 September 2016
United Kingdom of Great Britain and Northern Ireland	19 September 2016
United Republic of Tanzania	16 July 2019
United States of America	3 November 2016
Zambia	7 October 2016

Annex 2: Carbon offset credit supply analysis methodology

Our approach to analysing the potential supply of carbon offset credits from four programmes (CDM, VCS, Gold Standard and CAR) under different scenarios is based on previous studies which use the same modelling framework and data sources. Details of the methodology and key assumptions are set out in Chapter 3 of the report "Offset Credit Supply for CORSIA".[715]

In the following paragraphs we describe updates and amendments to the methodology that were used in this study.

Source of data and information dates

Our analysis of **CDM** projects is based on updated data published by the UNFCCC to reflect the latest information on CDM projects as at January 2020. The database for CDM project activities (PAs) and Programmes of Activities (PoAs) is available on the CDM website[716] and was downloaded on 12 February 2020.

Our analysis of **VCS** projects is based on the list of projects included in the VCS public registry[717], downloaded on 11 April 2020, as well as additional information including project milestone dates shared in an Excel file by the registry, dated 25 March 2020.

Our analysis of **Gold Standard** projects is based on an up-to-date list of projects shared by the registry in an Excel file, dated 24 February 2020, reflecting the information in the programme's online registry.[718] Data on credit issuances and retirements was downloaded directly from the programme's online registry on 11 April 2020.

Our analysis of **CAR** projects is based on information shared by the registry in an Excel file, dated 3 April 2020. The reflects information included in the programme's public online registry[719] with the addition of details on project milestone dates.

Scenario to match TAB recommendations

Previous analysis conducted using the same modelling framework assessed a number of different vintage restriction scenarios, but not one that exactly matches the eligible emissions units approved by ICAO. We therefore adjusted the scenario definitions within the model to identify only projects that started their first crediting period on or after 1 January 2016 and included carbon offset credits for emission reductions up to the end of 2020. For the majority of projects analysed across the four programmes the start of the first crediting period is either reported in the public registries or can be inferred from data reported for credit issuances.

For those projects with missing data in the public registries we estimated the start of the first crediting period based on information on the start of a project's operations or its registration date with the programme. For Gold Standard projects we were not able to identify up-to-date information on crediting period start dates for projects, but used information from a previous study based on data at the beginning of 2018. For all new

[715] Fearnehough, Harry, Carsten Warnecke, Lambert Schneider, Stephanie La Hoz Theuer, and Derick Broekhoff. "Offset Credit Supply for CORSIA." NewClimate Institute, 2019.

[716] https://cdm.unfccc.int/Projects/projsearch.html

[717] https://registry.verra.org/

[718] https://registry.goldstandard.org/projects?q=&page=1

[719] https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=111

projects registered since 2018 we assumed that they started their first crediting period on 1 January 2019 as the mid-point between the beginning of 2018 (information date for previous data) and the beginning of 2020 (information date for an updated list of registered Gold Standard projects).

Programme specific methodology

The following adjustments relate to our assessment of the carbon offset credit supply potential for the **CDM**:

- We adjust the estimates of supply potential based on our assessment of the ability of the project to issue carbon credits only for projects registered prior to 1 January 2016. Our model incorporates information on a number of factors that influence the ability of a project to issue carbon credits based on an extensive survey of registered CDM projects conducted in 2014-15. In previous work, we applied these factors to all projects, including those that registered from 2016, to refine the estimates of the supply potential. However, given that the information was based on data collected in 2015, we now do not apply these adjustments to more recently registered projects.
- We remove an adjustment that limited the supply potential from projects which have not renewed their crediting period within the timeframe set out in the CDM rules. In our previous work, if a project had not requested to renew its crediting period 180 days prior to its end then it would not be able to receive credits for emission reductions delivered between the end of the lapsed crediting period and the date on which the crediting period is deemed renewed. The CDM Executive Board agreed in August 2018 (at CDM-EB100) to waive this requirement during a grace period initially until the end of 2019, and which was subsequently extended to 30 September 2020 (at CDM-EB105).
- We assume that the pipeline of non-registered CDM projects could register by 1 August 2020 and begin credited emission reduction activities from that date. By definition the date at which these projects could register must be in the future.

For other programmes the key adjustment we made to our assumptions was to update the date on which non-registered projects register with the respective programme to reflect the fact that, by definition, this must be after the information date on which the project data is based. We assumed that all non-registered projects listed in the programme registries at various stages of their validation and approval would register on 1 January 2021. As described in the previous "Offset Credit Supply for CORSIA" report, we apply conservative adjustments to the supply potential from non-registered projects to reflect the probability that they may not successfully achieve registration.

Annex 3: AIM model and modelling methodology

The Aviation Integrated Model (AIM) is a global aviation systems model which simulates interactions between passengers, airlines, airports and other system actors into the future, with the goal of providing insight into how policy levers and other projected system changes will affect aviation's externalities 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)[720], and was updated as part of the ACCLAIM project (2015-2018) between University College London, Imperial College and Southampton University (e.g. Dray et al., 2019)[721], with additional input from MIT regarding electric aircraft (e.g. Schäfer et al., 2018)[722]. The model is open-source, with code, documentation and a simplified version of model databases which omit confidential data available from the UCL Air Transportation Systems Group website[723].

AIM uses a modular, integrated approach to simulate the global aviation system and its response to policy. The basic model structure is shown in Figure 71. AIM consists of seven interconnected modules. The Demand and Fare Module projects true origin-ultimate destination demand between a set of cities representing approximately 95% of global scheduled RPK[724], using a gravity-type model based on origin and destination population and income, average journey generalized cost, and other factors, as detailed in Dray et al. (2014). Within each city-city passenger flow, airport choice and routing choice (including hub airport for multi-segment journeys) are handled using a multinomial logit model. Itinerary choice is modelled as a function of journey time, cost, number flight segments, available flight frequency and characteristics of the origin and destination airports. This model is described further in Dray & Doyme (2019)[725]. Fares per individual itinerary are simulated using a fare model (Wang et al., 2017)[726] based on airline costs by type per segment, demand, route-level competition, low-cost carrier presence and other factors. These models are estimated primarily on detailed disaggregate global passenger

[720] 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; Dray, L., Evans, A., Reynolds, T., Schäfer, A., Vera-Morales, M. and Bosbach, W., 2014. Airline fleet replacement funded by a carbon tax: an integrated assessment. Transport Policy, 34, 75-84.

[721] 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.

[722] 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.

[723] http://www.atslab.org; note that the website code and databases do not include model edits introduced specifically for this project, for example the cost pass-through specification used here.

[724] Note that non-scheduled flights and freight are also modelled for this report. Because less information is available on routing for these flights, they are dealt with using a segment-based scaling approach.

[725] Dray, L. and Doyme, K., 2019. "Carbon Leakage in Aviation Policy", *Climate Policy,* 19 (10), 1284-1296.

[726] Wang, B., O'Sullivan, A., Dray, L., Al Zayat, K. and Schäfer, A., 2017. Modelling the Pass-Through of Airline Operating Costs on Average Fares in the Global Aviation Market. 21st ATRS conference, Antwerp, 5-8 July 2017.

routing and fare data from Sabre (2017)[727].

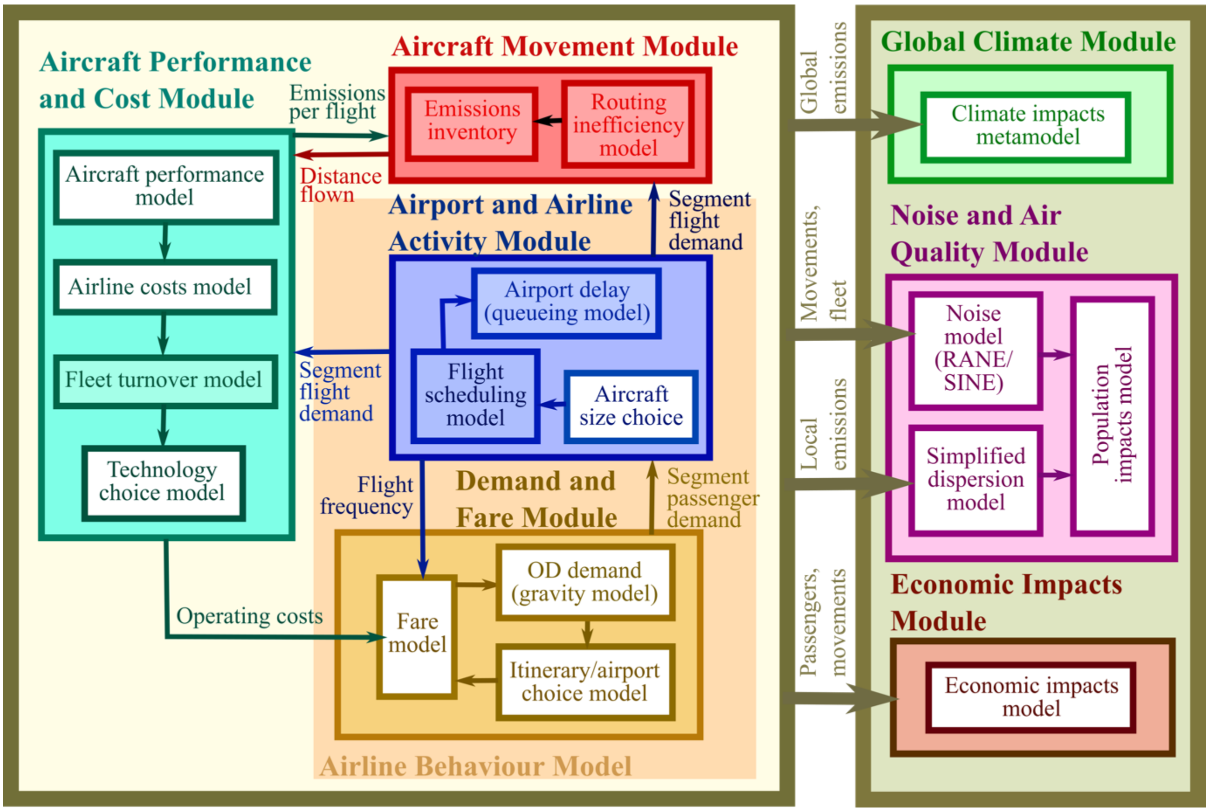


Figure 71. AIM model structure

AIM model structure

The Airline and Airport Activity Module, given segment-level demand, assesses which aircraft will be used to fly these routes and at what frequency, using a multinomial logit model estimated from historical scheduling data (Sabre, 2017) and dividing the fleet into nine size categories. Given these aircraft movements per airport, a queuing model then estimates what the resulting airport-level delays would be (Evans, 2008)[728]. Given the lack of long-term airport capacity forecasts, in most cases this delay model is used to estimate the amount of (city-level) capacity that would be required to keep delays at current levels.

The aircraft movement module assesses the corresponding airborne routes and the consequent location of emissions. In particular, routing inefficiencies which increase ground track distance flown beyond great circle distance, and fuel use above optimal for

[727] Sabre, 2017. Market Intelligence passenger demand, routing and aircraft schedule databases. https://www.sabreairlinesolutions.com.

[728] Evans, A., 2008. "Rapid Modelling of Airport Delay". 12th Air Transport Research Society (ATRS) World Conference, Athens, Greece, July 6-10.

the given flight distance, are modelled using distance-based regional inefficiency factors based on an analysis of radar track data, as discussed in Reynolds (2008)[729].

Given typical aircraft utilization, the aircraft technology and cost module assesses the size, composition, age and technology use of the aircraft fleet, and the resulting costs for airlines and emissions implications. First, aircraft movements by size class including routing inefficiency from the Aircraft Movement Module are input to a performance model (estimated from outputs of the PIANO-X[730] model with reference aircraft types and missions for CO_2 and NOx, the FOX methodology (Stettler et al. 2013)[731] for PM2.5, and Wood et al. (2008)[732] for NO_2). Second, the costs of operating this fleet for the given schedule are estimated based on historical cost data by category and aircraft type (Al Zayat et al, 2017[733]). Third, emissions and costs are adjusted to account for the current age distribution and technology utilization of the fleet, including typical retirement and freighter conversion behavior (e.g. Dray, 2013)[734]. Finally, any shortfall in aircraft required to perform the given schedule is assumed made up by new purchases, and the uptake of technology and emissions mitigation measures by both new aircraft and existing ones is assessed on a net present value basis, as described in Dray et al. (2018)[735], and the impact of this on costs and emissions is assessed.

These four modules are run iteratively until a stable solution is reached. Data is then output which can be used in the impacts modules, shown on the right of Figure 71. The global climate module is a rapid, reduced-form climate model which calculates the resulting climate metrics (e.g. CO_2e in terms of global temperature potential (GTP) and global warming potential (GWP) at different time horizons; see Krammer et al., 2013[736]). The air quality and noise module are similarly rapid, reduced-form models which provide metrics by airport for the noise and local/regional air quality impacts of the projected aviation system. In the case of air quality, dispersion modelling for primary pollutants uses a version of the RDC code (e.g. Yim et al., 2015)[737]. The type of noise modelling carried out depends on whether data on standard flight routes per airport is available, but for all airports noise modelling based on total noise energy is carried out (Torija et al. 2016, 2017)[738]. The regional economics module looks in more detail at the economic impacts,

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729 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.

730 Lissys, 2017. The PIANO X Aircraft Performance Model. www.piano.aero.

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including benefits such as increased employment as well as costing of noise and air quality impacts.

The output data from the first four AIM modules can also be used more generally as input to external impacts models: for example, the model includes the option to produce detailed emissions inventories which can be input into climate models. Further information on the individual sub-models, on model validation, and on typical model inputs and outputs can be found in the papers cited above and in the model documentation[739].

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Annex 4: Impacts of changes in cost pass-through rates

The wide range of literature assumptions for cost pass-through is discussed in Sections 4 and 3.1.1.1. The cost pass-through assumptions used here typically result in average pass-through of 70-80% depending on route type. Assumptions used in the literature range from 0% pass-through (in which case all carbon costs go towards reductions in airline profits, typically leading to the conclusion that airlines will be severely impacted) to 100% pass-through including of opportunity costs for free allowances (in which case airline profits increase, sometimes substantially).

In this section, we rerun models for policy options 1-6 with all uncertain variables at nominal values and pass-through at these two extreme values. Note that this is not an assessment of the likelihood of either assumption. As discussed in Section 4, there is evidence to suggest that present-day cost pass-through is in between these values, and we draw on the analysis in Section 4 in the assumptions about pass-through for the main grid of model runs. However, because the range of values in the literature for cost pass-through is very wide, testing extreme values for pass-through can be useful to assess how different studies came to different conclusions.

Airline costs per RPK for all three pass-through cases (0%, 100% and use of the values derived from the pass-through study in this report) are similar, and are close to those in Section 3.2.6. In the case that there is zero cost pass-through, these costs would go directly to reducing airline operating margin, i.e. the comparison made in Table 23 and Table 24. For intra-EU/EFTA flights this would result in a 15-20% decrease in operating margin for all options other than Option 3 (assuming all uncertain scenario variables at nominal values; this means that a 7% total operating margin would decrease to just below 6%). For extra-EU/EFTA flights a decrease in operating margin of 34% would occur in the case of Option 1, whereas other options would be little-affected. These values are close to those discussed in Ernst and Young & York Aviation (2007, 2008), which assume low levels of cost pass-through. In the case that there is full pass-through including opportunity costs for free allowances, intra-EU/EFTA airline profit margins will increase by around 7-12% for all options other than Option 3 (i.e. a 7% total operating margin would approximately increase to an 8% total operating margin; note that the relative change will be smaller for scenarios with higher demand growth).

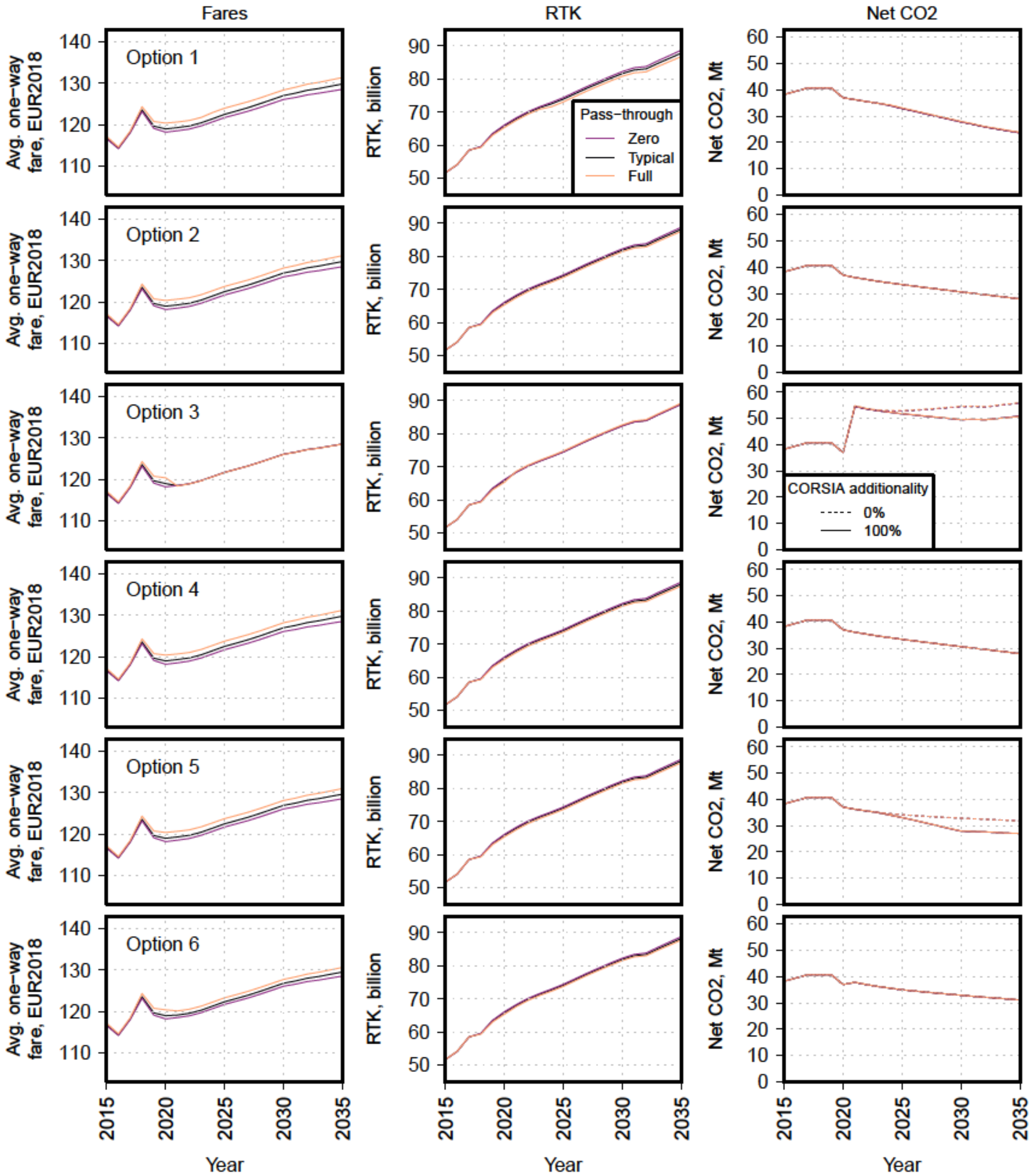

Figure 72. Comparison of fare, RTK and net (after adjusting for allowances and offsets) intra-EU/EFTA aviation CO_2 for different cost pass-through scenarios.

Figure 72 shows the impact (by policy) of applying different levels of cost pass-through on fares, RTK and net aviation CO_2 (after adjusting for allowances and offsets), for intra-European flights (EU/EFTA, excluding UK). 100% pass-through increases year-2035 intra-European fares by around 1.1%. These changes correspond to roughly €1.5 - 2 per flight increase in ticket prices. 0% pass-through decreases year-2035 intra-European fares by around 1.0%. As with airline costs, these figures are broadly consistent across policy options with the exception of Option 3, where the impacts of changing cost pass-through are minimal (under 0.1%).

By 2035, these fare changes for Options 1, 2, 4, 5 and 6 result in typical changes of total intra-European RTK of up to -1.2% (for full cost pass-through) to +1.0% (for zero cost pass-through). Because aviation CO_2 emissions remain above both the CORSIA baseline and EU ETS cap, the change in direct CO_2 resulting from these changes in RTK is offset or leads to reductions in other EU ETS sectors via the purchase of EUAs, leading to minimal differences in net CO_2 between the three pass-through scenarios if all offsets are assumed additional. If CORSIA offsets are assumed to have zero additionality, impacts of changing cost pass-through assumptions are still very small (<0.2% on net CO_2). This is because pass-through assumptions have limited impact on demand and direct emissions on CORSIA routes, due to the low carbon prices assumed.

Based on these calculations, we conclude that changing assumptions about cost pass-through reproduces the range of conclusions about ETS airline profit impacts seen in the literature (from large reductions in airline operating margin, to increases), has small (up to 1.2%) impacts on RTK demand, and has almost no impact on net CO_2 under nominal scenario conditions.

Annex 5: Impacts of specific policy variants

Option 1 applying to outgoing flights only

In this case, Option 1 is applied, including coverage of intra-EU/EFTA flights and flights to and from outermost regions). However, differently to Option 1, extra-EU/EFTA incoming flights are not covered by any policy. Extra-EU/EFTA outgoing flights remain fully covered by the EU ETS. Similarly to the main case Option 1, this is assumed to come into effect in 2024. The EU ETS aviation cap is adjusted accordingly. This option is termed 'Option 1a' below.

Because passenger demand is typically on a round-trip basis, the impacts of this option are roughly half-way between those of Option 1 and Option 2[740]. For example, the total year 2023-2030 EUAA auction revenue for Option 1 is €4230 (year 2018 Euros), without any changes in auctioning percentage, as discussed in Section 3.2.13. For Option 1a, this figure is €2560. The main differences between Option 1 and Option 1a occur on extra-EU/EFTA flights. Figure 73 shows extra-EU/EFTA airline costs and RTK, and the global net CO_2 impacts, of Option 1a in comparison to Option 1.

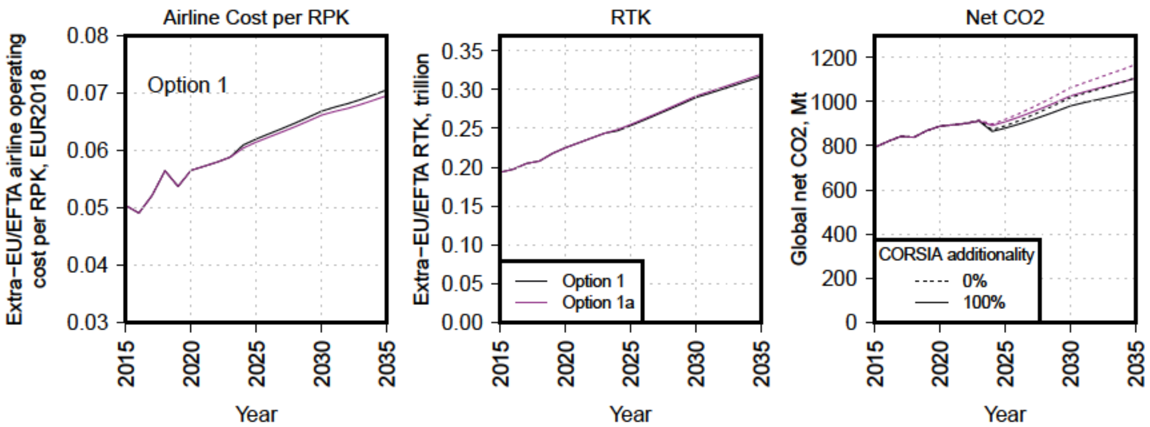

Figure 73. Impact of option 1 on extra-EEA departing flights only, in comparison to option 1 on all extra-EEA flights: extra-European airline cost per RPK, RTK and global net CO_2.

By 2035, airline costs on flights to and from EU/EFTA countries are 1.4 % lower than in Option 1 (1.0% lower in 2030) – i.e., the relative carbon cost burden is halved in comparison to Option 1 as shown in Table 24. At typical levels of pass-through for extra-EU/EFTA routes, this leads to RTK that is 0.9% higher in Option 1a in 2035 (0.7 % higher for Option 1a in 2030). Because it is assumed that no policy applies on EU/EFTA incoming flights, the impact in terms of net CO_2 emissions is also half-way between that of Option 1 and Option 2. If CORSIA offsets are assumed to be fully additional, year-2035 global net aviation CO_2 in Option 1a is 1110 Mt, compared to 1050 Mt in Option 1 (980 and 1030 Mt in 2030, respectively).

Option 1a therefore behaves almost exactly as a 'mid-point' between Options 1 and 2.

[740] Note that we do not model the directional impact of winds. On an individual route group basis winds will introduce asymmetries in terms of fuel use for the same great-circle RTK (e.g., transatlantic flights use less fuel travelling West to East than East to West).

Options 4, 5 and 6 including outermost regions

In this case, Options 4, 5 and 6 are applied with intra-EU/EFTA flights to and from outermost regions included in the EU ETS (referred to as Options 4a, 5a and 6a), and additionally Option 4 is applied with international intra-EU/EFTA flights to and from outermost regions included in CORSIA (referred to as Option 4b). Note that international flights between non-EU/EFTA countries and outermost regions are covered by CORSIA for all options, including the baseline options 4, 5 and 6. In each case, the EU ETS aviation cap is adjusted accordingly. Note that Option 6 excludes domestic flights (as shown in Section 3.2.12, the majority of RTK to and from outermost regions other than Madeira and the Canary Islands is on domestic routes). Including flights to and from outermost regions in the EU ETS adjusts the Option 6a cap upwards from Option 6 values by approximately 3%, and the Option 4a and 5a caps up by 6.4% in comparison to Options 4 and 5. The smaller impact on the Option 6 cap is because of the lack of domestic flight coverage. ETS auctioning revenue, as shown in Table 58, reflects these small cap increases. Over the time frame to 2035, Option 4a and Option 5a behave similarly, i.e. there is a relatively small amount of CO_2 over the CORSIA baseline, leading to average costs that are similar to those in Option 4a. Option 4b does not affect EUAA auctioning revenues at all.

Table 58. Metrics assessing the inclusion of outermost regions in policy options 4, 5 and 6. CO_2 totals assume that CORSIA offsets are fully additional.

Policy option	EUAA auctioning revenue, million €2018		Airline cost per RPK, flights to/from OMRs, €2018		RTK to/from OMRs, billion		Global net aviation CO_2, Mt	
	2030	2035	2030	2035	2030	2035	2030	2035
Option 4	100	114	0.059	0.062	17.5	19.4	1070	1154
Option 4a	107	121	0.060	0.064	17.3	19.1	1063	1143
Option 4b	100	114	0.059	0.062	17.5	19.4	1070	1157
Option 5	100	114	0.059	0.062	17.5	19.4	1072	1155
Option 5a	107	121	0.060	0.064	17.3	19.1	1065	1145
Option 6	75	87	0.060	0.062	17.5	19.4	1070	1157
Option 6a	77	87	0.060	0.063	17.4	19.3	1069	1154

The primary impact of these options is on routes to and from outermost regions. The characteristics of these routes are discussed in Section 3.2.12. The vast majority of routes to and from outermost regions are intra-EU/EFTA routes. This means that the impact of including flights to and from outermost regions in the EU ETS in Options 4a and 5a is similar to outermost regions impacts for Option 1, as detailed in Section 3.2.12. By 2035, this is up to around a 3% increase in total operating costs. Figure 74 shows airline cost per RPK on routes to and from outermost regions, RTK on flights to and from outermost regions, and net global aviation CO_2 for Options 4, 5, 6, 4a, 5a and 6a. RTK decreases by less than 2% when the EU ETS is applied to these flights under nominal scenario conditions; for Option 6a the difference is closer to 0.5%. The final impact in terms of net aviation CO_2 is a yearly fall of about 10 Mt by 2035 (Options 4a and 5a) or 3 Mt by 2035 (Option 6a). This is largely independent of assumptions about the additionality of CORSIA offsets. In contrast, Option 4b has almost no (under 0.02%) impact on airline costs or RTK to and from OMRs. This is because aviation demand and CO_2 emissions are projected to grow only slowly on routes to and from OMRs, so the total fraction of CO_2 above the CORSIA baseline is small (roughly 2.3% of totals in 2030) and the carbon price that is applied to it is low. The main impact of applying CORSIA on routes to and from OMRs is therefore to increase the CORSIA baseline. Because these routes are projected to grow slowly, Option 4b actually increases net aviation CO_2 because the slightly higher baseline slightly reduces offsetting requirements for all airlines.

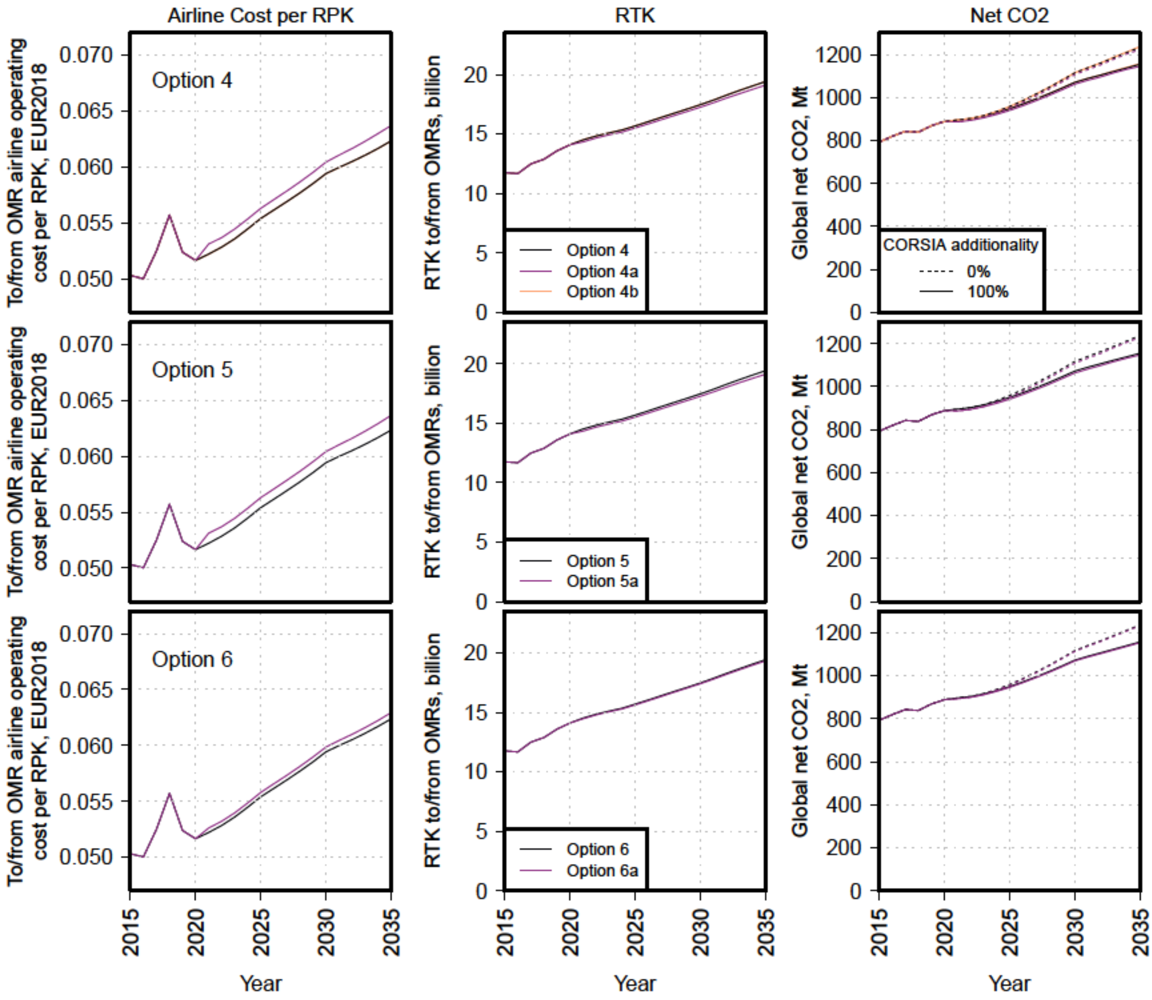

Figure 74. The impact of including flights to and from outermost regions in the EU ETS in policy options 4, 5 and 6: airline cost per RPK to and from OMRs, RTK to and from OMRs, and global net aviation CO_2.

Changes in CORSIA offset requirements

This section explores the impact of imposing additional requirements on CORSIA credits for routes to and from or within the EU/EFTA. Possible restrictions include accepting only EUAs for CORSIA offsets, or higher quality international credits. Two broad impacts of this are likely in the context of the current modelling:

- CORSIA carbon prices on affected routes will be higher than they would be if no restrictions were placed on acceptable credits (if EUAs are required, equal to the EU ETS carbon price).
- CORSIA offsets on affected routes will be of higher quality (e.g. greater additionality, less double-counting, higher level of permanence), i.e. net aviation emissions accounting for offsets will reduce to a greater extent.

The exact relationship between these two impacts will depend on the relationship between offset quality and carbon price, which is uncertain. In this section we examine the broad impact of both changes separately, so that impacts in both areas can be linked for any given hypothetical class of offsets with known quality and cost characteristics. For CORSIA carbon prices, we model a range of values between the base scenario used here and the base EUA price scenario modelled (keeping EUA prices constant at baseline values, and with all other scenario variables at nominal values). For offset quality, we simulate a range of values for effective reduction in net CO_2 of between 0 and 100% for the routes affected. Note that there is relatively little within-system link between net aviation CO_2 and CORSIA offset cost at typical estimated values. This is because higher quality offsets typically impose higher carbon costs, which reduce demand; however, provided demand is not reduced below the CORSIA baseline, the main effect of this is to reduce the number of offsets needed to reach the same net CO_2.

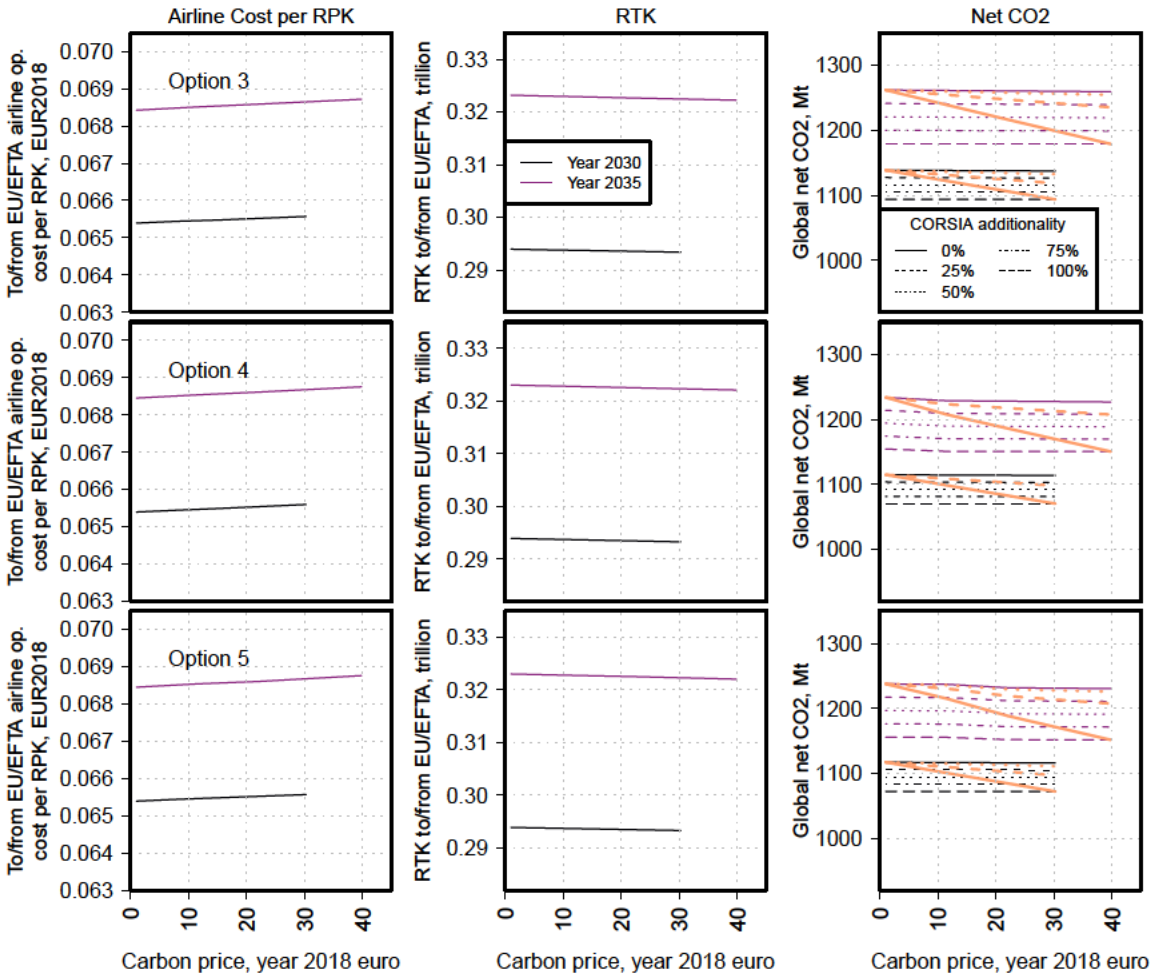

Figure 75. Impact on intra-EU/EFTA flights and global net CO_2 of changing CORSIA offset costs and additionality, simulating offsets of different quality levels. Orange lines show schematic relationships in the case that offset additionality varies linearly with carbon price, for higher-price offsets applied globally (solid orange line) and for flights to/from and within Europe (dashed orange line) and only for CORSIA-covered flights within Europe (dotted line).

Figure 75 shows Options 3, 4 and 5 with different offset prices (up to EUA prices) and levels of offset quality. Carbon prices are applied globally but the impacts shown here are similar on the case that higher carbon prices are applied only to routes to, from and/or within (where CORSIA is applied on any intra-EU/EFTA routes) the EU/EFTA region. This is because of the feedback effect mentioned above, i.e., carbon price-related reductions in demand go towards reducing the number of offsets needed (and hence slightly lowering the effective carbon price) rather than reductions in global net aviation CO_2, unless those reductions take emissions below the CORSIA baseline. The lines for different levels of offset quality for plotted net CO_2 are based on average global assumed offset quality. However, additionally we plot schematic relationships for three hypothetical cases where offset quality is linearly related to carbon price, from zero to a maximum of 100% for EUA-price offsets. Solid orange lines in Figure 75 show the impact on net CO_2 in this case of higher-quality/price offsets being required globally. Dashed orange lines show the case in which only offsets on routes to, from and within the EU/EFTA region require higher quality/price offsets. Dotted orange lines show the case where only intra-EU/EFTA routes require higher quality/price offsets.

In general, the impact of higher CORSIA offset prices on airline costs and demand is much less than the impact of EU ETS prices at the same level. This is because the CORSIA baseline is much higher than the ETS cap, and emissions below the CORSIA baseline do not incur any carbon costs (unlike the EU ETS, where some emissions below the cap require auctioned allowances). This means that, although CORSIA carbon prices up to around €40 are modelled, the effective carbon price once the baseline is taken into account is much less than this – typically 10% or less of the CORSIA carbon price. Because of this, the difference between the highest and lowest carbon price case by 2035 on airline operating costs to and from the EU/EFTA region is only around 0.45%, and the difference in terms of RTK is around 0.3%. For intra-EU/EFTA routes in Option 3, the impact on operating costs of requiring EUA-price offsets is only 0.23%, leading to a decrease in RTK of 0.18%. This reflects both the smaller percentage of operating cost which is fuel-related for intra-EU/EFTA flights, and slower growth rates in emissions leading to a smaller percentage of total emissions being under the CORSIA cap.

As discussed above, these small reductions in demand typically lead to a slightly smaller offsetting requirement and hence slightly lower effective carbon price, rather than having an impact on net CO_2. Some small differences in global-level net CO_2 at a given level of offset additionality do result if changes in carbon price are applied globally; these differences, which are typically under 0.3%, arise from differences in which routes are able to reduce emissions below the CORSIA baseline under individual responsibility for emissions, reductions in demand on itineraries which contain a mixture of CORSIA and non-policy segments.

In the hypothetical case shown in Figure 75 where offset quality is linearly related to carbon price, the difference between €1 offsets of low quality and €40 offsets with of high quality applied globally is around 7% of year-2035 net aviation CO_2. If these higher quality offsets are applied just for routes to, from and within the EU/EFTA region, the impact is closer to 3% of year-2035 net aviation CO_2. If higher quality offsets are applied just for routes within the EU/EFTA region, there is no impact on Option 4, but Option 3 net global aviation CO_2 in 2035 is reduced by around 0.9%.

Option 5 with EU ETS on domestic flights above the CORSIA baseline

Option 5 applies the EU ETS to intra-EU/EFTA flights up the CORSIA baseline. This includes EU/EFTA domestic flights (other than those to and from outermost regions) up to their level in the CORSIA baseline year. Above this level, the main Option 5 does not cover EU/EFTA domestic flights. This section examines Option 5 with full EU ETS coverage on domestic flights (Option 5b).

Domestic flights accounted for roughly 20% of intra-European CO_2 in 2015. CO_2 from domestic EU-28 aviation decreased from a high of 19.5 Mt in 2005 to 15.0 Mt in 2014, although it has increased slightly since then (EC, 2019)[741]. Under nominal scenario conditions, we project that this general trend of long-term decreases in domestic flight CO_2 with occasional periods of increase will continue to 2035. In particular, we project total EU/EFTA domestic CO_2 decreasing after the CORSIA baseline year. However, this masks underlying trends of increases in some countries and decreases in others (for example, direct CO_2 for domestic flights in Eastern European countries tends to increase in our projections). This means there is still a non-zero impact of applying the policy to emissions above the CORSIA baseline.

[741] EC, 2019. EU Transport in Figures – Statistical Pocketbook 2019. https://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2019_en

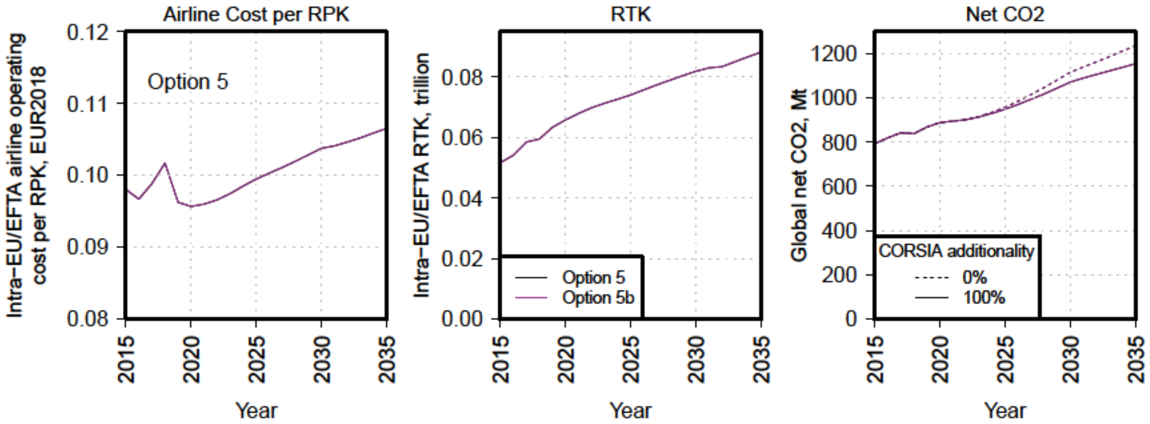

Figure 76. Impacts on intra-EU/EFTA airline costs, RTK and global Net CO_2 of adjusting Option 5 to fully include EU/EFTA domestic flights in the EU ETS.

Figure 76 shows the impact on intra-EEA average airline costs per RPK, intra-EU/EFTA RTK, and global net CO_2 of applying the EU ETS to intra-EU/EFTA domestic flights above the CORSIA baseline. Because on average intra-EU/EFTA domestic flight CO_2 emissions decrease after the CORSIA baseline year, impacts are negligible. Average operating cost per RPK on intra-European routes differs by less than 0.01% between Option 5 and Option 5b. Similarly, intra-European RTK differs by less than 0.01% between the two options. Net global aviation CO_2 is 0.1 Mt lower in Option 5b than in Option 5 by 2035 (0.01% of the total).

Option 5b is therefore projected to have almost identical outcomes to Option 5 unless intra-EU/EFTA domestic CO_2 growth departs substantially from recent trends.

Annex 6: Supplementary tables and figures from the aviation modelling

Table 59. Yearly Demand (tkm), direct CO_2, and net CO_2 adjusted for allowances and offsets, by policy for nominal scenario conditions

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Aviation tonne-km, billion, global																					
Option 1	892	923	953	963	1036	1092	1138	1185	1233	1279	1330	1387	1446	1506	1569	1634	1684	1734	1786	1840	1893
Option 2	892	923	953	963	1036	1092	1138	1185	1233	1282	1334	1390	1450	1510	1573	1638	1689	1740	1793	1846	1900
Option 3	892	923	953	963	1036	1092	1138	1186	1234	1283	1334	1391	1450	1511	1574	1639	1690	1740	1793	1847	1901
Option 4	892	923	953	963	1036	1092	1139	1185	1233	1282	1334	1390	1450	1510	1573	1638	1689	1740	1793	1846	1900
Option 5	892	923	953	963	1036	1092	1139	1185	1233	1282	1334	1390	1450	1510	1573	1638	1689	1740	1793	1847	1901
Option 6	892	923	953	963	1036	1092	1139	1185	1233	1282	1334	1390	1450	1510	1573	1638	1689	1740	1793	1847	1901
Aviation tonne-km, billion, routes to and from Europe (EU/EFTA, excluding UK)																					
Option 1	194	197	205	208	218	225	231	238	244	247	254	261	268	275	282	290	295	300	306	311	317
Option 2	194	197	205	208	218	225	231	238	244	250	257	264	271	279	286	294	300	305	311	317	323
Option 3	194	197	205	208	218	225	231	238	244	250	257	264	271	279	286	294	300	305	311	317	223
Option 4	194	197	205	208	218	225	231	238	244	250	257	264	271	279	286	294	300	305	311	317	323
Option 5	194	197	205	208	218	225	231	238	244	250	257	264	271	279	286	294	300	305	311	317	323
Option 6	194	197	205	208	218	225	231	238	244	250	257	264	271	279	286	294	300	305	311	317	323
Aviation tonne-km, billion, routes within Europe (EU/EFTA, excluding UK)																					
Option 1	52	54	58	59	63	66	68	70	71	73	74	76	77	79	80	82	83	83	85	86	88
Option 2	52	54	58	59	63	66	68	70	71	73	74	76	77	79	80	82	83	83	85	87	88
Option 3	52	54	58	59	63	66	68	70	72	73	75	76	78	79	81	82	84	84	86	87	88
Option 4	52	54	58	59	63	66	68	70	71	73	74	76	77	79	80	82	83	83	85	87	88
Option 5	52	54	58	59	63	66	68	70	71	73	74	76	77	79	80	82	83	83	85	87	88
Option 6	52	54	58	59	63	66	68	70	71	73	74	76	77	79	81	82	83	83	85	87	88
Aviation direct CO2, Mt, global																					
Option 1	808	835	862	857	888	907	913	920	933	951	975	1003	1033	1065	1100	1135	1159	1183	1209	1236	1263
Option 2	808	835	862	857	888	907	913	920	933	953	977	1005	1036	1068	1103	1138	1163	1188	1214	1241	1269
Option 3	808	835	862	857	888	907	914	920	934	954	977	1005	1036	1078	1103	1139	1163	1188	1215	1242	1270
Option 4	808	835	862	857	888	907	913	920	933	953	977	1005	1036	1068	1103	1138	1163	1188	1214	1241	1269
Option 5	808	835	862	857	888	907	913	920	933	953	977	1005	1036	1068	1103	1138	1163	1188	1214	1241	1269
Option 6	808	835	862	857	888	907	913	920	933	953	977	1005	1036	1068	1103	1138	1163	1188	1214	1241	1269

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Aviation direct CO_2, Mt, routes to and from Europe (EU/EFTA, excluding UK)																					
Option 1	161	164	171	172	175	177	176	175	175	174	176	179	181	184	187	191	192	194	196	198	200
Option 2	161	164	171	172	175	177	176	175	175	176	178	181	183	186	190	193	195	197	200	202	205
Option 3	161	164	171	172	175	177	176	175	175	177	178	181	183	186	190	193	195	198	200	202	205
Option 4	161	164	171	172	175	177	176	175	175	176	178	181	183	186	190	193	195	197	200	202	205
Option 5	161	164	171	172	175	177	176	175	175	176	178	181	183	186	190	193	195	197	200	202	205
Option 6	161	164	171	172	175	177	176	175	175	176	178	181	183	186	190	193	195	197	200	202	205
Aviation direct CO_2, Mt, routes within Europe (EU/EFTA, excluding UK)																					
Option 1	50	52	55	55	55	55	54	53	53	52	52	53	53	53	54	54	54	54	54	55	55
Option 2	50	52	55	55	55	55	54	53	53	53	52	53	53	53	54	54	54	54	54	55	55
Option 3	50	52	55	55	55	55	55	54	53	53	53	53	53	54	54	54	55	54	55	55	55
Option 4	50	52	55	55	55	55	54	53	53	53	52	53	53	53	54	54	54	54	54	55	55
Option 5	50	52	55	55	55	55	54	53	53	53	53	53	53	53	54	54	54	54	54	55	55
Option 6	50	52	55	55	55	55	54	53	53	53	53	53	53	53	54	54	54	54	54	55	55
Aviation net CO_2 adjusted for offsets and allowances, Mt, global, assuming 100% additional offsets																					
Option 1	793	819	843	838	869	889	894	900	912	865	880	897	916	936	958	980	994	1007	1020	1032	1046
Option 2	793	819	843	838	869	889	894	900	912	928	947	970	995	1021	1049	1077	1097	1115	1133	1152	1171
Option 3	793	819	843	838	869	889	913	920	933	949	968	990	1014	1039	1066	1094	1112	1129	1145	1162	1179
Option 4	793	819	843	838	869	889	895	901	913	929	948	969	993	1017	1043	1070	1088	1105	1121	1138	1154
Option 5	793	819	843	838	869	889	895	902	915	931	949	971	994	1019	1045	1072	1091	1107	1123	1139	1155
Option 6	793	819	843	838	860	889	897	903	915	931	949	971	995	1019	1045	1073	1091	1107	1124	1141	1157
Aviation net CO_2 adj. for offsets and allowances, Mt, routes to/from Europe (EU/EFTA, exc. UK), assuming 100% additional offsets																					
Option 1	158	161	167	168	171	177	176	175	175	114	111	109	107	104	102	99	96	94	91	89	86
Option 2	158	161	167	168	171	177	176	175	175	176	178	181	183	186	190	193	195	197	199	202	204
Option 3	158	161	167	168	171	177	176	175	175	175	175	176	176	177	178	179	180	181	182	183	185
Option 4	158	161	167	168	171	177	176	175	175	174	175	175	175	176	176	177	178	180	181	182	184
Option 5	158	161	167	168	171	177	176	175	175	175	175	176	176	177	178	179	180	181	182	183	185
Option 6	158	161	167	168	171	177	176	175	175	174	175	175	175	176	176	177	178	180	181	182	184

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035

Aviation net CO_2 adj. for offsets and allowances, Mt, routes within Europe (EU/EFTA, exc. UK), assuming 100% additional offsets																					
Option 1	38	39	41	41	41	37	36	36	35	34	33	32	31	30	29	28	27	26	25	24	24
Option 2	38	39	41	41	41	37	36	35	35	34	33	33	32	32	31	31	30	30	29	28	28
Option 3	38	39	41	41	41	37	55	54	53	52	52	51	51	50	50	49	50	49	50	50	51
Option 4	38	39	41	41	41	37	36	35	35	34	33	33	32	32	31	31	30	30	29	28	28
Option 5	38	39	41	41	41	37	36	36	35	34	33	32	31	30	29	28	28	28	27	27	27
Option 6	38	39	41	41	41	37	38	37	36	36	35	35	34	34	33	33	32	32	32	31	31

Annex 7: Comparison of direct CO_2 emissions covered by the EU ETS and CORSIA, by policy option and participation

This annex includes supplementary data from the sections on CORSIA and EU ETS coverage. This includes estimates of total EU ETS allowance demand from aviation in comparison to the projected total number of allowances, and direct comparisons of CO_2 covered under the EU ETS and CORSIA in absolute and percentage terms.

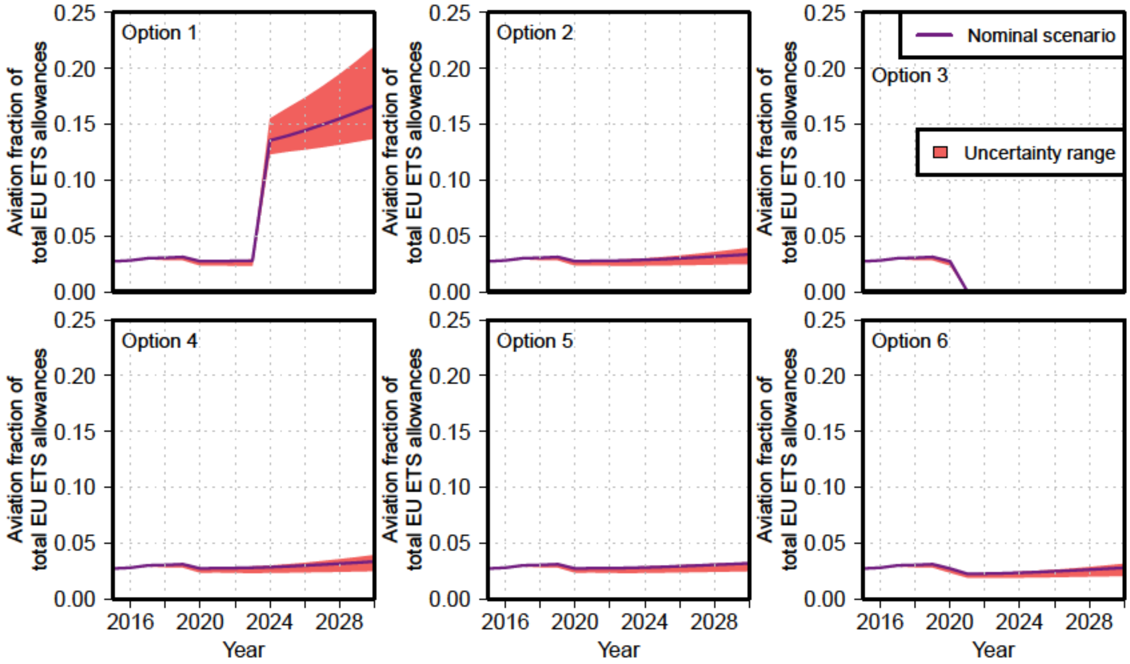

Figure 77. *Fraction of total EU ETS (EUA + EUAA) allowances purchased by aircraft operators, to 2030, by policy option. Solid lines show outcomes with all uncertain scenario variables set to nominal values. Shaded ranges show the range of outcomes across all values for uncertain scenario variables.*

The overall EU ETS cap in 2015 for fixed installations was around 2000 $MtCO_2$ (EC, 2019)[742]. To achieve the EU's greenhouse gas emission reduction targets, the cap has decreased by 1.74% of this value per year to 2021, and will decrease by 2.2% per year thereafter to 2030. The exact number of allowances available in a given year may differ from the cap depending on specific market details (for example, the interaction between any oversupply of allowances and the Market Stability Reserve). ETC/CME (2019)[743] project trends in demand for allowances, and registered emissions, to 2030. It should be noted that they project CO_2 emissions to slightly exceed the EU ETS cap based on existing and projected emissions-reduction measures, although this may be compensated for by an

[742] EC, 2019. Emissions cap and allowances. https://ec.europa.eu/clima/policies/ets/cap_en

[743] ETC/CME, 2019. Trends and projections in the EU ETS in 2019. https://www.eionet.europa.eu/etcs/etc-cme/products/etc-cme-reports/etc-cme-report-3-2019-trends-and-projections-in-the-eu-ets-in-2019

anticipated strengthening of the EU ETS price. The figure above shows demand for allowances from aviation (EUAs and EUAAs) as an approximate percentage of total EU ETS allowances over time, assuming the UK (accounting for nearly 8% of stationary allowances in 2019; ETS Data Viewer, 2020) no longer participates after 2020. Under most combinations of policy and uncertain variables, allowances submitted by aircraft operators (EUAs and EUAAs) remain at a similar fraction of total EU ETS allowances as at present (around 2.5%). The exception is Option 1. Under option 1, increasing CO_2 from flights to and from the EU/EFTA area leads to aviation emissions which are up to around 20% of the total EU ETS year-2030 cap, necessitating greater reductions from other sectors than the other policy options and implying that Option 1 may be associated with higher carbon prices.

In this annex, we also present different ways of directly comparing the coverage of the EU ETS and CORSIA by policy option. This includes in terms of percentage of global CO_2 covered, percentage of global CO_2 offset, and in terms of absolute amounts of CO_2 covered and offset. As CORSIA coverage varies substantially by participation scenario, outcomes are divided by CORSIA participation scenario and the uncertainty ranges presented refer to variation across all other uncertain scenario variables. Note that the numbers shown here are percentages of *total* global direct aviation CO_2 (as distinct from international direct aviation CO_2, which is shown in Table 18). This is necessary to compare EU ETS and CORSIA coverage on a similar basis, as the EU ETS covers domestic flights and CORSIA does not. Offsets may be less than the total direct CO_2 above the CORSIA baseline or ETS cap due to biofuel exemptions (typically by small amounts; see Figure 25-3.15). Note also that in option 5 some CO_2 is double-counted between both schemes (intra-European international flight CO_2 below the CORSIA baseline is additionally counted in the EU ETS-covered CO_2 total). Offsets refer to the percentage of global aviation CO_2 which is offset by a reduction in emissions from other sectors directly paid for by aviation carbon costs (i.e. via CORSIA offsets or purchase of EUAs), and does not include biofuel exempt emissions. Note also that the scenario with the minimum or maximum percent of CO_2 offset does not necessarily correspond to the scenario with the smallest or largest absolute amount of CO_2 offset.

Table 60. CORSIA and EU ETS total coverage, and CO_2 offset, as a percentage of global direct aviation CO2.

Policy option	Direct CO_2 covered by CORSIA, % of total		Direct CO_2 offset under CORSIA, % of total		Direct CO_2 covered by EU ETS, % of total		Direct CO_2 offset under EU ETS, % of total	
	2030	2035	2030	2035	2030	2035	2030	2035
Initial Assumed CORSIA Participation								
Option 1	19.2 (18.1-19.6)	19.2 (18.2-19.5)	3.3 (0.1-5.7)	4.9 (1.4-8.3)	21.5 (20.4-24.8)	20.2 (18.8-24.5)	10.4 (8.0-14.6)	11.3 (8.6-16.9)
Option 2	19.2 (18.1-19.5)	19.1 (18.1-19.5)	3.3 (0.1-5.7)	4.9 (1.4-8.3)	4.0 (3.6-4.3)	3.7 (3.2-4.0)	2.1 (1.3-2.5)	2.2 (1.2-2.7)
Option 3	33.9 (32.9-35.9)	32.9 (31.9-35.8)	3.9 (0.2-9.9)	6.5 (1.9-14.3)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.0 (0.0-0.0)
Option 4	30.3 (29.3-32.2)	29.6 (28.5-32.4)	3.9 (0.1-9.2)	6.3 (1.9-13.4)	4.0 (3.6-4.3)	3.7 (3.2-4.0)	2.1 (1.3-2.5)	2.2 (1.2-2.7)
Option 5	33.9 (32.9-35.9)	32.9 (31.9-35.8)	3.9 (0.2-9.9)	6.5 (1.9-14.2)	3.8 (3.2-4.0)	3.4 (2.6-3.6)	1.9 (1.2-1.9)	1.9 (1.2-1.9)
Option 6	30.3 (29.3-32.2)	29.6 (28.5-32.4)	3.9 (0.1-9.2)	6.3 (1.9-13.4)	3.3 (2.9-3.5)	3.0 (2.6-3.2)	1.9 (1.2-2.1)	1.9 (1.1-2.2)
High CORSIA Participation								
Option 1	30.5 (29.7-31.0)	30.5 (30.1-31.6)	6.8 (1.3-10.5)	9.4 (3.9-14.7)	21.5 (20.4-24.8)	20.2 (18.8-24.5)	10.4 (8.0-14.6)	11.3 (8.6-16.9)
Option 2	30.4 (29.6-30.9)	30.4 (30.0-31.3)	6.8 (1.3-10.5)	9.5 (3.9-14.6)	4.0 (3.6-4.3)	3.7 (3.2-3.0)	2.1 (1.3-2.5)	2.2 (1.2-2.7)
Option 3	48.2 (47.1-51.3)	47.2 (46.0-51.7)	8.0 (0.7-16.2)	11.7 (4.6-22.7)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.0 (0.0-0.0)
Option 4	44.6 (43.4-47.6)	43.8 (42.6-48.3)	8.0 (1.1-15.5)	11.5 (4.8-21.8)	4.0 (3.6-4.3)	3.7 (3.2-4.0)	2.1 (1.3-2.5)	2.2 (1.2-2.7)
Option 5	48.2 (47.1-51.3)	47.2 (46.0-51.7)	7.9 (0.7-16.1)	11.7 (4.6-22.6)	3.8 (3.2-4.0)	3.4 (2.6-3.6)	1.9 (1.2-1.9)	1.9 (1.2-1.9)
Option 6	44.6 (43.4-47.6)	43.8 (42.6-48.3)	7.9 (1.1-15.5)	11.5 (4.8-21.8)	3.3 (2.9-3.5)	3.0 (2.6-3.2)	1.9 (1.2-2.1)	1.9 (1.1-2.2)
Low CORSIA Participation								
Option 1	11.4 (10.2-11.7)	11.7 (10.3-12.1)	2.4 (0.1-3.8)	3.7 (0.9-5.3)	21.5 (20.4-24.8)	20.2 (18.8-24.5)	10.4 (8.0-14.6)	11.3 (8.6-16.9)
Option 2	11.4 (10.1-11.7)	11.6 (10.3-12.0)	2.4 (0.1-3.8)	3.7 (0.9-5.3)	4.0 (3.6-4.3)	3.7 (3.2-4.0)	2.1 (1.3-2.5)	2.2 (1.2-2.7)
Option 3	22.4 (21.1-23.3)	22.1 (20.8-23.4)	3.0 (0.1-6.7)	5.0 (1.4-9.7)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.0 (0.0-0.0)
Option 4	18.8 (17.7-19.6)	18.7 (17.7-20.0)	3.0 (0.1-6.1)	4.8 (1.4-8.8)	4.0 (3.6-4.3)	3.7 (3.2-4.0)	2.1 (1.3-2.5)	2.2 (1.1-2.7)
Option 5	22.4 (21.1-23.3)	22.0 (20.8-23.3)	3.0 (0.1-6.7)	5.0 (1.4-9.6)	3.8 (3.2-4.0)	3.4 (2.6-3.6)	1.9 (1.2-1.9)	1.9 (1.2-1.9)
Option 6	18.8 (17.7-19.6)	18.7 (17.7-20.1)	3.0 (0.1-6.1)	4.8 (1.4-8.8)	3.3 (2.9-3.5)	3.0 (2.6-3.2)	1.9 (1.2-2.1)	1.9 (1.1-2.2)

Table 61. CORSIA and EU ETS total coverage, and CO_2 offset, absolute values.

Policy option	Direct CO_2 covered by CORSIA, Mt		Direct CO_2 offset under CORSIA, Mt		Direct CO_2 covered by EU ETS, Mt			Direct CO_2 offset under EU ETS, Mt		
	2030	2035	2030	2035	2015	2030	2035	2015	2030	2035
Initial Assumed CORSIA Participation										
Option 1	218 (174-256)	242 (181-380)	37 (1-76)	62 (13-132)	55	245 (212-232)	255 (217-379)	16	118 (74-195)	143 (86-270)
Option 2	219 (174-257)	243 (181-311)	37 (1-77)	63 (13-133)	55	46 (36-54)	46 (34-59)	16	23 (12-32)	27 (12-40)
Option 3	386 (321-474)	418 (331-566)	45 (2-133)	83 (19-229)	55	0 (0-0)	0 (0-0)	16	0 (0-0)	0 (0-0)
Option 4	345 (289-427)	375 (299-513)	44 (2-124)	79 (18-215)	55	46 (36-54)	46 (34-59)	16	23 (12-32)	27 (12-40)
Option 5	386 (320-474)	418 (330-565)	45 (2-132)	82 (19-229)	55	43 (36-45)	43 (34-44)	16	21 (12-23)	24 (12-25)
Option 6	345 (289-427)	375 (299-514)	44 (1-124)	79 (18-215)	55	38 (29-43)	38 (28-47)	16	21 (11-26)	24 (11-33)
High CORSIA Participation										
Option 1	346 (279-410)	385 (297-502)	77 (12-140)	119 (38-234)	55	245 (212-322)	255 (217-379)	16	118 (74-195)	143 (86-270)
Option 2	346 (279-411)	386 (297-502)	78 (12-140)	120 (38-235)	55	46 (36-54)	46 (34-59)	16	23 (12-32)	27 (12-40)
Option 3	549 (463-681)	599 (484-822)	91 (7-216)	149 (45-364)	55	0 (0-0)	0 (0-0)	16	0 (0-0)	0 (0-0)
Option 4	507 (429-633)	556 (452-770)	90 (10-218)	145 (47-350)	55	46 (36-54)	46 (34-59)	16	23 (12-32)	27 (12-40)
Option 5	549 (463-681)	599 (484-822)	90 (6-216)	148 (45-364)	55	43 (36-45)	43 (34-44)	16	21 (12-23)	24 (12-25)
Option 6	507 (429-634)	556 (452-770)	90 (10-208)	145 (47-350)	55	38 (29-43)	38 (28-47)	16	21 (11-26)	24 (11-33)
Low CORSIA Participation										
Option 1	129 (95-151)	147 (102-183)	27 (1-49)	46 (9-85)	55	245 (212-322)	255 (217-379)	16	118 (74-195)	143 (86-270)
Option 2	129 (95-151)	148 (102-183)	28 (1-49)	47 (9-85)	55	46 (36-54)	46 (34-59)	16	23 (12-32)	27 (12-40)
Option 3	226 (203-308)	280 (210-370)	35 (1-90)	64 (14-155)	55	0 (0-0)	0 (0-0)	16	0 (0-0)	0 (0-0)
Option 4	214 (170-261)	237 (179-318)	34 (1-81)	61 (13-141)	55	46 (36-54)	46 (34-59)	16	23 (12-32)	27 (12-40)
Option 5	255 (202-308)	280 (210-369)	34 (1-90)	64 (14-155)	55	43 (36-45)	43 (34-44)	16	21 (12-23)	24 (12-25)
Option 6	214 (170-261)	237 (179-318)	34 (1-81)	61 (13-141)	55	38 (29-43)	38 (28-47)	16	21 (11-26)	24 (11-33)

Annex 8: National and regional sector classifications used in the macroeconomic analysis

Table 62. National and regional sector classifications

Sector aggregation: 4 sectors (regional results)	Sector aggregation: 10 sectors (national results)	NACE code	NACE activity	E3ME Sector
Agriculture, forestry, fishing, and industry (except construction)	Agriculture, forestry and fishing	A	Agriculture, forestry and fishing	1 Crop production
				2 Forestry
				3 Fishing
	Industry (except construction)	B	Mining and quarrying	4 Coal
				5 Oil and Gas
				6 Other mining
		C	Manufacturing	7 Food, drink & tobacco
				8 Textiles & leather
				9 Wood & wood prods
				10 Paper & paper prods
				11 Printing
				12 Manufactured fuels
				13 Chemicals nes
				14 Pharmaceuticals

Sector aggregation: 4 sectors (regional results)	Sector aggregation: 10 sectors (national results)	NACE code	NACE activity	E3ME Sector
				15 Rubber & plastic
				16 Non-Met. Min. prods.
				17 Basic metals
				18 Metal products
				19 Electronics
				20 Electrical equipment
				21 Machinery, equip. nec
				22 Motor vehicles
				23 Oth. transport equip.
				24 Manufacuring nes
				25 Repair & installation
		D	Electricity, gas, steam and air conditioning supply	26 Electricity
				27 Gas, steam & air con
		E	Water supply; sewerage, waste management and remediation activities	28 Water supply
				29 Sewerage & waste

Sector aggregation: 4 sectors (regional results)	Sector aggregation: 10 sectors (national results)	NACE code	NACE activity	E3ME Sector
Construction, wholesale and retail trade, transport, accommodation and food service activities	Construction	F	Construction	30 Construction
	Wholesale and retail trade, transport, accommodation and food service activities	G	Wholesale and retail trade; repair of motor vehicles and motorcycles	31 Sale of cars
				32 Other wholesale
				33 Other retail
		H	Transportation and storage	34 Land transport
				35 Water transport
				36 Air transport
				37 Warehousing
				38 Postal & courier act.
		I	Accommodation and food service activities	39 Hotels & catering
Information and communication; financial and insurance activities; real estate	Information and communication	J	Information and communication	40 Publishing activities

Sector aggregation: 4 sectors (regional results)	Sector aggregation: 10 sectors (national results)	NACE code	NACE activity	E3ME Sector
activities; professional, scientific and technical activities; administrative, and support service activities				
				41 Broadcasting & movies
				42 Telecommunications
				43 Computer services
	Financial and insurance activities	K	Financial and insurance activities	44 Financial services
				45 Insurance
				46 Auxiliary to finance
	Real estate activities	L	Real estate activities	47 Real estate
				48 Imputed rents
	Professional, scientific and technical activities; administrative and support service activities	M	Professional, scientific and technical activities	49 Legal, account. etc

Sector aggregation: 4 sectors (regional results)	Sector aggregation: 10 sectors (national results)	NACE code	NACE activity	E3ME Sector
				50 Architect & engineer
				51 R&D activities
				52 Advertising
				53 Other professional
		N	Administrative and support service activities	54 Rental & leasing
				55 Employment activities
				56 Travel agency, tours
				57 Security & admin.
Public administration, defence, education, human health, and social work; arts, entertainment, and recreation; other service activities; activities of household and extra-territorial organizations and bodies	Public administration, defence, education, human health and social work activities	O	Public administration and defence; compulsory social security	58 Public admin. & def.
		P	Education	59 Education

Sector aggregation: 4 sectors (regional results)	Sector aggregation: 10 sectors (national results)	NACE code	NACE activity	E3ME Sector
		Q	Human health and social work activities	60 Human health activ.
				61 Residential care
	Arts, entertainment and recreation; other service activities; activities of household and extra-territorial organizations and bodies	R	Arts, entertainment and recreation	62 Arts & ent activ.
				63 Sports activities
		S	Other service activities	64 Membership orgs.
				65 Repair hold goods
				66 Other personal serv.
		T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	67 Households employers
		U	Activities of extra-territorial organizations and bodies	68 Extraterritorial org.

Sector aggregation: 4 sectors (regional results)	Sector aggregation: 10 sectors (national results)	NACE code	NACE activity	E3ME Sector
-	-	-	-	69 Unallocated/Dwellings
				70 Hydrogen Supply

Annex 9: Description of the E3ME model

Overview

E3ME is a computer-based model of the world's economic and energy systems and the environment. It was originally developed through the European Commission's research framework programmes and is now widely used in Europe and beyond for policy assessment, for forecasting and for research purposes. The global version of E3ME provides:

1. better geographical coverage
2. better feedbacks between individual European countries and other world economies
3. better treatment of international trade with bilateral trade between regions
4. new technology diffusion sub-modules

This model description provides a short summary of the E3ME model. For further details, please read the full model manual available online from www.e3me.com.

Applications of E3ME

Scenario-based analysis

Although E3ME can be used for forecasting, the model is more commonly used for evaluating the impacts of an input shock through a scenario-based analysis. The shock may be either a change in policy, a change in economic assumptions or another change to a model variable. The analysis can be either forward looking (ex-ante) or evaluating previous developments in an ex-post manner. Scenarios may be used either to assess policy, or to assess sensitivities to key inputs (e.g. international energy prices).

For ex-ante analysis a baseline forecast up to 2050 is required; E3ME is usually calibrated to match a set of projections that are published by the European Commission and the International Energy Agency but alternative projections may be used. The scenarios represent alternative versions of the future based on a different set of inputs. By comparing the outcomes to the baseline (usually in percentage terms), the effects of the change in inputs can be determined.

Price or tax scenarios

Model-based scenario analyses often focus on changes in price because this is easy to quantify and represent in the model structure. Examples include:

- changes in tax rates including direct, indirect, border, energy and environment taxes
- changes in international energy prices

Regulatory impacts

All of the price changes above can be represented in E3ME's framework reasonably well, given the level of disaggregation available. However, it is also possible to assess the effects of regulation, albeit with an assumption about effectiveness and cost. For example, an increase in vehicle fuel-efficiency standards could be assessed in the model with an assumption about how efficient vehicles become, and the cost of these measures. This would be entered into the model as a higher price for cars and a reduction in fuel consumption (all other things being equal). E3ME could then be used to determine:

- secondary effects, for example on fuel suppliers
- rebound effects[744]
- overall macroeconomic impacts

Comparison with CGE models and econometric specification

E3ME is often compared to Computable General Equilibrium (CGE) models. In many ways the modelling approaches are similar; they are used to answer similar questions and use similar inputs and outputs. However, underlying this there are important theoretical differences between the modelling approaches.

In a typical CGE framework, optimal behaviour is assumed, output is determined by supply-side constraints and prices adjust fully so that all the available capacity is used. In E3ME the determination of output comes from a post-Keynesian framework and it is possible to have spare capacity. The model is more demand-driven and it is not assumed that prices always adjust to market clearing levels.

The differences have important practical implications, as they mean that in E3ME regulation and other policy may lead to increases in output if they are able to draw upon spare economic capacity. This is described in more detail in the model manual.

The econometric specification of E3ME gives the model a strong empirical grounding. E3ME uses a system of error correction, allowing short-term dynamic (or transition) outcomes, moving towards a long-term trend. The dynamic specification is important when considering short and medium-term analysis (e.g. up to 2020) and rebound effects[745], which are included as standard in the model's results.

Key strengths of E3ME

In summary the key strengths of E3ME are:

- the close integration of the economy, energy systems and the environment, with two-way linkages between each component
- the detailed sectoral disaggregation in the model's classifications, allowing for the analysis of similarly detailed scenarios
- its global coverage, while still allowing for analysis at the national level for large economies
- the econometric approach, which provides a strong empirical basis for the model and means it is not reliant on some of the restrictive assumptions common to CGE models
- the econometric specification of the model, making it suitable for short and medium-term assessment, as well as longer-term trends

Limitations of the approach

As with all modelling approaches, E3ME is a simplification of reality and is based on a series of assumptions. Compared to other macroeconomic modelling approaches, the assumptions are relatively non-restrictive as most relationships are determined by the

[744] In the example, the higher fuel efficiency effectively reduces the cost of motoring. In the long-run this is likely to lead to an increase in demand, meaning some of the initial savings are lost. Barker et al (2009) demonstrate that this can be as high as 50% of the original reduction.

[745] Where an initial increase in efficiency reduces demand, but this is negated in the long run as greater efficiency lowers the relative cost and increases consumption. See Barker et al (2009).

historical data in the model database. This does, however, present its own limitations, for which the model user must be aware:

The quality of the data used in the modelling is very important. Substantial resources are put into maintaining the E3ME database and filling out gaps in the data. However, particularly in developing countries, there is some uncertainty in results due to the data used.

- Econometric approaches are also sometimes criticised for using the past to explain future trends. In cases where there is large-scale policy change, the 'Lucas Critique' that suggests behaviour might change is also applicable. There is no solution to this argument using any modelling approach (as no one can predict the future) but we must always be aware of the uncertainty in the model results.
- The other main limitation to the E3ME approach relates to the dimensions of the model. In general, it is very difficult to go into a level of detail beyond that offered by the model classifications. This means that sub-national analysis is difficult[746] and sub-sectoral analysis is also difficult. Similarly, although usually less relevant, attempting to assess impacts on a monthly or quarterly basis would not be possible.

E3ME basic structure and data

The structure of E3ME is based on the system of national accounts, with further linkages to energy demand and environmental emissions. The labour market is also covered in detail, including both voluntary and involuntary unemployment. In total there are 33 sets of econometrically estimated equations, also including the components of GDP (consumption, investment, international trade), prices, energy demand and materials demand. Each equation set is disaggregated by country and by sector.

E3ME's historical database covers the period 1970-2014 and the model projects forward annually to 2050. The main data sources for European countries are Eurostat and the IEA, supplemented by the OECD's STAN database and other sources where appropriate. For regions outside Europe, additional sources for data include the UN, OECD, World Bank, IMF, ILO and national statistics. Gaps in the data are estimated using customised software algorithms.

The main dimensions of the model

The main dimensions of E3ME are:

- 61 countries – all major world economies, the EU28 and candidate countries plus other countries' economies grouped
- 44 or 70 (Europe) industry sectors, based on standard international classifications
- 28 or 43 (Europe) categories of household expenditure
- 22 different users of 12 different fuel types
- 14 types of air-borne emission (where data are available) including the 6 GHG's monitored under the Kyoto Protocol

Standard outputs from the model

As a general model of the economy, based on the full structure of the national accounts, E3ME is capable of producing a broad range of economic indicators. In addition there is

[746] If relevant, it may be possible to apply our E3-India or E3-US (currently under development) models to give state-level analysis.

range of energy and environment indicators. The following list provides a summary of the most common model outputs:

- GDP and the aggregate components of GDP (household expenditure, investment, government expenditure and international trade)
- sectoral output and GVA, prices, trade and competitiveness effects
- international trade by sector, origin and destination
- consumer prices and expenditures
- sectoral employment, unemployment, sectoral wage rates and labour supply
- energy demand, by sector and by fuel, energy prices
- CO_2 emissions by sector and by fuel
- other air-borne emissions
- material demands

This list is by no means exhaustive and the delivered outputs often depend on the requirements of the specific application. In addition to the sectoral dimension mentioned in the list, all indicators are produced at the national and regional level and annually over the period up to 2050.

E3ME as an E3 model

The E3 interactions

Each data set has been constructed by statistical offices to conform with accounting conventions. Exogenous factors coming from outside the modelling framework are shown on the outside edge of the chart as inputs into each component. For each region's economy the exogenous factors are economic policies (including tax rates, growth in government expenditures, interest rates and exchange rates). For the energy system, the outside factors are the world oil prices and energy policy (including regulation of the energy industries). For the environment component, exogenous factors include policies such as reduction in SO2 emissions by means of end-of-pipe filters from large combustion plants. The linkages between the components of the model are shown explicitly by the arrows that indicate which values are transmitted between components.

The economy module provides measures of economic activity and general price levels to the energy module; the energy module provides measures of emissions of the main air pollutants to the environment module, which in turn can give measures of damage to health and buildings. The energy module provides detailed price levels for energy carriers distinguished in the economy module and the overall price of energy as well as energy use in the economy.

Treatment of international trade

An important part of the modelling concerns international trade. E3ME solves for detailed bilateral trade between regions (similar to a two-tier Armington model). Trade is modelled in three stages:

- econometric estimation of regions' sectoral import demand
- econometric estimation of regions' bilateral imports from each partner
- forming exports from other regions' import demands

Trade volumes are determined by a combination of economic activity indicators, relative prices and technology.

The labour market

Treatment of the labour market is an area that distinguishes E3ME from other macroeconomic models. E3ME includes econometric equation sets for employment, average working hours, wage rates and participation rates. The first three of these are disaggregated by economic sector while participation rates are disaggregated by gender and five-year age band.

The labour force is determined by multiplying labour market participation rates by population. Unemployment (including both voluntary and involuntary unemployment) is determined by taking the difference between the labour force and employment. This is typically a key variable of interest for policy makers.

The role of technology

Technological progress plays an important role in the E3ME model, affecting all three E's: economy, energy and environment. The model's endogenous technical progress indicators (TPIs), a function of R&D and gross investment, appear in nine of E3ME's econometric equation sets including trade, the labour market and prices. Investment and R&D in new technologies also appears in the E3ME's energy and material demand equations to capture energy/resource savings technologies as well as pollution abatement equipment. In addition, E3ME also captures low carbon technologies in the power sector through the FTT power sector model.[747]

[747] See Mercure (2012)

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