www.oeko.de

Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

Fit for purpose?
Key issues for the first review of CORSIA

Berlin,
April 2022

Authors

Dr. Lambert Schneider
Nora Wissner

Oeko-Institut e.V.

With contributions from Aki Kachi, NewClimate Institute

Contact
info@oeko.de
www.oeko.de

Head Office Freiburg
P. O. Box 17 71
79017 Freiburg

Street address
Merzhauser Straße 173
79100 Freiburg
Phone +49 761 45295-0

Office Berlin
Borkumstraße 2
13189 Berlin
Phone +49 30 405085-0

Office Darmstadt
Rheinstraße 95
64295 Darmstadt
Phone +49 6151 8191-0

This publication is funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK)

This publication is funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK)

Implemented by

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Impressum

Publisher: Oeko-Institut e.V.

Editors and Project Management: Lydia Ondraczek (GIZ), Dennis Tänzler (adelphi), Denis Machnik (adelphi)

Authors: Dr. Lambert Schneider, Nora Wissner

With contributions from Aki Kachi, NewClimate Institute

Date: 01.04.2022

This paper has been commissioned by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry for Economic Affairs and Climate Action (BMWK)

Disclaimer

The analysis, results and recommendations in this paper, funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK), represent the opinion of the authors and are neither necessarily representative of the position of the funder nor of the Gesellschaft für Internationale Zusammenarbeit (GIZ GmbH).

Acknowledgements

The authors wish to thank the Federal Ministry for Economic Affairs and Climate Action (BMWK) and the Gesellschaft für Internationale Zusammenarbeit (GIZ) for their contribution in defining specific trends and topics of analysis and for sharing their insights and experiences. Needless to say, this does not imply that they endorse the analysis or recommendations included in the publication.

Suggested Citation

Schneider, Lambert; Wissner, Nora (2022): Fit for purpose? Key issues for the review of CORISA. Oeko-Institut.

Table of Contents

Summary table 4

1 Introduction 5

2 A long-term goal for ICAO 6

2.1 Addressing aviation's full climate impact 6

2.2 Aligning ICAO's long-term goal with the Paris Agreement 9

3 Key aspects for the review of CORSIA 11

3.1 CORSIA's goals and trajectory 11

3.1.1 Aligning goal and trajectory with a long-term goal and the Paris Agreement 11

3.1.2 Baseline 11

3.1.3 Coverage of routes 12

3.1.4 Scope of emissions 13

3.2 CORSIA Eligible Fuels (CEF) 13

3.3 Quality of carbon credits 15

3.3.1 Vintage restrictions 16

3.3.2 Additionality 16

3.3.3 Robust quantification of emission reductions and removals 17

3.3.4 Addressing non-permanence 17

3.3.5 Avoiding double counting 18

4 Conclusions 19

List of References 20

Summary table

Key areas of review for CORSIA
Long-term goal for ICAO • To achieve the objectives of the Paris Agreement, adopt a long-term goal of climate neutrality and zero in-sector CO_2 emissions by 2050, with offsetting used only to compensate for any residual non-CO_2 effects in 2050.
Alignment of CORSIA with a long-term goal • Shift ICAO's focus from using offsetting as a key emission reduction measure to using in-sector measures and align CORSIA with the long-term goal. Revise CORSIA accordingly by: a) setting an appropriate in-sector CO_2 emissions reduction target for 2035, in line with the target of zero CO_2 emissions in 2050; b) adopting a *net* zero emissions target for 2035, including the possibility to use offsetting; and c) adjusting the emissions trajectory up to 2035 accordingly. • For all phases after 2023, define a pathway towards net zero emissions by 2035, starting from the average of 2019/2020.
Addressing the full climate impact of aviation • Start monitoring non-CO_2 effects. • Adopt policies that reduce non-CO_2 effects such as re-routing in the near-term. • Require that any residual non-CO_2 effects are offset after 2030.
CORSIA eligible fuels • Introduce an overall minimum quota for sustainable alternative fuels to ensure the necessary uptake of these fuels in line with the 2035 and 2050 emission targets. • Only allow sustainable aviation fuels and abandon lower carbon aviation fuels for compliance. • Strengthen minimum greenhouse gas reduction requirements.
Quality of carbon credits • Vintage restrictions: emissions units eligible from 2024 onwards should come from projects for which the investment decision was taken after ICAO's decision on unit eligibility. • Additionality: limit eligibility to project types with a high assurance of additionality. • Non-permanence: considerably strengthen the requirements for addressing reversals, including by monitoring and compensating for reversals for 100 years, and exclude activities with high risks.
Transparency • Enhance the transparency throughout ICAO, including its decision making.

1 Introduction

Aviation is an important driver of climate change. The sector was responsible for about 2.4% of global anthropogenic CO_2 emissions in 2018 and – despite a significant decline due to the COVID-19 pandemic – air travel is expected to grow further in the future. Moreover, aviation's climate impact goes well beyond CO_2 emissions: CO_2 emissions only contribute about one third to aviation's effect on global warming, the rest is caused by so-called non-CO_2 effects (Lee et al. 2021).

During the negotiations for the Kyoto Protocol in 1997, countries agreed that greenhouse gas (GHG) emissions from international aviation and maritime transport would not be included in the national climate targets of industrialised countries under the Kyoto Protocol. Instead, the International Civil Aviation Organization (ICAO) was tasked with addressing these emissions (UNFCCC 1998). While emissions from international aviation were not included in targets under the Kyoto Protocol, the Paris Agreement is applicable to all anthropogenic greenhouse gas emissions not controlled under the Montreal Protocol and thus includes emissions from international aviation. To date, however, only the EU considers including emissions from international aviation in its Nationally Determined Contribution (NDC).

In 2016, the ICAO Assembly adopted the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) to achieve its goal of 'carbon-neutral growth' from 2020 onwards (ICAO 2016). CORSIA's aim is to compensate for any CO_2 emissions above a baseline of the average CO_2 emissions from the years 2019 and 2020. For its pilot phase from 2021 to 2023, the baseline was changed to the year 2019 in response to the decline in 2020 emissions due to the COVID-19 pandemic. The scheme only covers flights on international routes between participating countries. CORSIA is part of ICAO's so-called 'basket of measures' to reduce emissions which consists of the following measures:

- technical and operational measures to increase fuel efficiency;
- the use of sustainable aviation fuels (SAF); and
- the purchase of carbon offsets (CORSIA).

The scheme has a timeline from 2021 to 2035 and is divided into three phases: a voluntary pilot phase (2021-2023); a phase one (2024-2026) with voluntary participation; and a mandatory phase two (2027-2035). Over the past years, ICAO adopted detailed rules for the implementation of CORSIA.

While CORSIA is the first international agreement to address emissions for a sector, it has also been heavily criticised for its shortcomings, including the lack of ambition of its goal of 'carbon-neutral growth,' the coverage of CO_2 emissions only, the limited participation in the voluntary phase, the quality of the eligible carbon credits, and its weaknesses in terms of ensuring compliance and enforceability (ICF Consulting et al. 2020; Broekhoff et al. 2020; Siemons et al. 2021).

Considering these shortcomings, CORSIA would need to be substantially reformed to reduce emissions from international aviation. The upcoming review of CORSIA in 2022 is an opportunity to consider "*improvements that would support the purpose of the Paris Agreement, in particular its long-term goals*" (ICAO 2016, p. 6). In addition to CORSIA, other ICAO technical bodies are pursuing climate mitigation measures under several other workstreams. These include workstreams on the use of SAF in the Fuels Task Group (FTG) of the Committee on Aviation Environmental Protection (CAEP) and the consideration of the adoption of a long-term aspirational goal (LTAG). A reform of CORSIA is interlinked with, and depends on, these other processes.

This paper aims to contribute to the forthcoming review of CORSIA by identifying key issues that should be addressed in relevant ICAO decision making bodies. As the discussion on the LTAG is closely interlinked with the review of CORSIA, the paper starts by discussing options for a long-term goal under ICAO. Moreover, this paper is written from the viewpoint of what would be necessary to make CORSIA an effective climate mitigation tool and to align it with the goals of the Paris Agreement, noting that there are difficulties to make progress on this complex and highly debated issue under ICAO. Given these difficulties, it is important that domestic policies complement international efforts under ICAO and that any decisions taken by ICAO do not undermine the adoption of more ambitious policies at domestic level.

2 A long-term goal for ICAO

To reach the goals of the Paris Agreement, emissions need to be rapidly reduced in all sectors to achieve a balance between emissions and removals as soon as possible (Masson-Delmotte et al. 2021). A growing number of countries, jurisdictions and companies are therefore adopting long-term climate goals, usually net zero emissions or climate neutrality targets. Such long-term goals are important because they set a vision which can shape the adoption of pathways and policies needed to achieve these goals.

The adoption of a long-term climate goal is also an important ongoing debate under ICAO and in the aviation industry. To date, ICAO has only set a goal of carbon neutral growth from 2020 onwards (ICAO 2013), with CORSIA serving as the main measure to achieve this target. However, CORSIA does not address the long term – notably, the scheme is currently planned to terminate in 2035. Other actors in the realm of aviation have already adopted long-term goals.

ICAO is set to consider a long-term target at its next Assembly in 2022. At its 40th session in 2019, the ICAO Assembly requested the ICAO Council to continue to explore the feasibility of "*a long-term global aspirational goal for international aviation*" (ICAO 2019d, p. 1). At the 41st session in 2022, studies on the feasibility and impact of any proposed long-term goals should be presented. Until then, the CAEP conducts workshops, stakeholder consultations and analysis.

Adopting a long-term target in 2022 would be just in time to inform the global stocktake (GST) process due in 2023 under the Paris Agreement. The GST is part of the Paris Agreement's ambition mechanism, which should ensure that Parties take more action over time to achieve the long-term goals of the Paris Agreement. A long-term target could influence the next round of NDCs and potentially the inclusion of international aviation emissions in NDCs.

This paper discusses two key issues for the consideration of a long-term goal and its implications for CORSIA: addressing aviation's full climate impact (section 2.1), aligning the long-term goal with the Paris Agreement (section 2.2).

2.1 Addressing aviation's full climate impact

ICAO's current climate goals only address CO_2 emissions and not the entire climate impact of aviation. Aviation releases more gases than just CO_2. The climate impacts caused by non-CO_2 emissions have a net warming effect and are estimated to be responsible for about two thirds of the net radiative forcing of aviation globally, depending on the metrics used to compare these climate effects (Lee et al. 2021). These non-CO_2 effects have different spatial and temporal distributions. An overview of the climate impacts from aviation caused by non-CO_2 emissions

compared to CO_2 emissions is provided in Table 1. For example, contrails and contrail cirrus, i.e. clouds composed of ice crystals that can be generated by aircraft engines at high altitudes, have a strong warming effect; more research is needed, however, on the details of cloud formation (EASA 2020; UBA 2019). The breakdown of methane (CH_4) in the atmosphere by nitrogen oxide (NO_x) can have a cooling effect whereas NO_x emissions also contribute to ozone (O_3) formation with a warming effect on the climate. Generally, the climate impact of non-CO_2 emissions is - in contrast to CO_2 emissions - not linear to fuel consumption. The overall climate impact of an individual flight thus depends not only on fuel consumption, but also on the specific flight altitude and climatic conditions (UBA 2019).

Table 1: Climate impact and scientific understanding of CO_2 and non-CO_2 effects

Emissions / non-CO_2 effect	CO_2	NO_x -> O_3 increase	NO_x -> CH_4 decrease	NO_x -> O_3 decrease	Sulfate aerosols	Soot	Contrails and cirrus clouds
Climate impact	Warming	Warming	Cooling	Cooling	Cooling	Warming	Warming
Duration of impact	Centuries	Weeks to months	Decades	Decades	Days to weeks	Days to weeks	Contrails: hours Cirrus clouds: hours to days
Spatial distribution	Global	Continental to global	Continental to global	Continental to global	Continental to global	Local to global	Local to global
Scientific understanding	Good	Fair	Fair	Fair	Direct effects: good Indirect cloud effects: poor	Direct effects: good Indirect cloud effects: poor	Poor to fair

Source: Derived from Lee et al. (2021) and Carbon Offsetguide (2020)

Technical and operational measures to reduce non-CO_2 effects include using fuels and combustion techniques that cause fewer non-CO_2 emissions, and the avoidance of spatial or temporal areas where non-CO_2 effects are more likely to occur (UBA 2019). An example of the first measure is SAF (e.g. synthetic kerosene), which typically burn more cleanly than conventional fossil fuels and thus cause fewer non-CO_2 effects (EASA 2020). An example of the avoidance of certain flight areas would be a reduction of the flight altitude. A recent paper by Teoh et al.(2020) found that the diversion of only a small fraction of flights from the original route would bring about a significant reduction of the climate forcing of contrails and induced-cirrus cloudiness in the respective Japanese region. Re-routing, or rather the avoidance of certain climate-sensitive areas, can be regarded as low hanging fruit in reducing the overall climate impact of aviation that could be implemented much faster than other measures.

Currently, there is no global monitoring of aviation's non-CO_2 emissions. Since the ICAO decision to consider only CO_2 emissions, the research on non-CO_2 effects has advanced. Even though more research is needed on some aspects of non-CO_2 effects (Table 1), the net impact of the non-CO_2 emissions is known. In other sectors (like agriculture), there is also uncertainty about emissions, but the climate impact is nevertheless addressed through targets and policies. We therefore recommend that non-CO_2 emissions and their effect on climate should be addressed by ICAO.

There is therefore a need for a monitoring and reporting system. Common calculation methods or metrics will be needed in that regard. A common scale in a monitoring system for non-CO_2 emissions such as CO_2-equivalents can be useful to capture potential trade-offs resulting from measures to reduce the different emission species and allow for a uniform evaluation (EASA 2020, p. 36). One example is fuel-efficient engines which reduce CO_2 emissions but may produce more NO_x (UBA 2019, p. 89).

At the same time, ICAO could implement policies to reduce the non-CO_2 climate impacts of aviation. Several policies can be implemented to address non-CO_2 effects from aviation. Table 2 provides an overview of potential policies, including the non-CO_2 effect which they address and their time horizon for implementation. To avoid non-CO_2 emissions in climate-sensitive areas, spatial and temporal no-fly zones (climate-restricted areas) could be established (EASA 2020; UBA 2019). Alternatively, a flight through these areas could be imposed with a charge (UBA 2019). Furthermore, an aircraft- and route-specific NO_x levy could specifically address NO_x emissions (EASA 2020). With regard to fuels, the maximum limit of aromatics in aviation fuel specifications could be reduced. Fuels with a lower share of aromatic compounds burn more cleanly and emit fewer soot particles. Also, the (mandatory) use of SAF can reduce non-CO_2 effects because SAF typically have a lower aromatics and sulphur content than conventional fossil kerosene (EASA 2020, p. 95). Voigt et al. (2021) show that blends of SAF with conventional jet kerosene can already significantly reduce contrail cloudiness. We recommend that ICAO urgently begins discussing such potential measures, so that corresponding decisions can be made in a timely manner after a monitoring system has been established.

Table 2: Policies to address non-CO_2 effects

Policy	Non-CO_2 effects addressed	Time frame for implementation
No-Fly zones	Contrail cirrus	Short-term for a pilot Mid-term more comprehensively
Climate charge	All climate impacts	Long-term
NO_x charge	NO_x	Mid-term
Maximum limit of aromatic content in fuel	Contrail formation, particulate matter	Short- to mid-term
(Mandatory) use of SAF	Contrail formation and sulphur oxides	Short- to mid-term
Multiplier	generic	Short-term

Note: Short term here refers to 2-5 years; Medium-term refers to 5-8 years; and Long-term refers to 8+ years
Source: Own compilation based on EASA (2020)

Considering the importance of non-CO_2 effects, ICAO should include the full climate impact of aviation and not only CO_2 in its long-term goal and any offsetting schemes after 2030. This could be implemented in different ways: either by determining the non-CO_2 effects for each individual flight or by adding a multiplier to the CO_2 emissions to reflect the additional climate impact of non-CO_2 effects. Graichen and Graichen (2020, p. 5) suggest that such a factor should be based on the radiative forcing of non-CO_2 effects and should be between 3 and 5.

2.2 Aligning ICAO's long-term goal with the Paris Agreement

Different approaches could be pursued to define a long-term goal for ICAO that is aligned with the Paris Agreement.

One approach could be deriving a CO_2 emissions target based on the concept of remaining carbon budgets (RCBs). RCBs are the remaining amount of CO_2 which can be emitted into the atmosphere while keeping the global temperature increase to 2°C or 1.5°C. RCBs are a simplified concept of a very complex system. There are different definitions and estimates using different assumptions. This results in considerable uncertainties regarding the exact RCB, which depend, inter alia, on how uncertain processes are included and accounted for (Matthews et al. 2021; IPCC 2018). A recent study by Matthews et al. (2021) estimates the RCB for remaining at or below 2°C and 1.5°C global temperature increase to be about 1,110 $GtCO_2$ and 230 $GtCO_2$ respectively for the period 2020 to 2100 (with a 67% probability).The challenge is then to distribute the RCB among different sectors or actors. The IPCC concluded, also based on RCBs, that global CO_2 emissions need to reach net-zero around mid-century (IPCC 2018). At COP26 in November 2021, this was explicitly recognised and all countries were urged to adopt long-term low greenhouse gas emission development strategies to achieve net zero emissions by or around mid-century (UNFCCC 2021). A growing number of countries have already adopted such targets.

At COP26, the International Aviation Climate Ambition Coalition (consisting of 23 state representatives) committed to "*advanc[ing] ambitious actions to reduce aviation CO_2 emissions at a rate consistent with efforts to limit the global average temperature increase to 1.5°C*" at ICAO while referring to a target of net zero CO_2 emissions by 2050.[1] The coalition also includes 10 members of the ICAO Council, such as Canada, France, Japan, Spain, the United Kingdom and the United States.

Many actors in the aviation industry have also committed to net zero CO_2 emission targets. The European aviation sector agreed in context of the initiative Destination2050 to reach net zero CO_2 emissions by 2050 from all flights within and departing from the EU.[2] More specifically, the Destination2050 scenario assumes a reduction of CO_2 emissions by 92% in 2050 with the remaining 8% being compensated through carbon removal/offset projects. The "Toulouse Declaration", a public-private partnership signed by a number of airports, also commits to net zero CO_2 emissions by 2050 and to "interim milestones" on the way to 2050.[3] The International Air Transport Association (IATA) with 290 airline members similarly announced a target of net-zero CO_2 by 2050.[4] Various airlines including the International Consolidated Airlines Group (which owns British Airways, Iberia); Delta, United, and EasyJet also have announced net-zero targets.[5] Moreover, several reports explore the feasibility of climate targets for aviation in line with the Paris Agreement (Sharmina et al. 2020; Bows-Larkin 2015; Cames et al. 2015; Leipold et al. 2021).

An analysis of Climate Action Tracker (Climate Action Tracker 2021) determines a potential trajectory of CO_2 emissions from international aviation which is assumed to be in line with the goals of the Paris Agreement. To define the necessary contribution to the global emission reductions, the sector is treated as other energy and industrial processes. A "1.5°-compatible pathway" was constructed

1 https://ukcop26.org/cop-26-declaration-international-aviation-climate-ambition-coalition/
2 Destination2050: https://www.destination2050.eu/commitments/
3 Toulouse Declaration: https://www.aci-europe.org/toulouse-declaration
4 https://www.iata.org/en/pressroom/2021-releases/2021-10-04-03/
5 https://sciencebasedtargets.org/companies-taking-action#table

with a linear reduction of global CO_2 emissions from a maximum of 300 Mt in 2030 to 77 Mt in 2050, reaching zero in-sector emissions in 2060. This corresponds to 228 Mt or less in 2035. For comparison, CO_2 emissions from international aviation amounted to approx. 600 Mt in 2018 (IEA 2020). International aviation would thus have to halve emissions by 2030 according to the analysis by Climate Action Tracker (2021). This approach relies on the assumption that the aviation sector decarbonizes in line with the rest of the harder-to-abate industrial sectors.

Another approach could be to define an in-sector target based on the technical feasibility of emission reduction measures, as pursued under ICAO. The aviation sector can reduce a large share of its climate impact via emission reductions within the sector. CO_2 emissions can be mitigated through alternative fuels, such as hydrogen, power-to-liquid or fuels derived from waste, as well as alternative propulsion systems. The main question is how fast these alternatives can be scaled up and how the price gap to conventional fossil fuels will develop (Heinemann et al. 2019; UBA 2019; Leipold et al. 2021). A very challenging but still feasible timeline would be to achieve zero CO_2 emissions within the sector by around mid-century, e.g. 2050 (Climate Action Tracker 2020; Cames et al. 2015).

A second important consideration is the inclusion of non-CO_2 effects into the long-term goal, as discussed in section 2.1 above. This could be achieved by adopting a long-term goal of achieving "climate neutrality", rather than only referring to CO_2 emissions. A growing number of countries, like the EU, already aim for climate neutrality.[6] Non-CO_2 effects can be reduced via various technical and operational measures but not be fully eliminated, though alternative fuels cause less non-CO_2 effects compared to conventional fossil fuels (section 2.1). Hence, if a goal of climate neutrality should be achieved, offsetting would need to play a role to compensate for these residual effects.

This raises the question of the overall role that offsetting should play in achieving that goal. Two aspects are important to consider in defining this role. Firstly, in addition to aviation, there are some other processes, such as cement production or agriculture, for which complete elimination of their GHG emissions is not technically possible. A limited supply of offsets will thus need to be shared between different sectors. Secondly, in the long-term, only negative emission technologies, such as direct air capture (DAC) or afforestation, will be available to compensate for these remaining emissions. Afforestation, however, is vulnerable to reversal and cannot guarantee long-term carbon storage. At the same time, the storage capacity of these technologies is limited. A large body of scientific literature calls into question the overall potential of negative emissions, their feasibility, as well as sustainability implications (IPCC 2018). Notably, the land and freshwater requirements for large-scale negative emissions are likely to have substantial impacts on sustainable development including environmental services, ecosystems, agriculture and food systems, and also threaten food security. For these reasons, it can be argued that the use of negative emission technologies should focus on compensating for truly unavoidable emissions. This holds for the unavoidable non-CO_2 effects from aviation but not for its CO_2 emissions.

Based on these considerations, we recommend that ICAO should adopt a long-term goal of climate neutrality by 2050 or earlier. This overarching goal should be complemented by an in-sector goal to reduce CO_2 emissions to zero by 2050 and measures to reduce non-CO_2 effects to the extent possible. By 2050, carbon credits should only be used to balance out unavoidable non-CO_2 emissions and the carbon credits should only be based on negative emission technologies. All

[6] EU – 2050 long-term strategy: https://ec.europa.eu/clima/policies/strategies/2050_en

climate-related measures at ICAO should be measured and evaluated by these long-term goals, including CORSIA.

3 Key aspects for the review of CORSIA

3.1 CORSIA's goals and trajectory

3.1.1 Aligning goal and trajectory with a long-term goal and the Paris Agreement

CORSIA is part of ICAO's so-called 'basket of measures' to reduce emissions, which includes aircraft technology and operational improvements, the use of SAF as well as market-based measures. Once ICAO has a adopted a long-term goal, CORSIA should be aligned with this goal. Whatever long-term goal ICAO adopts, CORSIA's current purpose – to achieve the goal of 'carbon-neutral growth' beyond 2020 – will need to be revisited.

One possible approach could be to adopt a linear emission reduction trajectory from 2024 to 2035 that is aligned with a goal of achieving climate neutrality and zero in-sector CO_2 emissions by 2050. A 2035 in-sector target for CO_2 emissions would need to consider the time required for ramping up capacity for alternative fuels. In this period, a larger share of the CO_2 emissions may still need to be compensated through offsets. With offsetting it is possible, however, to pursue a more ambitious target. We recommend adopting a goal of "net" zero emissions level by 2035, which includes the possibility for offsetting. This would be in line with the approach of some airlines, which already have pledged net zero emission targets for the short term. In line with the proposed 2050 target for ICAO (section 2.2), an absolute in-sector CO_2 emission target for 2035 would be required as well to ensure the necessary trajectory towards 2050.

3.1.2 Baseline

CORSIA is designed to compensate for CO_2 emissions above 2019-2020 levels. In June 2020, the ICAO Council changed the baseline for the pilot phase to the year 2019 only, instead of the average of 2019/2020, in response to the impact of the COVID-19 pandemic on international aviation.[7] This decision still has to be formally adopted by the ICAO Assembly in 2022.

In the context of the review of CORSIA in 2022, the impact of COVID-19 should be re-evaluated, and the issue of the baseline revisited (ICF Consulting et al. 2020). According to Schneider and Graichen (2020) changing the baseline to the year 2019 will delay climate efforts of the sector for several years. This is because a baseline of 2019 represents a higher emissions level than the average emissions of the years 2019 and 2020. Offsetting requirements will likely be reduced compared to pre-COVID-19 scenarios. Schneider and Graichen (2020, p. 5), expect that "*offsetting requirements would be entirely waived in the pilot phase*" with a 2019 baseline and significantly reduced thereafter. An analysis by ICAO's CAEP (ICAO 2021a) also shows that keeping the 2019 baseline would considerably lower offsetting requirements from 2024 to 2035: with a 2019/2020 baseline, offsetting requirements could range between 1600 and 3200 Mt CO_2 (for a low and

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

high/fast recovery scenario) whereas offset requirements with a 2019 baseline could be reduced to 230 and 1700 Mt CO_2 for the respective scenarios. These projections are highly dependent on recovery projections for global aviation which is still affected by international travel restrictions. The Climate Action Tracker, based on IATA data, has found that there may be no offsetting obligations until 2029 when international aviation is back to pre-COVID levels.[8]

However, based on our recommendation to achieve net zero emissions by 2035 (section 3.1.1), the emission reduction trajectory up to 2035 would need to be revisited. We suggest that a pathway towards net zero emissions by 2035 is defined which starts from the average of 2019/2020.

3.1.3 Coverage of routes

CORSIA covers all routes/flights between countries which participate in the scheme. Any flights to/from/between non-participating countries are not included in the scheme. CORSIA includes a monitoring, reporting and verification (MRV) system which applies to all countries, including those not covered by offsetting requirements. The MRV started in 2019. Administrative requirements, MRV rules, and the calculation of the number of offset obligations are laid down in ICAO's Convention Annex 16 Volume IV, also called Standards and Recommended Practices (SARPs) (ICAO 2018). Participation is voluntary in the pilot and first phase of CORSIA. Although ICAO has no enforcement mechanisms to ensure compliance, from 2027, ICAO Member States (MS) are expected to participate if they are not exempted (ICF Consulting et al. 2020). There are two kinds of exemptions:

- States which are classed as SIDS, LDCs, or landlocked countries;
- States whose share of total revenue tonnes kilometres (RTKs)[9] was less than 0.5% of all ICAO MS in 2018 and which do not belong to the top 90% of the cumulative share of activity.

While 159 states would be exempted based on these rules from the second and mandatory CORSIA phase, exempted states can still choose to participate voluntarily (ICF Consulting et al. 2020, p. 47). Considering the large number of states which are theoretically exempted in the second phase, it should be noted that only 25 countries account for approx. 80% of global CO_2 emissions from international aviation (ICF Consulting et al. 2020). States should notify ICAO about their decision to participate in June of the preceding year. As of June 2021, over 100 states of ICAO's 193 MS announced their participation in the voluntary pilot phase.[10] While participation in the voluntary phases has recently increased, multiple states with high aviation emissions, e.g. China, India, Brazil, Russia, and South Africa, have not committed to participating and have publicly objected to CORSIA's approach as a violation of the principle of common but differentiated responsibilities of the UNFCCC. Before the COVID-19 pandemic, these countries represented some of the world's largest growing aviation markets. As of August 2021, the USA, which ICAO counts as a participating country, has not yet proposed legislation to implement the SARPs in US domestic regulation. It is unclear to what extent states that decline to participate before 2027 will participate in the second phase from 2027 to 2035. In July 2021, the European Commission proposed that flights between EEA member states be covered by the EU ETS and not CORSIA. Further, the Commission has

8 CAT – International Aviation Targets: https://climateactiontracker.org/sectors/aviation/targets/

9 RTK= activity metric based on the weight and distance of both passengers and cargo that are transported annually by all airplane operators registered in a state

10 CarbonPulse (2021) - ICAO moves forward CORSIA emissions recovery forecast, drops offset cost estimates: https://carbon-pulse.com/133154/?utm_source=CP+Daily&utm_campaign=5cdddbd83f-CPdaily06072021&utm_medium=email&utm_term=0_a9d8834f72-5cdddbd83f-110245809

proposed that in line with agreements with Switzerland and the UK, flights between EEA member states and Switzerland, and flights between EEA member states and the UK would be covered through the respective ETS by outgoing flight.[11]

The coverage of global CO_2 emissions would significantly grow if larger countries which do not yet participate joined the scheme.

3.1.4 Scope of emissions

CORSIA covers only CO_2 emissions (ICAO 2016). However, to align CORSIA with a long-term goal of climate neutrality and the Paris Agreement, the non-CO_2 effects should also be considered under CORSIA. In order to accomplish this, a first important step is to establish a system to monitor and report non-CO_2 effects as proposed in section 2.1, for example through a pilot phase for monitoring non-CO_2 effects. After the pilot phase and the experience gained, monitoring could be made mandatory through an amendment to the SARPs and CORSIA. As a subsequent step, policies to reduce non-CO_2 effects such as re-routing could be pursued. Alternatively, or in addition, a multiplier representing the additional climate impact of non-CO_2 effects could be implemented in CORSIA. As non-CO_2 effects constitute a large part of aviation's climate impact, the inclusion of these effects into policies could be envisaged for around 2030 in order to have a significant effect for the emissions development in this century.

3.2 CORSIA Eligible Fuels (CEF)

Airlines can use CORSIA Eligible Fuels (CEF) to reduce their offsetting requirements under CORSIA. In determining the airline's total offsetting requirements, any emission reductions achieved through the use of CEF are subtracted (ICAO 2018, p. 32). ICAO developed a framework, including sustainability criteria, to define what fuels are eligible. There are two types of CEF: sustainable aviation fuels (SAF) and lower carbon aviation fuels (LCAF). SAF are renewable or waste-derived fuels, whereas LCAF are fossil-based with lower life-cycle emissions. The CEF needs to be supplied by a certified fuel producer with full supply chain certification. The certification is carried out by sustainability certification schemes (SCS). As of August 2021, two SCS are approved by ICAO to certify fuel producers (and other economic operators along the supply chain) if they meet the requirements set out in ICAO (2020b) and ICAO (2019b). For the pilot phase, two sustainability "themes" (with sub-criteria) apply to both SAF and LCAF (ICAO 2021e):

- **Lower greenhouse gas emissions on lifecycle basis**: net GHG emissions from CEF should be 10% lower compared to the baseline life cycle emissions of aviation fuels.
- **No biomass from land with high carbon stock**: CEF should not be made of biomass from land with a high carbon stock that underwent land-use conversion after 2008. If land-use conversion occurred after 2008, direct land-use change (DLUC) emissions shall be calculated. If the DLUC value exceeds the induced land-use change (ILUC) value, a default value for indirect land-use change (ILUC) shall be replaced by the DLUC value.

[11] EU-Commission (2021) – Delivering the European Green Deal: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en

These sustainability themes need to be met for a fuel to be eligible under CORSIA. Lifecycle emissions of SAF can be determined either by using ICAO approved default values (ICAO 2021b), or by calculating lifecycle emissions via a CORSIA actual value methodology (ICAO 2021d).

CAEP is tasked with further developing the sustainability framework for LCAF (ICAO 2019a). Currently, no methodology and detailed sustainability framework has been adopted for LCAF making them not operational under CORSIA.

The current framework for using and accounting for CEF should be improved in several ways. Firstly, the eligibility of LCAF under CORSIA is problematic for two reasons (ICF Consulting et al. 2020):

- There is little improvement potential for the lifecycle emissions. Most life cycle emissions of LCAF occur during combustion and only a small share during production. The emissions from production can be reduced, for example, by using carbon capture and storage or reducing methane emissions from crude oil operations. However, the potential emission reductions remain limited compared to SAF.
- There is a risk of double counting of emission reductions: emission reductions associated with the production of the fuel could be claimed both under CORSIA as well as by the countries producing the fuel by reporting lower emission levels in demonstrating the achievement of their NDCs. Moreover, several jurisdictions have adopted legislation under which the same emission reductions may be claimed towards achieving domestic compliance schemes. For example, in several jurisdictions refineries are included under emissions trading systems (ICAP 2021) and the European Union has adopted a Fuel Quality Directive under which upstream emissions from the production of fuels in other countries may be used towards meeting obligations to reduce emissions in the fuel supply chain (EU 2009).

Furthermore, aeroplane operators willing to use LCAF for compliance purposes could alternatively claim emission reduction units under CORSIA from projects addressing the same life cycle emissions as LCAF. Therefore, we recommend that the eligibility of LCAF under CORSIA should not be further pursued.

Secondly, CORSIA's threshold for emission reductions from CEF is relatively low, at 10%. This value should be increased over time considering the important role of CEF in decarbonisation and higher ambitions for aviation (chapter 2). Strengthening the threshold might also ensure that renewable synthetic fuels (so-called e-fuels), for which no production pathway has been listed in the CORSIA methodology to date (ICAO 2021b), are only eligible if they have not been produced with fossil fuels.

For CORSIA's first phase starting in 2024, 12 additional sustainability themes (including 17 associated sustainability criteria) are applicable to CEF (ICAO 2021e). These include, among other things, safeguards to avoid or minimise impacts on water, biodiversity, labour and land-use rights.

Production costs for SAF are predicted to be much higher compared to conventional fuels over the timeline of CORSIA. A study by Pavlenko et al. (2019) estimates alternative fuels to be two to eight times more expensive than conventional jet fuel. As long as prices for carbon credits remain very low, the incentive to reduce offset obligations under CORSIA by using SAF remains very limited. SAF are essential, however, to decarbonising the aviation sector . Therefore, the transition of the industry towards SAF needs to be supported by policies other than those currently pursued in the context of CORSIA. Towards this end, ICAO should consider introducing a minimum quota for SAF that is consistent with the proposed targets for 2035 and 2050 (section 2.2 and 3.1.1). Some countries are already pursuing such quotas: the European Commission recently proposed a quota

for SAF in the context of its ReFuelEU Aviation initiative, which also addresses the issue of tankering (EC 2021).

3.3 Quality of carbon credits

Considering the expected growth in international aviation, which far outpaces the progress of technical and operational measures to increase efficiency, and the higher costs of sustainable aviation fuels as compared to using carbon credits, it is likely that the majority of the CORSIA obligations will be fulfilled by using carbon credits. To deliver the required emission reductions, ensuring a high quality of carbon credits is essential. Key criteria for the quality of carbon credits include additionality, robust quantification of emission reductions or removals, addressing non-permanence and avoiding double counting (Schneider and La Hoz Theuer 2019; ICAO 2019c).

To comply with CORSIA, airlines can only purchase carbon credits from programmes that have been approved by ICAO's Council. In March 2019, the Council adopted emissions unit eligibility criteria (EUC), which specify the requirements for programmes and their carbon credits in order to be eligible under CORSIA (ICAO 2019c). The EUC include key design elements for eligible programmes as well as 'carbon offset credit integrity assessment criteria' for the carbon credits of these programmes. ICAO does not assess whether specific carbon credits fulfil these criteria, but evaluates whether the carbon crediting programs issuing carbon credits have requirements in place to address the EUC. As of August 2021, the ICAO Council has approved eight programmes to supply CORSIA eligible emissions units for the pilot phase of CORSIA (ICAO 2021c): American Carbon Registry, Architecture for REDD+ Transactions, China GHG Voluntary Emission Reduction Program, Clean Development Mechanism, Climate Action Reserve, Global Carbon Council, Gold Standard, and Verified Carbon Standard. The programmes were mostly approved for all types of carbon credits that they issue. Sometimes certain unit types or activities are excluded, for example afforestation and reforestation activities under the Clean Development Mechanism (CDM) (ICAO 2021c). The approval is based on recommendations by a Technical Advisory Body (TAB).

Overall, the available evaluations suggest that the current process and criteria do not ensure environmental integrity (TAB 2019; ICF Consulting et al. 2020; Broekhoff et al. 2020; Schneider et al. 2019). ICF Consulting et al. (2020) concluded that, while eligible programmes meet many of the required design elements and carbon credit criteria, the TAB process was not consistent in its application of the EUC. Generally, the approval process was based on an assessment of whether programmes have measures in place to address the EUC. It was not based on how well these measures perform to ensure carbon credit quality, or of individual projects or project types. Key areas of concern include the vintage restrictions for eligible carbon credits, ensuring additionality, robust quantification of emission reductions, addressing non-permanence, and the avoidance of double counting (ICF Consulting et al. 2020).[12]

The following sections summarise these environmental integrity concerns and identify options for how these issues could be addressed, taking into account the approaches pursued under the various ongoing initiatives to enhance the quality of carbon credits in the market, e.g. the Taskforce on Scaling Voluntary Carbon Markets[13] and the Carbon Credit Quality Initiative[14].

[12] It was also found that safeguards and sustainable development criteria were inconsistently applied.
[13] https://www.iif.com/tsvcm
[14] https://carboncreditquality.org/

3.3.1 Vintage restrictions

A key consideration in determining the environmental impact of using carbon credits are restrictions on the use of 'older' carbon credits, often referred to as 'vintage restrictions'. Using carbon credits from already implemented projects does not necessarily trigger any further emission reductions (Warnecke et al. 2019). In a market situation in which the supply of credits considerably exceeds demand, many of these existing projects would continue to reduce GHG emissions even without revenues from carbon credits. In this situation, creating new demand for carbon credits, e.g. from CORSIA, would not result in new investments in emission reduction projects, especially if the emission reductions or removals occurred in the past.

The ICAO Council decided to restrict the use of carbon credits in the pilot phase from 2021 to 2023 to projects with the first crediting period starting on or after 1 January 2016 (ICAO 2021c). A similar restriction was adopted at COP26 for using certified emission reductions (CERs) from the CDM towards achieving NDCs.[15] Following the change of CORSIA's baseline to 2019 (section 3.1.2), demand for carbon credits is likely to be zero over this period (Climate Action Tracker 2020; Schneider and Graichen 2020). At the same time, there is a considerable amount of supply from eligible carbon credits. With the adopted vintage restrictions, supply from the CDM alone is estimated to amount to 140-169 million credits (Ishikawa et al. 2020). Supply from other programs is less certain but could still be significant (Fearnehough et al. 2019), because some programs like the Architecture for REDD+ Transactions allow for retroactive crediting of past emission reductions. Overall, this means that there will be a large supply of carbon credits with low quality in the pilot phase of CORSIA. Any demand from CORSIA will thus not trigger new investments in emission reduction activities and also have no impacts on global emissions.

Adopting effective vintage restrictions for the next phases of CORSIA from 2024 onwards is thus a key prerequisite for achieving any emission reductions. We recommend that projects should be eligible if their investment decision was made after the date of the ICAO Council decision on this matter. This would facilitate that new projects are implemented in response to the new demand for CORSIA. An alternative or complementary approach could be to allow projects that have already been implemented but that are at risk of discontinuing GHG abatement without carbon credit revenue - also referred to as 'vulnerable' projects (Warnecke et al. 2019). This could, for example, include vulnerable CDM projects that have transitioned to the new mechanism established by Article 6.4 of the Paris Agreement. Supporting these projects could enable them to continue GHG abatement which would otherwise not be realised and thus also deliver actual emission reductions.

3.3.2 Additionality

Emission reductions or removals from a project are additional if the project would not have been implemented in the absence of the added incentive created by the carbon credits (Gillenwater 2012; Schneider et al. 2020). The definition of additionality and the respective tests to prove additionality vary among programmes (Broekhoff et al. 2020). For example, some programmes use project-specific approaches, while others apply standardised approaches like positive lists. The current approach and process under ICAO is very unlikely to ensure additionality, for two main reasons. Firstly, the EUC are very basic minimum requirements for additionality. To provide for a meaningful

[15] Decision -/CMA.3 (Rules, modalities and procedures for the mechanism established by Article 6, paragraph 4, of the Paris Agreement).

evaluation, Graichen et al. (2019) and Broekhoff et al. (2020) suggest, for example, several improvements to the additionality criterion in the EUC, in particular:

- the exclusion of certain project types which are at risk of not being additional;
- the specification that additionality procedures provide “high assurance” that the emission reductions would not have occurred without the carbon credit programme; and
- improved requirements for governance arrangements for carbon crediting programs, such as approved procedures for evaluating key aspects for additionality, including legal requirements and the financial feasibility of the relevant activities, and involvement of independent experts to review such assessments.

Secondly, the EUC do not seem to be applied consistently by ICAO. According to an EU impact assessment of CORSIA, several of the programmes do not fulfil the EUC related to additionality but have nevertheless been approved (ICF Consulting et al. 2020). Many project types that are currently eligible under CORSIA have been assessed as having a low likelihood of additionality (Cames et al. 2017; Broekhoff et al. 2019).

3.3.3 Robust quantification of emission reductions and removals

A further important consideration is the robust quantification of emission reductions and removals. This requires establishing robust baselines, addressing any carbon leakage (including global leakage), robust measurement of project emissions, and choosing appropriate crediting period durations. Baselines involve considerable uncertainty and are not always determined in a conservative manner. The available literature suggests that some emission reductions or removals are determined in a reasonable manner, but that some quantification methodologies result in considerable over-estimation, such as for forest credits in the California forest carbon offset program and efficient cook stoves projects (Cames et al. 2017; Kollmuss et al. 2015; Bailis et al. 2015; Badgley et al. 2021). These types of activities are also eligible under CORSIA, though overall these shortcomings are likely to be a smaller risk compared to the other aspects discussed here.

At COP26 in Glasgow, countries adopted new principles for the quantification of emission reductions. The Article 6 decisions require that baselines are set below business-as-usual and are consistent with NDCs, long-term low greenhouse gas emission development strategies, and the Paris Agreement goals. These new requirements should be incorporated in the EUC and carbon crediting programs should be assessed against these requirements. This requires a revision of most existing quantification methodologies. As this takes time, a short-term approach could be to introduce "ambition coefficients" to existing baselines with the view to setting them at a more ambitious level (Michaelowa et al. 2021).

3.3.4 Addressing non-permanence

With some types of carbon credits, especially in the land-use and forestry sector, there is a risk that the emission reduction or removal is reversed. This occurs through natural or human-caused disturbance, like forest fire, leading to no net reduction or even net emissions (Broekhoff et al. 2020). The likelihood of such reversals increases, the worser the effects of climate change become. Aviation emissions from the combustion of fossil fuels will stay in the atmosphere for thousands of years (Archer et al. 2009). A corresponding robust guarantee for long-term biological carbon is beyond the capability of most carbon offsetting programmes, particularly programmes based on biological carbon storage. ICAO’s current approach towards addressing non-permanence does not sufficiently

recognise these risks, has severe shortcomings and the EUC therefore need to be strengthened considerably.

Firstly, the EUC on non-permanence do not specify the time period for which programmes have to ensure the permanence of the emission reduction and avoid reversal (ICAO 2019c). Based on a recommendation by the TAB (ICAO 2020a), the ICAO Council approved programmes which provide monitoring and compensation for reversals only until the end of the CORSIA implementation period (about 20 years). Considering the long-term impact of CO_2 emissions from aviation, this approach could seriously undermine CORSIA's environmental impact as well as its economic effectiveness. Consistent with the best practice by some carbon crediting programmes, we recommend that monitoring and compensation for reversals is conducted for 100 years. Moreover, the EUC should require that project owners have legal obligations to compensate for intentional or avoidable reversals; that all carbon credits are replaced in instances where monitoring ceases and that pooled buffer reserves be sufficiently capitalized and diversified. Projects with high risks should be excluded from eligibility.

3.3.5 Avoiding double counting

Double counting of emission reductions or removals occurs if the same emission reduction or removal is counted more than once to achieve climate mitigation targets (Schneider et al. 2019a). Double counting can occur in three forms, all of which are addressed by the EUC (ICAO 2019c):

- double issuance of carbon credits;
- double use of carbon credits; or
- double claiming of the same emissions reduction or removals by both the country in which the emission reductions occur and the buyer of carbon credits (the airplane operator).

Double claiming of emissions reductions can occur in a number of ways (Broekhoff et al. 2020; Schneider et al. 2019). In the context of CORSIA, the avoidance of double claiming of emission reductions and removals that are covered under Nationally Determined Contributions (NDCs) is the most challenging issue and will become more important in the future (Broekhoff et al. 2020). The guidelines of the EUC foresee that the programmes receive a letter from the host country in which the emission reductions or removals occur, which includes a commitment by the host country to take necessary steps to avoid double claiming (Schneider et al. 2019).

At COP26 in Glasgow, countries adopted international guidance on cooperative approaches under Article 6. This guidance mainly addresses the use of internationally transferred mitigation outcomes (ITMOs) towards NDCs, but also includes specific provisions that facilitate the avoidance of double claiming in the context of CORSIA. The guidance allows countries to authorise the use of mitigation outcomes for "international mitigation purposes", which is meant to cover CORSIA. If such authorisations are provided, countries are required to apply "corresponding adjustments," thereby ensuring that they cannot use the authorised emission reductions to achieve their own NDCs. Implementing this approach will require close cooperation and coordination between ICAO, the approved programmes, and the countries hosting and authorizing ITMOs for use under CORSIA.

Most of the programmes approved by ICAO do not yet have sufficient procedures, provisions or measures in place to avoid the three forms of double counting, in particular with regard to avoiding double claiming with NDCs (ICF Consulting et al. 2020; Broekhoff et al. 2020; Schneider et al. 2019). This was initially accounted for by ICAO by only approving carbon credits for emission reductions up

to 2020 (ICAO 2021c). Programmes have, however, increasingly addressed double issuance and double use, and have become more aware of double claiming (Broekhoff et al. 2020). Following the adoption of international guidance at COP26 in November 2021, it can be expected that some carbon crediting programs will develop procedures to enable and facilitate the avoidance of double claiming between aeroplane operators and host countries.

While the approach of the EUC to address double claiming is generally appropriate, we recommend that the criterion could be more specific by making reference to best practices from current programmes, drawing on guidelines developed by ClimateWorks Foundation; Meridian Institute; Stockholm Environment Institute (2019) for avoiding double counting with CORSIA and recommendations in the Broekhoff et al. (2020). The definition of double claiming should be expanded to include not only emission reductions or removals in host countries, but also other competing claims like commitments under the Montreal Protocol. Broekhoff et al. (2020, p. 30) suggest a list of basic requirements to be added to the EUC to help the avoidance of double counting.

ICAO should also incorporate relevant decisions adopted under the Paris Agreement. This includes, in particular, clarifying the nature of host country authorisations needed to supply emissions units to CORSIA. Letters of authorisation should only be valid for CORSIA if they have been issued by the respective designated focal points for Article 6 authorisations. Moreover, letters of authorisation should only be accepted if the countries fulfil the participation requirements in relation to Article 6 and after they have submitted an initial report specifying necessary information for participation in Article 6. Finally, ICAO should clarify what information must be provided in the host country letters in order to be accepted (e.g. a reference to CORSIA or “international mitigation purposes”).

4 Conclusions

The current design and rules of CORSIA are insufficient to achieve the objectives of the Paris Agreement.

The upcoming review of CORSIA is an opportunity to begin a broader discussion on aligning international aviation with the Paris Agreement, in addition to fundamental reforms to CORSIA which are needed to deliver actual emission reductions. This relates in particular to the ambition of CORSIA’s goal, the exclusion of non-CO_2 effects, and the quality of the carbon credits used under the scheme.

At the same time, multiple technical aspects can already be improved in the shorter term, for the period beyond the pilot phase and addressed at the level of the ICAO Council. A critical short-term measure is defining the starting point for a trajectory towards net zero emissions by 2035 (average of the years 2019/2020). Improving the EUC and ensuring that they are applied consistently in evaluating programs might enhance the currently low environmental integrity of the CORSIA eligible units. GHG emission reduction thresholds for CEF need to be strengthened.

Finally, CORSIA has further significant weaknesses in terms of ensuring participation, compliance and enforceability. The scheme is implemented via a set of SARPs, which must be transposed into national law. States may file “differences” to notify ICAO in instances in which they will not implement a SARP or will implement it in a different way. ICAO has not published the differences that states have filed, though the EU has published its own difference (EU 2018). All key information on ICAO should be made publicly available.

List of References

Archer, D.; Eby, M.; Brovkin, V.; Ridgwell, A.; Cao, L.; Mikolajewicz, U.; Caldeira, K.; Matsumoto, K.; Munhoven, G.; Montenegro, A.; Tokos, K. (2009): Atmospheric Lifetime of Fossil Fuel Carbon Dioxide. In: *Annu. Rev. Earth Planet. Sci.* 37 (1), pp. 117–134. DOI: 10.1146/annurev.earth.031208.100206.

Broekhoff, D.; Gillenwater, M.; Colbert-Sangree, T.; Cage, P. (2019): Securing Climate Benefit: A Guide to Using Carbon Offsets: Greenhouse Gas Management Institute / Stockholm Environment Institute. Online available at http://www.offsetguide.org/wp-content/uploads/2019/11/11.15.19.pdf.

Broekhoff, D.; Schneider, L.; Tewari, R.; Fearnehough, H.; Warnecke, C. (2020): Options for Improving the Emission Unit Eligibility Criteria under the Carbon Offsetting and Reduction Scheme for International Aviation, 36/2020. Umweltbundesamt. Berlin, 2020, last accessed on 10 Jun 2021.

Cames, M.; Graichen, J.; Siemons, A.; Cook, V. (2015): Emission reduction targets for international aviation and shipping. Oeko-Institut. European Parliament (ed.), 2015. Online available at http://www.europarl.europa.eu/RegData/etudes/STUD/2015/569964/IPOL_STU(2015)569964_EN.pdf, last accessed on 11 Nov 2019.

Cames, M.; Harthan, R.; Füssler, J.; Lazarus, M.; Lee, C.; Erickson, P.; Spalding-Fecher, R. (2017): How additional is the clean development mechanism? Analysis of the application of current tools and proposed alternatives. Berlin. Oeko-Institut e.V. Online available at https://ec.europa.eu/clima/sites/clima/files/ets/docs/clean_dev_mechanism_en.pdf.

Climate Action Tracker (2020): International Shipping/Aviation Assessment, June 2020 Release, 2020. Online available at https://climateactiontracker.org/press/international-shipping-and-aviation-emissions-goals-both-critically-insufficient/, last accessed on 4 Oct 2021.

Climate Action Tracker (2021): International Shipping/Aviation Assessment, August 2021 Update, 2021. Online available at https://climateactiontracker.org/sectors/aviation/, last accessed on 20 Dec 2021.

ClimateWorks Foundation; Meridian Institute; Stockholm Environment Institute (2019): Guidelines on Avoiding Double Counting for the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), by the Avoiding Double Counting Working Group, 2019. Online available at https://3515dcb4-3ad4-4296-902a-4e1f83b3dd98.filesusr.com/ugd/ab534e_d65b234cea994eaf8194c13bf11a9bdf.pdf, last accessed on 23 Aug 2021.

EASA - European Union Aviation Safety Agency (2020): Updated analysis of the non-CO2 climate impacts of aviation and potential policy measures pursuant to the EU Emissions Trading System Directive Article 30(4), Report from the European Commission to the European Parliament and the Council (COM(2020)747final), 2020. Online available at

https://ec.europa.eu/clima/news/updated-analysis-non-co2-effects-aviation_en, last accessed on 2 Dec 2020.

EC - European Commission (2021): Proposal for a Regulation of the European Parliament and of the Council on ensuring a level playing field for sustainable air transport (COM(2021) 561 final), 2021. Online available at https://ec.europa.eu/info/sites/default/files/refueleu_aviation_-_sustainable_aviation_fuels.pdf, last accessed on 23 Aug 2021.

EU - Europäische Union (2018): Council Decision (EU) 2018/2027, 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), 2018. Online available at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018D2027&from=EN, last accessed on 23 Aug 2021.

EU - European Union (2009): Directive 2009/30 of the European Parliament and of the Countil of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC. In: *OJ L* (140), pp. 88–113. Online available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0088:0113:EN:PDF, last accessed on 25 Jun 2014.

Fearnehough, H.; Warnecke, C.; Schneider, L.; Broekhoff, D.; La Hoz Theuer, S. (2019): Offset credit supply potential for CORSIA. Umweltbundesamt. Berlin, 2019. Online available at https://newclimate.org/wp-content/uploads/2019/11/Offset-credit-supply-potential-for-CORSIA.pdf, last accessed on 3 Sep 2021.

Gillenwater, M. (2012): What is Additionality?. GHG Management Institute. Washington D.C., 2012. Online available at https://ghginstitute.org/research/.

Graichen, J.; Graichen, V. (2020): Analysis of potential reforms of aviation's inclusion in the EU ETS. Oeko-Institut. Transport & Environment (ed.), 2020. Online available at https://www.transportenvironment.org/sites/te/files/publications/2020_11_Oko_Institute_analysis_potential_reforms_aviation_inclusion_ETS.pdf.

Graichen, V.; Cames, M.; Gores, S.; Anderson, G.; Faber, J.; van Wijngaarden, L.; van Velzen, A. (2019): Further development of the EU ETS for aviation against the background of the introduction of a global market-based measure by ICAO (UBA Climate Change, 42/2020). Umweltbundesamt, 2019. Online available at https://www.umweltbundesamt.de/publikationen/further-development-of-the-eu-ets-for-aviation, last accessed on 22 Jul 2021.

ICAO - International Civial Aviation Organization (2018): First Edition to the International Standards and Recommended Practices. Environmental Protection. Annex 16 to the Convention on International Civil Aviation. Volume IV. Carbon Offset and Reduction Scheme for International

Aviation (CORSIA), 2018. Online available at https://www.icao.int/environmental-protection/CORSIA/Pages/SARPs-Annex-16-Volume-IV.aspx, last accessed on 4 Aug 2021.

ICAO - International Civial Aviation Organization (2021a): Update to Scenario Based Analyses of Potential Impacts of Covid19 on CORSIA, Council 223rd session, Presentation of the Executive Summary by CAEP. In collaboration with CAEP, International Civial Aviation Organization. Online available at https://www.icao.int/environmental-protection/CORSIA/Documents/CAEP_Update%20COVID-19%20impact%20analyses.pdf, last accessed on 29 Jul 2021.

ICAO - International Civial Aviation Organization (ed.) (2020a): Recommendations on CORSIA eligible emission units - TAB recommendations from its first assessment, excerpt from the TAB report of January 2020. Technical Advisory Body, 2020. Online available at https://www.icao.int/environmental-protection/CORSIA/Documents/TAB/Excerpt_TAB_Report_Jan_2020_final.pdf, last accessed on 22 Jul 2021.

ICAO - International Civil Aviation Organization (2016): Resolution A39-3: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Global Market-based Measure (MBM) scheme, 38th session of the Assembly. Montreal, 2016. Online available at http://www.icao.int/environmental-protection/Documents/Resolution_A39_3.pdf, last accessed on 20 Aug 2021.

ICAO - International Civil Aviation Organization (2019a): Committee on Aviation Environmental Protection Report, 11th Meeting, Doc 10126 CAEP/11, 2019. Online available at https://store.icao.int/en/committee-on-aviation-environmental-protection-report-doc-10126, last accessed on 9 Feb 2022.

ICAO - International Civil Aviation Organization (2019b): CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes, 2019. Online available at https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2003%20-%20Eligibility%20Framework%20and%20Requirements%20for%20SCS.pdf, last accessed on 23 Aug 2021.

ICAO - International Civil Aviation Organization (2019c): CORSIA Emissions Unit Eligibility Criteria, 2019. Online available at https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO_Document_09.pdf, last accessed on 21 Jul 2021.

ICAO - International Civil Aviation Organization (2019d): Resolution A40-18: Consolidated statement of continuing ICAO policies and practices related to environmental protection - Climate change, 40th session of the ICAO Assembly, 2019. Online available at https://www.icao.int/environmental-protection/Documents/Assembly/Resolution_A40-18_Climate_Change.pdf, last accessed on 7 Apr 2021.

ICAO - International Civil Aviation Organization (2020b): CORSIA Approved Sustainability Certification Schemes, 2020. Online available at https://www.icao.int/environmental-

protection/CORSIA/Documents/ICAO%20document%2004%20-%20Approved%20SCSs.pdf, last accessed on 23 Aug 2021.

ICAO - International Civil Aviation Organization (2021b): CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels, 2021. Online available at https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2006%20-%20Default%20Life%20Cycle%20Emissions%20-%20March%202021.pdf, last accessed on 4 Aug 2021.

ICAO - International Civil Aviation Organization (2021c): CORSIA Eligible Emission Units, 2021. Online available at https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20Document%2008%20_%20CORSIA%20Eligible%20Emissions%20Units_March%202021.pdf, last accessed on 4 Aug 2021.

ICAO - International Civil Aviation Organization (2021d): CORSIA Methodology for Calculating Actual Life Cycle Emissions Values, 2021. Online available at https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2007%20-%20Methodology%20for%20Actual%20Life%20Cycle%20Emissions%20-%20March%202021.pdf, last accessed on 23 Aug 2021.

ICAO - International Civil Aviation Organization (2021e): CORSIA Sustainability Criteria for CORSIA Eligible Fuels, Version November 2021, 2021. Online available at https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2005%20-%20Sustainability%20Criteria%20-%20November%202021.pdf, last accessed on 20 Jan 2022.

ICAO (2013): ICAO Assembly – 38th session. Resolution A38-18, Report of the executive committee on agenda item 17 (Section on Climate Change). Montreal, 2013. Online available at http://www.icao.int/Meetings/a38/Documents/Resolutions/a38_res_prov_en.pdf.

ICAP - International Carbon Action Partnership (2021): Emissions trading worldwide, Status Report 2021. Berlin, 2021. Online available at https://icapcarbonaction.com/en/?option=com_attach&task=download&id=723, last accessed on 2 Mar 2022.

ICF Consulting; Air Transportation Analytics; NewClimate Institute; Cambridge Econometrics; HFW; Sven Starckx (2020): Assessment of ICAO's global market-based measure (CORSIA) pursuant to Article 28b and for studying cost passthrough pursuant to Article 3d of the EU ETS Directive. European Commission (ed.). Brussels, 2020, last accessed on 18 Mar 2021.

IEA (2020): CO2 Emissions from Fuel Combustion: Overview, International Energy Agency. Online available at https://www.iea.org/reports/co2-emissions-from-fuel-combustion-overview, last accessed on 9 Jun 2021.

IPCC - Intergovernmental Panel on Climate Change (2018): 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, sustainable development, and efforts to eradicate poverty. Geneva, 2018. Online available at https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf, last accessed on 31 Aug 2021.

Ishikawa, T.; Yamasaki, S.; Fearnehough, H.; Schneider, L.; Warnecke, C.; Hemmi, T.; Yamaguchi, K.; Takahashi, K. (2020): CDM supply potential for emission reductions up to the end of 2020. Institute for Global Environmental Strategies; MUFG; NewClimate Institute; Oeko-Institut, 2020. Online available at https://www.oeko.de/publikationen/p-details/cdm-supply-potential-for-emission-reductions-up-to-the-end-of-2020, last accessed on 3 Sep 2021.

Lee, D. S.; Fahey, D. W.; Skowron, A.; Allen, M. R.; Burkhardt, U.; Chen, Q.; Doherty, S. J.; Freeman, S.; Forster, P. M.; Fuglestvedt, J.; Gettelman, A.; León, R. R. de; Lim, L. L. et al. (2021): The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. Atmospheric Environment 244, p. 117834. DOI: 10.1016/J.ATMOSENV.2020.117834.

Masson-Delmotte, V.; P. Zhai; A. Pirani; S. L. Connors; C. Péan; S. Berger; N. Caud; Y. Chen; L. Goldfarb; M. I. Gomis; M. Huang; K. Leitzell; E. Lonnoy et al. (2021): Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change. Cambridge University Press (ed.), 2021. Online available at https://www.ipcc.ch/report/ar6/wg1/, last accessed on 20 Aug 2021.

Matthews, D. H.; Tokarska, K. B.; Rogelj, J.; Smith, C. J.; MacDougall, A. H.; Haustein, K.; Mengis, N.; Sippel, S.; Forster, P. M.; Knutti, R. (2021): An integrated approach to quantifying uncertainties in the remaining carbon budget. In: *Commun Earth Environ* 2 (1), pp. 1–11. DOI: 10.1038/s43247-020-00064-9.

Michaelowa, A.; Hermwille, L.; Espelage, A.; Michaelowa, K. (2021): Ambition coefficients, aligning baseline for international carbon markets with net zero pathways (Carbon Mechanisms Review, Vol.9). Wuppertal-Institut für Klima, Umwelt, Energie (ed.), 2021. Online available at https://www.perspectives.cc/public/fileadmin/user_upload/ambition_coefficients-cmr10-21.pdf.

Pavlenko, N.; Searle, S.; Christensen, A. (2019): The cost of supporting alternative jet fuels in the European Union, Working Paper 2019-05. International Council on Clean Transportation, 2019. Online available at https://theicct.org/sites/default/files/publications/Alternative_jet_fuels_cost_EU_2020_06_v3.pdf, last accessed on 23 Aug 2021.

Schneider, L.; Graichen, J. (2020): Should CORSIA be changed due to the COVID-19 crisis?. Oeko-Institut. Berlin, 2020. Online available at https://www.oeko.de/fileadmin/oekodoc/Should-CORSIA-be-changed-due-to-the-COVID-19-crisis.pdf, last accessed on 4 Nov 2020.

Schneider, L.; Healy, S.; Fallasch, F.; Léon, F. de; Rambharos, M.; Schallert, B.; Holler, J.; Kizzier, K.; Petsonk, A.; Hanafi, A. (2020): What makes a high-quality carbon credit? Phase 1 of the “Carbon Credit Guidance for Buyers” project: Definition of criteria for assessing the quality of carbon credits. Berlin: World Wildlife Fund (WWF-US), Environmental Defense Fund (EDF),

Oeko-Institut. Online available at https://www.oeko.de/fileadmin/oekodoc/What-makes-a-high-quality-carbon-credit.pdf.

Schneider, L.; La Hoz Theuer, S. (2019): Environmental integrity of international carbon market mechanisms under the Paris Agreement. In: *Climate Policy* 19 (3), pp. 386–400. DOI: 10.1080/14693062.2018.1521332.

Schneider, L.; Michaelowa, A.; Broekhoff, D.; Espelage, A.; Siemons, A. (2019): Lessons learned from the first round of applications by carbon-offsetting programs for eligibility under CORSIA. Oeko-Institut; Perspectives Climate Change; SEI, 2019. Online available at https://www.oeko.de/en/publications/p-details/lessons-learned-from-the-first-round-of-applications-by-carbon-offsetting-programs-for-eligibility-u-1, last accessed on 4 Oct 2021.

Siemons, A.; Schneider, L.; Wissner, N.; Keimeyer, F.; Gores, S.; Graichen, J. (2021): Options for regulating the climate impacts of aviation. Oeko-Institut. Stiftung Klimaneutralität (ed.), 2021. Online available at https://www.oeko.de/fileadmin/oekodoc/Options-for-regulating-the-climate-impacts-of-aviation.pdf, last accessed on 1 Jun 2021.

TAB - Technical Advisory Body (2019): Public comments received on the responses to the Call for Applications for assessment by the TAB, 2019. Online available at https://www.icao.int/environmental-protection/CORSIA/Documents/TAB/TAB_Public comments_Consolidated.pdf.

Teoh, R.; Schumann, U.; Majumdar, A.; Stettler, M. E. J. (2020): Mitigating the Climate Forcing of Aircraft Contrails by Small-Scale Diversions and Technology Adoption. In: *Environ. Sci. Technol.* 54 (5), pp. 2941–2950. DOI: 10.1021/acs.est.9b05608.

UBA - Umweltbundesamt (2019): Umweltschonender Luftverkehr, lokal-national-international (UBA Texte, 130/2019), 2019. Online available at https://www.umweltbundesamt.de/publikationen/umweltschonender-luftverkehr, last accessed on 13 Dec 2019.

UNFCCC - United Nations Framework Convention on Climate Change (2021): Decision-/CMA.3, Glasgow Climate Pact, 2021. Online available at https://unfccc.int/sites/default/files/resource/cma3_auv_2_cover%20decision.pdf, last accessed on 13 Dec 2021.

UNFCCC (1998): Kyoto Protocol to the United Nations Framework Convention on Climate Change. UNFCCC, 1998. Online available at http://unfccc.int/resource/docs/convkp/kpeng.pdf, last accessed on 31 Aug 2021.

Voigt, C.; Kleine, J.; Sauer, D.; Moore, R. H.; Bräuer, T.; Le Clercq, P.; Kaufmann, S.; Scheibe, M.; Jurkat-Witschas, T.; Aigner, M.; Bauder, U.; Boose, Y.; Borrmann, S. et al. (2021): Cleaner burning aviation fuels can reduce contrail cloudiness. In: *Communications Earth & Environment* 2 (1), p. 114. DOI: 10.1038/s43247-021-00174-y.

Warnecke, C.; Schneider, L.; Day, T.; La Hoz Theuer, S.; Fearnehough, H. (2019): Robust eligibility criteria essential for new global scheme to offset aviation emissions. In: *NATURE CLIMATE CHANGE* 9 (3), pp. 218–221. DOI: 10.1038/s41558-019-0415-y.