Policy Brief | 16.05.2024

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

Aviation in the EU climate policy

Key issues for the EU 2040 and 2050 target

// Nora Wissner, Verena Graichen

This briefing provides an overview of the status quo (as of December 2023) and recent changes of EU legislation for the aviation sector. It is analysed whether the legislative situation after the Fit-for-55 package makes the sector fit for a potential 2040 target and the 2050 target of the EU.

Key recommendations

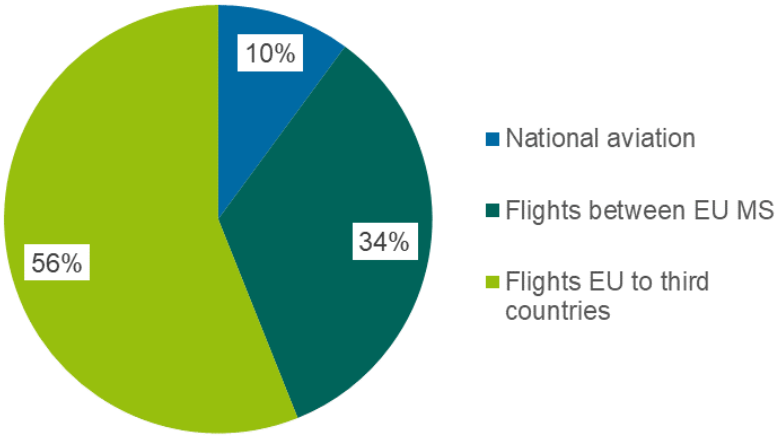
- Aviation has been covered by only one EU climate policy in the past (the EU ETS). The Fit-for-55 packages changes this. The policies start off slowly but get more ambitious over time.
- International transport needs to be included in the EU 2040 climate target to keep the momentum up - albeit the target might seem less ambitious in percentage terms. Although global policies are more suitable for a global sector, the EU cannot wait for the ICAO which has implemented CORSIA with little ambition and has no climate policies in place after its end in 2035.
- The EU ETS cap on aviation emissions is declining at a faster pace due to the Fit-for-55 revisions. The ETS thus gets more ambitious over time. The decision in 2027 about the inclusion of non-CO_2 emissions is important and will need to be ambitiously implemented.
- Carbon pricing alone will not suffice to accelerate the uptake of Sustainable Aviation Fuels (SAF). The adoption of ReFuelEU Aviation is a crucial step forward to incentivise the use of SAF. Enhancing the ambition of the regulation in the next review and spending revenues from the ETS on decarbonization will be important to accelerate in-sector reductions.
- Additional and complementary regulatory action should still be taken to minimize non-CO_2 effects from aviation, such as regulating the fuel quality of aviation fuels (reducing aromatic and sulphur) and promoting contrail avoiding flight paths.
- Exclusion of aviation fuels from energy taxes is an unresolved problem. While the revision of the ETD is still negotiated and the outcome uncertain, like-minded countries could and should go ahead by taxing (international) aviation fuels through bilateral agreements.
- Aviation emissions are highly dependent on economic growth and travel patterns, stepping up efforts to create convenient alternatives to air travel (e.g. trains) and change narratives about travelling by plane can lead to further emission reductions besides deploying SAF.

1 Aviation and the EU's climate targets/governance

1.1 CO_2 emissions

The aviation sector contributes considerably to global greenhouse gas (GHG) emissions. In 2018, national and international flights combined were responsible for approx. 905 Mt of CO_2 emissions which equals about 2.4% of global CO_2 emissions in that year (IATA 2019; Lee et al. 2021).International flights represent two thirds of total global aviation emissions. Before the drop in emissions due to the COVID-19 pandemic, flights within and between EU member states caused approx. 65 Mt CO_2 and international flights to third countries approx. 120 Mt CO_2 in 2019 (EEA 2021).[1] International flights are thus also responsible for the majority of EU-related aviation emissions (Figure 1). The climate impact of aviation is even higher (about three times) if non-CO_2 effects are considered (section 1.2).

Figure 1: Share of EU-related national and international aviation emissions from a total of 148 MtCO_2 in 2019

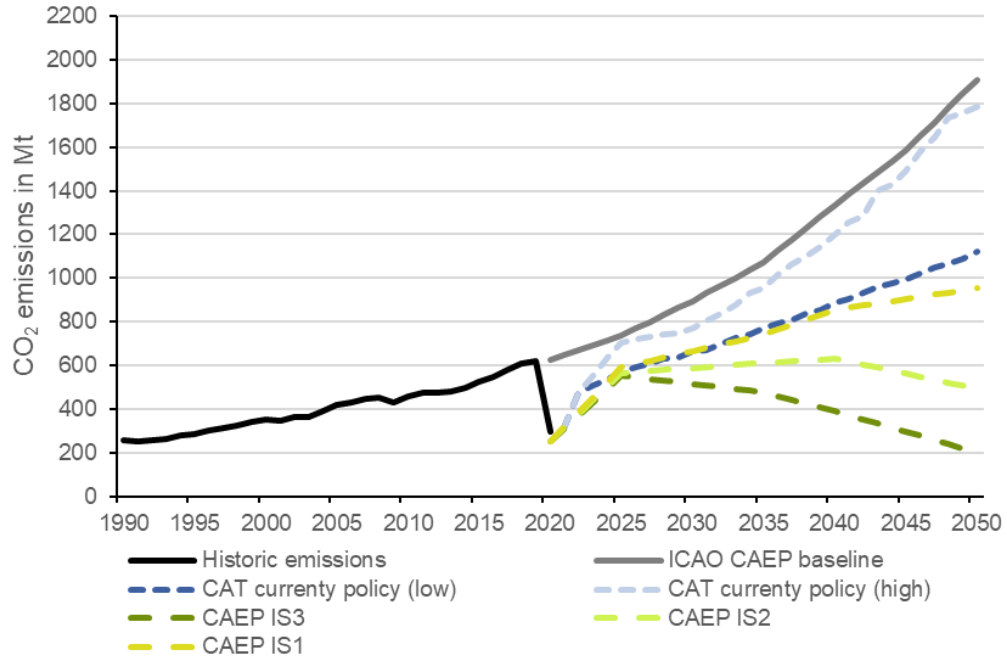


Source: National inventory for national EU emissions and international flights (EEA 2021). Emissions within the ETS scope: https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1

Figure 2 shows the historic development of CO_2 emissions from international aviation between 1990 and 2020 and projections up to 2050. The emission reduction scenarios modelled by the Committee on Aviation Environmental Protection (CAEP) of International Civil Aviation Organization (ICAO) for the new climate target (see below) also include various mitigation measures: sustainable aviation fuels (SAF), hydrogen aircrafts and technology improvements. The use of SAF contributes more than about 50-80% to the emissions reductions in 2050 depending on the scenario. These three scenarios still result in remaining emissions between 200 and 950 MtCO_2 in 2050.

[1] Emissions from flights within and between EU member states taken from: https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1; Estimation of international flights based on ETS emissions (minus domestic emissions) subtracted from inventory data for aviation bunkers.

Figure 2: Historic and projected emissions for international aviation

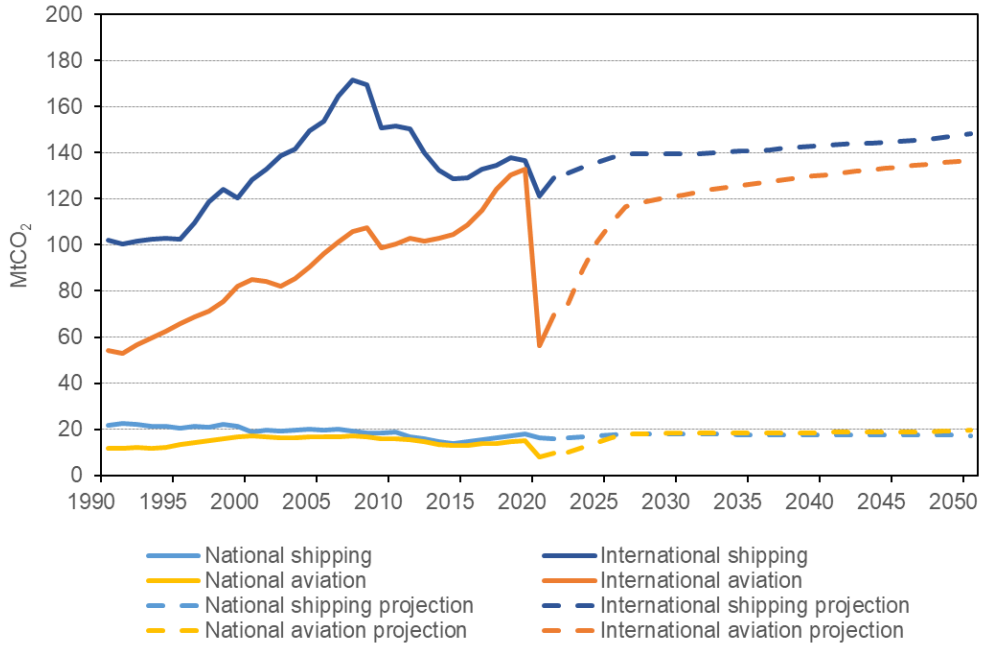


Source: Source: Authors' own compilation based on ICAO (2019), OECD (2023), CAT (2022), ICAO (2022d).

Note: The ICAO CAEP baseline shows a business-as-usual (BAU) scenario from ICAO. The other lines show projections for international aviation considering the impact of the COVID-19 pandemic.

The same development can be seen in emissions from EU-related international aviation as shown in Figure 3**.** In the last decades, emissions from international aviation have increased significantly. Projections do not foresee a significant decline in EU-related emissions – national aviation emissions are expected to remain stable and international aviation's emissions increase compared to today. All-cargo flights (not cargo in a passenger aircraft) normally make up 3-4% of total European flights but increased to more than 10% in early 2021 due to the Covid-19 pandemic.

Figure 3: Historic and projected CO_2 emissions from EU-related aviation and shipping



Source: TP and inventory data, projections only include existing measures (business-as-ususal).

The aviation sector experienced significant growth before the COVID-19 pandemic of approx. 140% over the past three decades (OECD 2023). However, international aviation emissions were significantly impacted by the COVID-19 pandemic, with passenger traffic being impacted the most (Millefiori et al. 2021; Roland Berger 2023). The decrease in emissions in 2020 can be clearly seen in the figures above.

The sector will likely recover to pre-pandemic levels in the mid-2020s (Roland Berger 2023). It is thus predicted that if no additional measures are adopted (business-as-usual) that aviation emissions will continue to increase, as seen in the projections for aviation globally and in the EU (Figure 2 and Figure 3).

1.2 Non-CO_2 effects

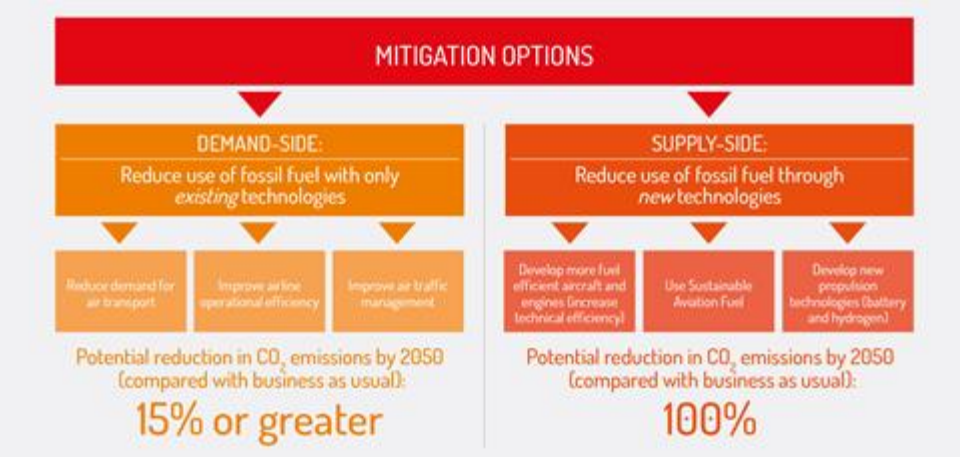
The climate impact of aviation goes beyond CO_2 emissions. In addition to CO_2 emissions, aircrafts also emit nitrogen oxides (NO_x), water vapour, soot, aerosols and sulphate aerosol particles. Condensation trails and contrail cirrus, i.e. clouds composed of ice crystals that can be produced by aircraft engines at high altitudes, are an important factor here. These non-CO_2 effects can have both warming and cooling effects (e.g. breakdown of methane in the atmosphere by nitrogen oxides). Although there are still uncertainties about the climate impact of some non-CO_2 effects, there is a scientific consensus that non-CO_2 effects increase radiation and thus have an overall warming effect (EASA 2020; Bopst et al. 2019). Different measures and potential policies to reduce non-CO_2 effects are addressed in the section below.

1.3 Mitigation options

To reduce emissions from aviation different measures can be applied (Figure 4). On shorter distances, flights should be avoided and attractive public transport alternatives established. Besides energy efficiency measures and a reduction of demand, the

technical efficiency of aircrafts or the operational efficiency of airlines and air traffic management can be improved. The main lever to reduce emissions from aviation is, however, the use of SAF, including sustainable biofuels and e-kerosene, and other propulsion technologies (like electric aircrafts) (ICAO 2022d).

Figure 4: Demand- and supply-side mitigation options in aviation



Source: https://www.unpri.org/pri-blog/climate-action-100-releases-first-sector-strategy-focused-on-aviation/6967.article

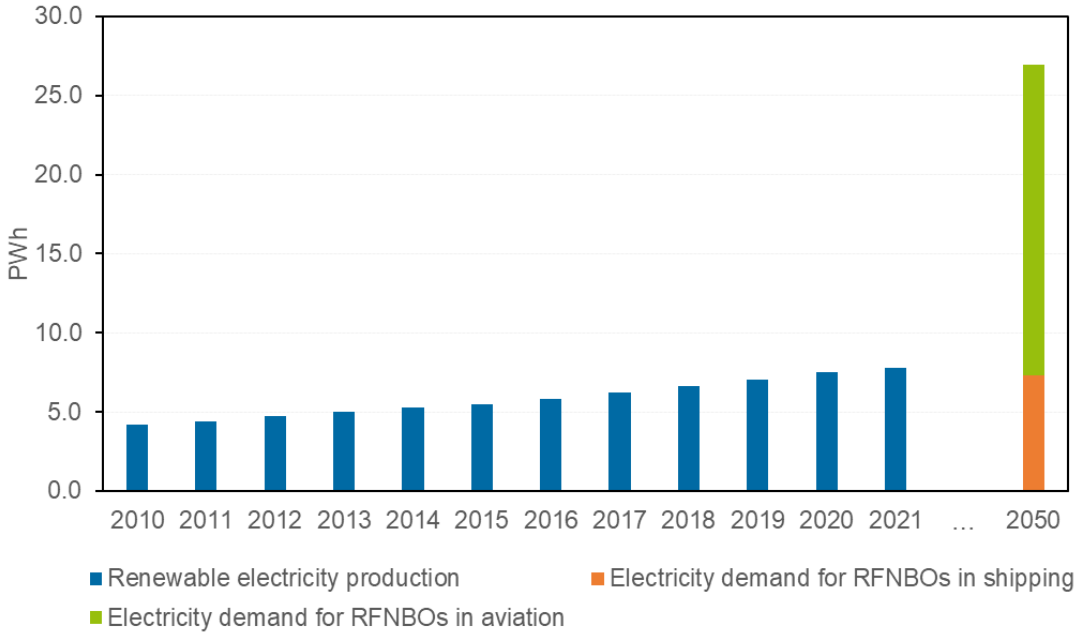
Moreover, given their ability to serve as a drop-in fuel, the limited technological maturity of electric and hydrogen airplanes and their greater energy density, SAF are likely to serve a preeminent role among options for the decarbonisation of aviation – at least in the short- to medium-term.

However, today SAF play no significant role in aviation. Their use needs hence to be scaled up rapidly which requires significant renewable energy capacities, new infrastructure and changes to aircraft turbines[2]. The worldwide capacity to produce truly sustainable biofuels for aviation will be limited, especially as there will be a high competition for sustainable feedstocks given the high biofuel demand in other sectors (e.g. heating/industry).

For example, Cames et al. (2023) estimate an annual energy demand of global aviation of 28.8-41.9 EJ in 2050. In their study, they assumed a conversion efficiency (Well-to-Tank) of approx. 50% to produce renewable fuels of non-biological origin (RFNBO)/e-kerosene, resulting in an electricity demand of 16-23.3 PWh in 2050. Global renewable electricity generation was approx. 7.5 PWh in 2020 (IRENA 2022). Thus, meeting aviation's growing energy demand in 2050 would require more than all of the renewable electricity generation of 2020. Additionally, other sectors will also have an increasing demand for green hydrogen and hydrogen-derived fuels (e.g. the steel or chemical industry). The scale of the necessary increase in renewable energy production is shown in Figure 5. Estimations in relation to the new EU policies can be found in section 2.

[2] Aircraft turbines rely today on aromatic content of fuels, but most SAF are free of aromatics.

Figure 5: Comparison renewable electricity production today versus demand from shipping



Source: Mean values for electricity demand for RFNBOS from Cames et al. (2023), historic renewable energy production from IRENA statistics time series: https://www.irena.org/Data/View-data-by-topic/Capacity-and-Generation/Statistics-Time-Series

Non-CO_2 effects can be reduced by using fuels and combustion techniques that cause fewer non-CO_2 emissions, and avoiding spatial or temporal areas where non-CO_2 effects are more likely to occur (Bopst et al. 2019). An example of the first measure is the use of alternative fuels (e.g. synthetic kerosene /SAF), which typically burn cleaner than conventional fossil fuels and therefore cause fewer non-CO_2 effects (EASA 2020). An example of avoiding certain flight areas would be to reduce flight altitude. A study by Teoh et al. (2020) found that diverting only a small fraction of flights from their original route would result in a significant reduction in the climate forcing of condensation trails and induced cirrus cloudiness in the region of Japan concerned. Re-routing, or rather avoiding certain climate-sensitive areas, can be seen as low-hanging fruit for reducing the overall climate impact of aviation that could be implemented much more quickly than other measures.

In terms of non-CO_2 effect mitigation policies, spatial and temporal no-fly zones (climate-restricted areas) could be established in climate-sensitive areas (Bopst et al. 2019; EASA 2020). Alternatively, a charge on flights through these areas could also be imposed (Bopst et al. 2019). There is also the option of an aircraft- and route-specific NO_x levy to address NO_x emissions specifically (EASA 2020). Further, the maximum level of aromatics in aviation fuel specifications could be reduced. Fuels with lower aromatic content burn cleaner and emit fewer soot particles. The (mandatory) use of SAF (e.g. through quotas) can also reduce non-CO_2 effects, as SAF typically have lower aromatics and sulphur content than conventional fossil kerosene. Voigt et al. (2021) show that blends of SAF with conventional jet kerosene can already significantly reduce contrail opacity.

1.4 EU regulations and targets

Within the EU, aviation is subject to few policy instruments regulating its emissions (Siemons et al. 2021). Domestic emissions from aviation and flights between EU member states are already covered by the EU Emission Trading System (ETS). Some EU Member States have put in place national legislation with the aim to incentivize emission reductions (like the German ticket tax, or the banning of certain domestic flights in France). Otherwise, aviation is generally not subject to energy taxes and no value-added tax (VAT) is charged on cross-border flights between two countries within the EU or international flights to non-EU countries (though individual member states might charge VAT on domestic flights like Germany). With the recently agreed Fit-for-55 legislative package, additional regulations will apply to national and intra-EU flights, and also international aviation will be increasingly covered by EU law (section 2).

Under the Paris Agreement, the vast majority of anthropogenic GHG emissions are included in the scope of Nationally Determined Contributions (NDCs). This includes emissions from aviation, but only within the respective jurisdiction (e.g. domestic aviation emissions). However, most NDCs do not include GHG emissions from international aviation despite its major share in absolute aviation emissions. Mitigation of emissions from international aviation is addressed by an organisation outside the UNFCCC process – the International Civil Aviation Organization (ICAO) which is discussed further below. The 2020 EU NDC only includes domestic aviation which is though "*subject to revision in light of the enhanced target*" (EU 2020, p. 9) as the NDC was published before the new EU 2050 target and the corresponding Fit-for-55 package. The recently updated EU NDC[3] includes CO_2 emissions from civil aviation from flights subject to effective carbon pricing through the EU ETS (so excluding CORSIA routes). These comprise flights within the European Economic Area, departing flights to Switzerland and departing flights to the United Kingdom. Flights to and from least developed countries and small island developing States are exempted both from the EU ETS and CORSIA. In case countries decide not to participate in CORSIA in the mandatory phase from 2027 onwards, these flights are subject to carbon pricing through the ETS. It is unclear how the reference emissions in 1990 will be calculated.

The 2050 target is an absolute target and must include international transport as the EU climate law states that "*[u]nion-wide greenhouse gas emissions and removals regulated in Union law shall be balanced within the Union at the latest by 2050, thus reducing emissions to net zero by that date*" (EP; EC 2021, Article 2). The EU's 2050 goal thus covers all emissions or sectors which are regulated by EU legislation. Aviation will have to reduce its emissions to zero or the remaining emissions will have to be compensated by sinks. As the sink capacity is limited, other sectors might have to increase their reduction efforts if aviation (and shipping) do not reduce the emissions to zero by 2050.

Also, the European Court of Auditors argued that international aviation and maritime transport are within the responsibility of the EU and should thus be included in the scope of the 2050 target.[4]

3 https://data.consilium.europa.eu/doc/document/ST-14286-2023-INIT/en/pdf
4 https://www.eca.europa.eu/en/news/news-sr-2023-18

Table 1 provides an overview of the coverage / scope of EU policies (more details in section 2) and the NDC. It can be seen that the EU already regulates international aviation which makes up the largest share of EU-related aviation emissions (Figure 1).

Table 1: Geographic coverage of EU policies and the NDC

	Domestic aviation emissions	Intra-EU international	Extra-EU international
Aviation EU ETS	100%	100%	0% (from 2027 onwards possibly some routes)[5]
ReFuelEU Aviation	100%	100%	50% (only outbound)
EU NDC	100%	100%	0%

Source: Overview compiled by Oeko-Institut

In June 2023, the European Scientific Advisory Board on Climate Change (ESABCC) published a report recommending a 2040 target and GHG budget up to 2050 for the EU (ESABCC 2023). The ESABCC recommends including (at least intra-EU) aviation and shipping in setting a 2040 target based on fairness and environmental integrity. Including international aviation and shipping would increase the remaining GHG budget between 2030 and 2050 from 11-14.4 GtCO2eq to 13.7-16.5 GtCO2eq indicating the significance of the sectors, especially in relative terms towards 2050 when other sectors have already reduced their emissions substantially (ESABCC 2023, p. 50).

This also means that including international shipping and aviation in an EU 2040 target scope decreases the relative emissions reduction that can be expected to be achieved by 2040, e.g. 88-92% (international and domestic aviation and shipping) versus 90-95% (only domestic aviation and shipping) (Table 2). This is because international transport emissions are expected to decline at a slower pace than other sectors. However, it also underlines the need for efforts to decarbonize these sectors to avoid even higher remaining emissions in 2040 (and 2050).

[5] From 2027 onwards, flights to/from third countries not participating in CORSIA will also be subject to the EU ETS (section 2.1) – this applies not to least developed countries and small island developing States.

Table 2: Overview of exemplary scenarios of EU 2040 targets

Scenario	Unit	2040 target incl. international transport	2040 target excl. international transport (intra-EU only)
ESABCC	%[6]	-88.3-92	-90.2-94.7
Strategic Perspectives, Scenario 1 -95% net	%	-95.5	-96.6
	$MtCO_2$[7]	210	111
Strategic Perspectives, Scenario 2 -90% net	%	-90.2	-92.8
	$MtCO_2$	462	278
Strategic Perspectives, Scenario 3 – 85% net	%	-85.4	-88.3
	$MtCO_2$	691	484

Sources: ESABCC (2023), Kalcher et al. (2023)

For this reason, international transport needs to be included in the 2040 climate target because it is very likely that it would otherwise not be or less ambitiously regulated. While 2040 targets excluding international transport may seem more ambitious when looking at the percentage reduction, this goes at the price of not covering a substantial share of residual emissions. Extending the target scope to international transport could thus benefit the climate overall – even though the reductions in 2040 in percent are lower.

1.5 ICAO regulations and targets

At global level, the International Civil Aviation Organisation (ICAO), a specialised UN agency based in Montreal, is the main international organisation responsible for regulating emissions from international aviation. ICAO has set two main climate targets (ICAO 2022a):

- A goal of "carbon neutral growth" from 2020 onwards,
- A long-term aspirational goal (LTAG) of net zero CO_2 emissions in 2050.

In 2023, ICAO additionally agreed to reduce CO_2 emissions in international aviation by 5% by 2030 through the use of SAF, low-carbon aviation fuels and other aviation technologies (like hydrogen) (ICAO 2023). Many details and consequences of the adoption of the LTAG have not yet been clarified (e.g. the question of interim targets). However, the LTAG fills the gap of a so far missing mid-century reduction for international aviation. To reduce emissions, ICAO plans to deploy a basket of measures: technical and operational measures to increase fuel or energy efficiency, the use of SAF and the purchase of offset certificates. The latter is implemented via the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) adopted in 2016 (ICAO 2016). CORSIA has though been criticized for a number of shortcomings

6 Reduction compared to 1990
7 Remaining (net) emissions in 2040

(section 2.2) and substantial policy instruments to achieve the new LTAG have not been adopted so far. In face of (again) increasing emissions of aviation and the urgency of the climate crisis, regional action can be a channel for first movers and to increase pressure on the global level (ICAO). The EU is taking now further steps to address aviation emissions (section 2.1 and 2.3).

2 Main policy instruments

2.1 Aviation in the EU ETS

Scope

The EU ETS Directive determines that CO_2 emissions from EU-related flights are subject to different rules depending on the routes (EU 2023b). The EU ETS for aviation has been limited to routes within and between countries of the European Economic Area (EEA) since 2013. In 2022, this scope included approx. 47 Mt CO_2 emissions.[8] This – temporary – limitation will be phased out by the end of 2026. After that, all flights within or to/from the EEA will either be covered by the EU ETS or CORSIA, except for flights to and from least developed countries and small island developing States. Table 3 provides an overview of the coverage per route. There are exemptions to the ETS obligations such as government, humanitarian, medical, military, or fire-fighting flights.

Table 3: Overview scope EU ETS vs. CORSIA

Route	2021-2023	2024-2026	2027 onwards
Flights within and between EEA countries and to UK and Switzerland	All operators: EU ETS Non-EEA-based operators: additional CORSIA on international routes if applicable		
Flights from EEA countries to/from outermost regions (without mainland connections)	Exempt	All operators: EU ETS Non-EEA-based operators: additional CORSIA if applicable	
Flights to/from and between third countries participating in CORSIA	All operators: CORSIA		
Flights to/from third countries NOT participating in CORSIA	Exempt		All operators: EU ETS
Flights to/from least developed countries and small island states	Exempt		

Source: Graichen and Wissner (2023)

Within the EEA and to the United Kingdom (UK) and Switzerland, flights are subject to the EU ETS. Flights from UK/Switzerland to EEA countries are covered by their national ETS in accordance with the agreements with these countries. If non-EEA-

[8] EEA EU ETS data viewer: https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1

based aircraft operators fly international routes within the EEA, a CORSIA cancellation obligation from their home country may additionally apply.

Flights to and from outermost regions will be covered by the EU ETS from 2024 onwards. Until 2030, these flights will be excluded if these outermost regions connect to the respective mainland (the Member State to whose territory they belong). With this extension, the EU ETS will cover almost a third of total aviation emissions.[9]

Routes which are already covered by CORSIA are exempted from the surrender obligation of the EU ETS and have to cancel offsets for their emissions according to CORSIA rules (section 2.2). The administration in the operator's home country is responsible for CORSIA compliance. This avoids double surrender or cancellation obligations and double reporting.

Flights to and from countries that do not participate in CORSIA, and do not fall in the scope of the ETS as laid out above, are initially exempt from all surrender obligations of the EU ETS. In the mandatory CORSIA phase from 2027 onwards, flights to/from countries refusing to participate in CORSIA will also fall under the EU ETS. This will imply a much higher and more costly surrender obligation than under CORSIA.

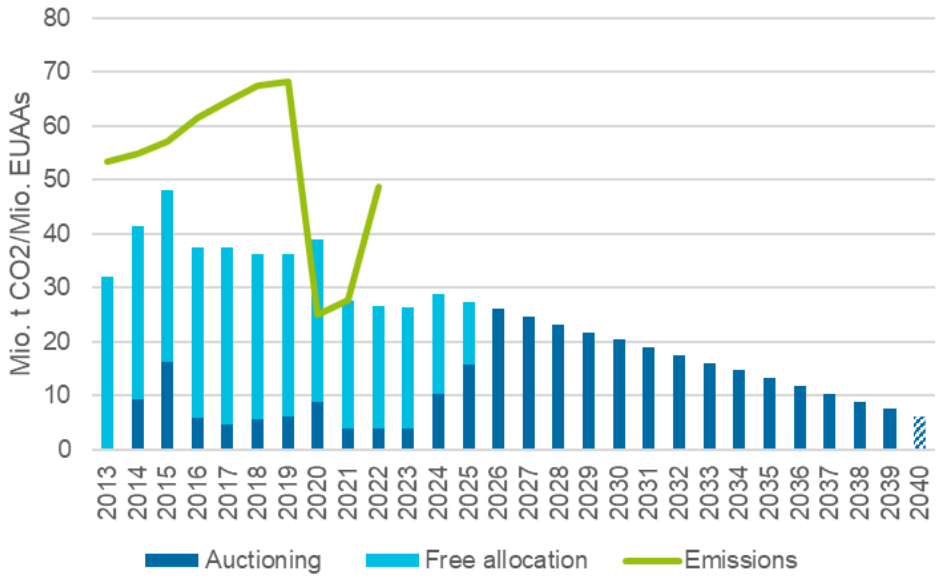
Domestic flights in non-EEA countries and flights to and from certain developing countries are exempted. The share of the latter of global emissions is though very small.

Allocation and cap

Emissions from the aviation sector have been higher than the aviation cap in all years except 2020/2021 when travelling was restricted due to the COVID-19 pandemic. To cover the gap aviation operators have been buying allowances from the stationary ETS sector (and some international credits when this was still allowed) to meet their obligations.

[9] Derived from Graichen and Wissner (2023): estimation based on the AERO MS model with emission data for 2016 based on landing and departing flights, calculation by André van Velzen (TAKS), September 2021.

Figure 6: Aviation in the EU ETS 2013-2040



Note: Auctions include auctions for Member States / Innovation fund and allowances for the uptake of SAF. EUAAs = European Union Aviation Allowances.

Source: Oeko-Institut MSR model based on EEA EU ETS data viewer: https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1, EU (2023b), EU (2023a)

In the past, aviation had a separate cap which defines the available number of emission allowances. Between 2013 to 2020, the aviation cap was constant at 95% of the covered 2004–2006 emissions. From 2021 onwards, the cap has been reduced by 2.2% per year based on the 2020 allocation. This linear reduction factor (LRF) is the same as for the stationary sector. Between 2024 to 2027, the LRF will be increased to 4.3% per year and related to the 2023 emission allowances for active aircraft operators. From 2028 onwards, the LRF will be 4.4%. While the joint cap for the stationary and maritime sector will drop to zero in 2040, the current legislation would imply that on behalf of aviation some allowances would still be available.

Free allowances

Allowances in the aviation sector have so far been mainly distributed for free with only 15% being auctioned up to 2023. With the revision of the EU ETS Directive, it was agreed that free allocation will be phased out until the end of 2025. From 2026 onwards, all allowances will thus be auctioned. There will though be free allowances for commercial aircraft operators for using SAF: between 2024 and 2030 a maximum of 20 million allowances out of the total quantity of allowances for aviation shall be allocated to operators for uplifting SAF to cover part of or all the price difference between SAF and fossil kerosene. The SAF allowances will be distributed on a first-come-first-serve basis, further details are to be determined. It is difficult to estimate to what extent the SAF allowances will increase SAF use in EU-related aviation. Firstly, the price gap between SAF and fossil kerosene is big, but it is uncertain how big the gap is because the SAF production is in its infancy. EASA; EEA; Eurocontrol (2022) estimate

the price to range from 2 to 6 times higher than fossil kerosene.[10] Secondly, there will be another ETS revision until 2030 which might revise the SAF allowance provisions depending on the market developments – again complicating an estimation of the impact until 2030. Generally, the use of SAF would be accounted with an emission factor of zero under the ETS thus reduce the surrender obligation for flights subject to the ETS. The benefit of receiving free allowances for SAF use on top is to bridge the price gap and provide an additional incentive for using SAF than just the zero emission accounting.

Use of revenues

There is no specific new fund to promote decarbonisation in the aviation sector within the ETS. However, 5 million allowances allocated to aviation in 2026 as well as allowances not issued due to closure of aircraft operators shall be made available for innovation support via the Innovation Fund, at a price of 85 Euro per EU allowance the innovation fund would receive at least 425 Mio. Euro additional funding. As such, the Innovation Fund can be used to support projects to produce low- and zero carbon fuels for aviation, electrification and actions to reduce the overall climate impacts of aviation, but no specific earmarking is foreseen, unlike for the maritime sector.

The remaining revenues from auctioning aviation allowances (after the diversion of revenues to the Innovation Fund) have so far entirely flowed to the Member States' budget. Here the revised ETS specifies that Member States must use the revenues for climate protection purposes or social compensation. This could include financing measures to support the decarbonisation of airports in accordance with the Alternative Fuels Infrastructure Regulation (AFIR) and ReFuelEU Aviation Regulation, as well as research and development of energy efficiency measures and clean technologies. Assuming an ETS price of 85 EUR/tCO_2, auctioning proceeds for Member States based on allowances from the aviation sector would result in 21 billion EUR in the time period 2024-2040.

Non-CO_2 effects

Currently, only CO_2 emissions from aviation are regulated by the EU ETS. However, the climate impact of aviation is about three times higher than the climate impact of CO_2 emissions if non-CO_2 effects (like contrails) are considered (Lee et al. 2021). The EU ETS directive now includes a staged approach to address these non-CO_2 effects: first, a monitoring, reporting and verification (MRV) framework will be set up to start in 2025; second, a legislative proposal will be made by 2027, if appropriate, to expand the EU ETS to include non-CO_2 effects building on an impact assessment due at the same time. This might include a respective adjustment of the cap. If non-CO_2 effects would be included in the EU ETS, this would in turn increase revenues from the aviation ETS. The combustion of SAF can lead to fewer non-CO_2 effects due to the composition (low or no aromatic components) (section 1.3). Pricing non-CO_2 effects could hence also help to make SAF more competitive. Also, the EU has a chance to go ahead on this topic, as CORSIA only covers CO_2 emissions thus far.

[10] Based on a price of 85 Euro per EU allowances 1.7 billion Euro could be spent to support SAF uptake. This could be used to cover the price difference for 600 000 to 5 Mio. t of SAF assuming that the price were 2-6 times higher compared to current jet fuel prices and the saved cost for EU allowances is taken into account when calculating the support to be provided.

Impact

So far, the aviation sector was a net buyer of emission allowances from the stationary sector. This is mainly because the allowance price is not sufficiently high to induce mitigation measures in the sector. Including non-CO_2 effects in the ETS would further increase costs but would also allow for new mitigation measures to reduce surrender obligations. However, demand and thus prices are expected to increase as free allowances for aviation are gradually phased out and as the overall ETS cap gets more stringent. The ETS for aviation alone will likely not be sufficient to decarbonize the sector and sufficiently incentivize SAF. Thus, the combination with other policy instruments is necessary (like ReFuelEU Aviation).

2.2 CORSIA and the EU ETS

Basics

In 2016, CORSIA was adopted by ICAO to achieve its goal of "carbon neutral growth" from 2020 (ICAO 2016). CORSIA aims to offset all CO_2 emissions above a baseline. The ICAO Council agreed to take 2019 emissions as the baseline for 2021-2023 instead of the average in 2019 and 2020 due to COVID-19 and the associated travel restrictions which resulted in unusually low emissions in 2020. This results in no offsetting requirements for the years 2021, 2022 and 2023 as the emissions subject to CORSIA offsetting requirements are lower in those reporting years compared to the baseline of 2019.[11] In 2022, ICAO contracting states agreed on a CORSIA baseline of 85% of 2019 emissions for the remaining phases of CORSIA from 2024 to 2035 (ICAO 2022b). Airlines can lower their offset obligation under CORSIA by using SAF, or so-called CORSIA eligible fuels, with defined criteria by ICAO (ICAO 2022c).

CORSIA has also been heavily criticised for its shortcomings, including: exclusive coverage of CO_2 emissions (and not non-CO_2 effects), limited participation in the voluntary phase, quality of eligible offset credits, and weaknesses in ensuring compliance and enforceability (Broekhoff et al. 2020; ICF Consulting et al. 2020; Siemons et al. 2021).

As of January 2023, 125 states have agreed to participate in the voluntary phase of CORSIA from 2024 onwards.[12] Big emitters, such as Russia and China, are not participating yet but are expected to join based on the activity requirements set out for the mandatory phase of CORISA starting in 2027.[13]

EU implementation

In the EU, CORSIA is implemented within the framework of the EU ETS with different coverages of routes as explained in section 2.1. A main difference between the two

[11] Total CO_2 emissions in baseline years: https://www.icao.int/environmental-protection/CORSIA/Documents/CCR%20Info%20Data%20Transparency_PartII_Oct2022.pdf; Total CO_2 emissions for the reporting year 2021: https://www.icao.int/environmental-protection/CORSIA/Documents/CCR%20Info%20Data%20Transparency_PartIII_Oct2022.pdf

[12] https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA%20States%20for%20Chapter%203%20State%20Pairs_4Ed_web.pdf

[13] As pointed out in the section on the EU ETS – if countries having to participate like Russia or China would not join CORSIA, flights from the EU to/from those countries would be covered by the EU ETS.

schemes is that under CORSIA operators only offset a part of the emissions (the increase compared to the baseline) whereas operators must surrender allowances for all their verified emissions in the EU ETS. Further, the surrender obligation in the EU ETS is based on the individual emissions of the respective aircraft operator. Under CORSIA the cancellation obligation is more complex to determine: the annual CO_2 emissions of an operator is multiplied with the sector's emissions growth factor until 2032, and from 2033 onwards the multiplied growth factor is not only based on a sectoral growth factor but is a combination of the sectoral growth (85%) and an individual operator's emissions growth factor (15%). Under CORSIA no auction revenues arise for states.

ICAO determines which offsets are eligible under CORSIA (ICAO 2021). For EEA aircraft operators, the ETS Directive prescribes additional requirements for offsets: only offsets from countries party to the Paris Agreement that participate in CORSIA and comply with advanced standards to avoid double counting of emission reductions can be used. In addition to the offsets according to the ICAO list, the EU ETS Directive allows further offsets to be used (e.g. offsets from an international mechanism established under Article 6(4) of the Paris Agreement).

Similar to the EU ETS, government, humanitarian, medical, military or firefighting flights are exempted.

Review of progress and options for adjustments

The EU Commission is obliged to report every three years from 2027 onwards on any progress of the ICAO on implementing measures to achieve ICAO's long-term aspirational goal of net zero emissions in 2050, any progress on CORSIA participation and other third country market-based measures. A proposal shall be made to also apply the EU ETS on departing flights from the EEA to third countries based on a report due by 2026 if CORSIA has not been sufficiently strengthened and participation increased. CORSIA offsetting costs would be deducted on those routes to avoid double charging. The EU also has the option to react to a distortion of competition regarding flights to/from third countries participating in CORSIA via implementing acts: if CORSIA is less stringently applied or the country in question is failing to enforce it, the flights to/from this country are exempted from the cancellation obligation.

Contribution to EU climate targets

CORSIA is scheduled to end in 2035. The scheme thus only impacts the EU's 2040 and 2050 climate targets by potentially impacting the emissions development of international flights up to 2035. Given its baseline and dependence on participation, it can be expected that the ETS provides a stronger incentive for EU-related flights to reduce their emissions and that only limited emission reductions are expected from EU-related flights subject to CORSIA. CORSIA will thus not substantially contribute to achieve the EU 2050 target and could even hinder its achievement if CORSIA is implemented weakly on international flights to/from CORSIA participating countries. However, with the newly adopted LTAG, CORSIA could be strengthened to align it with the LTAG or new measures might be implemented by ICAO. If so, any double burden resulting from the interaction with the ETS would need to be monitored and whether or not the ICAO measure would facilitate the achievement of the EU targets or undermine them. Further, the inclusion (and potential pricing) of non-CO_2 effects

would contribute to achieving the EU's targets as climate neutrality can only be achieved by addressing all climate impacts.

2.3 ReFuelEU Aviation Regulation

Scope and SAF quotas

A new important policy at EU level is the regulation on ensuring a level playing field for sustainable aviation (ReFuelEU Aviation)[14]. The regulation also applies to international flights as it does not only oblige fuel suppliers but also outgoing flights. It foresees an increasing blending rate of sustainable aviation fuels (SAFs) by distributors at EU airports. In addition, a sub-quota for renewable fuels of non-biological origin (RFNBOs), like e-kerosene, is set as well. The increasing quotas create a market for SAF with a long-term perspective (Table 4). Generally, the quotas are given as minimum shares required at each EU airport. However, there is a flexibility mechanism: a transitional period until 2034 allows fuel suppliers to reach the SAF blending mandate as a weighted average of the quantities they have supplied across EU airports. Additionally, average and minimum shares of RFNBOs are specified for first years of the sub-quota.

Table 4: Fuel quotas under ReFuelEU Aviation

	2025	2030	2035	2040	2045	2050
SAF quota	2%	6%	20%	34%	42%	70%
RNFBO Sub-quota		Average share: 1.2% (2030/31) 2% (2032/34)	5%	10%	15%	35%
		Min. share: 0.7% (2030/31) 1.2% (2032/33) 2% (2034)				

Source: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R2405 , quota as volumetric share of the total amount of fuel

Eligible SAF fuels

SAF are defined as in the Renewable Energy Directive (RED)[15]. The following SAF are eligible:

- Synthetic aviation fuels (RFNBOs incl. e-kerosene and renewable hydrogen);
- Biofuels;
- Recycled carbon fuels (from liquid/solid waste streams of fossil origin of unavoidable or unintentional industrial sources).

[14] Regulation (EU)2023/2405 of the European Parliament and of the Council on ensuring a level playing field for sustainable air transport: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R2405

[15] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023L2413

SAF eligible biofuels consist of advanced biofuels and biofuels from used cooking coil and animal fats (Part A and B in Annex IX in RED) and other biofuels (not listed in Annex IX) while excluding food and feed crops, intermediate crops, palm fatty acid distillate and palm and soy-derived materials, as well as soap stock and its derivatives. These "other biofuels" are all biofuels which fulfil the sustainability criteria of RED for fuels but are not listed in Annex IX of RED and which are not food and feed crops. These are, for example, edible animal fats (category 3) and other random feedstocks as identified by Baldino and Mukhopadhaya (2022). Although most problematic non-food- and feed-based crop feedstocks are excluded (see list above), feedstocks for "other biofuels" can risk fraud, indirect emissions and land use change impacts through diverting feedstocks from other uses and potentially exacerbating palm oil production (for a detailed explanation see EC (2021a) and Baldino and Mukhopadhaya (2022)). However, these other non-Annex-IX biofuels are capped at a maximum of 3% towards the SAF targets.

Obligation for airlines

In order to avoid policy evasion through strategic refuelling outside the EU, airlines are obliged to refuel at least 90% of the required fuel volume for outgoing flights at EU airports on an annual average. According to an analysis commissioned by T&E (2023), no substantial carbon leakage is expected before 2035 (also considering the continued increasing demand for air traffic). Reducing the price gap between SAF and fossil kerosene can help to mitigate the risk of carbon leakage in the long term.

Coverage of flights

The regulation applies to commercial air transport flights (requiring from aircraft operators a minimum yearly passenger or cargo transport flights departing from EU airports). The regulation defines a threshold of flight traffic below which small airports will be exempted. At least 95% of total traffic departing from airports in the EU should be covered by this threshold.[16] ReFuelEU Aviation applied to data from the year 2019 would thus cover approx. 1.85 EJ of fuel sold/bunkered or thus 133 Mt of CO_2 emissions.[17]

Penalties

Substantial penalties will be due for aircraft operators and distributors if they do not fulfil their obligations. The penalty for fuel suppliers is at least twice the difference between the yearly average price of fossil jet fuel and SAF multiplied with the amount of SAF not complying with the quota. For airlines, the penalty is at minimum twice as high as the yearly average price of conventional jet fuel multiplied by the quantity of SAF that has not been uplifted. SkyNRG has estimated that this would, for example, result in a penalty for airlines of 1,200 EUR per ton of non-tanked SAF based on an average market price of 600 EUR per ton of jet fuel.[18]

Any missing volumes of SAF must be additionally placed on the market or lifted up by airlines in the following year. There are reporting obligations for both fuel suppliers

[16] Recital 17 in https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R2405

[17] Assuming departing flights always refuel completely, based on inventory data which is based on fuel sales

[18] https://skynrg.com/a-summary-of-the-proposed-sustainable-aviation-fuel-mandate/

and aircraft operators. By 14 February of each reporting year, and for the first time in 2025, aviation fuel suppliers shall report in the Union database: the amount and energy content of total aviation fuel and SAF supplied at each EU airport, specifics on the SAF supplied (conversion process, characteristics and origin of feedstock, lifecycle emissions), aromatics and naphthalenes content of aviation fuel supplied. Fuel suppliers also need to provide information to aircraft operators for the reporting and compliance obligations that aircraft operators have towards the competent authorities. The airlines are required to report the SAF quantities used for flights under the EU ETS or CORSIA as part of their annual reporting.

Reviews

ReFuelEU Aviation shall be reviewed by 2027 and every four years thereafter including a possible inclusion of further mechanisms to support the production and uplift of SAF as well as a revision of the ambition (such as scope and quotas).

Interaction with the EU ETS

An important interaction with the ETS is that airlines can receive (a limited amount of) free allowances under the EU ETS for their uptake of SAF (section 2.3). The ETS and ReFuelEU Aviation are complementary as one prices the emissions and the other directly promotes the use of SAF (as the most important tool to reduce emissions). However, a 70% SAF quota might not be sufficiently high given that SAF are the main lever to reduce emissions. Higher SAF quotas – especially for e-kerosene – would ensure the high share of SAF needed in 2050 and that aviation emissions ideally are reduced to zero in 2050 (section 1).

Impact

ReFuelEU aviation influences the costs of flying as SAF are more expensive than fossil jet fuel. The price changes for customers will depend on the extent airlines pass-through the increased fuel costs. As SAF can nearly achieve a 100% CO_2 emission reduction compared to conventional kerosene, ReFuelEU aviation will lead to substantial emission reductions through the increasing SAF quotas in the long-term towards 2040 and 2050. The increase deployment of SAF will likely also reduce non-CO_2 emissions as SAF burn cleaner than fossil kerosene. The regulation establishes a clear demand for e-kerosene and thus impacts demand / production of renewable energy and incentivizes investments in renewable energy and RFNBO production plants. Neuling and Berks (2023) estimated that the 2% RFNBO sub-quota in 2032 (Table 4) would equal 205,000 t e-kerosene and require 7.5 TWh of renewable electricity which translates into 195 km^2 of photovoltaic plants (which equals 20% of the area of Berlin). For comparison, this equals 2% of the 254 TWh of renewable electricity produced in Germany in 2023 or constitutes six GW of additional photovoltaics capacity. Further, the penalties establish a kind of price level or certainty for fuel suppliers.

2.4 Interaction with other Fit-for-55 elements

So far, aviation fuel is exempted from any energy taxation at EU level through the **Energy Taxation Directive** (ETD). Member states are allowed to introduce energy taxes on aviation kerosene at national-level, but hitherto all member states exempt fuel used in commercial aviation from energy taxation. The proposal by the European

Commission from July 2021 (EC 2021b) foresees to change this, but is not agreed yet. The ETD sets minimum rates of taxation for energy sources used in transport and heat production. According to the proposal, the minimum tax rates for aviation correspond to those of road and rail transport. The minimum tax rate for aviation fuel should be gradually introduced over a period of 10 years. Sustainable and low-emission aviation fuels (e.g. RFNBOs) should not be taxed during this period. Electrical power for aircraft can also be fully or partially exempted during this period. The full minimum tax rate for fossil kerosene is 10.75 €/GJ which corresponds to an implicit CO_2 price of 145 €/tCO_2 compared to fuels in the lowest tax bracket. After the introduction period the tax amounts to 0.29 EUR/litre. For a flight to Palma de Mallorca from Berlin and back, the application of the full minimum tax rate would result in 37 EUR of additional costs per person/ticket.[19] An ETS price of 85 EUR/tCO_2 would result in 26 EUR for the same route and assumptions. In addition to the ETS revenues, the application of the energy tax on aviation would result in approx. 5 billion EUR in annual revenues in 2035 after the introduction period according to the impact assessment of the legislative proposal.[20] This compares to roughly 1 billion EUR in this year under the ETS.

The proposal would tax aviation within the EU. Taxation of solely cargo flights within the countries would be optional for member states, and on intra-European routes with member states that agree to it. Private flights for non-commercial purposes would be exempted. In contrast, the EU ETS covers all national and cargo flights and intra-European flights (including cargo-only flights) above a certain activity and airplane size threshold (section 2.1). The ETD proposal includes the option of also taxing flights to and from third countries and proposes the minimum tax rate here as well. This presupposes relevant adjustments to intergovernmental agreements. A unanimous decision is required in tax matters in the Council, which is currently impeding an agreement.

In October 2023, an amendment to the **Renewable Energy Directive** (RED) was adopted.[21] It is foreseen that every member state shall contribute to raise the share of renewable energy in the EU's overall energy consumption to 42.5% by 2030 with an additional 2.5% indicative top up that would allow to reach 45%. There are sector-specific sub-targets, also for transport. Member states can choose between fulfilling a binding target of 14.5% reduction of GHG intensity from the use of renewables in transport by 2030 or a binding share of at least 29% of renewables within the final consumption of energy in the transport sector by 2030. The RED also prescribes a combined sub-target of 1% and 5.5% in 2025 and 2030 respectively for advanced biofuels and RFNBOs in the share of renewable energies supplied to the transport sector. Within this target, there shall be a minimum share of 1% of RFNBOs. For the 29% transport energy target and the 5.5% sub-target for advanced biofuels and RFNBOs, multipliers for the use of certain fuels apply (e.g. RFNBOs count twice). Advanced biofuels and RFNBOs used in aviation will be counted 1.2x and in maritime transport 1.5x towards the target to incentivise the use of these fuels in the sectors. While multipliers generate this incentive, they effectively reduce the actual amount of alternative fuels needed to fulfil the targets. Generally, the amended RED fuel targets

[19] Assumptions: distance Berlin to Palma de Mallorca and back 3500km; 3.56 l/100 pkm fuel consumption.

[20] Impact assessment accompanying the ETD proposal: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021SC0641

[21] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023L2413

have to be achieved by the transport sector as a whole.[22] Alternative fuels counting towards the target hence do not necessarily have to be deployed in aviation – especially as the willingness to pay for expensive advanced biofuels and RFNBOs is higher in road transport. As RED is a directive, it has to be transposed into national legislation. In Germany, RED was implemented via the greenhouse gas quota which so far only refers for the target to road transport and fuels in rail transport. However, SAF could contribute to fulfil the quotas. This will need to be amended now.

The EU ETS and the RED are linked via the use of alternative fuels in aviation: their use reduces the surrender obligation in the EU ETS and contributes to the target fulfilment of the RED.

Both the RED and ReFuelEU Aviation prescribe the provision of alternative fuels to the transport sector and, in case of ReFuelEU, to aviation specifically. However, under RED the target scope includes aviation as one of the transport sectors obliged whereas under ReFuelEU airlines are indirectly required to bunker the SAF via the uplifting mandate for outgoing flights (section 2.3). Further, the definition of eligible SAF under ReFuelEU (list under section 2.3) is based on the definition in the RED. However, fewer biofuels are eligible as SAF under ReFuelEU: food and feed-based crops as defined in RED are excluded as a feedstock for the SAF quota although these can count towards the RED transport target. Unlike the revised RED, there is no cap on waste oils and fats[23] under ReFuelEU.

The **Alternative Fuels Infrastructure Regulation** (AFIR) prescribes that stationary aircrafts for commercial passenger and cargo transport at contact and remote stands must be supplied with electricity by 2025 and by 2030 respectively at TEN-T core and comprehensive network airports.[24] This does not, however, interact directly with the ETS as the ETS for aviation only covers emissions during flights.

3 Conclusions

Aviation has been covered by only one EU climate policy in the past: the EU ETS covering flights in and between EU since 2012. International flights were exempted in and aviation was not subject to any other pricing measures. The Fit-for-55 package changes the policy landscape for aviation and respective policies start off slowly but get more ambitious over time.

International transport should be included in the EU 2040 climate target because it is very likely that it would otherwise not be or less ambitiously regulated. 2040 targets excluding international transport seem more ambitious when looking at the percentage reduction. However, this goes at the price of not covering a substantial share of residual emissions. International transport emissions are expected to decline at a slower pace than emissions of other sectors. Extending the target scope to international transport could thus benefit the climate overall – even though the percentage reductions in 2040 are lower.

[22] There is no differentiation anymore between the sectors contributing to the denominator and to the numerator of the renewable share targets, deleting the optional contribution of maritime transport and aviation.
[23] As defined in RED Annex IX Part B
[24] https://www.europarl.europa.eu/doceo/document/TA-9-2023-0261_EN.html

CORSIA remains weak and not in line with the ICAO long term target. The scheme could be further weakened if not all countries de facto join the scheme that have to participate in the mandatory phase. If the ambition is not increased, the EU will have to consider further measures especially targeting international flights.

With the **Fit-for-55 package the EU has introduced or enhanced several policies:** the EU ETS for aviation is further strengthened. The adopted ReFuelEU Aviation regulation aims to accelerate the use of sustainable aviation fuels (SAF). The revised renewable energy directive (RED) foresees incentives for using renewables also in aviation. The energy taxation directive (ETD) is not agreed yet, the EU Commission proposed to stop exempting intra-EU aviation fuels.

The **EU ETS for aviation** continues to be an important policy measure to price CO_2 emissions and incentivize emission reductions. The cap on aviation emissions is declining at a faster pace due to the Fit-for-55 revisions (in line with other ETS sectors). The EU ETS thus gets more ambitious over time. While carbon prices have increased, there remains a significant price gap between fossil and e-kerosene. Spending revenues from the ETS on decarbonization thus will be important to accelerate in-sector reductions. Next to funding from the Innovation Fund, Member States are called upon to use ETS revenues to fund mitigation measures. Ensuring that this indeed is done and that the aviation sector does receive a share is important in the long run. The planned inclusion of non-CO_2 into the EU ETS is another crucial step forward, but still needs to be agreed. The decision in 2027 about the inclusion is important and will need to be ambitiously implemented. The EU ETS is well designed to allow ICAO the time to adopt further measures. There is a procedure in place that the EU ETS will be reviewed if ICAO action lacks: every three years ICAO's progress on implementing measures to achieve ICAO 2050 target is assessed, and by 2026 it will be assessed whether CORSIA has been sufficiently strengthened and participation increased. Otherwise, the option of applying the EU ETS on departing flights from the EEA to third countries should be pursued.

It is a crucial step forward that with the **ReFuelEU Aviation regulation** a targeted measure is now introduced to incentivise the use of SAF. This is because carbon pricing alone will not suffice to accelerate the uptake of alternative technologies/fuels. However, ReFuelEU Aviation will take time to show significant effects. It is questionable if the 70% quota is enough given that SAF are the main lever to reduce emissions and that emissions would need to reduce to almost zero until 2050. A RFNBO subquota could be higher given the limitations of sustainable biofuels and as waste oils (fraud risk etc.) are not capped with ReFuelEU Aviation in contrast to RED - which is also a danger for GHG emissions.

Aviation will be in **competition for (advanced) biofuels and RFNBOs** with other (hard-to-abate) sectors to achieve the necessary emission reductions until 2040 and 2050. Limited availability of climate-neutral fuels might increase fuel costs and require timely and large-scale investments in advanced biofuel and e-kerosene (and thus renewable energy) production capacities.

The exclusion of aviation fuels from **energy taxes** is an unresolved problem. The revision of the energy taxation directive is still negotiated, but the outcome is uncertain as unanimity is required to change the directive. However, like-minded countries could

and should go ahead by taxing (international) aviation fuels through bilateral agreements.

Other policies could be explored or extended for example: short-haul domestic flights could be banned (like France) and policies to reduce non-CO_2 effects (like fuel quality regulations) could be introduced. A group of ambitious member states could jointly implemented taxes between these countries (for example, extending the German ticket tax) (Siemons et al. 2021). However, further pricing aviation emissions might face opposition as increased costs are easier passed through to end-customers (than for example in maritime transport). Carbon leakage through different price elements of the Fit-for-55 package are though marginal.[25]

The policies presented indirectly influence **demand reduction or modal shift** through a price effect. Aviation emissions are highly dependent on economic growth and consumption/travel patterns, stepping up the efforts and implement further policies to create convenient alternatives to air travel (e.g. trains) and change narratives about travelling by plane can lead to further emission reductions besides deploying SAF.

Öko-Institut e.V | Freiburg | Darmstadt | Berlin

The Oeko-Institut is one of Europe's leading independent research and consultancy organisations working for a sustainable future. Since its establishment in 1977, it has been laying the groundwork and devising strategies to realise the vision of sustainable development at global, national and local level. The Oeko-Institut has offices in Freiburg, Darmstadt and Berlin.
www.oeko.de | info@oeko.de

Contact

Nora Wissner | +49 30 405085-394 | n.wissner@oeko.de
Verena Graichen | +49 30 405085-370 | v.graichen@oeko.de

This publication was commissioned by Agora Energiewende.

[25] https://www.transportenvironment.org/wp-content/uploads/2023/09/TE-Aviation-competitiveness-and-carbon-leakage-Briefing-2023-UPDATED-12-10-23.pdf

References

Baldino, C. and Mukhopadhaya, J. (2022): Considerations for the ReFuelEU aviation trilogue, Briefing. International Council on Clean Transportation. Online available at https://theicct.org/wp-content/uploads/2022/09/refueleu-definitions-trilogue-sep22.pdf, last accessed on 11 Aug 2023.

Bopst, J.; Herbener, R.; Hölzer-schopohl, O.; Lindmaier, J.; Myck, T.; Weiß, J. (2019): Umweltschonender Luftverkehr, lokal-national-international (UBA Texte, 130/2019). Umweltbundesamt. Dessau-Roßlau. Online available at https://www.umweltbundesamt.de/publikationen/umweltschonender-luftverkehr, last accessed on 15 Dec 2023.

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, last accessed on 10 Jun 2021.

Cames, M.; Graichen, J.; Kasten, P.; Kühnel, S.; Faber, J.; Nelissen, D.; Scheelhaase, J.; Grimme, W.; Maertens, S. (2023): Climate protection in aviation and maritime transport: Roadmaps for achieving the climate goal (Climate Change, 26/2023). Umweltbundesamt. Online available at https://www.umweltbundesamt.de/publikationen/climate-protection-in-aviation-maritime-transport, last accessed on 18 Oct 2023.

CAT - Climate Action Tracker (2022): International Shipping/Aviation Assessment, May 2022 Release. Online available at https://climateactiontracker.org/sectors/, last accessed on 2 Aug 2022.

EASA - European Aviation Safety Agency; EEA - European Environment Agency; Eurocontrol (2022): European aviation environmental report 2022. Online available at https://www.easa.europa.eu/eco/eaer/downloads#download-report-2022, last accessed on 3 Nov 2022.

EASA - European Union Aviation Safety Agency (2020): Updated analysis of the non-CO_2 climate impacts of aviation and potential policy measures pursuant to EU Emissions Trading System Directive Article 30(4) (SWD(2020) 277 final). Online available at https://eur-lex.europa.eu/resource.html?uri=cellar:7bc666c9-2d9c-11eb-b27b-01aa75ed71a1.0001.02/DOC_1&format=PDF, last accessed on 13 Dec 2020.

EC - European Commission (2021a): Assessment of the potential for new feedstocks for the production of advanced biofuels, Final report (ENER C1 2019-412). In collaboration with E4Tech; International Council for Clean Transportation (ICCT) and Ceruolgy, Wageningen University, Navigant, SCS globalservices. Online available at https://op.europa.eu/o/opportal-service/download-handler?identifier=ec9c1003-76a7-11ed-9887-01aa75ed71a1&format=pdf&language=en&productionSystem=cellar&part=, last accessed on 11 Aug 2023.

EC - European Commission (2021b): Proposal for a Council Directive restructuring the Union framework for the taxation of energy products and electricity (recast), COM(2021) 563 final. Online available at https://ec.europa.eu/info/sites/default/files/revision_of_the_energy_tax_directive_0.pdf, last accessed on 29 Jul 2021.

EEA (2021): Annual European Union greenhouse gas inventory 1990–2019 and inventory report 2021, Submission to the UNFCCC Secretariat. European Environment Agency. Online available at https://unfccc.int/documents/275968, last accessed on 27 Jul 2021.

EP - European Parliament; EC - European Council (2021): Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law'). Brussels. Online available at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R1119&from=EN, last accessed on 30 Apr 2022.

ESABCC - European Scientific Advisory Board on Climate Change (2023): Scientific advice for the determination of an EU-wide 2040 climate target and a greenhouse gas budget for 2030–2050. Online available at https://climate-advisory-board.europa.eu/reports-and-publications/scientific-advice-for-the-determination-of-an-eu-wide-2040, last accessed on 11 Aug 2023.

EU - European Union (2023a): Commission Decision (EU) 2023/2440 on the Union-wide total quantity of allowances to be allocated in respect of aircraft operators under the EU Emissions Trading System for 2024. Online available at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202302440, last accessed on 10 Nov 2023.

EU (2020): Submission by Germany and the European Commission on behalf of the European Union and its Member States: The update of the nationally determined contribution of the European Union and its Member States. Online available at https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/European%20Union%20First/EU_NDC_Submission_December%202020.pdf, last accessed on 27 Jul 2021.

EU (2023b): Directive 2023/959 of the European Parliament and of the Council of 10 May 2023 amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union and Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading system. In: *Official Journal of the European Union* (L 130/134). Online available at https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32023L0959&qid=1684218852261, last accessed on 27 Oct 2023.

Graichen, V. and Wissner, N. (2023): Aviation in the EU ETS and CORSIA in the 'Fit for 55' package, The EU agreement of June 2023. Oeko-Institut. Umweltbundesamt (ed.). Online available at https://www.umweltbundesamt.de/sites/default/files/medien/11850/publikationen/09_2023_factsheet_aviation_in_the_eu_ets_and_corsia.pdf, last accessed on 10 Nov 2023.

IATA (2019): Economic performance of the airline industry. IATA. Online available at https://www.iata.org/en/iata-repository/publications/economic-reports/airline-industry-economic-performance---december-2019---report/, last accessed on 25 Jan 2021.

ICAO - International Civial Aviation Organization (2022a): Resolution A41-21: Consolidated statement of continuing ICAO policies and practices related to

environmental protection - Climate change, A41-21. Online available at https://www.icao.int/environmental-protection/Documents/Assembly/Resolution_A41-21_Climate_change.pdf, last accessed on 3 Nov 2022.

ICAO - International Civial Aviation Organization (2022b): Resolution A41-22: Consolidated statement of continuing ICAO policies and practices related to environmental protection - Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). Online available at https://www.icao.int/environmental-protection/CORSIA/Documents/Resolution_A41-22_CORSIA.pdf, last accessed on 3 Nov 2022.

ICAO - International Civil Aviation Organization (2019): Global Environmental Trends, Present and Future Aircraft Noise And Emissions. Online available at https://www.icao.int/Meetings/a40/Documents/WP/wp_054_en.pdf, last accessed on 23 May 2020.

ICAO - International Civil Aviation Organization (2021): CORSIA Eligible Emission Units. 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 (2022c): CORSIA Sustainability Criteria for CORSIA Eligible Fuels, Version November 2022, Third Edition. Online available at https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2005%20-%20Sustainability%20Criteria%20-%20November%202022.pdf, last accessed on 13 Mar 2023.

ICAO - International Civil Aviation Organization (2022d): Report on the feasibility of a long-term aspirational goal (LTAG) for international civil aviation CO2 emission reductions, ICAO committee on aviation environmental protection. Online available at https://www.icao.int/environmental-protection/LTAG/Pages/LTAGreport.aspx, last accessed on 4 Aug 2022.

ICAO - International Civil Aviation Organization (2023): ICAO Global Framework for SAF, LCAF and other Aviation Cleaner Energies, Adopted by CAAF/3 on 24 November 2023. Online available at https://www.icao.int/Meetings/CAAF3/Documents/ICAO%20Global%20Framework%20on%20Aviation%20Cleaner%20Energies_24Nov2023.pdf, last accessed on 15 Dec 2023.

ICAO (2016): Assembly Resolution A39-22/2: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Global Market-based Measure (MBM) scheme. Online available at https://www.icao.int/Meetings/a39/Documents/WP/wp_530_en.pdf.

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 pass-through pursuant to Article 3d of the EU ETS Directive (Ref. Ares(2021)1483539). European Commission (ed.). Online available at https://www.transportenvironment.org/publications/eus-assessment-corsia-airline-co2-deal, last accessed on 12 May 2021.

IRENA (2022): Renewable energy highlights. Online available at https://www.irena.org/-

/media/Files/IRENA/Agency/Publication/2022/Jul/IRENA_Renewable_energy_highlights_July_2022.pdf?la=en&hash=F3180CE10D7EEB3409165D168ED6E4F494D58AB5, last accessed on 13 Dec 2022.

Kalcher, L.; Makaroff, N.; Krings, D.; Martin, B.; Defauw, J.; Lefebvre, A.; Lalieu, S.; Pestiaux, J.; Cornet, M. (2023): The post-2030 climate target debate starts now. Strategic Perspectives; Climact. Online available at https://strategicperspectives.eu/the-post-2030-climate-target-debate-starts-now/, last accessed on 19 Oct 2023.

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. In: *Atmospheric Environment* 244, p. 117834. DOI: 10.1016/J.ATMOSENV.2020.117834.

Millefiori, L. M.; Braca, P.; Zissis, D.; Spiliopoulos, G.; Marano, S.; Willett, P. K.; Carniel, S. (2021): COVID-19 impact on global maritime mobility. In: *Scientific reports* 11 (1), p. 18039. DOI: 10.1038/s41598-021-97461-7.

Neuling, U. and Berks, L. (2023): E-Fuels zwischen Wunsch und Wirklichkeit, Was strombasierte synthetische Kraftstoffe für die Energiewende im Verkehr leisten können - und was nicht. Agora Verkehrswende. Online available at https://www.agora-verkehrswende.de/veroeffentlichungen/e-fuels-zwischen-wunsch-und-wirklichkeit, last accessed on 18 Oct 2023.

OECD (2023): IEA CO2 Emissions from Fuel Combustion Statistics, GHG Emissions from fuel combustion (summary). Online available at https://www.oecd-ilibrary.org/energy/data/iea-co2-emissions-from-fuel-combustion-statistics-greenhouse-gas-emissions-from-energy/ghg-emissions-from-fuel-combustion-summary_445ec5dd-en?parentId=http%3A%2F%2Finstance.metastore.ingenta.com%2Fcontent%2Fcollection%2Fco2-data-en, last accessed on 7 Aug 2023.

Roland Berger (2023): Destination unknown: The future of long-distance travel, A study on the post-Covid recovery and consumer expectations. Online available at https://content.rolandberger.com/hubfs/07_presse/23_2015_WP_Long-haul_mobility-06.pdf, last accessed on 7 Aug 2023.

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.). Online available at https://www.oeko.de/fileadmin/oekodoc/Options-for-regulating-the-climate-impacts-of-aviation.pdf, last accessed on 1 Jun 2021.

T&E - Transport & Environment (2023): Flying via Istanbul: escaping climate measures?, Briefing: Assessing the impact of EU climate measures on the competitiveness of the EU's aviation industry. Online available at https://www.transportenvironment.org/wp-content/uploads/2023/09/TE-Aviation-competitiveness-and-carbon-leakage-Briefing-2023-UPDATED-12-10-23.pdf, last accessed on 15 Dec 2023.

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.

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.