CLIMATE CHANGE
37/2025

Final report

Policy incentives for the uptake of sustainable aviation fuels (SAFs)

Chain-of-custody approaches, administrative requirements and their impact

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Publisher:
German Environment Agency

Umwelt Bundesamt

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Ressortforschungsplan of the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection

Project No. (FKZ) 3722 42 508 0

FB001671/ENG

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On behalf of the German Environment Agency

Imprint

Publisher
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Report completed in:
October 2024

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Publication as pdf:
http://www.umweltbundesamt.de/publikationen

ISSN 1862-4359

Dessau-Roßlau, June 2025

Abstract: Policy incentives for the uptake of sustainable aviation fuels (SAFs)

Aviation is responsible for about 2.5% of global CO_2 emissions, with an even greater overall climate impact when non-CO_2 effects are considered. Sustainable aviation fuels (SAF), derived from sustainable feedstocks, can significantly reduce life-cycle emissions compared to fossil kerosene. However, SAF currently makes up only about 0.1% of aviation fuel consumption. This report examines the limited uptake of SAF and suggests changes to the reporting and claiming framework to encourage its adoption under the EU Emissions Trading System (EU ETS). Several policies aim to increase SAF use. Globally, the International Civil Aviation Organization's (ICAO) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) targets emissions from international flights. In the EU, the ReFuelEU Aviation Regulation and the inclusion of aviation in the EU ETS provide incentives for SAF adoption. Airlines may optimize carbon costs by using SAF on EU ETS-covered flights due to higher allowance prices. SAF can principally be reported through three chain-of-custody models: physical separation, mass balance, and book-and-claim elements. Current regulations favor the mass balance system, with potential future adoption of book-and-claim. Physical segregation requires high investment and can increase emissions due to separate transportation. The mass balance approach offers flexibility and traceability, while book-and-claim is cost-effective but less traceable, posing fraud risks. The report concludes that strict physical segregation and global book-and-claim are not ideal. Given the small global SAF production and early stages in Germany, a mass balance approach combined with national book-and-claim is recommended to maintain scheme integrity, build local knowledge, and manage costs without hindering production facility development.

Kurzbeschreibung: Politische Anreize für die Einführung nachhaltiger Flugkraftstoffe (SAFs)

Der Luftverkehr ist für etwa 2,5% der weltweiten CO_2-Emissionen verantwortlich, wobei die Gesamtwirkungen auf das Klima sogar noch größer sind, wenn man die Nicht-CO_2-Effekte berücksichtigt. Nachhaltige Flugkraftstoffe (Sustainable aviation fuels - SAF), die aus nachhaltigen Rohstoffen gewonnen werden, können die Lebenszyklusemissionen im Vergleich zu fossilem Kerosin erheblich reduzieren. Allerdings machen SAF derzeit nur etwa 0,1% des Flugkraftstoffverbrauchs aus. In diesem Bericht wird die begrenzte Nutzung von SAF untersucht und es werden Änderungen des Rahmens für die Berichterstattung und die Geltendmachung von Ansprüchen vorgeschlagen, um die Nutzung von SAF im Rahmen des EU-Emissionshandelssystems (EU ETS) zu fördern. Mehrere politische Maßnahmen zielen darauf ab, die Verwendung von SAF zu erhöhen. Auf globaler Ebene zielt CORSIA der ICAO auf Emissionen aus internationalen Flügen ab. In der EU bieten die ReFuelEU Aviation Verordnung und die Einbeziehung des Luftverkehrs in das EU-ETS Anreize für die Einführung von SAF. Fluggesellschaften können ihre Kohlenstoffkosten optimieren, indem sie SAF auf Flügen, die unter das EU-ETS fallen, einsetzen, da die Preise für Zertifikate höher sind. SAF können prinzipiell über drei „chain-of-custody"-Modelle berichtet werden: physische Trennung, Massenbilanz und Book-and-Claim. Die derzeitigen Vorschriften bevorzugen das Massenbilanzsystem, wobei in Zukunft möglicherweise Book-and-Claim- Elemente eingeführt werden. Die physische Trennung erfordert hohe Investitionen und kann die Emissionen aufgrund des separaten Transports erhöhen. Das Massenbilanzverfahren bietet Flexibilität und Rückverfolgbarkeit, während das Book-and-Claim-Verfahren zwar kosteneffizient, aber weniger rückverfolgbar ist und somit Betrugsrisiken birgt. Der Bericht kommt zu dem Schluss, dass eine strikte physische Trennung und ein globales Book-and-Claim-System nicht ideal sind. In Anbetracht der geringen weltweiten SAF-Produktion und des frühes Stadiums in Deutschland wird ein Massenbilanzansatz in Kombination mit einem nationalen Book-and-Claim-System empfohlen, um die Integrität des Systems zu wahren, lokales Wissen aufzubauen und die Kosten zu verwalten ohne die Entwicklung der Produktionsanlagen zu behindern.

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List of abbreviations

ASTM	American Society for Testing and Materials
AtJ	Alcohol-to-jet
AVR	Accreditation and Verification Regulation
Biokraft-NachV	Verordnung über Anforderungen an eine nachhaltige Herstellung von Biokraftstoffen (German Ordinance on requirements for the sustainable production of biofuels)
CB	Certification Body
CCR	CORSIA Central Registry
CCS	Carbon Capture and Sequestration
CEF	CORSIA-eligible Fuels
CEPS	Central European Pipeline System
CERT	CORSIA CO_2 Estimation and Reporting Tool
CNG	Carbon-Neutral Growth
CoC	Chain of Custody
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CO_2	Carbon dioxide
CSRD	Corporate Sustainability Reporting Directive
DEHSt	Deutsche Emissionshandelsstelle (German Emission Trading Authority)
DLUC	Direct land use change
EASA	European Union Aviation Safety Agency
EEA	European Economic Area
EHV	Emissionshandelsverordnung (German Ordinance on the Implementation of the Greenhouse Gas Emissions Trading Act)
ERF	Emission Reduction Factor
EU	European Union
EU ETS 1	European Union Emission Trading System
FEETS	Fuels eligible for ETS support
GHG	Greenhouse gas
GHGP	Greenhouse gas protocol
HBE	Hernieuwbare Brandstof Eenheden (Dutch for renewable fuel units)
HEFA	Hydrotreated Esters and Fatty Acids
ICAO	International Civil Aviation Organization
ILUC	Indirect land use change
ISCC	International Sustainability and Carbon Certification
LCA	Life-Cycle Analysis
LCAF	Lower carbon aviation fuels
LTAG	Long-Term Global Aspirational Goal
MRR	Monitoring and Reporting Regulation

ASTM	American Society for Testing and Materials
MRV	Monitoring, reporting and verification
Nabisy	Nachhaltige - Biomasse – System (Sustainable Biomass System)
NEPS	North European Pipeline System
PFAD	Palm fatty acid distillate
PoC	Proof of Compliance
PoS	Proof of Sustainability
RCF	Recycled carbon fuels
RED	Renewables Energy Directive
ReFuelEU Aviation	Regulation on ensuring a level playing field for sustainable air transport
RFNBO	Renewable Fuel of Non-Biological Origin
RSB	Roundtable on Sustainable Biomaterials
SAF	Sustainable Aviation Fuel
SBTi	Science Based Target initiative
SCS	Sustainability Certification Schemes
SGF	Sector Growth Factor
TEHG	Gesetz über den Handel mit Berechtigungen zur Emission von Treibhausgasen (German Act on the Trading of Greenhouse Gas Emission Allowances)
UCO	Used cooking oil
UDB	Union Database

Summary

Aviation contributes approximately 2.5% of global CO_2 emissions. When non-CO_2 effects are taken into account, its overall climate impact is even higher. To mitigate these emissions, the use of sustainable aviation fuels (SAF) is crucial. SAF, produced from sustainable feedstocks, can significantly reduce life-cycle emissions compared to fossil kerosene. Despite policies promoting SAF uptake, their current share in aviation fuel consumption remains minimal: SAF comprises only about 0.1% of total consumption.

This report analyses the reasons behind this limited uptake and identifies necessary changes in the reporting and claiming framework to better incentivise SAF adoption and reporting under the EU Emissions Trading System (EU ETS). There are several policies which aim to increase the use of SAF. On a global level, International Civil Aviation Organization's (ICAO) market-based measure Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) was introduced to reduce emissions from international aviation. In the EU, the main policy instrument for accelerating the uptake of SAF up to 2050 is the ReFuelEU Aviation Regulation, which aims to ensure a level playing field for sustainable air transport. The inclusion of aviation in the EU ETS increases the price of fossil kerosene and hence provides an additional incentive for the uptake of SAF. Under both EU ETS and CORSIA, there is an incentive to deploy SAF. However, as allowance/offset prices are higher, the EU ETS is more attractive for claiming SAF. Airlines that operate flights that are both covered by the EU ETS and flights falling under CORSIA may optimise their carbon costs by focusing SAF use on ETS flights.

SAF can be reported and claimed through various methods and schemes. There are three primary chain-of-custody models: physical separation, mass balance, and book-and-claim. Current regulations, such as ReFuelEU Aviation, the Renewable Energy Directive, and the EU ETS, support a mass balance system. In the future, ReFuelEU Aviation may also adopt a book-and-claim approach.

Among the three methodologies compared, physical segregation demands the highest investment and significant adjustments to the fuel supply chain. This method can also result in increased emissions due to the need for separate transportation. The mass balance approach mitigates these emissions by providing more flexible transportation and airport delivery options, while still allowing fuel traceability to specific airports. The book-and-claim system is the most logistically efficient, reducing both costs and the carbon footprint. However, its low traceability could elevate the risk of fraud.

We conclude that both the strict physical segregation and the global book-and-claim approach do not seem desirable because of their unintended side effect. Given that global production of SAF is still small and production in Germany is in its early stages, a mass balance approach which might be combined with national book-and-claim until the market matures further seems a better way to make sure the integrity of the scheme is protected. Local knowledge is built up while keeping additional costs manageable and posing no unnecessary obstacles hinder the ramp-up of production facilities.

The elements of the assessment are summarised in more detail below.

Overview of policies to incentivise the uptake of SAF

The **ICAO** is a UN agency that regulates global aviation emissions. It has set two main climate targets on a global level: achieving carbon-neutral growth from 2020 and net zero CO_2 emissions by 2050. In 2023, ICAO also aimed to cut CO_2 emissions in international aviation by 5% by 2030 using SAF and other technologies.

To meet these goals, ICAO plans to enhance fuel efficiency, use SAF, and implement CORSIA, which offsets emissions above a baseline. CORSIA has faced criticism and lacks substantial policy instruments for the new long-term goal.

As of September 2024, 129 states are participating in CORSIA's voluntary phase, with major countries expected to join by 2027. CORSIA offsets emissions from 2021 to 2035, using 2019 emissions as a baseline for initial years and 85% of 2019 emissions for later phases. Airlines can reduce offset obligations by using CORSIA-eligible fuels. The latter fuels include sustainable aviation fuels and low-carbon aviation fuels. The criteria for both types of fuels are defined by ICAO, which means a fuel considered a SAF under CORSIA is not necessarily a SAF under the EU's legislation.

The **EU** committed itself to a net target of 55% reduction of GHG emissions in 2030 compared to 1990 and to become climate-neutral by 2050. Although there is no specific target for reducing GHG emissions in aviation, emissions from all departing flights are included in both the 55% reduction target for 2030 and the climate neutrality target for 2050. The EU regulates both intra- and extra-EU aviation through different policy instruments.

The **Renewable Energy Directive (RED)** sets targets for renewable energy in the EU by 2030. The latest recast, RED III, aims to increase the share of renewable energy to 42.5%, with a potential top-up to 45%. Member States have to implement this directive, leading to variations in national rules.

RED III includes sector-specific targets, such as a 14.5% reduction in greenhouse gas (GHG) intensity or a 29% share of renewables in transport by 2030. It also sets sub-targets for advanced biofuels and renewable fuels of non-biological origin (RFNBOs), with specific multipliers to incentivise their use in aviation and maritime sectors. The SAF quota under ReFuelEU Aviation is expected to fulfil a significant portion of the RFNBO sub-target in RED III.

A mass balance system ensures compliance with RED targets. Furthermore, the RED III strengthens the sustainability criteria for biofuels. Both ReFuelEU Aviation and the EU ETS 1 refer to the RED. European legislation is thus largely harmonised. There are, however, slight differences between the policies in terms of which types of aviation fuel are eligible to count towards which targets.

ReFuelEU Aviation (EU 2023/2405) is part of the EU's 'Fit for 55' package, aiming to increase the use of SAF through blending obligations for fuel suppliers. Starting in 2025, the SAF quota will rise from 2% to 70% by 2050. There is also a sub-quota for RFNBOs starting in 2030.

The regulation mandates that airlines to refuel at least 90% of their required fuel for outgoing commercial flights at EU airports. This includes international flights departing from the EU.

To ease the uptake of the market, a flexibility mechanism allows fuel suppliers to meet SAF targets through a weighted average across EU airports up to 2034. This flexibility helps suppliers focus on larger airports or those with pipeline connections.

The revised **EU ETS** Directive regulates CO_2 emissions from flights based on their routes. It covers flights within and between EEA countries, and to the UK and Switzerland[1]. Additional flights to and from the outermost regions are to be included from 2024.

The cap on emission allowances for aviation decreases annually, with a linear reduction factor of 4.3% from 2024 to 2027, and 4.4% thereafter. Initially, most allowances were free, but from

[1] Flights from the UK to the EEA are covered by the UK ETS and flights from Switzerland to the EEA are covered by the Swiss ETS.

2026, all allowances will be auctioned, except for the 20 million allowances reserved for eligible fuel uptake.

Aircraft operators can reduce their surrender obligations by using fuels which have a zero emission factor under the ETS: biofuels; renewable fuels of non-biological origin (RFNBOs), recycled carbon fuels (RCFs) and synthetic low carbon fuels (SLCFs), provided that they meet the criteria set out in the RED for biomass feedstocks, that the electricity used for RFNBOs is renewable and additional, and that they achieve greenhouse gas emission savings (at least 70% compared to a comparable fossil fuel on a life-cycle basis). The EU ETS also defines how CORSIA offsets are implemented for EEA-based carriers, ensuring no double counting of emission reductions.

From 2027, flights to and from non-CORSIA countries may be subject to the EU ETS, increasing their surrender obligations. The EU Commission will report on ICAO's progress towards net zero emissions by 2050 and CORSIA participation every three years from 2027.

Eligible aviation fuels and definitions under each policy

ICAO defines two types of **CORSIA-eligible fuels** (CEFs): sustainable aviation fuels (SAF) and lower carbon aviation fuels (LCAF).

- **SAFs** are renewable or waste-derived biofuels, such as hydroprocessed esters and fatty acids (HEFA) from used cooking oil and alcohol-to-jet (AtJ) fuels from agricultural residues.
- **LCAFs** are fossil-based fuels with lower life-cycle emissions, achieved through methods like carbon capture and sequestration (CCS) and the use of renewable hydrogen.

To be eligible, fuels must be certified by approved sustainability certification schemes. CEFs produced before 2024 must meet criteria for lower GHG emissions and not use biomass from high carbon stock land converted after 2008. From 2024, additional sustainability criteria apply, covering aspects like emission reduction permanence, biodiversity, and human rights.

The life-cycle emissions of SAF can be determined using ICAO-approved default values or calculated using a CORSIA methodology. For LCAF, actual life-cycle emissions must be calculated. Baseline life-cycle emissions for conventional aviation fuels are set at 89 gCO_2e/MJ for jet fuels and 95 gCO_2e/MJ for aviation gasoline (AvGas).

The **RED** supports the EU ETS and ReFuelEU Aviation regulations with definitions and criteria. It defines, advanced biofuels, and RCFs. It sets emission savings and sustainability criteria for these fuels, which must be met to comply with the definitions of SAFs in other EU legislation. This includes specific criteria for hydrogen to be considered renewable.

ReFuelEU Aviation defines three types of fuels eligible to meet the SAF quota:

1. **Synthetic aviation fuels (RFNBOs)**: Includes e-kerosene and renewable hydrogen, which must meet life-cycle emission savings and certification criteria set by the RED.
2. **Low-Carbon aviation fuels**: These synthetic drop-in fuels, derived from low-carbon hydrogen, must achieve at least 70% life-cycle GHG emission savings. They are specifically for non-fossil, non-renewable hydrogen fuels and do not count towards RED III targets.
3. **Aviation biofuels**: Advanced biofuels produced from feedstock listed in Part A of Annex IX of the RED, and other biofuels including those from Part B of Annex IX and other biofuels not listed, excluding those from food and feed crops and Recycled Carbon Aviation Fuels produced from non-renewable waste streams or exhaust gases.

The renewable share of co-processed fuels is also eligible if produced from RED III-listed feedstock.

The **EU ETS** Directive includes provisions for alternative fuels that meet RED criteria, assigning them a zero emission factor to reduce surrender requirements. For mixed fuels, operators can estimate the eligible content using a mass balance approach or purchase records.

From 2024 to 2030, up to 20 million allowances will be allocated to commercial aircraft operators to offset the price difference between eligible fuels and fossil kerosene. Eligible fuels for this support include:

- hydrogen from renewable sources,
- advanced biofuels,
- RFNBOs, and
- other non-fossil origin fuels.

The specifics of this support mechanism are still being developed, with implementing acts expected in 2025. This delay has caused market uncertainty, making airlines hesitant to purchase SAFs without knowing the support details.

SAF certification and administrative requirements under different policies

The aim of SAF certification and administrative requirements are to monitor the environmental impacts of SAF usage and to prevent unintended negative impacts and fraud. Certification schemes establish rules and requirements for issuing certificates of conformity or compliance with regulatory regimes as the RED[2], CORSIA or voluntary schemes to economic operators. Although there are differences between the schemes, all cover the following aspects:

- feedstock production sustainability including type of feedstock and indirect land use change (ILUC);
- traceability and the chain of custody (CoC) of sustainable materials through the supply chain; and
- verified reduction of GHG emissions.

The main differences and similarities between the schemes are summarised in Table 1.

[2] ReFuelEU Aviation and the EU ETS Directive both refer to the RED for the sustainability criteria of SAF.

Table 1: Allowed feedstocks and required GHG reductions for eligible fuels in RED and CORSIA[3]

	RED	CORSIA
Coverage	– RED applies to the entire transport sector with no specific aviation targets. However, Member States may enforce stricter regulations in their national implementation. – ReFuelEU Aviation refers to the RED for the definition of eligible fuels but has stricter criteria regarding the use of certain feedstocks.	– CORSIA is aviation-specific
Feedstocks	– Food- and feed-based feedstocks (conventional biofuels): Limited by the 2020 share of those fuels in the final energy consumption in each Member State, with a maximum of 7% – 1.7% cap on UCO and animal fats – High ILUC feedstocks: Capped at the level of consumption in 2019 of each Member State. Starting from 31 December 2023, this will be gradually phased out by 2030 latest	– SAF made from biomass obtained from land converted after 1 January 2008 with high carbon stock is not allowed (DLUC) – ILUC is allowed, but indirectly regulated via Life-Cycle Analysis – Additional social and environmental criteria addressing the impacts on water, soil, air, conservation, waste and chemicals, human and labour rights, land use rights and land use, water use rights, local and social development and finally food security
GHG reduction	– Fossil fuel baseline: 94 g CO_2e/MJ – Minimum reduction: 65% – Maximum GHG emissions SAF: 32.9g CO_2e/MJ for biofuels and 28.2 g CO_2e/MJ for RFNBOs	– Fossil fuel baseline: 89 g CO_2e/MJ – Minimum reduction: 10% – Maximum GHG emissions SAF: 80.1 g CO_2e/MJ

Source: Authors' own compilation

For each shipment along the supply chain, i.e. each batch of outgoing sustainable material, either raw material, an intermediate product or the end product SAF, an economic operator must provide a Proof of Sustainability (PoS) documentation, which cannot be duplicated and only used once. The certification schemes ISCC and RSB propose a Proof of Compliance (PoC) concept, which serves the same purpose as an PoS, but is issued in the case where the PoS has already been surrendered to competent authorities. At the time of writing, the PoC concept has not yet been implemented. For RED, the Union Database (UDB) is currently set up with the goal of facilitating the tracing and verification of proofs of sustainability of biofuels and all other types of alternative fuels.

The administrative requirements for EU ETS, ReFuelEU Aviation and CORSIA are summarised in the following table:

[3] Since ReFuelEU Aviation is mainly based on the provisions of the RED, a comparison of RED and CORSIA is offered here.

Table 2: Overview of administrative requirements

	ReFuelEU Aviation	EU ETS	CORSIA
Regulated identities	Fuel suppliers Aircraft operators	Aircraft operators	Aircraft operators
Relation to SAF	Blending obligation with SAF target and sub-target for RFNBOs	Zero emission factor for eligible SAF	Emission reduction (based on LCA method) achieved by using SAF is subtracted from the airline's total emissions.
Compliance[4]	– Fuel suppliers: report amount, energy content and SAF specification of aviation fuel and SAF supplied at each EU airport – Aircraft operators: required and uplifted aviation fuel at each EU airport	– Aircraft operators have to monitor and record their emissions throughout the year and submit an emission report, which must be verified. The verified emission report determines the number of EU ETS allowances that an aircraft operator must surrender. – To qualify for a zero emission factor for SAF used in flights covered by the EU ETS, physical delivery to an airport is necessary, thus a mass balance system at airport level.	– Aircraft operators develop an emission monitoring plan, which is approved by the administrating authority – Aircraft operators report actual fuel consumption, calculated emission data, and CORSIA eligible fuels used for emission reductions claims – Aircraft operators with total annual CO_2 emissions for flights subject to offsetting requirements below 50,000 tonnes may use a simplified approach and calculate emissions with the ICAO CERT tool.

Source: Authors' own compilation

SAF supply chain

The use of SAF makes adjustments necessary in aircraft fuel production and delivery from the production sites to aircraft (fuel infrastructure) and the development of a chain of custodies (CoC) for SAF. The latter is a chronological documentation of the properties and impacts and required to comply with the policies. SAF is currently treated as a "drop-in" fuel. Drop-in means that, after blending with traditional kerosene up to 50%, it can be used in today's aircraft without requiring changes to aircrafts and existing infrastructure like storage, delivery and fueling systems.

There are different chain-of-custody methodologies:

- **Physical segregation** is a system whereby SAF is physically kept separate from conventional Jet A kerosene in the supply chain. The exact share of SAF is known for each batch of fuel delivered to the airport and even to the aircraft.
- **Mass balance** is a method whereby the administrative SAF record is connected to the physical SAF flow through the supply chain. SAF is inserted in the supply chain somewhere and physically mixed with fossil jet fuel. The share of SAF in the fuel mix at an airport or

[4] The PoS of a batch of SAF can be required by multiple actors or under multiple policy frameworks. To address this issue, a PoC concept is developed. After the UDB is ready to be used, this issue will be resolved.

country will (on average) match the initial proportions. A mass balance system ensures that there still is a physical traceable link between the SAF input and output.

- **Book-and-claim** also allows for mixing SAF and Jet A kerosene in the supply chain. The main difference with mass balance is that book-and-claim can be seen as a certificate trading model. The administrative SAF record does not necessarily connect to the physical SAF flow through the supply chain. The SAF can be injected into the supply chain everywhere as physical delivery to a customer is not necessary.

From the three methodologies compared, physical segregation requires the highest investment and adjustments to the fuel supply chain. Additionally, it can lead to increased emissions due to the separate transport needs. A mass balance approach reduces these emissions by offering more flexible transportation options and airport delivery requirements. It also enables to trace the fuel to a specific airport. A book-and-claim system is the most efficient in terms of logistics, minimising both logistical costs and carbon footprint. Traceability is low, however, which might increase the risk of fraud.

Impacts of claiming SAF-related emission reductions under EU ETS and CORSIA for European airlines

Airlines have a financial incentive to maximise the claim of SAF-related emission reductions under the EU ETS. This is because prices of EU ETS allowances are expected to be higher compared to prices of CORSIA offsets. For three European airlines (a network carrier, a cargo carrier and a low-cost carrier), the impacts of claiming SAF-related emission reductions under the EU ETS and CORSIA have been quantified. We have compared three options:

- Option 0 (reference): No SAF-related reduction of EU ETS allowances and CORSIA offset,
- Option 1: SAF-related reduction proportionally allocated to all flights,
- Option 2: SAF-related reduction maximally allocated to EU ETS.

The main impacts considered are the demand for EU ETS allowances and CORSIA offsets and the total policy-induced cost increases for an airline. Total policy-induced cost increases contain the incremental costs of SAFs and the costs to purchase EU ETS allowances and CORSIA offsets.

If SAF-related emission reductions are proportionally allocated to flights which fall under EU ETS and CORSIA (option 1), both the demand for EU ETS allowances and CORSIA offsets are reduced compared to the reference. For airlines this implies a reduction in policy-induced costs. Because of the higher EU ETS prices, the reduction in costs is mainly related to a reduction of costs to purchase EU ETS allowances. For the different airlines considered in the analysis, total policy-induced costs are reduced by about 5% in 2030 and 15% in 2035 if SAF-related emission reductions are proportionally allocated. If a blending strategy allows the maximum amount of SAF-related emission reductions to be allocated to the EU ETS, network carriers can generally further reduce their EU ETS-related costs. The additional reduction of total policy-induced costs amounts to about 4% in 2030 and about 8% in 2035. Low-cost carriers generally have a limited share of emissions on flights covered by CORSIA; therefore, these airlines have limited potential to further reduce their EU ETS-related costs.

Further chain-of-custody considerations and recommendations

This report evaluates three chain-of-custody methodologies for SAFs: physical segregation, mass balance, and book-and-claim.

- **Physical segregation**: This method faces challenges and high costs due to additional transport and infrastructure needs.
- **Mass balance**: Already included in EU legislation, mass balance reduces transport costs and is used at airport levels under ReFuelEU Aviation's flexibility mechanism. It can include exemptions for small airports.
- **Book-and-claim**: This system can be national, European, or global. A national system offers flexibility and cost reduction by concentrating SAF supply initially at one airport. A European system is efficient but may not build local capacity. A global system is not recommended due to higher fraud risk and less alignment with EU climate targets.

The report concludes that a mass balance approach, possibly combined with a national book-and-claim system, is preferable at this stage. This approach balances integrity, cost management, and production ramp-up without unnecessary obstacles.

The report also highlights the need for a common definition of SAFs across schemes, noting that EU regulations are largely harmonised but differ from international definitions like CORSIA. It suggests additional incentives for SAFs with higher GHG savings to encourage innovation and investment, aligning incentives across Europe to minimise market distortion.

Zusammenfassung

Der Luftverkehr trägt etwa 2,5% zu den weltweiten CO_2-Emissionen bei. Berücksichtigt man die Nicht-CO_2-Effekte, ist die Gesamtwirkung auf das Klima sogar noch höher. Um diese Emissionen zu verringern, ist die Verwendung von nachhaltigen Flugkraftstoffen (SAF) von entscheidender Bedeutung. SAF, die aus nachhaltigen Rohstoffen hergestellt werden, können die Lebenszyklusemissionen im Vergleich zu fossilem Kerosin erheblich reduzieren. Trotz politischer Maßnahmen zur Förderung des Einsatzes von SAF ist ihr Anteil am Flugkraftstoffverbrauch derzeit minimal: SAF machen nur etwa 0,1% des Gesamtverbrauchs aus.

In diesem Bericht werden die Gründe für diese begrenzte Akzeptanz analysiert und notwendige Änderungen des Rahmens für die Berichterstattung und Anrechnung aufgezeigt, um bessere Anreize für die Einführung von SAF und die Berichterstattung im Rahmen des EU-Emissionshandelssystems (EU-ETS) zu schaffen. Es gibt mehrere politische Maßnahmen, die darauf abzielen, den Einsatz von SAF zu erhöhen. Auf globaler Ebene wurde die marktbasierte Maßnahme Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) der Internationalen Zivilluftfahrtorganisation (ICAO) eingeführt, um die Emissionen des internationalen Luftverkehrs zu reduzieren. In der EU ist das wichtigste politische Instrument zur Beschleunigung der Einführung von SAF bis 2050 die ReFuelEU Aviation Verordnung, die gleiche Wettbewerbsbedingungen für den nachhaltigen Luftverkehr gewährleisten soll. Die Einbeziehung des Luftverkehrs in das EU-ETS erhöht den Preis für fossiles Kerosin und bietet somit einen zusätzlichen Anreiz für die Einführung von SAF. Sowohl im Rahmen des EU-ETS als auch im Rahmen von CORSIA gibt es einen Anreiz für den Einsatz von SAF. Da jedoch die Preise für Zertifikate/Ausgleiche höher sind, ist das EU-ETS für die Inanspruchnahme von SAF attraktiver. Fluggesellschaften, die Flüge durchführen, die sowohl unter das EU-ETS als auch unter CORSIA fallen, können ihre CO_2-Kosten optimieren, indem sie die Nutzung von SAF auf ETS-Flüge konzentrieren.

SAF kann durch verschiedene Methoden und Systeme gemeldet und geltend gemacht werden. Es gibt drei Hauptmodelle für die Nachweiskette: physische Trennung, Massenbilanz und Book-and-Claim. Aktuelle Politikmaßnahmen wie ReFuelEU Aviation, die Erneuerbare-Energien-Richtlinie und das EU-ETS unterstützen ein Massenbilanzsystem. In Zukunft könnte ReFuelEU Aviation auch einen Book-and-Claim-Ansatz anwenden.

Von den drei verglichenen Methoden erfordert die physische Trennung die höchsten Investitionen und erhebliche Anpassungen in der Kraftstofflieferkette. Diese Methode kann auch zu erhöhten Emissionen führen, da ein separater Transport erforderlich ist. Der Massenbilanzansatz verringert diese Emissionen, indem er flexiblere Transport- und Flughafenlieferoptionen bietet und gleichzeitig die Rückverfolgbarkeit des Kraftstoffs zu bestimmten Flughäfen ermöglicht. Das Book-and-Claim-System ist logistisch am effizientesten und reduziert sowohl die Kosten als auch den CO_2-Fußabdruck. Die geringe Rückverfolgbarkeit könnte jedoch das Risiko von Betrug erhöhen.

Wir kommen zu dem Schluss, dass sowohl die strikte physische Trennung als auch der globale Book-and-Claim-Ansatz wegen ihrer unbeabsichtigten Nebenwirkung nicht wünschenswert erscheinen. In Anbetracht der Tatsache, dass die weltweite SAF-Produktion noch klein ist und die Produktion in Deutschland noch in den Kinderschuhen steckt, scheint ein Massenbilanzansatz, der bis zur weiteren Reifung des Marktes mit einem Book-and-Claim-System kombiniert werden könnte, ein besserer Weg zu sein, um die Integrität des Systems zu gewährleisten. Lokales Wissen wird aufgebaut, während die zusätzlichen Kosten überschaubar bleiben und keine unnötigen Hindernisse für den Aufbau von Produktionsanlagen entstehen.

Die Elemente der Analyse werden im Folgenden ausführlicher zusammengefasst.

Überblick über politische Maßnahmen mit Anreizwirkung zur Einführung von SAF

Die **ICAO** ist eine UN-Organisation, die die weltweiten Luftverkehrsemissionen regelt. Sie hat sich auf globaler Ebene zwei wichtige Klimaziele gesetzt: ein kohlenstoffneutrales Wachstum ab dem Jahr 2020 und netto-null CO_2-Emissionen bis zum Jahr 2050. Im Jahr 2023 hat sich die ICAO außerdem zum Ziel gesetzt, die CO_2-Emissionen im internationalen Luftverkehr bis 2030 durch den Einsatz von SAF und anderen Technologien um 5% zu senken.

Um diese Ziele zu erreichen, plant die ICAO, die Treibstoffeffizienz zu verbessern, SAF einzusetzen und CORSIA zu implementieren (welches Emissionen über einer Basislinie kompensiert). CORSIA ist auf Kritik gestoßen, und es fehlt an wesentlichen politischen Instrumenten für das neue langfristige Ziel.

Bis September 2024 nehmen 129 Staaten an der freiwilligen CORSIA-Phase teil, und es wird erwartet, dass sich bis zum Jahr 2027 weitere Länder anschließen werden. CORSIA kompensiert Emissionen im Zeitraum 2021 bis 2035, wobei die Emissionen des Jahres 2019 als Basiswert für die ersten Jahre und 85% der Emissionen des Jahres 2019 für die späteren Phasen verwendet werden. Die Fluggesellschaften können ihre Kompensationsverpflichtungen verringern, indem sie CORSIA-fähige Kraftstoffe verwenden. Zu den letztgenannten Kraftstoffen gehören nachhaltige Flugkraftstoffe und kohlenstoffarme Flugkraftstoffe. Die Kriterien für beide Arten von Kraftstoffen werden von der ICAO festgelegt, was bedeutet, dass ein Kraftstoff, der nach CORSIA als SAF gilt, nicht unbedingt auch ein SAF im Sinne der EU-Gesetzgebung ist.

Die **EU** hat sich das Ziel gesetzt, die Treibhausgasemissionen bis zum Jahr 2030 um 55% gegenüber dem Jahr 1990 zu senken und bis zum Jahr 2050 klimaneutral zu werden. Obwohl es kein spezifisches Ziel für die Verringerung der Treibhausgasemissionen im Luftverkehr gibt, werden die Emissionen aller abfliegenden Flüge sowohl in das 55%-Reduktionsziel für das Jahr 2030 als auch in das Ziel der Klimaneutralität für das Jahr 2050 einbezogen. Die EU reguliert sowohl den Intra- als auch den Extra-EU-Luftverkehr durch verschiedene politische Instrumente.

Die **Richtlinie über erneuerbare Energien (RED)** setzt Ziele für erneuerbare Energien in der EU bis zum Jahr 2030. Die jüngste Neufassung, RED III, zielt darauf ab, den Anteil der erneuerbaren Energien auf 42,5% zu erhöhen, mit einer möglichen Aufstockung auf 45%. Die Mitgliedstaaten müssen diese Richtlinie umsetzen, was zu unterschiedlichen nationalen Regelungen führt.

RED III enthält sektorspezifische Ziele, wie z. B. eine Reduzierung der Treibhausgasintensität um 14,5% oder einen Anteil von 29% erneuerbarer Energien im Verkehrssektor bis zum Jahr 2030. Außerdem werden Unterziele für fortschrittliche Biokraftstoffe und erneuerbare Kraftstoffe nicht-biologischen Ursprungs (RFNBOs) festgelegt, mit spezifischen Multiplikatoren, um Anreize für ihre Verwendung im Luft- und Seeverkehr zu schaffen. Es wird erwartet, dass die SAF-Quote im Rahmen von ReFuelEU Aviation einen erheblichen Teil des RFNBO-Unterziels in RED III erfüllen wird.

Ein Massenbilanzsystem stellt die Einhaltung der RED-Ziele sicher. Außerdem stärkt die RED III die Nachhaltigkeitskriterien für Biokraftstoffe. Sowohl ReFuelEU Aviation als auch das EU ETS 1 beziehen sich auf die RED. Die europäische Gesetzgebung ist also weitgehend harmonisiert. Es gibt jedoch leichte Unterschiede zwischen den Politiken in Bezug darauf, welche Arten von Flugkraftstoff auf welche Ziele angerechnet werden können.

ReFuelEU Aviation (EU 2023/2405) ist Teil des EU-Pakets „Fit for 55“, das darauf abzielt, die Verwendung von SAF durch Beimischungsverpflichtungen für Kraftstofflieferanten zu erhöhen.

Ab dem Jahr 2025 wird die SAF-Quote von 2% auf 70% bis zum Jahr 2050 steigen. Außerdem gibt es ab 2030 eine Unterquote für RFNBOs.

Die Verordnung schreibt vor, dass die Fluggesellschaften mindestens 90% ihres Treibstoffbedarfs für abgehende kommerzielle Flüge auf EU-Flughäfen tanken müssen. Dies gilt auch für internationale Flüge, die von der EU abfliegen.

Um den Markthochlauf zu erleichtern, ermöglicht ein Flexibilitätsmechanismus den Kraftstofflieferanten, die SAF-Ziele bis zum Jahr 2034 durch einen gewichteten Durchschnitt aller EU-Flughäfen zu erreichen. Diese Flexibilität hilft den Anbietern, sich auf größere Flughäfen oder solche mit Pipeline-Anbindung zu konzentrieren.

Die überarbeitete **EU-ETS**-Richtlinie regelt die CO_2-Emissionen von Flügen auf der Grundlage ihrer Flugrouten. Sie gilt für Flüge innerhalb und zwischen EWR-Ländern sowie in das Vereinigte Königreich und die Schweiz.[5] Zusätzliche Flüge von und nach Regionen in äußerster Randlage sollen ab dem Jahr 2024 einbezogen werden.

Die Obergrenze für Emissionszertifikate für den Luftverkehr sinkt jährlich, mit einem linearen Reduktionsfaktor von 4,3% von 2024 bis 2027 und 4,4% danach. Ursprünglich waren die meisten Zertifikate kostenlos, aber ab dem Jahr 2026 werden alle Zertifikate versteigert, mit Ausnahme der 20 Millionen Zertifikate, die für den Hochlauf förderfähiger Kraftstoffe reserviert sind.

Flugzeugbetreiber können ihre Abgabeverpflichtungen verringern, indem sie Kraftstoffe verwenden, die im Rahmen des ETS einen Emissionsfaktor von Null haben: Biokraftstoffe, erneuerbare Kraftstoffe nicht-biologischen Ursprungs (RFNBOs), rezyklierte kohlenstoff-basierte Kraftstoffe (RCF) und synthetische kohlenstoffarme Kraftstoffe (SLCF), sofern sie die in der RED festgelegten Kriterien für Biomasse-Rohstoffe erfüllen, dass der für RFNBO verwendete Strom erneuerbar und zusätzlich ist und sie Treibhausgasemissionen einsparen (mindestens 70% gegenüber einem vergleichbaren fossilen Kraftstoff auf Lebenszyklusbasis). Das EU-ETS legt auch fest, wie CORSIA-Kompensationen für im EWR ansässige Transportunternehmen umgesetzt werden, um sicherzustellen, dass Emissionsreduzierungen nicht doppelt gezählt werden.

Ab dem Jahr 2027 werden Flüge von und nach Nicht-CORSIA-Ländern möglicherweise dem EU-ETS unterliegen, wodurch sich die Verpflichtungen zur Abgabe von Emissionszertifikaten erhöhen. Die EU-Kommission wird ab dem Jahr 2027 alle drei Jahre über die Fortschritte der ICAO auf dem Weg zu Netto-Null-Emissionen bis zum Jahr 2050 und zur Teilnahme an CORSIA berichten.

Anrechenbare/Zulässige Flugkraftstoffe und Definitionen je Politikmaßnahme

Die ICAO definiert zwei Arten von **CORSIA-anrechenbaren Kraftstoffen** (CEFs): nachhaltige Flugkraftstoffe (SAF) und kohlenstoffärmere Flugkraftstoffe (LCAF).

- **SAF** sind erneuerbare oder aus Abfällen gewonnene Biokraftstoffe, wie z. B. hydrierend aufbereitete Ester und Fettsäuren (HEFA) aus Altspeiseöl und Alkohol-zu-Jet-Kraftstoffe (AtJ) aus landwirtschaftlichen Reststoffen.
- **LCAFs** sind fossil basierte Kraftstoffe mit geringeren Lebenszyklusemissionen, die durch Methoden wie Kohlenstoffabscheidung und -bindung (CCS) und die Verwendung von erneuerbarem Wasserstoff erreicht werden.

[5] Flüge aus dem Vereinigten Königreich in den EWR fallen unter das britische ETS und Flüge aus der Schweiz in den EWR unter das Schweizer ETS.

Um unter CORSIA angerechnet werden zu können, müssen die Kraftstoffe durch anerkannte Nachhaltigkeitszertifizierungssysteme zertifiziert sein. CEFs, die vor dem Jahr 2024 hergestellt werden, müssen Kriterien für geringere Treibhausgasemissionen erfüllen und dürfen keine Biomasse von Flächen mit hohem Kohlenstoffbestand verwenden, die nach dem Jahr 2008 umgewandelt wurden. Ab dem Jahr 2024 gelten zusätzliche Nachhaltigkeitskriterien, die Aspekte wie die Dauerhaftigkeit der Emissionsminderung, die biologische Vielfalt und die Menschenrechte abdecken.

Die Lebenszyklusemissionen von SAF können anhand von ICAO-genehmigten Standardwerten bestimmt oder anhand einer CORSIA-Methode berechnet werden. Für LCAF müssen die tatsächlichen Lebenszyklusemissionen berechnet werden. Die Basis-Lebenszyklusemissionen für konventionelle Flugkraftstoffe werden auf 89 gCO_2e/MJ für konventionelles Kerosin und 95 gCO_2e/MJ für Flugbenzin (AvGas) festgelegt.

Die **RED** unterstützt das EU-ETS und die ReFuelEU Aviation Verordnung mit Definitionen und Kriterien. Sie definiert fortschrittliche Biokraftstoffe und RCFs. Sie legt Emissionseinsparungen und Nachhaltigkeitskriterien für diese Kraftstoffe fest, die erfüllt werden müssen, um den Definitionen von SAFs in anderen EU-Rechtsvorschriften zu entsprechen. Dazu gehören auch spezifische Kriterien für Wasserstoff, der als erneuerbar gilt.

ReFuelEU Aviation definiert drei Arten von Kraftstoffen, die für die Erfüllung der SAF-Quote in Frage kommen:

1. **Synthetische Flugtreibstoffe (RFNBOs):** Umfasst E-Kerosin und erneuerbaren Wasserstoff, die die von der RED festgelegten Kriterien für Lebenszyklus-Emissionseinsparungen und Zertifizierung erfüllen müssen.
2. **Kohlenstoffarme Flugkraftstoffe**: Diese synthetischen Drop-in-Kraftstoffe, die aus kohlenstoffarmem Wasserstoff gewonnen werden, müssen über den gesamten Lebenszyklus mindestens 70% Treibhausgasemissionen einsparen. Sie sind speziell für nicht-fossile, nicht-erneuerbare Wasserstoffkraftstoffe gedacht und werden nicht auf die Ziele der RED III angerechnet.
3. **Biokraftstoffe für die Luftfahrt**: Fortgeschrittene Biokraftstoffe, die aus den in Anhang IX Teil A der RED aufgeführten Rohstoffen hergestellt werden, sowie andere Biokraftstoffe, einschließlich der in Anhang IX Teil B aufgeführten, und andere nicht aufgeführte Biokraftstoffe, mit Ausnahme von Biokraftstoffen aus Nahrungs- und Futtermittelpflanzen und rezyklierten kohlenstoffhaltigen Flugkraftstoffen, die aus nicht erneuerbaren Abfallströmen oder Abgasen hergestellt werden.

Der erneuerbare Anteil von mitverarbeiteten Kraftstoffen ist ebenfalls zulässig, wenn sie aus in der RED III aufgeführten Rohstoffen hergestellt werden.

Die EU-ETS-Richtlinie enthält Bestimmungen für alternative Kraftstoffe, die die RED-Kriterien erfüllen, indem ihnen ein Null-Emissionsfaktor zugewiesen wird, um die Abgabeanforderungen zu verringern. Bei gemischten Kraftstoffen können die Betreiber den zulässigen Anteil anhand eines Massenbilanzansatzes oder anhand von Kaufbelegen schätzen.

Von 2024 bis 2030 werden den Betreibern von Verkehrsflugzeugen bis zu 20 Millionen Zertifikate zugeteilt, um die Preisdifferenz zwischen förderfähigen Kraftstoffen und fossilem Kerosin auszugleichen. Zu den förderungswürdigen Kraftstoffen gehören:

- Wasserstoff aus erneuerbaren Quellen,
- fortschrittliche Biokraftstoffe,
- RFNBOs, und

- andere Kraftstoffe nichtfossilen Ursprungs.

Die Einzelheiten dieses Fördermechanismus werden derzeit noch ausgearbeitet, die Durchführungsbestimmungen werden für das Jahr 2025 erwartet. Diese Verzögerung hat zu einer Verunsicherung des Marktes geführt, so dass die Fluggesellschaften zögern, SAF zu kaufen, ohne die Einzelheiten der Förderung zu kennen.

SAF-Zertifizierung und administrative Anforderungen im Rahmen verschiedener Politiken

Ziel der SAF-Zertifizierung und der administrativen Anforderungen ist es, die Umweltauswirkungen der Verwendung von SAF zu überwachen und unbeabsichtigte negative Auswirkungen und Betrug zu verhindern. Zertifizierungssysteme legen Regeln und Anforderungen für die Ausstellung von Konformitätsbescheinigungen oder Konformitätszertifikaten für Betreiber fest, die gesetzliche Regelungen wie die RED,[6] CORSIA oder freiwillige Regelungen einhalten. Obwohl es Unterschiede zwischen den Systemen gibt, decken alle die folgenden Aspekte ab:

- Nachhaltigkeit der Rohstoffproduktion, einschließlich der Art des Rohstoffs und der indirekten Landnutzungsänderung (ILUC);
- Rückverfolgbarkeit und Chain of Custody (CoC) nachhaltiger Materialien in der Lieferkette; und
- Verifizierte Reduzierung der Treibhausgasemissionen.

Die wichtigsten Unterschiede und Ähnlichkeiten zwischen den Systemen sind in Tabelle 1 zusammengefasst.

Tabelle 1: Zulässige Rohstoffe und erforderliche THG-Reduktionen für zulässige Kraftstoffe in RED und CORSIA[7]

	RED	CORSIA
Abdeckung	– Die RED gilt für den gesamten Verkehrssektor und enthält keine spezifischen Ziele für den Luftverkehr. Die Mitgliedstaaten können jedoch bei ihrer nationalen Umsetzung strengere Vorschriften durchsetzen. – ReFuelEU Aviation bezieht sich bei der Definition der anrechenbaren Kraftstoffe auf die RED, hat aber strengere Kriterien hinsichtlich der Verwendung bestimmter Rohstoffe.	– CORSIA ist Luftverkehrs-spezifisch
Rohstoffe	– Lebens- und futtermittelbasierte Rohstoffe (konventionelle Biokraftstoffe): Begrenzt durch den Anteil dieser Kraftstoffe am Endenergieverbrauch in jedem Mitgliedstaat im Jahr 2020, mit einem Maximum von 7%	– SAF aus Biomasse, die von nach dem 1. Januar 2008 umgewandelten Flächen mit hohem Kohlenstoffbestand stammt, ist nicht erlaubt (DLUC) – ILUC ist erlaubt, wird aber indirekt über die Lebenszyklusanalyse geregelt

[6] ReFuelEU Aviation und die EU-ETS-Richtlinie verweisen beide auf die RED bezüglich Nachhaltigkeitskriterien für SAF.
[7] Da sich ReFuelEU Aviation hauptsächlich auf die Bestimmungen der RED stützt, wird hier ein Vergleich zwischen RED und CORSIA dargestellt.

	RED	CORSIA
	— 1,7% Obergrenze für UCO und tierische Fette — Rohstoffe mit hohem ILUC-Gehalt: Begrenzt auf die Höhe des Verbrauchs jedes Mitgliedstaats im Jahr 2019. Ab dem 31. Dezember 2023 wird diese Obergrenze bis spätestens 2030 schrittweise abgebaut.	— Zusätzliche soziale und ökologische Kriterien, die die Auswirkungen auf Wasser, Boden, Luft, Naturschutz, Abfall und Chemikalien, Menschen- und Arbeitsrechte, Landnutzungsrechte und -nutzung, Wassernutzungsrechte, lokale und soziale Entwicklung und schließlich Ernährungssicherheit berücksichtigen
Treibhaus-gasminderung	— Basiswert fossile Kraftstoffe: 94 g CO_2e/MJ — Treibhausgasminderung mind.: 65% — Maximale Treibhausgasemissionen SAF: 32.9g CO_2e/MJ für Biokraftstoffe und 28.2 g CO_2e/MJ für RFNBOs	— Basiswert fossile Kraftstoffe: 89 g CO_2e/MJ — Treibhausgasminderung mind.: 10% — Maximale Treibhausgasemissionen SAF: 80.1 g CO_2e/MJ

Quelle: Eigene Zusammenstellung

Für jede Sendung entlang der Lieferkette, d.h. für jede Charge eines ausgehenden nachhaltigen Materials, sei es ein Rohstoff, ein Zwischenprodukt oder das Endprodukt SAF, muss ein Betreiber einen Nachhaltigkeitsnachweis (Proof of Sustainability, PoS) vorlegen, der nicht dupliziert und nur einmal verwendet werden kann. Die Zertifizierungssysteme ISCC und RSB schlagen ein Konzept des Konformitätsnachweises (Proof of Compliance, PoC) vor, das demselben Zweck dient wie ein PoS, aber für den Fall ausgestellt wird, dass der PoS bereits bei den zuständigen Behörden abgegeben wurde. Zum Zeitpunkt der Erstellung dieses Berichts wurde das PoC-Konzept noch nicht umgesetzt. Für RED wird derzeit die Unionsdatenbank (Union Database, UDB) eingerichtet, um die Rückverfolgung und Überprüfung von Nachhaltigkeitsnachweisen für Biokraftstoffe und alle anderen Arten von alternativen Kraftstoffen zu erleichtern.

Die administrativen Anforderungen für EU-ETS, ReFuelEU Aviation und CORSIA sind in der folgenden Tabelle zusammengefasst:

Tabelle 2: Überblick administrative Anforderungen

	ReFuelEU Aviation	EU-ETS	CORSIA
Regulierte Identitäten	Kraftstofflieferanten Luftfahrzeugbetreiber	Luftfahrzeugbetreiber	Luftfahrzeugbetreiber
Bezug zu SAF	Beimischungsquote für SAF und RFNBO-Unterziel	Null-Emissionsfaktor für zulässige SAF	Emissionsreduktion (basierend auf der LCA-Methode) wird von den Gesamtemissionen der Fluggesellschaft abgezogen
Konformität[8]	— Kraftstofflieferanten: Meldung der Menge, des Energiegehalts und der SAF-	— Die Luftfahrzeugbetreiber müssen ihre Emissionen das ganze	— Die Luftfahrzeugbetreiber erstellen einen Emissionsüberwachungsplan, der von der

[8] Der PoS einer Charge von SAF kann von mehreren Akteuren oder unter mehreren politischen Rahmenbedingungen benötigt werden. Um dieses Problem zu lösen, wird ein PoC-Konzept entwickelt. Sobald die UDB einsatzbereit ist, wird dieses Problem gelöst sein.

	ReFuelEU Aviation	EU-ETS	CORSIA
	Spezifikation des an jedem EU-Flughafen gelieferten Flugkraftstoffs und SAF – Luftfahrzeugbetreiber: Benötigtes und getanktes Flugbenzin auf jedem EU-Flughafen	Jahr über überwachen und aufzeichnen und einen Emissionsbericht vorlegen, der geprüft werden muss. Der geprüfte Emissionsbericht bestimmt die Anzahl der EU-ETS-Zertifikate, die ein Luftfahrzeugbetreiber abgeben muss. – Um einen Null-Emissionsfaktor für SAF zu erhalten, die bei unter das EU-ETS fallenden Flügen verwendet werden, ist eine physische Lieferung an einen Flughafen erforderlich, also ein Massenbilanzsystem auf Flughafenniveau.	Verwaltungsbehörde genehmigt wird. – Die Luftfahrzeugbetreiber melden den tatsächlichen Treibstoffverbrauch, die berechneten Emissionsdaten und die für CORSIA in Frage kommenden Treibstoffe, die für Ansprüche auf Emissionsreduzierungen verwendet werden. – Luftfahrzeugbetreiber, deren jährliche CO_2-Gesamtemissionen für ausgleichspflichtige Flüge unter 50.000 Tonnen liegen, können einen vereinfachten Ansatz wählen und die Emissionen mit dem ICAO CERT-Tool berechnen.

Quelle: Eigene Zusammenstellung

SAF-Lieferkette

Die Verwendung von SAF erfordert Anpassungen bei der Produktion von Flugzeugtreibstoff und der Lieferung von den Produktionsstätten zu den Flugzeugen (Treibstoffinfrastruktur) sowie die Entwicklung einer Lieferkette (Chain of Custody, CoC) für SAF. Bei Letzterem handelt es sich um eine chronologische Dokumentation der Eigenschaften und Auswirkungen, die zur Einhaltung der Richtlinien erforderlich ist. SAF wird derzeit als „Drop-in"-Kraftstoff behandelt. Drop-in bedeutet, dass SAF nach einer Beimischung von bis zu 5 % zu herkömmlichem Kerosin in heutigen Flugzeugen verwendet werden kann, ohne dass Änderungen an den Flugzeugen und der bestehenden Infrastruktur wie Lager-, Liefer- und Betankungssysteme erforderlich sind.

Es gibt verschiedene CoC-Methoden:

- **Physische Trennung** ist ein System, bei dem SAF in der Lieferkette physisch von herkömmlichem Jet-A-Kerosin getrennt wird. Der genaue SAF-Anteil ist für jede an den Flughafen und sogar an das Flugzeug gelieferte Treibstoffcharge bekannt.
- **Massenbilanz** ist eine Methode, bei der die administrative SAF-Aufzeichnung mit dem physischen SAF-Fluss durch die Versorgungskette verbunden wird. SAF wird irgendwo in die Versorgungskette eingespeist und physikalisch mit fossilem Kerosin vermischt. Der Anteil von SAF im Treibstoffmix eines Flughafens oder Landes wird (im Durchschnitt) den ursprünglichen Anteilen entsprechen. Ein Massenbilanzsystem stellt sicher, dass es immer noch eine physisch nachvollziehbare Verbindung zwischen dem SAF-Input und dem Output gibt.

- **Book-and-Claim** ermöglicht auch die Vermischung von SAF- und Jet-A-Kerosin in der Lieferkette. Der Hauptunterschied zur Massenbilanz besteht darin, dass Book-and-Claim als ein Modell für den Handel mit Zertifikaten angesehen werden kann. Der administrative SAF-Datensatz ist nicht unbedingt mit dem physischen SAF-Fluss durch die Lieferkette verbunden. SAF kann überall in die Lieferkette eingespeist werden, da eine physische Lieferung an einen Kunden nicht erforderlich ist.

Von den drei verglichenen Methoden erfordert die physische Trennung die höchsten Investitionen und Anpassungen in der Kraftstofflieferkette. Darüber hinaus kann sie aufgrund des separaten Transportbedarfs zu erhöhten Emissionen führen. Der Ansatz der Massenbilanzierung reduziert diese Emissionen, da er flexiblere Transportmöglichkeiten und Anforderungen an die Anlieferung am Flughafen bietet. Es ermöglicht auch die Rückverfolgung des Kraftstoffs zu einem bestimmten Flughafen. Ein Book-and-Claim-System ist in Bezug auf die Logistik am effizientesten und minimiert sowohl die Logistikkosten als auch den CO_2-Fußabdruck. Die Rückverfolgbarkeit ist jedoch gering, was das Betrugsrisiko erhöhen kann.

Auswirkungen der Geltendmachung von SAF-bezogenen Emissionsreduktionen im Rahmen des EU-ETS und CORSIA für europäische Fluggesellschaften

Für die Fluggesellschaften besteht ein finanzieller Anreiz, im Rahmen des EU-ETS möglichst viele SAF-bezogene Emissionsreduktionen geltend zu machen. Dies liegt daran, dass die Preise für EU-ETS-Zertifikate höher sein dürften als die Preise für CORSIA-Offsets. Für drei europäische Fluggesellschaften (eine Netzwerkfluggesellschaft, eine Frachtfluggesellschaft und eine Billigfluggesellschaft) wurden die Auswirkungen der Inanspruchnahme von SAF-bezogenen Emissionsreduzierungen im Rahmen des EU-ETS und von CORSIA quantifiziert. Wir haben drei Optionen miteinander verglichen:

- Option 0 (Referenz): Keine SAF-bedingte Reduzierung der EU-ETS-Zertifikate und CORSIA-Ausgleich,
- Option 1: SAF-bezogene Reduzierung, die anteilig auf alle Flüge verteilt wird,
- Option 2: SAF-bedingte Reduzierung, die maximal auf das EU-ETS angerechnet wird.

Die wichtigsten Auswirkungen sind die Nachfrage nach EU-ETS-Zertifikaten und CORSIA-Ausgleichszahlungen sowie die durch die Politikmaßnahmen verursachten Gesamtkostensteigerungen für eine Fluggesellschaft. Die durch die Politikmaßnahmen verursachten Gesamtkostensteigerungen umfassen die zusätzlichen Kosten der SAF und die Kosten für den Erwerb von EU-ETS-Zertifikaten und CORSIA-Offsets.

Werden die SAF-bedingten Emissionsreduktionen anteilig den Flügen zugewiesen, die unter das EU-ETS und CORSIA fallen (Option 1), sinkt sowohl die Nachfrage nach EU-ETS-Zertifikaten als auch nach CORSIA-Offsets im Vergleich zur Referenz. Für die Fluggesellschaften bedeutet dies eine Verringerung der durch die Politikmaßnahmen verursachten Kosten. Aufgrund der höheren EU-ETS-Preise ist die Kostensenkung hauptsächlich auf eine Verringerung der Kosten für den Erwerb von EU-ETS-Zertifikaten zurückzuführen. Für die verschiedenen in der Analyse berücksichtigten Fluggesellschaften verringern sich die durch die Politikmaßnahmen bedingten Gesamtkosten um etwa 5% im Jahr 2030 und 15% im Jahr 2035, wenn die SAF-bedingten Emissionsreduktionen anteilig zugewiesen werden. Wenn eine Beimischungsstrategie es ermöglicht, die maximale Menge an SAF-bezogenen Emissionsreduktionen dem EU-ETS zuzuweisen, können die Netzbetreiber ihre EU-ETS-bezogenen Kosten im Allgemeinen weiter senken. Die zusätzliche Senkung der gesamten politikbedingten Kosten beläuft sich auf etwa 4% im Jahr 2030 und etwa 8% im Jahr 2035. Billigfluggesellschaften haben im Allgemeinen einen begrenzten Anteil an den Emissionen auf Flügen, die unter CORSIA fallen; daher haben diese Fluggesellschaften nur ein begrenztes Potenzial, ihre EU-ETS-bezogenen Kosten weiter zu senken.

Weitere Überlegungen und Empfehlungen zur Überwachung der Lieferkette

In diesem Bericht werden drei CoC-Methoden für SAF bewertet: physische Trennung, Massenbilanz und Book-and-Claim.

- **Physische Trennung**: Diese Methode ist aufgrund des zusätzlichen Transport- und Infrastrukturbedarfs mit Herausforderungen und hohen Kosten verbunden.
- **Massenbilanz**: Die Massenbilanz ist bereits in der EU-Gesetzgebung enthalten, senkt die Transportkosten und wird auf Flughäfen im Rahmen des Flexibilitätsmechanismus von ReFuelEU Aviation eingesetzt. Er kann Ausnahmen für kleine Flughäfen vorsehen.
- **Book-and-Claim**: Dieses System kann national, europäisch oder global ausgestaltet sein. Ein nationales System bietet Flexibilität und Kostensenkung, indem es das SAF-Angebot zunächst auf einen Flughafen konzentriert. Ein europäisches System ist effizient, baut aber möglicherweise keine lokalen Kapazitäten auf. Ein globales System wird aufgrund des höheren Betrugsrisikos und der geringeren Übereinstimmung mit den EU-Klimazielen nicht empfohlen.

Der Bericht kommt zu dem Schluss, dass ein Massenbilanzansatz, möglicherweise in Kombination mit einem nationalen Book-and-Claim-System, in diesem Stadium vorzuziehen ist. Dieser Ansatz schafft ein Gleichgewicht zwischen Integrität, Kostenmanagement und Produktionsanlauf ohne unnötige Hindernisse.

Der Bericht unterstreicht auch die Notwendigkeit einer gemeinsamen Definition von SAF in allen Systemen und stellt fest, dass die EU-Verordnungen zwar weitgehend harmonisiert sind, sich aber von internationalen Definitionen wie CORSIA unterscheiden. Er schlägt zusätzliche Anreize für SAFs mit höheren Treibhausgaseinsparungen vor, um Innovation und Investitionen zu fördern und die Anreize europaweit anzugleichen, um Marktverzerrungen zu minimieren.

1 Introduction

The biggest lever for reducing CO_2 emissions from aviation is the use of alternative fuels. Aviation is responsible for approx. 2.5% of global CO_2 emissions.[9] The sector's climate impact is even higher if non-CO_2 effects are considered: they make up about two thirds of the overall impact (EASA 2020). While improvements in energy efficiency measures are needed, the use of sustainable aviation fuels (SAFs) and propulsion technologies will be important to progress the emission reduction pathway of aviation – which is much slower than in other sectors.

SAFs are alternative fuels produced with sustainable feedstocks which achieve a substantial emission reduction on a life-cycle basis compared to fossil kerosene. SAF can be produced via two main routes: based on biomass (bio-kerosene) and based on renewable hydrogen and the Fischer-Tropsch process[10] to generate synthetic kerosene – also called e-fuels or renewable fuels of non-biological origin (RFNBOs). SAFs are drop-in fuels which can be blended with fossil fuels. Policies have been introduced in recent years to incentivise the uptake of SAFs in aviation at EU and global levels.

Before the Covid-19 pandemic, aviation globally consumed 345 Mtoe of aviation fuel in 2019.[11] After a sharp drop in aviation activity in 2020, fuel demand has steadily increased again, reaching 90% of 2019 levels in 2023.[12] Almost all of this is fossil jet kerosene; SAFs comprise only approx. 0.1% of total consumption.[13] 600 million litres of SAF (0.5 Mt) were produced in 2023 – and all of it was bought and used.[14] Since 2013, approx. 53 billion litres of SAFs were purchased under offtake agreements according to ICAO.[15] Offtake agreements were signed by numerous airlines, such as Air France, KLM and Air New Zealand. All SAFs produced are currently used in fuel blends to meet the existing fuel specifications. In Germany, Lufthansa covered approx. 0.2% of its total fuel consumption via SAFs in 2023.[16]

SAFs can be reported and claimed in different ways and under different schemes. Generally, three main chain-of-custody models are to be distinguished: physical separation, mass balance, book-and-claim. ReFuelEU Aviation, the Renewable Energy Directive (RED) and the Emissions Trading System (EU ETS 1) allow for a mass balance system. Under ReFuelEU Aviation a book-and-claim approach might be introduced in future. However, SAFs do not have a significant share in the global and European aviation fuel mix to date. Furthermore, very little SAF use has been claimed under the EU ETS to reduce surrender obligations.

The aim of this report to explore the reasons for this and to identify the changes that might be needed in the framework for reporting and claiming SAFs in order to better incentivise SAF uptake and reporting under the EU ETS.

Today, the SAF supply market is still nascent. The availability and production capacities of SAFs influence the uptake, reporting and blending strategies. This report is thus written from a

[9] Based on the year 2019: https://ourworldindata.org/global-aviation-emissions

[10] ‚Fischer Tropsch reaction is a process which converts syngas, a mixture of H2 and CO, into hydrocarbons mainly for fuel applications but also for the synthesis of valuable chemicals' https://www.sciencedirect.com/topics/engineering/fischer-tropsch#:~:text=Fischer%E2%80%93Tropsch%20reaction%20(FT),the%20synthesis%20of%20valuable%20chemicals

[11] Final consumption – Key World Energy Statistics 2021 – Analysis - IEA, own conversion.

[12] https://www.iea.org/commentaries/oil-demand-growing-at-a-slower-pace-as-post-covid-rebound-runs-its-course.

[13] https://www.iea.org/energy-system/transport/aviation#tracking

[14] https://www.iata.org/en/pressroom/2023-releases/2023-12-06-02/

[15] https://www.icao.int/environmental-protection/SAF/Pages/Offtake-Agreements.aspx

[16] https://www.lufthansagroup.com/en/responsibility/climate-environment/sustainable-aviation-fuel.html

perspective which assumes that sufficient SAFs are available. Where appropriate, it also highlights what challenges or different conclusions might arise if this assumption is not made.

The report is mainly based on a literature review of relevant publications and legislative texts. Additionally, stakeholder interviews are conducted to gather further information and validate findings from the literature review.

Chapter two provides an overview of SAF-relevant policies and forms the basis for the following chapters. Chapter three focuses on reporting and verification requirements and chapter four on the supply chain and infrastructure and provides further specific information. In chapter five the impact of using SAF under different policy regimes is explored. Building on these chapters, the final chapter draws conclusions on future blending strategies of airlines including policy recommendations.

2 Overview of policies to incentivise the uptake of sustainable aviation fuels (SAFs)

SAFs are an important measure to reduce GHG emissions from aviation. Their uptake is incentivised both by general GHG reduction policies and dedicated policy measures.

At international level, in 2022, the International Civil Aviation Organization (ICAO) adopted the long-term global aspirational goal (LTAG) for aviation of net-zero carbon emissions by 2050. The goal to stabilise aviation emissions despite the growth of the sector has been set previously and is backed by a market-based measure, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), for international flights. The use of SAFs reduces the offset obligations.

The EU committed itself to a net target of a 55% reduction of greenhouse gas (GHG) emissions in 2030 compared to 1990 and of becoming climate-neutral by 2050. All departing flights are included in the EU climate target. The EU ETS 1 covers all EEA-internal flights; flights that fall under CORSIA are exempted. SAFs[17] are zero-rated within the ETS and thus reduce the emissions for which operators have to surrender allowances. Furthermore, aircraft operators can apply to receive free allocation to cover part of the cost differential between SAFs and conventional fossil fuels.

The EU has furthermore adapted a target for renewable energy in the EU's overall energy consumption and specific sub-target for advanced biofuels and RFNBOs in the transport sector (RED). The target is not aviation-specific. The gap is filled by the ReFuelEU Aviation Regulation. This regulation specifies blending obligations of SAF for fuel suppliers with a RFNBO sub-quota. The regulation applies to commercial air transport flights. Therefore, the regulation applies to the whole aviation sector in the EU, regardless of flight destination or origin (it thereby includes outgoing international flights).

Figure 1: Policies to incentivise SAF uptake

Source: Authors' own compilation

[17] SAFs are non-fossil based alternative aviation drop-in fuels that can be blended with fossil kerosene and used in current aircraft. There are different production routes for SAF, which are either based on biogenic material (biofuels) or on a synthetic process in which carbon and hydrogen are combined (synthetic or e-fuels).

In this chapter, these policies are presented in a concise fashion to provide an overview of the targets, the scope and the definition of eligible SAFs. This chapter forms the basis for the following chapters and is based on a literature study of relevant legislative texts. Details on national legislation and implementation of EU policies as well as an overview of SAF categories can be found in the annex.

2.1 Policy targets and scopes

2.1.1 ICAO - CORSIA

ICAO framework

The ICAO, a specialised UN agency, is the main international organisation responsible for regulating emissions from international aviation at global level. ICAO has set two main climate targets (ICAO 2022e):

- 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 SAFs, low-carbon aviation fuels and other aviation technologies (like hydrogen) (ICAO 2023d).

The implications of the LTAG's adoption have to be further clarified, including the question of interim targets. However, the LTAG addresses the absence of a mid-century reduction target for international aviation. In order to reduce emissions, ICAO plans to implement a range of measures, including technical and operational measures to enhance fuel or energy efficiency, the use of SAFs, and the purchase of offset certificates. The latter is implemented via CORSIA, which was adopted in 2016. CORSIA has the objective of offsetting all CO_2 emissions above a certain baseline. Nevertheless, CORSIA has been subject to criticism on account of a number of shortcomings (Broekhoff et al. 2020; ICF Consulting et al. 2020; Siemons et al. 2021). Furthermore, the adoption of substantial policy instruments to achieve the new LTAG has not yet occurred.

As of September 2024, 129 states have agreed to participate in the voluntary phase of CORSIA from 2024 onwards.[18] Five major countries (Brazil, China, India, the Russian Federation and Vietnam) have not signed up to CORSIA, but are expected to join based on the activity requirements set out for the mandatory phase of CORSIA starting in 2027.

Scope of CORSIA

CORSIA has the objective of offsetting all CO_2 emissions above a baseline within the time-frame of 2021 to 2035. The ICAO Council has agreed to use 2019 emissions as the baseline for the 2021-2023 period, rather than the average for 2019 and 2020, due to the impact of the global pandemic and the associated travel restrictions, which resulted in unusually low emissions in 2020. This has resulted in no offsetting requirements for 2021 and 2022; no offsetting requirements are expected for 2023 either. Hence, emissions of the State Pairs subject to CORSIA offsetting requirements are lower in these reporting years compared to the baseline of 2019. For the remaining phases (2024-2035 period), ICAO Member States agreed on a baseline of 85% of 2019 emissions (ICAO 2022a). Offsets are called “eligible emission units” under CORSIA. ICAO has defined eligibility criteria for offsets to be used under CORSIA, for example on

[18] https://www.icao.int/environmental-protection/CORSIA/Pages/state-pairs.aspx

permanence and double counting (ICAO 2019). There is also an approved list of carbon crediting programs and their eligible emission units (ICAO 2021).

Airlines may reduce their offset obligation under CORSIA by using SAFs, or so-called CORSIA-eligible fuels (see below). How CORSIA is implemented in the EU is described in section 2.1.4 below.

2.1.2 EU - RED

Scope and targets

The RED (Directive (EU) 2018/2001) sets targets for the share of renewable energy in the EU in 2030. The RED II was amended in October 2023 (now RED III,[19] EU (2024)). As the RED is a directive, national implementation may differ (in contrast to the situation with a regulation). Implementation is currently underway; Member States have 18 months to implement the newly adopted RED III (see Annex A.1 for Germany's implementation). Several stakeholders pointed out in the interviews that differences in national transposition of the RED, especially with a view to the feedstocks, are an obstacle in the uptake of SAFs as aviation is by its very nature international. Additionally, one of the stakeholders required more clarity on whether national e-SAF obligations are to be expected. This is because investment cycles take at least seven years for already available technologies and may take longer for new technologies.

According to RED III, the share of renewable energy in the EU's overall energy consumption shall be increased to 42.5% by 2030, with a collective effort to reach 45%. There are sector-specific sub-targets, including for transport (to which aviation contributes). Member States can choose between fulfilling a binding target of an at least 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 has a specific combined sub-target for advanced biofuels and RFNBOs in the share of renewable energy supplied to the transport sector: 1% and 5.5% in 2025 and 2030 respectively, of which RFNBOs have to constitute a minimum of one percentage point in 2030.

Generally, the RED III fuel targets have to be achieved by the transport sector as a whole, without specific targets for the aviation sector.[20] However, since ReFuel aviation contains an ambitious SAF-quota specifically for aviation, it is likely that a substantial share of the RFNBO (and possibly the combined advanced biofuel/RFNBO) target of RED III will be fulfilled with SAF.

RED also established a mass balance system as a chain-of-custody system under Article 30(1) for the fulfillment of the RED targets.

Multipliers for advanced biofuels and 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 and advanced and waste-based biofuels count twice). On top of the general multipliers, advanced biofuels used in aviation (or maritime) will count 1.2x towards the target. RFNBOs supplied to aviation (and maritime transport) will count 1.5x towards the respective target. The multipliers for aviation and maritime transport are additional in order to incentivise the use of these fuels specifically in those sectors. Hence, RFNBOs used in aviation (or maritime) add up to a multiplier of 3. These multipliers effectively reduce the actual amount of alternative fuels needed to fulfil the targets.

[19] The RED III is formally a recast of the RED II, see consolidated version of RED: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02018L2001-20240716

[20] There is no differentiation anymore between the sectors contributing to the denominator and to the numerator of the renewable share targets (as in RED II), deleting the optional contribution of maritime transport and aviation.

2.1.3 EU: ReFuelEU Aviation Regulation

Scope and targets (SAF quotas)

ReFuelEU Aviation (EU 2023/2405) is a new regulation on EU level and part of the 'Fit for 55' package. The regulation aims to promote the uptake of SAF through SAF blending obligations for fuel suppliers. The blending obligation or fuel quota starts in 2025 and increases to 70% in 2050. Besides an overall SAF quota, there is a sub-quota for RFNBOs, which starts in 2030 (Table 3). The quotas are given as minimum shares to be provided by fuel suppliers at each Union airport.[21] ReFuelEU Aviation also obliges airlines to refuel at least 90% of the annually required fuel volume for outgoing flights at EU airports. The regulation applies to commercial air transport flights (aircraft operators with a minimum yearly passenger or cargo transport flights departing from EU airports). Therefore, the regulation applies to the whole aviation sector in the EU, regardless of flight destination or origin. It thus includes outgoing international flights.

Table 3: Fuel quotas under the ReFuelEU Aviation

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

Source: Regulation on ensuring a level playing field for sustainable air transport https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R2405, quota as volumetric share of the total amount of fuel

The quotas aim to create a market for SAF with a long-term perspective. To accommodate the initial incomplete market, ReFuelEU Aviation includes a flexibility mechanism in Article 15: a transitional period up to 2034 allows fuel suppliers to reach the SAF target through a weighted average of the quantities that they have supplied across EU airports. Clarifications on this flexibility mechanism have not been published at the time of writing (although scheduled for July 2024). However, according to Agora Verkehrswende – based on indications from the Commission – this flexibility mechanism will probably apply at Member State level. Hence, the targets should be fulfilled with a weighted average at EU airports within each Member State (Agora Verkehrswende; PtX Hub 2024).

One of the interview partners welcomed that the flexibility system allows aviation fuel suppliers to concentrate their supply on bigger airports and/or those connected to a pipeline system.

[21] "Union airport" is defined in the ReFuelEU Aviation Regulation (EU 2023/2405, Art.3) as an airport "where passenger traffic [is] higher than 800 000 passengers or where the freight traffic [is] higher than 100 000 tonnes in the previous reporting period, and which is not situated in an outermost region".

2.1.4 EU: EU ETS

Scope and targets

The revised EU ETS Directive covers CO_2 emissions from flights depending on the route.[22] Currently, flights within and between EEA countries and to the UK and Switzerland are covered by the EU ETS. Flights from the UK and Switzerland to EEA countries are covered by their national emissions trading systems in accordance with the agreements with these countries. From 2024 onwards, additional flights to and from outermost regions will be covered by the EU ETS unless they connect to the respective mainland (the Member State to whose territory they belong). The temporary limitation of EU emissions trading may be phased out by the end of 2026 (Article 28a(1) EU Emissions Trading Directive). According to Article 28b(2), the Commission shall publish a report assessing CORSIA`s environmental integrity by 1 July 2026, including its general ambition in relation to targets under the Paris Agreement. The report shall be accompanied by a legislative proposal, as appropriate, to amend the EU ETS Directive in a way that is consistent with the Paris Agreement temperature goal and the Union's economy-wide greenhouse gas goals (Article 28b(3). Flights to/from and between third countries participating in CORSIA are covered by CORSIA. Exemption from the above-mentioned regulations pertains solely to domestic flights within non-EEA countries and flights to and from some least developed countries and small island states. In the special case of non-EEA-based aircraft operators that operate international routes within the EEA, a CORSIA cancellation obligation from their home country may additionally apply.

Table 4: Overview scope of 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. Flights connecting the outermost region with other aerodromes of the same Member State are exempt until 2030. Non-EEA-based operators: additional CORSIA if applicable	
Flights to/from and between third countries participating in CORSIA	All operators: CORSIA (Administration in the home country in each case)		
Flights to/from third countries NOT participating in CORSIA	Exempt		All operators: EU ETS (subject to review mechanism in Art. 28 EU ETS Directive)
Flights to/from least developed countries and small island states	Exempt		

Source: Adapted from Graichen and Wissner (2023)

[22] EU ETS Directive (2003/87/EC), consolidated version 2024: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02003L0087-20240301 EU ETS Directive (2003/87/EC), consolidated version 2024: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02003L0087-20240301

Cap and allocation

The cap defines the available number of emission allowances. The directive anticipates the continued calculation of a separate cap for aviation, in accordance with the previous approach. Nevertheless, emission allowances are freely tradable with other sectors within the EU ETS and may be used by all sectors to fulfil their emissions obligations.

From 2013 to 2020, the aviation cap was fixed at 95% of the emissions in 2004–2006 (Article 3c). In the years 2021-2023, the cap was reduced by 2.2% per year based on the 2020 allocation. In the period of 2024 to 2027, the reduction factor is increased to 4.3% per year and related to the 2023 emission allowances for active aircraft operators. After 2027, the linear reduction factor shall be 4.4%. The linear reduction factor is hence the same as for the stationary sector (Article 9). Furthermore, the cap is adjusted to account for newly covered flights from 2024 onwards and may also be adjusted for new flights from 2027, as appropriate. In contrast to the stationary sector, no one-off reduction in the number of emission allowances is foreseen. While the joint cap for the stationary and maritime sector will drop to zero in 2040, the current legislation would mean that the aviation cap would drop to zero only a few years later.

To date, the majority of emission allowances in the aviation sector have been allocated for free to operators. Only 15% of aviation allowances have been auctioned. In 2024 and 2025, the proportion of allowances to be auctioned is gradually increased. In 2024, 25% of the amount previously allocated for free is to be auctioned, and in 2025, this figure is to be increased to 50%. From 2026 onwards, all allowances (with the exception of 20 million allowances to be allocated for the uptake of SAF, as detailed below) will be auctioned (Recital 14 and Article 3d(1)). The free allocation of emission allowances in the two-year period in question is distributed according to the aircraft operators' share of verified emissions for 2023 (Article 3d(1a)). Furthermore, emissions from additional routes will be included in the share calculation from 2024 onwards.

The EU ETS Directive lists alternative fuels for which the emission factor shall be zero: biofuels; renewable fuels of non-biological origin (RFNBOs), recycled carbon fuels (RCFs) and synthetic low carbon fuels (SLCFs), under the condition of compliance with the criteria set out in the RED on biomass feedstocks, that the for electricity used for RFNBO is renewable and additional and GHG emission savings (at least 70% compared to a comparable fossil fuel on a life-cycle basis). Aircraft operators using such fuels on routes covered by the ETS reduce their surrender obligation under the ETS for these flights.

The Monitoring and Reporting Regulation (EU 2018/2066, Art. 54 and 54a) specifies the rules under which eligible aviation fuels may be claimed within the ETS. They should be certified in accordance with the RED and the relation between claimed eligible fuel and usage during flight should be established. For mixed aviation fuels, a mass balance approach or purchase records may be used to establish the exact shares of fossil and eligible fuels.

Routes covered by CORSIA and EU implementation of CORSIA

EEA-based operators and operators from other countries on flights to and from states outside the European Economic Area participating in CORSIA need to cancel CORSIA offsets for these flights if the emissions of the entire sector are higher than in the baseline year 2019, minus 15% ("Carbon Neutral Growth") and are exempted from the surrender obligation of the EU ETS (Article 25a(4) of the EU ETS Directive). As non-EEA operators are already subject to the obligation to cancel offsets under CORSIA in their home country, this avoids the imposition of a double surrender or cancellation regulation and double reporting.

Flights to and from countries that do not participate in CORSIA are initially exempt from all surrender obligations, as set forth in Article 25a(5) and 28 of the EU ETS Directive. However, from 1 January 2027, they may be subject to the EU ETS. This will result in a considerably higher surrender obligation than that which currently applies under CORSIA.

Within the EU ETS Directive, the EU has also defined how CORSIA shall be implemented for EEA-based carriers. Generally, ICAO decides which offsets are acceptable under CORSIA. The revised ETS Directive further defines different offset requirements for EEA aircraft operators (Article11a(2,3)): 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 (Article 11a(1)). These are offsets from:

- an international mechanism established under Article 6(4) of the Paris Agreement,
- from projects in third countries given the aircraft operator has not used up their 2008-2012 budget, and
- emission reductions from projects in EU Member States according to Article 24a.

Based on implementing acts, the EU Commission will draw up a list of acceptable offsets for use under CORSIA (Article 11a(8)).

Further, the use of sustainable fuels (CORSIA eligible fuels) can be credited within the framework of CORSIA.

The EU Commission is obliged to report every three years from 2027 on any progress made by the ICAO on implementing measures to achieve ICAO's LTAG of net zero emissions in 2050, any progress on CORSIA participation and other third country market-based measures. Based on a report due by 2026, a proposal shall be made to expand the scope of the EU ETS to include departing flights from the EEA to third countries if CORSIA has not been sufficiently strengthened and participation increased. CORSIA offsetting costs would be deducted on these routes to avoid double charging. The EU also has the option of reacting 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. This extension might also impact future (blending) strategies of assigning SAF to different routes.

2.2 Eligible aviation fuels and definitions under each policy

2.2.1 CORSIA-eligible fuels

Any emission reductions achieved through the use of CORSIA-eligible fuels (CEFs) can be subtracted when determining an airline's total offsetting requirements (ICAO 2023a). Batches of CEF can only be claimed under one GHG scheme, i.e. either CORSIA or the EU ETS. Besides this, the ICAO requirements on CEF do not specify on which routes CEFs have to be used. Consequently, CEF use might be claimed under CORSIA even though they were supplied to aircraft on international flights not subject to CORSIA or on domestic flights. The latter could be favourable for airlines from countries which have a relatively large domestic market (e.g. USA and China).

ICAO developed a framework to define what fuels are eligible. This framework also includes sustainability criteria. There are two types of CEFs:

- sustainable aviation fuels (SAFs) – renewable or waste-derived biofuels[23]; and
- lower carbon aviation fuels (LCAFs) - fossil-based fuels with lower life-cycle emissions.

Examples of SAFs are biofuels such as Hydroprocessed Esters and Fatty Acids (HEFA) from used cooking oil and Alcohol-to-jet (AtJ) fuels based on agricultural residues (ICAO 2022b). LCAF are fuels for which, for example, lower life-cycle emissions come about by means of measures such as carbon capture and sequestration (CCS), the use of renewable and low carbon intensity hydrogen, and renewable and low carbon intensity electricity (ICAO 2024b). For a fuel to be eligible, it 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 June 2023, two SCS have been approved by the ICAO (ICAO 2023c) for certifying fuel producers and other economic operators along the supply chain if they meet certain requirements (ICAO 2024a). The two SCS approved are International Sustainability and Carbon Certification (ISCC) and Roundtable on Sustainable Biomaterials (RSB). Under CORSIA, certified fuel producers are allowed to apply a mass balance system at site level (ICAO 2024a, p. 10). A working paper from ICAO's 41st Assembly further acknowledges that a book-and-claim system could accelerate SAF deployment – though without any binding commitments (ICAO 2022d, p. 4).

CEFs produced before 2024 need to meet two sustainability "themes" or criteria (with sub-criteria) to be eligible, which apply to both SAF and LCAF (ICAO 2022c):

- Lower GHG emissions on a life-cycle basis: net GHG emissions from CEFs 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.

Life-cycle emissions of SAF can be determined either by using ICAO approved default values (ICAO 2022b), or by calculating actual life-cycle emissions via a CORSIA methodology (ICAO 2024b). For LCAFs, no default values are provided; actual life-cycle emissions need to be calculated.

Baseline life-cycle emissions for conventional aviation fuels are given as 89 gCO_2e/MJ for Jet-A / Jet-A1/ Jet-B / TS-1 / No. 03 Jet Fuel and as 95 gCO_2e/MJ for AvGas in (ICAO 2024b, p. 2). Two sets of sustainability criteria apply to fuel batches of SAFs and LCAFs respectively if produced in 2024 or later (ICAO 2022c). The criterium on lower GHG emissions still applies to both fuel types and the carbon stock criterium from above has been refined for both fuels. There are 12 new requirements or safeguards for both fuel types: permanence of emission reductions, water, soil, air, (biodiversity) conservation, waste and chemicals, seismic and vibrational impacts, human and labour rights, land use rights and land use, water use rights, local and social development, and food security. There are small differences between the two criteria sets: criterium 3 on permanence of emission reduction has more sub-criteria for LCAFs, and criterium 9 on seismic and vibrational impacts is not applicable to SAFs.

[23] Sustainability criteria for synthetic kerosene (e-fuels) still have to be defined under CORSIA (Agora Verkehrswende, PtX Hub 2024).

2.2.2 RED fuel definition and sustainability criteria

The RED plays a fundamental, supportive role for both the EU ETS Directive and ReFuelEU Aviation Regulation on three levels.

Firstly, the RED lays down the definition of RFNBOs, advanced biofuels and recycled carbon fuels (RCF). ReFuelEU Aviation and the EU ETS Directive refer to the RED for the definition of those fuels.

Secondly, the RED sets the emission savings and sustainability criteria for those fuels. These criteria – and the verification of compliance with these criteria - need to be followed to comply with the definition of SAFs in other pieces of EU legislation. Emission savings criteria are specified in Art. 29 of the RED III and the verification of compliance is described in Art. 30 of the RED III. The RED has also been supplemented with two delegated acts that specify the calculation rules for hydrogen to be regarded as renewable.[24] The first delegated act describes the conditions of additionality of electricity production when hydrogen is produced by electrolysis. This is to ensure that hydrogen is produced from additional electricity in the same area and does not hamper direct electrification. The second delegated act sets the methodology for calculating the full life-cycle GHG emission savings resulting from RFNBOs and RCFs.

Thirdly, the RED prescribes a multiplier for advanced and waste-based biofuels and RFNBOs, an additional multiplier of 1.2 for advanced biofuels and 1.5 for RFNBO applies when the fuel is supplied to the aviation (and maritime) sector (section 2.1.2). The RED also sets a cap on the use of biofuels produced from feedstock listed in Annex IX B. As described above, these multipliers are intended to stimulate the use of the relevant fuels.

2.2.3 ReFuelEU-eligible SAFs

ReFuelEU Aviation sets out which fuels are eligible to fulfil the SAF quota. There are three types of eligible fuels which are defined in the regulation in reference to RED:

- **Synthetic aviation fuels** (RFNBOs like e-kerosene and renewable hydrogen), as defined in Article 2, second paragraph, point 36 of the RED, which comply with the life-cycle emission savings threshold referred to in Article 25(2), first sub-paragraph of that directive and are certified in compliance with Article 30 of that directive;
    - **low-carbon fuels for aviation** (like synthetic drop-in aviation fuels derived from low-carbon hydrogen, the usage of which results in life-cycle GHG emission savings of at least 70%) are allowed to be used to fulfil SAF obligations. This is also the case for low-carbon hydrogen. The category of low-carbon aviation fuels does not count towards the RED III targets and is specifically set up to accommodate non-fossil, non-renewable hydrogen (derived) fuels (i.e. from nuclear energy).
- **Aviation biofuels**, which fall into one of the following categories:
    - advanced biofuels as defined in Article 2, second paragraph, point 34 of the RED. Meaning biofuels that are produced from feedstocks listed in Part A of Annex IX of the RED;
    - biofuels produced from the feedstocks listed in Part B of Annex IX to the RED; or
    - other biofuels (not listed in Annex IX) with the exception of biofuels produced from ‘food and feed crops’ (such as starch-rich crops, sugar crops or oil crops produced on

[24] Delegated regulation - 2023/1185 - EN - EUR-Lex (europa.eu); EUR-Lex - 02023R1184-20240610 - EN - EUR-Lex (europa.eu)

agricultural land as a main crop excluding residues, waste or ligno-cellulosic material) and intermediate crops (such as catch crops and cover crops, provided that the use of such intermediate crops does not trigger demand for additional land), and palm fatty acid distillate and palm and soy-derived materials, and soap stock and its derivatives (if not included in Annex IX). These 'other biofuels' shall comply with the sustainability and life-cycle emission savings criteria laid down in Article 29 of the RED and are certified in compliance with Article 30 of that directive.

- **Recycled carbon aviation fuels** as defined in the RED. This means liquid and gaseous fuels that are produced from liquid or solid waste streams of non-renewable origin which are not suitable for material recovery in accordance with Article 4 of the Waste Framework Directive, or from waste processing gas and exhaust gas of non-renewable origin which are produced as an unavoidable and unintentional consequence of the production process in industrial installations.

The **renewable share of fuels produced through co-processing** is also eligible under the definition of biofuels (and hence SAF) as long as the renewable share is produced from feedstocks listed in RED III.

For synthetic aviation fuels (e.g. RFNBOs) – which are not yet on the market – a sub-quota is introduced from 2030 onwards. For aviation biofuels other than biofuels from Annex IX feedstocks, a maximum of 3% of fuel supplied required by the target is applied.

2.2.4 SAFs under the EU ETS and fuels eligible for ETS support (FEETS)

The EU ETS Directive lists alternative fuels for which the emission factor shall be zero if compliant with the criteria set out in the RED: biofuels; renewable fuels of non-biological origin, recycled carbon fuels and synthetic low carbon fuels. Thus, aircraft operators using SAFs and claiming this use in their annual emission reports can lower the amount of allowances to be surrendered. For mixed aviation fuels (partly alternative and partly fossil), the aircraft operator may estimate the eligible content on the basis of a mass balance approach or purchase records for the emissions report, with evidence to the competent authority. In addition, flights must have actually taken place from the relevant airports within the scope of the EU ETS. The exact requirements are laid down in the Monitoring and Reporting Regulation (EC 2024).

There is now an additional support for the uptake of SAFs provided in the ETS Directive. Between 2024 and 2030 a maximum of 20 million allowances of the total quantity of allowances for aviation shall be allocated to commercial aircraft operators for the uplifting of SAF to cover part of or all of the price difference between SAF and fossil kerosene (Article 3c(6)). The ETS Directive defines the types of SAFs which are considered 'eligible aviation fuels' for FEETS support (Art.3c(6)):

- hydrogen from renewable energy sources as defined in RED,
- advanced biofuels as defined in RED,
- RFNBOs as defined in RED, and
- other eligible fuels of non-fossil origin.

The details of this support mechanism for ETS-eligible aviation fuels (FEETS) are currently still under development with respective implementing acts expected in 2025. During the stakeholder interviews, a fuel provider highlighted that this rather late timing contributed to the uncertainty in the market; airlines were reluctant to purchase SAFs as long as they cannot approximate the amount of support provided.

2.3 Conclusions

On an EU level, the three key EU policy instruments for the uptake of sustainable aviation fuels are the RED, the EU ETS and the ReFuelEU Aviation Regulation. The EU ETS creates a carbon market for obligated parties, mainly large industrial sites, but also aviation and recently maritime transport. The RED contains targets for renewable energy, including specifically for the transport sector, to which aviation contributes. ReFuelEU Aviation is a recent regulation and constitutes the cornerstone legislation for the uptake of SAF.

On a global level, CORSIA is currently the only policy instrument for the uptake of SAFs. Further measures are still being negotiated at the ICAO.

In the EU, ReFuelEU Aviation is the main policy instrument for accelerating the uptake of SAF by setting specific targets up to 2050. The inclusion of aviation in the EU ETS increases the price of fossil kerosene and hence provides an additional incentive for the uptake of SAF. Under both EU ETS and CORSIA, there is an incentive to deploy SAFs, but as allowance/offset prices are higher, the EU ETS is more attractive for claiming SAFs.

The RED III defines sustainability criteria for different SAF types and is referred to in both the EU ETS Directive and ReFuelEU Aviation. European legislation is thus largely harmonised. There are, however, slight differences between the policies in terms of which types of aviation fuel are eligible to count towards which targets.

A more detailed overview of SAF categories across the different legislation is provided in the annex. While the RED also sets targets for biofuels and RFNBOs, with additional incentives if these fuels are used in aviation, the effect of RED also depends on the national implementation of RED III. The national implementation in Germany is still ongoing.

3 SAF certification and administrative requirements under different policies

The main goal of SAF replacing fossil kerosene is to reduce the negative climate impact of aviation. To safeguard that this goal is achieved and to prevent unintended negative impacts on the environment, SAF certification is required for the use in aviation. To certify the final product, quality control of the entire supply chain is necessary.

In this chapter, we first describe the certification process of SAFs and the different requirements between regulatory frameworks. Following this, we outline the administrative requirements of the relevant aviation policies. Section 3.3 explains the national context regarding certification, reporting and verification. The differences between the requirements and the conclusions are summarised in section 3.4.

3.1 SAF certification

SAF certification is the process of confirming compliance with regulatory requirements from policy frameworks. This section first describes the SAF certification process for neat SAFs. When blending the SAFs with fossil fuels, the certificates are transferred to the blend. Furthermore, we touch on the specific requirements for SAF production in co-processing. We elaborate on the differences and similarities of the regulatory regimes in terms of feedstock sustainability. Finally, we address practical issues that arise with SAF certification, e.g. the Proof of Sustainability (PoS), voluntary certification schemes, fraud and the relation with the Union Database (UDB).

3.1.1 General overview

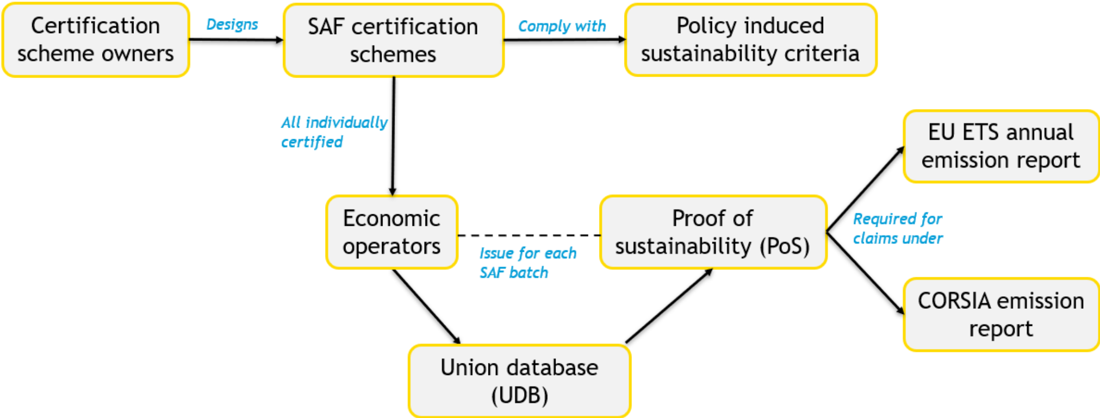
Certification schemes establish rules and requirements for issuing certificates of conformity or compliance with regulatory regimes as the RED[25] and CORSIA to economic operators. Economic operators are, for example, feedstock producers, SAF production plants, traders and storage units (ISCC 2023b). Each economic operator in the supply chain who handles a sustainable product needs to be certified, and re-certified or checked regularly. This is carried out by certification bodies (CB) (third-party certification) against the requirements set out in the certification schemes. Generally, a certification scheme ensures the following (IATA 2024c; ISCC 2023a):

- feedstock production sustainability;
- traceability and chain of custody (CoC) of sustainable materials through the supply chain; and
- verified reduction of GHG emissions.

Figure 2 shows a schematic overview of the SAF certification process. The sustainability of feedstock production concerns the type of feedstock (e.g. used cooking oil (UCO), palm, soy, waste, algae etc.) and indirect land use change (ILUC). Crop biofuels, for instance, can contribute to deforestation. ILUC refers to the clearing of land to allow for the expansion of the overall agricultural area to meet additional demand for land for energy production (T&E 2023).

[25] ReFuelEU Aviation and the EU ETS Directive both refer to the RED for the sustainability criteria of SAFs.

Figure 2: Schematic overview of the SAF certification process



Source: Authors' own illustration, based on IATA (2024c), ISCC (2023a) and https://www.iscc-system.org/certification/union-database-udb . Once operational, the PoS is transferred via the UDB.

The ICAO currently recognises only the International Sustainability and Carbon Certification (ISCC) and the Roundtable on Sustainable Biomaterials (RSB) certification schemes. Although the European Commission formally approved 15 certification schemes for SAF certification, only the schemes of the ISCC and RSB are currently used in the market. All 15 approved certification schemes can be found on the homepage of the EU Commission.[26] These certification schemes are currently only approved for biofuels. The European Commission is currently reviewing the proposed extensions to the scope of current approved certification schemes and new certification schemes that approve RFNBO.

For both regulatory frameworks, the ISCC and RSB developed specific certification schemes. Table 5 presents an overview of these schemes, including the schemes allowed in the voluntary market.

Table 5: SAF certification schemes

	ISCC	RSB
ICAO CORSIA compliance	ISCC CORSIA	RSB ICAO CORSIA
EU RED compliance	ISCC EU	RSB EU RED
Voluntary market	ISCC CORSIA, ISCC EU, ISCC PLUS	RSB ICAO CORSIA, RSB EU RED, RSB GLOBAL

Source: IATA (2024c)

3.1.2 Co-processing certification

Co-processing is a method by which renewable feedstocks (biomass) are co-processed with crude oil in a single process within refineries.[27] Since kerosene and other products like diesel are not strictly separated during the refining process but split at the end, it is important to define the final products in which the renewable feedstocks end up and whether the molecules from biological origin are traceable. If the renewable materials end up in the light aviation fuel, a

[26] https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/voluntary-schemes_en

[27] https://www.sustainableaviationfutures.com/saf-spotlight/coprocessing-topsoe

blend of fossil and biofuel is produced and no blending is necessary (see discussion on supply chains in Section 4.4). Depending on the exact process, the SAF blend can be certified under the certification schemes. To qualify for the RED, it is essential that the biofuel molecules can be tracked and actually end up in the jet fuel and not in other final products.

3.1.3 Difference and similarities between the certification schemes

Feedstock sustainability in RED and CORSIA

RED allowed feedstocks are listed in Annex IX of the regulation. Part A of Annex IX lists the allowed feedstocks of advanced biofuels; and Part B refers to the allowed feedstocks for biofuels from used cooking oil and animal fats (EU 2018). Certain feedstocks are capped in the RED (Table 6). This serves the purpose of, for instance, phasing out the use of palm- and soy-derived fuels which are likely to contribute to deforestation or to limit fraud and competing uses for used cooking oil (UCO) and animal fats (T&E 2023). Furthermore, feedstocks with high ILUC are capped. The delegated regulation (EU) 2019/807 determines in Recital 1 that "*high ILUC feedstocks for which a significant expansion of the production of area into land with high carbon stock is observed and the certification of low indirect land-use change-risk biofuels, bioliquids and biomass fuels*". In this delegated regulation, a feedstock is classified as high ILUC risk if the expansion into land with high-carbon stock, such as forests, wetlands and peat land is higher than 10%, causing additional GHG emissions which are held there (EC 2019).

Table 6: RED capped feedstocks and fuels

Feedstock	Cap
Food- and feed-based feedstocks (conventional biofuels)	Limited by the 2020 share of those fuels in the final energy consumption in each member state, with a maximum of 7%
UCO and animal fats (Annex IX part B)	1.7% cap
High ILUC feedstock	Capped at the level of consumption in 2019 of each member state. Starting from 31 December 2023, this will be gradually phased out by 2030 at the latest

Source: EC (2019)

The RED applies to the entire transport sector, resulting in no strict exclusion of certain feedstocks or feedstocks with high ILUC risk for aviation specifically. Nevertheless, Member States may enforce stricter regulations in their national implementation. Member States can reduce the cap on food- and feed-based biofuels. By doing so, they reduce the target level for the renewable fuel share in transport.

Under CORSIA, direct land use change (DLUC) in terms of SAFs made from biomass obtained from land converted after 1 January 2008 with high carbon stock is not allowed.[28] The ILUC are addressed via Life-Cycle Analysis (LCA) estimations of the emissions of a SAF batch. The total LCA emission value consists of ILUC emissions and the core LCA emissions (e.g. feedstock processing and conversion to fuel, fuel transportation and distribution, fuel combustion, etc.).

Consequently, ILUC is allowed, but indirectly regulated since they are counted as extra emissions. Both RED and CORSIA thus address ILUC, but in a different manner.

[28] Life Cycle Emissions of Sustainable Aviation Fuels: https://www.icao.int/environmental-protection/pages/SAF_LifeCycle.aspx

Compared to the RED, CORSIA requires additional social criteria for SAF. From 1 January 2024, criteria address the impact on water, soil, air, conservation, waste and chemicals, human and labour rights, land use rights and land use, water use rights, local and social development and finally food security. The principle behind the themes and the criteria can be found in ICAO (2022c).

Both the ReFuelEU Aviation Regulation and the EU ETS Directive refer to the RED and relevant Union law (Directive (EU) 2024/1788) to define eligible fuels[29]. ReFuelEU Aviation, however, has stricter regulations regarding the use of certain feedstocks compared to the RED. The differences are as follows (T&E 2023; NOW 2024):

- Biofuels other than the ones listed in Annex IX are capped at 3% to count towards the SAF target of ReFuelEU Aviation;
- Feed and food crop-based biofuels, palm and soy-derived materials, palm fatty acid distillate (PFAD), (non-Annex IX) intermediate crops and soap stock and its derivatives are all excluded from the definition of SAFs and thus excluded from the SAF target.

Voluntary certification schemes

The choice of a certification scheme depends on the regulatory or voluntary framework the PoS is required for. Examples for voluntary markets are presented in Table 7. In the voluntary market (e.g. firms reporting under the GHG protocol) all SAF certification schemes are allowed, while ISCC plus[30] and RSB[31] global are not allowed for the RED and CORSIA. The main difference between the voluntary and regulatory certification schemes are the scope / feedstocks that can be certified. While the RED excludes and/or caps biofuels made from food and feed feedstock, all types of renewable feedstocks are allowed under ISCC plus certification, including the ones outside the framework of the RED.

Table 7: Voluntary markets in which SAFs are used

Name of initiative	Explanation
Greenhouse Gas Protocol (GHGP)	Sets global standard for companies to measure and manage their GHG emissions. Category 6 Business Travel falls under scope 3 emissions and can be reduced by SAF claimed reductions.
Science Based Target initiative (SBTi)	SAF follows the precedent for bioenergy use outlined in the SBTi Criteria and Recommendations document and the GHG Protocol guidance.
Corporate Sustainability Reporting Directive (CSRD)[32]	Feedstock must comply with sustainability criteria defined in the Renewable Energy Directive (RED II).

Source: GHGP: https://ghgprotocol.org/, SBTi: https://sciencebasedtargets.org/sectors/aviation, CSRD: https://normative.io/insight/csrd-explained/

GHG emission reductions

Different GHG emission savings are required under RED and CORSIA. Firstly, the fossil fuel baseline is not the same. Under the RED, it is set at 94 g CO_2e/MJ, while under CORSIA it is set at

[29] According to ReFuelEU Aviation Art.4, this encompasses SAF, renewable hydrogen for aviation and low-carbon aviation fuels.

[30] https://www.iscc-system.org/certification/iscc-certification-schemes/iscc-plus/

[31] https://rsb.org/programmes/projects/fuelling-the-sustainable-bioeconomy/

[32] Currently voluntary; depending on the business size, it will become mandatory between 2025 and 2029.

89 g CO_2e/MJ.[33] Additionally, the required GHG reduction differs. CORSIA requires a minimum reduction of 10%, whereas the RED requires at least 65% for biofuels and a 70% reduction for RFNBO's. Consequently, the maximum GHG emission factors for SAFs are 32.9g CO_2e/MJ for biofuels and 28.2 g CO_2e/MJ for RFNBO's under the RED, while under CORSIA the maximum is significantly higher at 80.1 g CO_2e/MJ.

3.1.4 Proof of Sustainability (PoS) and Proof of Compliance (PoC)

For each shipment along the supply chain, i.e. each batch of outgoing sustainable material, either raw material, an intermediate product or the end product SAF, an economic operator must provide a proof of sustainability (PoS) documentation. The PoS can only be used once. Meaning that if a fuel supplier needs it for ReFuelEU Aviation or, for instance, for national regulations (the HBE[34] system in the Netherlands), the fuel supplier cannot duplicate the PoS for aircraft operators who would need for exemption from surrendering EU ETS allowances or CORSIA offsets (IATA 2024c). To address this issue, ISCC and RSB have proposed a Proof of Compliance (PoC) concept (IATA 2024c). This document serves the same purpose as a PoS, but is issued if the PoS has already been surrendered to competent authorities. The competent authorities of Member States can allow this to be used as long as the UDB or a national database cannot reflect use by two parties. In Germany, no such communication has yet taken place.

In addition, a rising number of corporate travelers try to comply with their scope 3 emissions reduction targets (e.g. business travel) and want to claim these reductions under voluntary schemes. This was also mentioned in an interview with an airline. Due to the additionality problem, this SAF is not claimed under EU ETS as the customers want to claim the additional environmental benefit and pay a premium to use it for communication purposes[35].

3.1.5 Union Database (UDB)

The Union database (UDB), set up by the European Commission, shall facilitate the tracing of biofuels and renewable fuels (RED III, Art. 31a). It has been developed to avoid the risk of double counting (i.e. claiming the emission reduction of one batch of SAF twice) and mitigate the risk of fraud. The UDB is expected to be fully operational on 21 November 2024 for liquid and gaseous renewable fuels (RED III, Art. 31a).[36] The tracing of RFNBOs and RCFs will follow in further expansion stages. A bi-directional connection from Nabisy to the UDB is planned, but the recognition of biofuels via the UDB for Germany was not permitted at the time of writing. While stakeholders welcomed the UDB in our interviews, they highlighted that the late implementation posed a major obstacle for its use in 2025.

All economic operators participating in the SAF fuel supply chain will be obliged to record their transactions in the UDB. Certification schemes will then verify that transactions are properly recorded in the UDB by the economic operators (IATA 2024c).

The UDB is expected to contribute to the mitigation of fraud. Biofuel fraud can occur when, for instance, UCO as feedstock is mislabeled as 'used' to take advantage of the value of these supposedly sustainable fuels. The share of biofuels imports is very high. Currently, 80% of UCOs

[33] https://www.easa.europa.eu/eco/eaer/topics/sustainable-aviation-fuels/how-sustainable-are-saf#additional-effects-from-use-of-saf

[34] Hernieuwbare Brandstof Eenheden (HBE) is Dutch for renewable fuel units.

[35] This situation increases, on the one hand, the competition for scarce biomass and clean energy while, on the other hand, being an additional emission reduction on top of the policy mandates.

[36] https://www.iscc-system.org/certification/union-database-udb/#:~:text=The%20UDB%20covers%20gaseous%20fuels,for%20the%20EU%20interconnected%20grid.

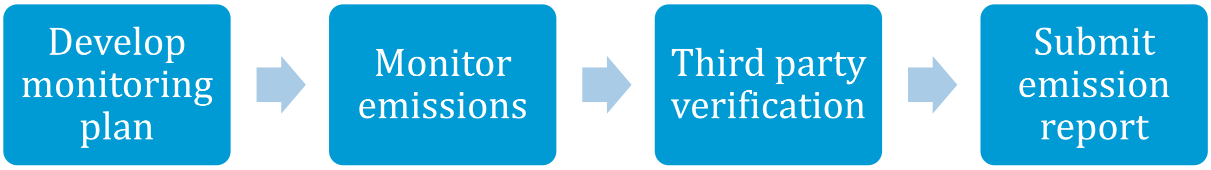
used in Europe are imported, of which 60% comes from China. The European Commission is currently examining the fraud allegations against biofuel imports from China.[37]

3.2 Administrative requirements

3.2.1 CORSIA

Since 1 January 2009, CORSIA has required all operators with annual emissions exceeding 10,000 tons of CO_2 emissions to report the annual emissions of their international flights.[38] The compliance cycle of CORSIA includes three steps: monitoring, reporting and verification (MRV) of the CO_2 emissions. Below is a brief summary of these steps; a more detailed explanation is found in the CORSIA handbook (IATA 2024a).

Figure 3: Compliance steps in CORSIA (simplified)



Source: Authors' own illustration

The first step for an aircraft operator is to develop an emission monitoring plan, which outlines how the data on actual fuel use will be collected and the method for calculating the CO_2 emissions. This plan must be approved by the administrating authority.

After each reporting year, aircraft operators must submit an annual emission report, which includes actual fuel consumption, calculated emission data, and CORSIA-eligible fuels used for emission reduction claims. Prior to the submission of the annual emission report to an administrating authority, the report needs to be verified by an impartial third-party verification body. The deadline for submitting the verified emission report is 30 April of the following year.

Aircraft operators may use a simplified monitoring method for flights not subject to offsetting requirements or if their total annual CO_2 emissions for flights subject to offsetting requirements are below 50,000 tonnes. If emissions exceed 50,000 tonnes for two consecutive years, they are no longer eligible for the simplified method. In this case, operators may use the ICAO CORSIA CO_2 Estimation and Reporting Tool (CERT) to calculate emissions based on the great circle distance or block time for a given aircraft type.

3.2.2 EU ETS

The EU ETS compliance cycle consists of the annual procedure of MRV. The rules related to the compliance cycle are harmonised in two regulations:

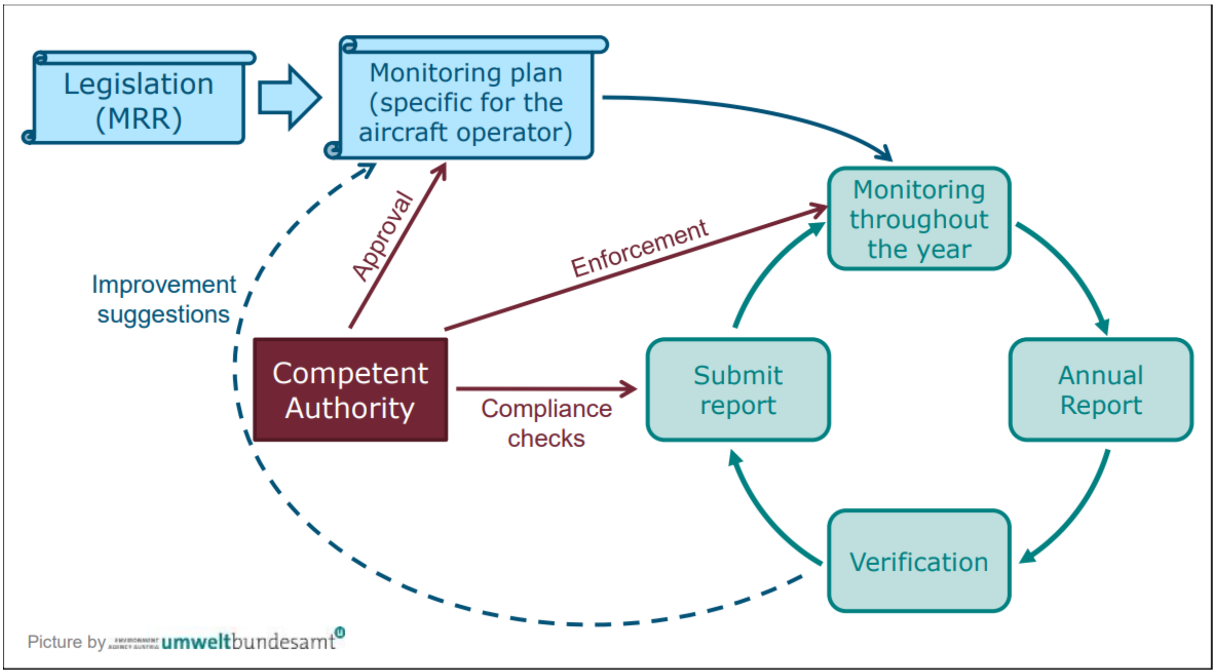
- Monitoring and Reporting Regulation (MRR);
- Accreditation and Verification Regulation (AVR).

[37] https://www.europarl.europa.eu/doceo/document/P-9-2024-000407-ASW_EN.html

[38] https://www.iata.org/en/programs/sustainability/corsia/#:~:text=Under%20CORSIA%2C%20all%20airline%20operators,to%20calculate%20their%20CO2%20emissions

Figure 4 shows the EU ETS compliance cycle. Airlines are obliged to develop a monitoring plan for tracking their annual emissions, which must be approved by the competent authority. Aircraft operators then monitor and record their emissions throughout the year and submit an emission report, which must be verified by an accredited or certified verifier by 31 March of the following year. The verified emission report determines the number of EU ETS allowances that an aircraft operator must surrender. From 2024, the deadline is set as 30 September of the following year.

Figure 4: Schematic overview of the EU ETS compliance cycle



Source: EC (2023) – The Monitoring and Reporting Regulation, general guidance for Aircraft Operators: https://climate.ec.europa.eu/system/files/2023-05/gd2_guidance_aircraft_en.pdf

3.2.2.1 MRR history and current status

Regulation (EU) 2018/2066 sets rules for the monitoring and reporting of GHG emissions in the EU (EC 2024). It is implemented in accordance with Directive 2003/87/EC which established the EU ETS and it amends and updates the previous regulation (No 601/2012). In October 2020, the regulation was amended with provisions on how to handle biofuels used for combustion.[39] In October 2023, the 2018 regulation was further amended, to take the revised EU ETS Directive (2023/958) into account.[40] This first batch of MRR revisions apply from 1 January 2024. The first batch amends, among others, Article 54 as follows:

- If the purchased biofuel is not physically delivered to a specific aircraft, the aircraft operator shall attribute the biofuels to its flights for which allowances have to be surrendered, proportionally to the emissions from those flights departing from the respective airport.
- The aircraft operator is only allowed to use purchase records of biofuels if it provides evidence to the competent authority that the biofuel was delivered to the airport fuelling

[39] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32020R2085, https://climate.ec.europa.eu/document/download/5309413f-8832-4803-b053-ce3714ec2739_en?filename=1.2%20Kunst%20-%20ETS_MRR%20progress%20ETS_0.pdf

[40] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=OJ:L_202302122#d1e1667-1-1

system during the reporting period or 3 months prior or 3 months after the period has ended.

These amendments specify that in order to qualify for a zero emission factor for the biogenic portion of fuel used in flights covered by the EU ETS, physical delivery to an airport is necessary, thus a **mass balance system at airport level**. Furthermore, the amendment states that there is no double counting of biofuel quantity as the purchased biofuel is not claimed in an earlier report by anyone else in another system.

One of the interview partners explicitly welcomed the recognition of the Central European Pipeline System (CEPS) as a mass balance system.

The second batch of revisions was published on 27 September 2024 and all articles shall apply from 1 January 2025. The updated regulation includes the following amendments[41]:

- From 1 January 2025, aircraft operators must monitor and report non-CO_2 aviation effects annually. However, for 2025 and 2026, mandatory reporting will apply only to routes between airports in the European Economic Area (EEA) and those between the EEA and Switzerland or the UK. The monitoring plan for CO_2 emissions should then also include non-CO_2 effects.
- Article 39a provides guidelines for determining and applying the RFNBOs, RCFs and synthetic low-carbon fuels (SLCFs) fractions within aviation fuel.

3.2.3 ReFuelEU Aviation

3.2.3.1 Reporting requirements

ReFuelEU Aviation (EU 2023) targets both fuel suppliers and aircraft operators. **Fuel suppliers** are obliged to report on the previous year to the Union Database by 14 February of each reporting year (starting in 2025). Reported data include the amount and energy content of aviation fuel and SAF supplied at each EU airport, specifics on the SAF supplied (production process, characteristics, feedstock, emissions, aromatics and naphthalene content).

ReFuelEU Aviation reporting obligations for **aircraft operators** (Article 8) require aircraft operators to report to the competent authorities and the Agency by 31 March each year, starting from 2025. The information to be reported includes the required and uplifted aviation fuel at each Union airport, the (non-)tanked quantity per Union airport, specifics on the SAF purchased (total amount, conversion process, characteristics, feedstock origin and emissions) and total flights operated covered by the Regulation (EU 2023).

The European Union Aviation Safety Agency (EASA) has developed a Sustainability Portal[42] for aircraft operators to fulfil the reporting obligations specified under Article 8 of the regulation. As of June 2024, competent authorities can invite aircraft operators to create an account ensuring they are ready before the reporting obligation begins.

In one of the stakeholder interviews, concerns were raised about the definition of fuel suppliers. The airline group purchases the fuel centrally and was unsure whether they would be classified as a fuel supplier even though the regulation might not intend this. Another interview partner drew attention to the fact that the level of the penalty is not known in advance, but only the year after. This creates uncertainty about the price differences for airlines.

[41] The second batch of amendments was published only after the paper was nearly complete. As a consequence, we only (partially) included it here.
[42] https://www.easa.europa.eu/en/domains/environment/refueleu-aviation-digital-reporting-tool

3.2.3.2 Verification requirements

The information entered by fuel suppliers in the UDB must be verified and audited by Member States, therefore requiring a necessary legal and administrative framework at national level to ensure the information is entered in a timely and accurate way.

Reports must be verified by independent verifiers and submitted to the competent authority and to the Agency for the purpose of monitoring and assessment of compliance. Independent verifiers should determine the accuracy of the yearly aviation fuel reported by the aircraft operators using a tool (i.e. ReFuelEU Aviation Sustainability Portal) approved by the Commission, in accordance with the requirements set out in Articles 14 and 15 of Directive 2003/87/EC.

3.3 German national context of reporting, verification and certification requirements

ReFuelEU Aviation reporting requirements do not need to be transposed into national law as it is not a directive but a regulation. EASA has developed a portal and a template[43] which can be used by operators and the German competent authority.

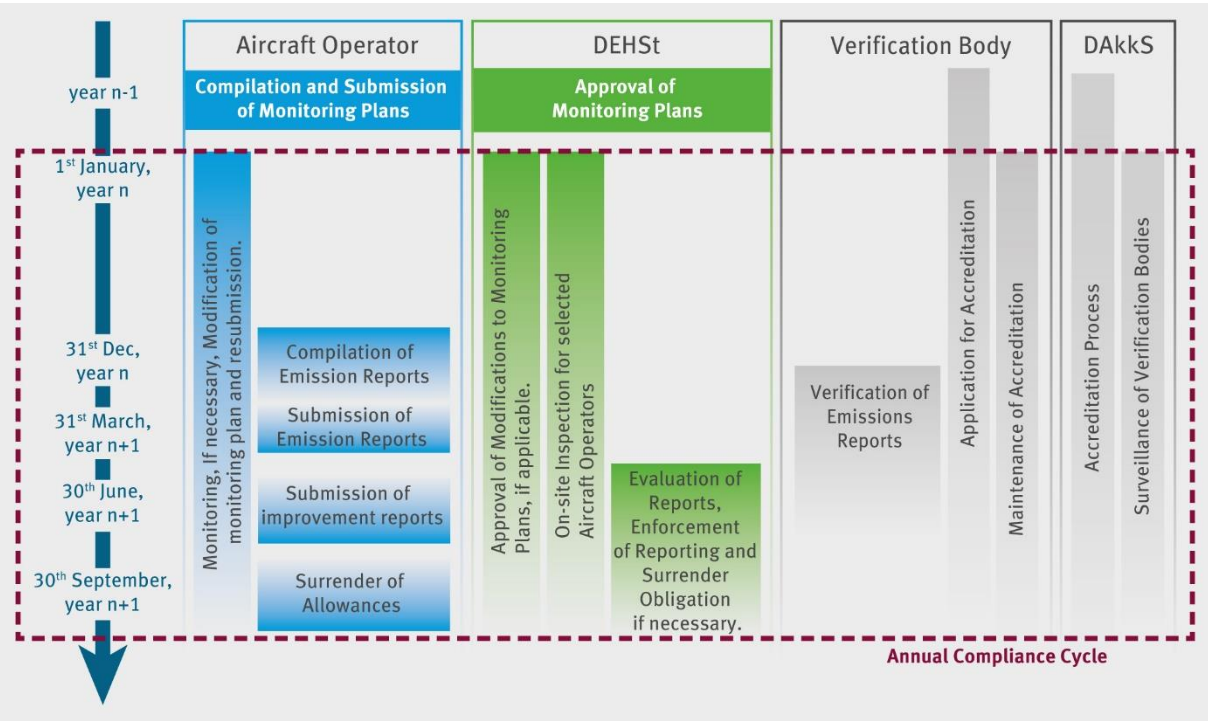
It can be assumed that there are some similarities between the information contained in ReFuelEU reports and EU ETS reports and that this information can be used for plausibility checks by operators, verifiers and competent authorities.

Some details of administrative requirements under the EU ETS are further specified on the national level in its own processes.

EU ETS

Generally, rules on monitoring, reporting and verification are specified in the EU ETS Directive and especially in the MRR. As described in the annex, some further details are specified in German legislation. The German administering authority for the EU ETS is the German Emissions Trading Authority (DEHSt). The following figure provides an overview of the compliance cycle for airlines in the EU ETS:

Figure 5: Compliance cycle for airlines in Germany



Source: Provided by Deutsche Emissionshandelsstelle (DEHSt) im Umweltbundesamt

The compliance cycle generally follows the requirements set out by the EU ETS Directive and the MRR. In short, the verified reports must be submitted to the DEHSt by 31 March of the following year at the latest and allowances need to be surrendered by 30 September thereafter.

[43] Both can be found here: https://www.easa.europa.eu/en/domains/environment/refueleu-aviation-digital-reporting-tool

In Germany, airlines are required to use a server-based application called "Formular Management System" (FMS). To date, airlines have two options for reporting SAFs via the FMS that are in line with the MRR[44]:

4. Share of biogenic SAF can be reported for a single airport pair (covered by the ETS) if SAF is delivered physically to the flight in question (physical segregation, section 4.4); remaining airport pairs without SAF use or blend are reported with the fossil kerosene type;
5. Determination of SAF share based on reported energy content in sustainability certificates with no necessary matching of SAF use/blends with airport pairs (simplified approach, mass balance at airport level in section 3.2.2.1).

The revised MRR also requires a matching of SAF use/blends with airport pairs for the second option. The DEHSt has changed the options in FMS so that option 2 can only be used if the SAF has physically been delivered to the airport from which the flights within the ETS in question departed.

The MRR specifies that the emission factor for biofuels shall be zero (Art. 54, para. 4, see above). In Germany, the German Ordinance on the Implementation of the Greenhouse Gas Emissions Trading Act (EHV) further prescribes that the sustainability of the biofuels needs to be proven/verified in accordance with the German Ordinance on requirements for the sustainable production of biofuels (Biokraft-NachV). The latter ordinance details what proofs of sustainability are recognised and what content they shall have. These proofs of sustainability need to be submitted via the public web-application "Nachhaltige - Biomasse – System" (Nabisy). Airlines and fuel suppliers need an account for Nabisy. Airlines need to transfer the PoS from their account in Nabisy to the DEHSt account to provide the relevant biofuel proofs in line with their submitted emission report. Without a PoS, any used and reported biofuels will be treated as fossil kerosene in terms of emissions in the ETS reports.

If airlines fuel SAF at non-German airports, it is possible to transfer a PoS from another EU system to an active German account in Nabisy. Such a transfer would ensure compliance with German regulations and make it possible for German airlines to claim SAF uptake in other EU countries. However, there is no widespread evidence of this happening according to DEHSt. It might be that foreign fuel suppliers are unaware of the requirements and/or do not have a Nabisy user account. There is only a direct linkage with the Austrian obligatory web-based system elNa ("elektronischer Nachhaltigkeitsnachweis") from which PoS can be transferred to the German Nabisy.

The Union database (UDB), set up by the European Commission, shall facilitate the tracing and verification of sustainability certificates of biofuels and renewable fuels across the EU (RED III, Art. 31a). The UDB shall be set up by 21 November 2024. As of June 2024, it is operational – but not yet for the aviation sector. Germany can in principle retain the Nabisy and FMS because Member States may (continue to) use an already existing national database and align it to and link it with the UDB via an interface as long as data transfer and transparency is ensured (RED III, Art. 31a (5), MRR provisions such as Art.38/5(6),39(4) and 54(6a)[45]). Hence, the UDB will likely facilitate that airlines can prove the sustainability of their SAF used –irrespective of where SAF was fuelled.

[44] Also refer to the guidance document for aircraft operators: https://climate.ec.europa.eu/document/download/311412c0-e980-420b-8d54-5c1e45e7c358_en?filename=gd2_guidance_aircraft_en.pdf.

[45] Database references also in articles Art 39a/3; Art. 39a/4; Art. 39a/5; Art. 53a/4; Art. 54a/2 of the MRR. Consolidated version available as of October 2024 from 01.07.2024: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02018R2066-20240701; and Implementing Regulation (EU) 2024/2493: https://eur-lex.europa.eu/eli/reg_impl/2024/2493/oj

Further, the RED requirements for RFNBOs (and synthetic kerosene) are implemented in German law through the 37. BimSchV[46] in the context of the German greenhouse gas quota (see annex A.1). A respective database is currently being developed; corresponding certification systems are still missing. Several stakeholders highlighted in the interviews that Nabisy lacks a dedicated code for aviation biofuel and that this should be added. In the meantime, they may use the code for road transport.

3.4 Conclusions

This section provides an overview of the SAF certification and administrative requirements under different policies. The main goals of this process are to monitor the environmental impacts of SAF usage and to prevent unintended negative impacts and fraud. Certification schemes establish rules and requirements for issuing certificates of conformity or compliance with regulatory regimes such as the RED, CORSIA or voluntary schemes to economic operators. Although there are differences between the schemes, all cover the following aspects:

- feedstock production sustainability including type of feedstock and indirect land use change (ILUC);
- traceability and chain of custody (CoC) of sustainable materials through the supply chain; and
- verified reduction of GHG emissions.

The main differences and similarities between the schemes in summarised in Table 8.

Table 8: Allowed feedstocks and required GHG reductions for eligible fuels in the RED and CORSIA[47]

	RED	CORSIA
Coverage	– RED applies to the entire transport sector with no specific aviation targets. However, Member States may enforce stricter regulations in their national implementation. – ReFuelEU Aviation refers to the RED for the definition of eligible fuels but has stricter criteria regarding the use of certain feedstocks.	– CORSIA is aviation-specific
Feedstocks	– Food- and feed-based feedstocks (conventional biofuels): Limited by the 2020 share of those fuels in the final energy consumption in each Member State, with a maximum of 7% – 1.7% cap on UCO and animal fats – High ILUC feedstocks: Capped at the level of consumption in 2019 of each member state. Starting from 31	– SAF made from biomass obtained from land converted after 1 January 2008 with high carbon stock is not allowed (DLUC) – ILUC is allowed, but indirectly regulated via Life-Cycle Analysis – Additional social and environmental criteria addressing the impacts on water, soil, air, conservation, waste and chemicals, human and labour rights, land use rights and land use, water use rights,

[46] 37. BimSchV, 17.04.2024: https://www.gesetze-im-internet.de/bimschv_37_2024/BJNR0830A0024.html

[47] Because ReFuelEU Aviation is mainly based on the provisions of the RED, a comparison between RED and CORSIA has been presented here.

	RED	CORSIA
	December 2023, this will be gradually phased out by 2030 at the latest.	local and social development and finally food security.
GHG reduction	– Fossil fuel baseline: 94 g CO_2e/MJ – Minimum reduction: 65% – Maximum GHG emissions SAF: 32.9g CO_2e/MJ for biofuels and 28.2 g CO_2e/MJ for RFNBOs	– Fossil fuel baseline: 89 g CO_2e/MJ – Minimum reduction: 10% – Maximum GHG emissions SAF: 80.1 g CO_2e/MJ

Source: Authors' own compilation

For each shipment along the supply chain – i.e. each batch of outgoing sustainable material, either raw material, an intermediate product or the end product SAF – an economic operator must provide a PoS documentation, which cannot be duplicated and can be used only once. The ISCC and RSB certification schemes proposed a PoC concept, which serves the same purpose as an PoS, but is issued in the case where the PoS has already been surrendered to competent authorities. Member States may allow their use as long as the UDB or a dedicated national database cannot reflect it. For the RED the UDB is currently set up with the goal to facilitate the tracing and verification of proofs of sustainability of biofuels and all other type of alternative fuels.

The administrative requirements for EU ETS, ReFuelEU Aviation and CORSIA are summarised in the following table:

Table 9: Overview of administrative requirements

	ReFuelEU Aviation	EU ETS	CORSIA
Regulated identities	Fuel suppliers Aircraft operators	Aircraft operators	Aircraft operators
Relation to SAF	Blending obligation with SAF target and sub-target for RFNBOs	Zero emission factor for eligible SAFs	Emission reduction (based on LCA method) achieved by using SAF is subtracted from the airline's total emissions.
Compliance[48]	– Fuel suppliers: report amount, energy content and SAF specification of aviation fuel and SAF supplied at each EU airport – Aircraft operators: required and uplifted aviation fuel at each EU airport	– Aircraft operators have to monitor and record their emissions throughout the year and submit an emission report, which must be verified. The verified emission report determines the number of EU ETS allowances that an aircraft operator must surrender. – To qualify for a zero emission factor for SAF used in flights covered by the EU ETS, physical	– Aircraft operator develop an emission monitoring plan, which is approved by the administrating authority – Aircraft operators report actual fuel consumption, calculated emission data, and CORSIA-eligible fuels used for emission reductions claims – Aircraft operators with total annual CO_2 emissions for flights subject to offsetting

[48] The PoS of a batch of SAF can be required by multiple actors or under multiple policy frameworks. To address this issue, a PoC concept has been developed. Once the UDB is ready to be used, this issue will be resolved.

	ReFuelEU Aviation	EU ETS	CORSIA
		delivery to an airport is necessary, thus a mass balance system at airport level	requirements below 50,000 tonnes may use a simplified approach and calculate emissions with the ICAO CERT tool.

Source: Authors' own compilation

4 SAF supply chain

The policies described in the previous section which aim to reduce the climate impacts of aviation incentivise the replacement of fossil fuels by SAF. Stakeholders confirmed in the interviews that the supply of SAF is currently concentrated on selected airports in countries that provide additional incentives such as the Netherlands or the UK and countries with a blending obligation. To date, the amounts delivered to Germany are comparably low.

The share of SAF in the used blends is currently low, but will increase over time. This usage of SAF requires adjustments in the aircraft fuel production and delivery from the production sites to aircraft (fuel infrastructure) and the development of a chain of custodies (CoC) for SAF, which is a chronological documentation of the properties and impacts and required to comply with the policies described in Section 2.

This chapter examines the physical infrastructure for the SAF production, distribution and storage and the fuel infrastructure implications for different CoC. In section 4.1, the current fuel supply chain to airports is described, distinguishing between airports connected to a pipeline network and airports which are not. SAF production routes and standards are explained in 4.2. In section 4.3, SAF distribution is described, including the blending of neat SAF and traditional kerosene. The different chain-of-custody methodologies (physical segregation, mass balance and book-and-claim) are explained in 4.4. In section 4.5, the implications of these methodologies on the (physical) fuel infrastructure are examined.

We describe the basic principles and analyse the implications of aircraft operators wanting to opt for different blending percentages for specific flights to reduce their operational costs. Intra-EEA flights fall under the scope of EU ETS. Thus, SAF usage on those flights is financially more attractive as it reduces the number of EU ETS allowances that must be purchased by airlines. As part of this study, we have quantified the potential financial benefits of applying different blending percentages to EU ETS flights versus CORSIA flights for two airlines (Chapter 5).

4.1 Current fuel supply chain to airports

The set-up of the supply chain for SAF depends on existing fuel infrastructure as well as the regulatory environment. In this section, we describe how the fuel is transported to different airports (pipeline, truck, train or barge) and how the fuel is then delivered to the aircraft at the airport.

4.1.1 Airports with fuel transport via pipeline

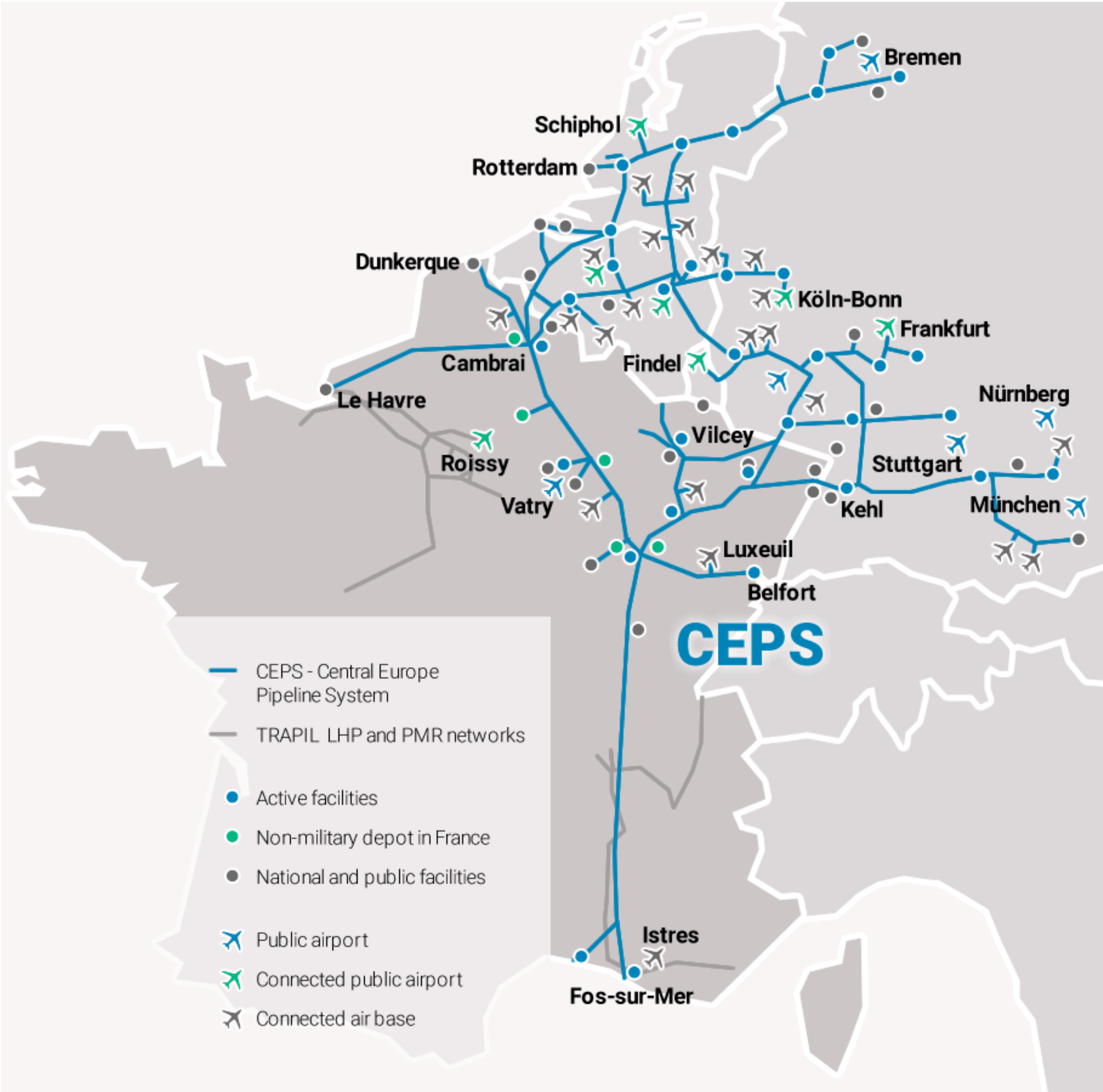
Aviation fuel is currently delivered to many German and European airports through the Central European Pipeline System (CEPS). The CEPS is one of the two multinational pipeline systems of the NATO pipeline system.[49] The CEPS covers Belgium, France, Germany, Luxembourg and the Netherlands. The other multinational system is called the North European Pipeline System (NEPS) and covers only Denmark and Germany. Throughout Europe, CEPS[50] connects 36 depots (for storage), three rail loading stations, 16 truck loading stations, connected to 11 refineries and 6 sea entry points. Along with the military airports, CEPS is directly connected to civilian airports including Zaventem and Liège in Belgium, Köln/Bonn and Frankfurt in Germany, Findel in Luxembourg and Schiphol in the Netherlands. Fuel producers and purchasers can use the

[49] https://www.nato.int/cps/en/natohq/topics_56600.htm?selectedLocale=en#:~:text=The%20two%20multinational%20pipeline%20systems,Germany%2C%20Luxembourg%20and%20the%20Netherlands

[50] https://www.nspa.nato.int/about/ceps/ceps-network

system if access is granted. This pipeline network can (at a given time) solely transport one fuel (blend). Since January 2023, airports can receive sustainable aviation fuels via the pipeline network.[51] Figure 7 shows the CEPS network and its connected public airports in Europe.[52]

Figure 6: Connected public airports and airbases to the CEPS



Source: https://www.cim-ccmp.com/en/operations.php#ceps-network

4.1.2 Airports with fuel transport via truck, train or barge

For airports not connected to a pipeline system, aviation fuel is transported by truck, train or barge to the airport. The mode of transportation is primarily based on cost considerations, but

[51] https://www.neste.com/news/brussels-airlines-starts-new-year-with-a-first-delivery-of-neste-my-sustainable-aviation-fuel-to-brussels-airport-via-ceps-pipeline

[52] For a more detailed overview of CEPS, including truck, rail and barge loading stations and refineries we refer to: https://www.cim-ccmp.com/fr/ceps.html

for rail and barge there are specific conditions as these can only be used if there are unloading facilities present near the airport.

One interview partner highlighted that the volume of the neat SAF batch delivered has to match with the blending capacity – the bigger the vessel with neat SAF, the larger the tank size has to be at the location at which the fuel is blended.

4.1.3 Fuel storage and delivery to aircraft

After the fuel has arrived at the airport, it is often stored at fuel depots or airport fuel storage facilities prior to its use for aircraft refuelling. These storage facilities ensure that airports can continue to refuel aircraft even during supply disruptions, thereby maintaining operational continuity (IATA 2008). However, there is a trade-off between the storage capacity and the operational reliability and costs.

At airports, aircraft are typically refuelled in two ways. Major airports often use a hydrant system whereby fuel is pressured and transported via a fixed pipeline network from the airport fuel depot to hydrant pits at aircraft fueling positions. Smaller airports often have refuelling vehicles. For these airports, no fuel depot is required as refuelling can happen directly from the production facility to the aircraft. Refuelling vehicles offer more flexibility compared to hydrant systems. However, hydrant systems enable simultaneous refuelling of multiple aircraft and reduce fuel spillage and evaporation.

4.1.4 Fuel delivery to German airports

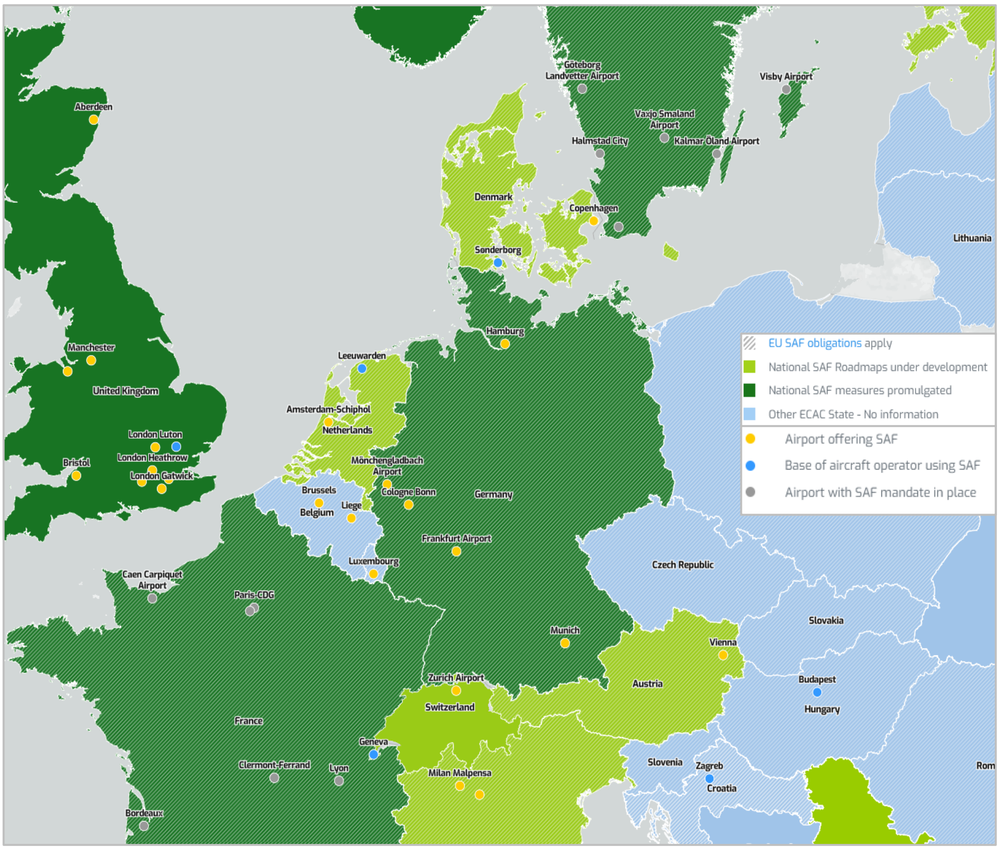
As stated above, some German airports are connected to kerosene pipelines via the CEPS. For example, at **Frankfurt** Airport kerosene is supplied exclusively via pipelines.[53] In **Munich**, there are several fuel tanks, 60% of which are fuelled via tank wagons and 40% via pipelines (Fruhstorfer et al. 2024). At the airport, the tanks are connected to the 17 km-long hydrant refuelling system which supplies 80% of the airplanes there; the rest is refueled via airfield tank trucks. **Berlin**'s BER Airport is supplied mainly by train, and partially by truck (ibid). On the airport premises, refuelling takes place via a hydrant system. At **Düsseldorf** airport, there are two separate tank farms (ibid). The tank farms are supplied via trucks from refineries in nearby cities. The tank farm at **Hamburg** airport is supplied via truck from the refinery in Heide (ibid). The **Cologne-Bonn** airport is supplied with kerosene via pipeline (ibid).

While the delivery of kerosene by trucks on the road is typical if there is no pipeline connection (see sections above), the amount of trucks needed can become quite high. Fr example, at Düsseldorf airport, the tank farms with a total capacity of 6,400 m^3 require truck deliveries of around 85 arrivals per day on average (Fruhstorfer et al. 2024).

The following map shows that five German airports offer SAFs: Hamburg, Mönchengladbach, Cologne, Frankfurt and Munich.

[53] https://www.luftfahrtmagazin.de/aviation/zivile-luftfahrt/neue-kerosin-pipeline-am-frankfurter-flughafen-181567.html

Figure 7: Map of airports offering SAFs in and around Germany



Source: https://flying-green.eurocontrol.int/#/fuelling-decarb, last updated in May 2024.

There is, for example, a dedicated tank/fuel storage system at Munich airport for biofuel blends. It was built in 2021 and the bio-kerosene blend is transported to the aircraft parking positions via a 17-kilometre underfloor pipe system.[54] If no dedicated storage system exists or such a system is in the early stages of SAF use, SAF is typically supplied via trucks to and at the airport.

While total fuel and SAF fuel consumption is not available for each German airport, total aviation fuel taken up at German airports can be derived from GHG emissions inventory data. In 2019, 8,513 TJ of aviation fuel were consumed by national flights and 404,367 TJ by international flights (UBA 2022).

4.2 SAF production and standards

The production of neat SAFs can be carried out via multiple technology pathways, which are described in section 4.2.1. The subsequent section assesses the worldwide SAF production and the SAF production in Germany specifically. Co-processing SAF with traditional kerosene is described in section 4.2.3. In 4.2.4 and 4.2.5 we explore the current and future blending standards, i.e. maximum blending percentages and fuel safety standards.

4.2.1 SAF production pathways

The first step in the SAF supply chain is the production of 100% neat SAFs from renewable feedstock. The current certified pathways are shown in the table below.

[54] https://www.aerotelegraph.com/am-flughafen-muenchen-kann-ab-juni-biokerosin-getankt-werden

Table 10: SAF technology pathways

Name	Allowed feedstocks	Process	Maximum blend ratio
Hydrotreated Esters and Fatty Acids (HEFA)	Animal fats, vegetable oils and used cooking oil (UCO)	First the oxygen is removed from the feedstock whereafter the molecules are cracked and isomerised to jet fuel length.	50%
Alcohol to Jet (AtJ)	Ethanol and iso-butanol	Converts alcohol into SAF by removing the oxygen and linking the molecules together to get the desired carbon chain length.	50%
Fischer-Tropsch (FT)	Coal, natural gas, biomass	It breaks the carbon containing material into individual blocks in gas form (synthesis gas). FT synthesis then combines these building blocks into SAF and other fuels. Two FT processes are currently ASTM-certified: Hydroprocessed Synthesized Paraffinic Kerosene (SPK) which produces straight paraffinic jet fuel and Synthetic Aromatic Kerosene (SAK) which produces additional aromatic compounds.	50%
Synthesized Iso-Paraffins (SIP)	Biomass used for sugar production	Microbes convert C6 sugars into farnesene, which is treated with hydrogen and can then be used as SAF.	50%
Catalytic-Hydrothermolysis (CHJ)	Animal fats, vegetable oils and used cooking oil (UCO)	It converts fatty acids and fatty acid esters via catalytic hydrothermolysis and a combination of hydrotreatment, hydrocracking and hydrodimerisation and fractionation into SAF.	50%
Hydroprocessed Hydrocarbons, esters and Fatty Acids (HC-HEFA)	Algae	Bio-derived hydrocarbons and free fatty acids and fatty acid esters are processed in a similar way to the HEFA process.	10%

Source: SkyNRG: https://skynrg.com/sustainable-aviation-fuel/technology-basics/, IATA (2024b)

4.2.2 SAF production

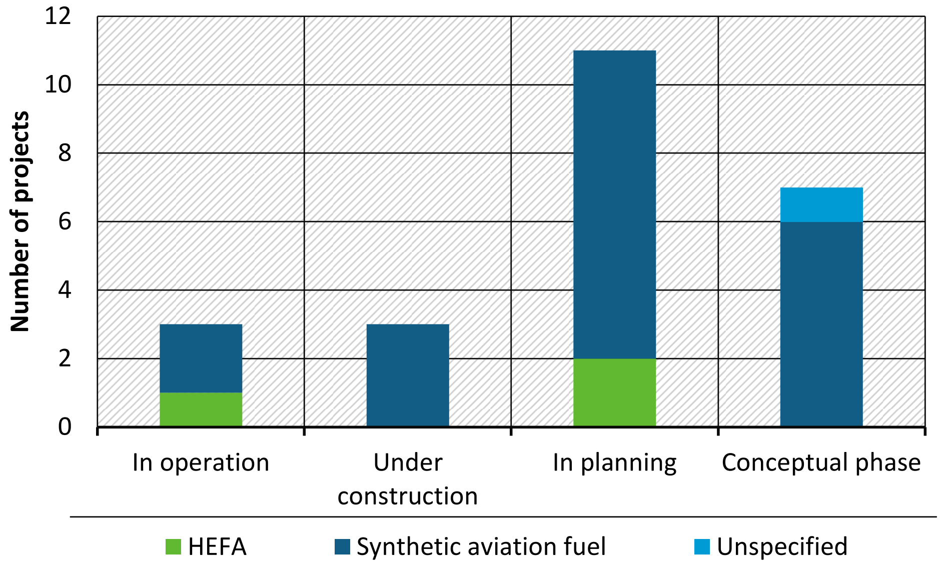
The SAF monitor reports 197 production (facility) projects worldwide in more than 30 countries.[55] In 2024, these are expected to produce 1.9 Mt of SAF (HEFA). Based on the projects announced, a production of approx. 34 Mt per year is projected for 2030. In the EU, a SAF production of between 8-9 Mt is projected for 2030.

There are 28 SAF production projects reported for Germany.[56] However, only six of 20 projects in Germany are actually in operation or are being built (Figure 8). These six facilities are also almost exclusively research and demonstration plants.

[55] https://erneuerbarekraftstoffe.de/saf-monitor/

[56] https://erneuerbarekraftstoffe.de/saf-monitor/

Figure 8: SAF projects in Germany (as of August 2024)



Source: Own illustration based on https://erneuerbarekraftstoffe.de/saf-monitor/

According to the SAF Monitor by NOW, the three production facilities in operation are from Sunfire in Dresden (synthetic aviation kerosene), from atmosfair in Wertle (synthetic aviation kerosene), and from bp in Lingen (HEFA/HVO). Volumes produced in 2023 are still very small, at less than 0.1 Mt (Dietrich et al. 2024). In contrast to the globally announced projects, most projects (by number and fuel volume) announced in Germany up to 2030 will produce synthetic aviation fuels, also called e-kerosene.[57]

4.2.3 Co-processing

Co-processing means that renewable feedstocks are used in an existing hydrotreating unit with fossil fuel and thus processed simultaneously in the refinery, resulting in only one blend. This technique is approved and allowed by an amendment to the ASTM D1655 standard (section 4.2.4). This implies that the blend is directly produced at the production site and no blending facilities are required. The process can be carried out in existing fossil fuel refineries, which require only minor modifications. Therefore, no significant financial investments in new SAF production facilities and blending facilities are required, thereby saving both time and money.

Moreover, as there is no separate SAF produced but rather a finished product, no separate SAF transport to an airport or aircraft is possible. The co-processed fuel is transported to airports using the current modes of transportation (i.e. pipeline systems, barge, rail and/or truck).

There is currently a limit of 5% renewable feedstock allowed in co-processing (ASTM D1655). This means that co-processing alone cannot lead to high shares of SAF. However, co-processing is a cost-efficient method of SAF production which can be realised relatively short-term due to the low financial and time investment compared to building a stand-alone SAF production facility, the absence of blending equipment and facilities and the ease of transport. It requires the same feedstocks as neat SAF production: animals fat, UCOs and vegetable oils, which are scarce resources.

[57] https://erneuerbarekraftstoffe.de/saf-monitor/

In addition, an ASTM taskforce has been established to investigate the possibility of increasing the approved limit of renewable feedstock from 5% to 30%.

4.2.4 Blending standards

Aviation is an international sector in which aircraft operate between multiple countries. This implies that airlines purchase fuel for their aircraft at airports in multiple countries. There are currently two kerosene fuel types used in civil aviation: Jet A-1 and Jet A. The main difference is that Jet A-1 fuel has lower freezing point compared to Jet A, making it suitable for long-haul flights, especially overflying polar routes where colder temperatures can be encountered.[58] Jet A is often only used in North America.[59]

To ensure equal fuel quality in different countries, the *American Society for Testing and Materials* (ASTM) developed international standards for aviation fuel. In order to substitute conventional kerosene as a “drop-in” fuel, SAF must have the same characteristics and qualities as conventional jet fuel kerosene, making it completely fungible. This ensures that no re-design of engines, aircraft and fuel delivery systems is necessary.[60]

Three ASTM standards are relevant for (sustainable) aviation fuel:

- ASTM D1655: “Standard Specification for Aviation Turbine Fuels”. This standard constitutes the global basis of all jet fuel quality specifications and sets requirements for composition, volatility, fluidity, combustion, corrosion, thermal stability, contaminants and additives among others to ensure operational safety and reliability.
- ASTM D7566 “Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons”. The ASTM issued this standard that regulates the technical certification of SAF in June 2009. It specifies the production routes that are allowed to produce neat SAF and describes the fuel quality specifications for each qualified SAF production pathway. A SAF production pathway can only be included in the ASTM D7566 if it is approved as matching the criteria under ASTM D4045.
- ASTM D4054 “Standard Practice for Evaluation of New Aviation Turbine Fuels and Fuels Additives”. Describes the procedure required for all new SAF technology pathway before being included in ASTM D7566. The fuel from a SAF production pathway must undergo extensive testing to define the maximum blend ratio with conventional jet fuel and demonstrate that the blend is fit for purpose.

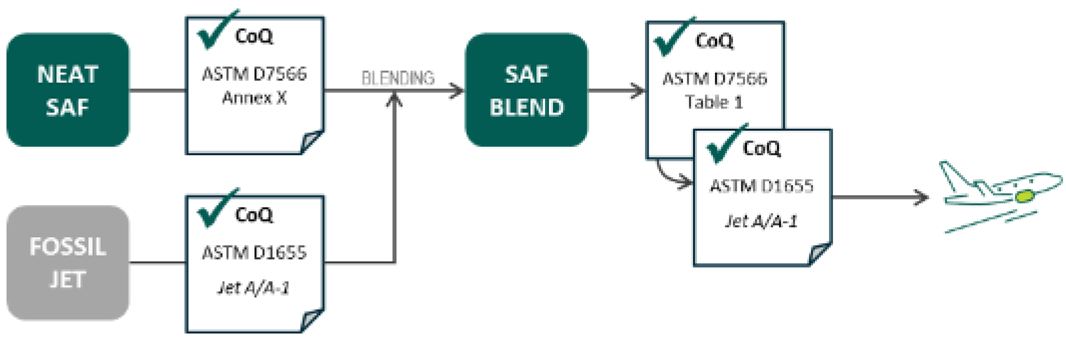
ASTM standards currently do not allow for 100% neat SAF. Depending on the SAF technology pathway, a maximum of 50% is allowed. After blending conventional jet fuel with SAF, the fuel is tested and certified again to ASTM D7566 blend requirements and then automatically receives the D1665 certification. From that point on, the fuel is regarded as conventional Jet A or Jet A1 kerosene. At each step in the supply chain, a fuel must be certified again to ensure safety.

[58] https://www.amspecgroup.com/news/types-of-jet-fuel/#:~:text=Although%20flight%20operators%20can%20use,particularly%20those%20overflying%20polar%20routes

[59] https://www.shell.com/business-customers/aviation/aviation-fuel/civil-jet-fuel-grades.html https://www.shell.com/business-customers/aviation/aviation-fuel/civil-jet-fuel-grades.html

[60] IATA Factsheet on sustainable aviation fuel and technical certification: https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/saf-technical-certifications.pdf

Figure 9: Illustration of the ASTM certification process of (blended) SAF



Source: SkyNRG - Sustainable Aviation Fuel Certification and ASTM International: https://skynrg.com/sustainable-aviation-fuel-certification-and-astm-international-what-is-it-why-does-it-matter/

4.2.5 Future blending standards

SAF is currently treated as a "drop-in" fuel. Drop-in means that it can be used in today's aircraft without requiring changes to aircraft and existing infrastructure like storage, delivery and fueling systems.[61]

ASTM standards do not allow neat SAF use in aircraft. Depending on the SAF technology pathway, currently a maximum blending percentage of 50% is allowed, see Table 10 for an overview of the maximum blend ratio for these different pathways.[62] Currently, not all aircraft allow for higher SAF percentages as airplane systems and materials were designed for traditional kerosene. Compared to Jet A kerosene, most neat SAF does not contain aromatic hydrocarbons with lubricating properties.[63] This difference affects both aircraft fuel systems and ground fuel infrastructure due to SAF's distinct density, lubricity and chemical composition (ACI; ATI 2022). However, aircraft original equipment manufacturers (OEMS) Airbus, Boeing and Embraer among others, have committed to making their airplanes 100% compatible with SAF by 2030. As often there is only one fuel blend inserted in all aircraft at an airport via the hydrant system, the blending percentage is restricted by the aircraft with the lowest blending allowance. Nevertheless, in practice this is not a problem since all aircraft currently allow 50% SAF blends – far above current blending rates. Aircraft manufacturers have pledged that in 2030 their airplanes will be 100% SAF-compatible.

4.3 SAF distribution and blending

Neat SAF is transported via barge, rail or truck to a SAF blending facility. The required Jet A kerosene is transported to the SAF blending facility as well. The transport mode of the neat SAF and fossil kerosene depends on, for example, the location of the SAF blending facility, the

[61] https://www.shell.com/business-customers/aviation/the-future-of-energy/sustainable-aviation-fuel.html#%3A%7E%3Atext=SAF+is+a+%E2%80%9Cdrop-in%2Ccompared+with+conventional+jet+fuel.&iframe=L2wvODc3OTYyLzIwMjMtMDUtMjIvNHdiNjh2, https://skynrg.com/sustainable-aviation-fuel/

[62] On 28 November 2023, Virgin Atlantic successfully operated a 100% SAF flight from London to New York on a commercial aircraft. For this flight a one-off approval has been permitted by the UK Civil Aviation Authority (CAA) as an UK originating and UK airline operated the flight. In addition approvals were required from Ireland, Canada and the American civil aviation authorities as it was a transatlantic route overflying these countries.

[63] https://www.aerospacemanufacturinganddesign.com/news/100-saf-most-read-2023/

unloading facility (for instance, for rail and barge), the fuel volumes and the capacity of a transport mode. Until the point at which the SAF blend is produced, the supply chain is the same, independently of the chosen chain-of-custody methodology.

Currently, the maximum blending percentages of SAF is not reached in practice. Although theoretically 50% SAF is allowed, the actual SAF percentages in fuel batches tend to range between 35-40%. This is due to the fossil fuel quality. ASTM D7566 standards set the minimum aromatic content of aviation fuel at 8%. CE Delft (2022) provides an overview of the aromatic content of fossil jet fuel reported in the literature. The mean lies at around 18% - however some samples showed an aromatic content of 5.9% as a minimum. The only SAF that is currently commercially available SAF is HEFA, which has no aromatic content as it is produced by hydrotreatment (CE Delft 2022). Therefore, not all fossil fuel batches blended with SAF at a 50/50 ratio would meet the minimum standard of 8%. The maximum blending percentage is determined by fuel suppliers. This lower blending percentage is currently not yet an issue as the key is to increase SAF volumes in general and not the blending ratio in specific fuel batches.

4.4 Chain-of-custody methodologies for the supply chain

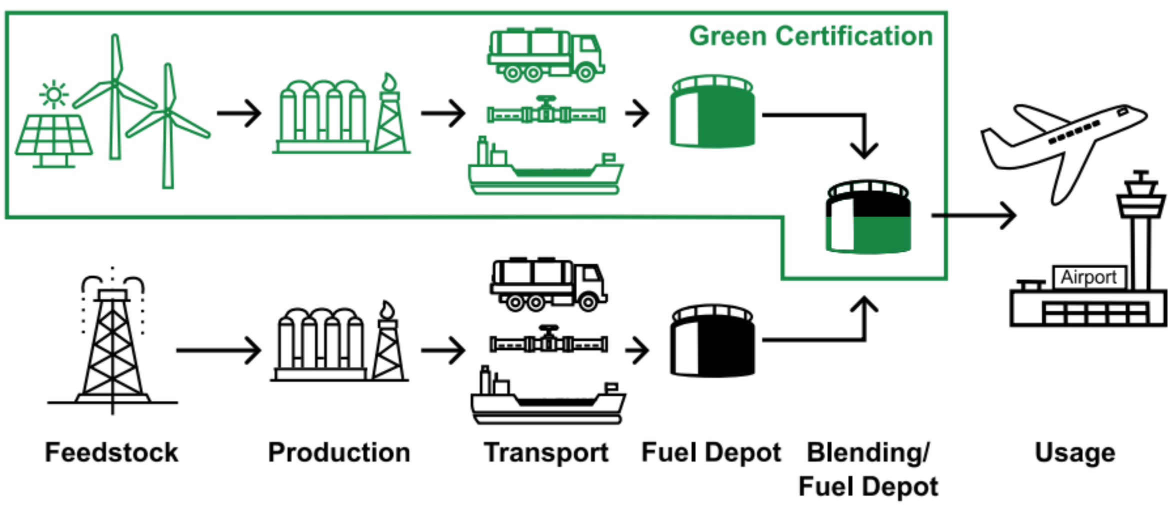
In this section, we introduce the basic concepts of the three methodologies (also called *Chain of Custody* (CoC) methods[64]) for accounting and reporting of SAF (ICAO 2023b; Schwuchow et al. 2024).

1. Physical segregation
2. Mass balance
3. Book-and-claim

The next sub-section (4.5) will compare the three methods in detail concerning their implications on the fuel infrastructure.

- **Physical segregation** is a system whereby SAF is physically kept separate from conventional Jet A kerosene in the supply chain. The exact share of SAF is known for each batch of fuel delivered to the airport or even to the aircraft.

Figure 10: Schematic overview of physical segregation of SAF (green) and fossil fuel (black)

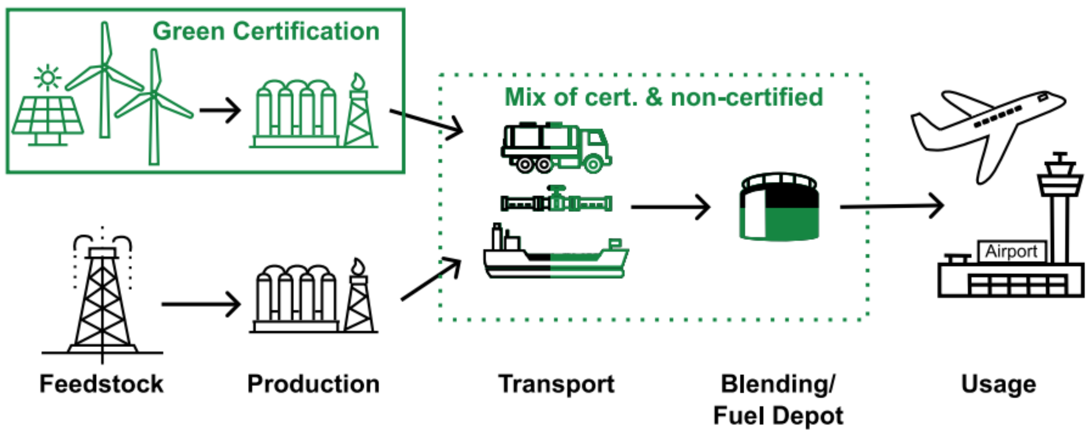


[64] https://www.circularise.com/blogs/four-chain-of-custody-models-explained

Source: Schwuchow et al. (2024)

- **Mass balance** is a method whereby the administrative SAF record is connected to the physical SAF flow through the supply chain. SAF is inserted in the supply chain somewhere and physically mixed with fossil jet fuel. The share of SAF in the fuel mix at an airport or country will (on average) match the initial proportions. A mass balance system ensures there still is a physical traceable link between the SAF input and output.

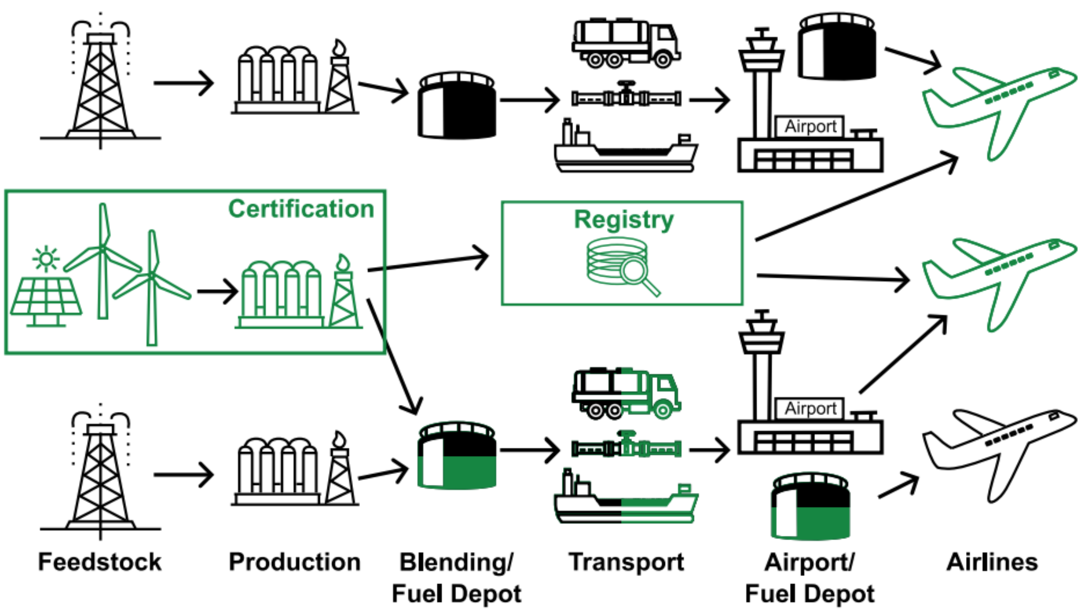
Figure 11: Mass balance approach



Source: Schwuchow et al. (2024)

- **Book-and-claim** also allows for mixing SAF and Jet A kerosene in the supply chain. The main difference with mass balance is that book-and-claim can be seen as a certificate trading model. The administrative SAF record does not necessarily connect to the physical SAF flow through the supply chain. The SAF can be injected into the supply chain everywhere, as physical delivery to a customer is not necessary.

Figure 12: Book-and-claim concept



Source: Schwuchow et al. (2024)

4.5 Comparison of chain-of-custody methodologies

The requirements to prove the chain of custody do not directly impact the SAF supply infrastructure but can indirectly do so. If the regulator requires physical segregation to claim the green characteristics of the SAF, a separate supply chain needs to be ensured. In this section we describe the implications of the chain-of-custody methodology on the fuel supply infrastructure. These implications are input for the total comparison of all future blending strategies in chapter 6.

Table 11 provides a brief overview of the implications on the infrastructure fuel supply chain for the three methods. Although the fuel supply chain begins with sourcing renewable feedstock for SAF production and crude oil for fossil jet fuel, the impact of a chain-of-custody methodology only becomes relevant at the blending process of neat SAF and fossil jet fuel.

Table 11: Overview of implications of the chain-of-custody methodologies on the fuel supply chain

Chain of custody methodology	Fuel delivery at the airport	Fuel transport	SAF blending
Physical segregation	Physical delivery to aircraft requires refuelling by truck. Using hydrant refuelling systems does not enable attribution to specific flights. Logistically complex to introduce an extra fuel blend. Separate storage required	Separate transport required	Incentivises blending facilities near airports to reduce costs for separate transport (blended SAF has higher volumes than neat SAF)
Mass balance	No changes required	Depends on the current fuel transport of an airport if separate transport is required.	Depends on system boundaries (airport only or pipeline also allowed).
Book-and-claim	No changes required	No changes required	No changes required

Source: Authors' own compilation

4.5.1 SAF production and blending

In the book-and-claim system, SAFs are delivered to airports with the lowest transportation costs, typically those connected to pipelines near blending facilities. Only when the airport reaches saturation – i.e. when all delivered fuel is SAF – does delivery shift to the next most cost-effective airport. If the book-and-claim system operates at national level (e.g. only within Germany), one blending facility per country would suffice at the start of the scheme. If it operates at EU or global level, even fewer blending facilities would be required.

In contrast, with physical segregation or mass balance at airport level, SAF must be delivered to specific airports. This can lead to higher transportation costs, especially if there are only a few blending facilities available. Consequently, a trade-off arises between incurring higher transportation costs with fewer blending facilities versus lower transportation costs with higher investment in additional blending facilities. If the mass balance system boundaries allow for pipeline transport, the number of required blending facilities is reduced to one per pipeline at the start of the scheme.

4.5.2 Fuel transport

Physical segregation requires different fuel blends at airports, while mass balance allows for mixing fuel without requiring distinct blends, although it does necessitate the delivery of SAF to specific airports. In contrast, a book-and-claim system does not affect the existing fuel supply chain as the physical fuel is completely segregated from the certification processes.

Separate infrastructure is necessary in the case of physical segregation. Establishing a new pipeline system is very expensive – approx. 1 million Euro per kilometre – making it an unrealistic option. Consequently, airports that currently receive fuel via pipeline must rely on alternative modes for the transport of SAF such as truck, train or barge. The decision for truck, train or barge depends on the geographical location of the airport, the distance, the SAF volume and related to that the capacity of the transport mode. Either way, setting up new logistics for transporting SAF to an airport is inefficient, both in terms of costs and carbon footprint. If fuel is already delivered to an airport by truck, train or barge, the same transport mode can be used for SAF, ensuring the batches are kept separated.

Using the mass balance methodology allows for physical mixing of SAF with fossil fuel, but the traceability of the SAF must be maintained. For airports receiving fuel via a pipeline network, the traceability depends on the network type. In point-to-point pipeline networks, traceability is possible. However, for networks with branching like the CEPS which has multiple offtake points, no complete traceability of a batch is possible in theory[65].

4.5.3 Fuel delivery at the airport

Changes to fuel storage and delivery systems are only required when implementing physical segregation. In the case of book-and-claim and mass balance after SAF is delivered to the airport physical delivery to a specific aircraft is not required. Physical segregation, however, requires separate storage tanks for different fuel types (i.e. SAF and traditional Jet A kerosene).

At airports with a hydrant system, physical segregation is practically impossible. The fuel is transported via an underground pipeline system, making it logistically complex, costly and undesirable to deliver a different fuel blend to a specific aircraft via refueling vehicles.

At airports at which refuelling via refuelling vehicles is standard, having two different fuel blends is also complex, but in theory possible. In practice, however, this would still lead to significant logistical challenges and costs, given the strict time schemes for aircraft refuelling which are planned well in advance (source: stakeholder interview). If airlines can use mass balance or book-and-claim to comply with the regulatory framework, the introduction of multiple fuel blends offer no benefits and would only lead to additional efforts and costs.

4.5.4 Conclusion

From the three methodologies compared, physical segregation requires the highest investment and adjustments to the fuel supply chain. Additionally, it can lead to increased emissions due to the separate transport needs. A mass balance approach reduces these emissions by offering more flexible transportation options and airport delivery requirements. It also enables to trace the fuel. A book-and-claim system is the most efficient in terms of logistics, minimising both logistical costs and carbon footprint. Traceability is low, however, which might increase the risk of fraud. See chapter 6 for a comprehensive comparison of the chain-of-custody methodologies, taking into account aspects that go beyond infrastructure requirements.

[65] The German government permits the CEPS under the EU ETS, which follows a mass balance approach.

Several stakeholders commented in their interviews on the chain-of-custody methodologies. While the mass balance system was welcomed compared to physical segregation, one airline claimed that only with book-and-claim did they feel that the science-based climate targets could be reached. Especially for airlines fuelling at small airports, they saw no possibility of claiming SAF use as the supply chains are considered less advanced and without pipeline connection SAF delivery costs are expected to be high. The interview partners conceded that book-and-claim might delay the build-up of SAF infrastructure in some areas but they expected that this would be overcome with increasing SAF volumes.

5 Impacts of claiming SAF-related emission reductions under EU ETS and CORSIA for European airlines

5.1 Set-up and scope of impact analysis

Under the EU ETS, SAFs are assumed to have zero CO_2 emissions (chapter 2), and hence the use of SAFs reduces the number of EU ETS allowances to be surrendered. Under CORSIA, the use of SAFs leads to a reduction of the offset obligation. CORSIA documentation includes life-cycle emission values for different types of CORSIA-eligible fuels including SAFs (section 2.2). Based on the life-cycle emission value for a specific fuel, an Emission Reduction Factor (ERF) can be calculated. The ERF expresses the percentage of CO_2 emission reductions from the use of a SAF relative to the CO_2 emissions resulting from the use of fossil fuels. The ReFuelEU Aviation Regulation (EU 2023) states that aircraft operators shall not claim benefits for the use of an identical batch of SAF under more than one greenhouse gas scheme (i.e. EU ETS or CORSIA). With flights within and between EEA countries and flights from the EEA to the UK and Switzerland being subject to the EU ETS and flights between the EEA and third countries being subject to CORSIA (for more details, see section 2.1.4), aircraft operators have to decide which flights to attribute their SAF use to.

Airlines have a financial incentive to maximise the claim of SAF-related emission reductions under the EU ETS. This is because prices of EU ETS allowances are expected to be higher compared to prices of CORSIA offsets. Therefore, airlines may want to use different fuel blends for flights covered by EU ETS and CORSIA. A spreadsheet tool has been developed to assess the impacts for an individual airline of different options to allocate emissions reductions from the ReFuelEU Aviation related use of SAF to the EU ETS and CORSIA. The options considered are:

- Option 0: No SAF-related reduction of the needed EU ETS allowances and CORSIA offsets,
- Option 1: SAF-related reduction proportionally allocated to flights,
- Option 2: SAF-related reduction maximally allocated to the EU ETS.

The impacts are assessed for 2030 and 2035. The main outputs of the tool are the demand for EU ETS allowances and CORSIA offsets and the total policy-induced cost increases for an airline in case of the three options. The policy-induced cost increases include the costs for:

- SAFs (incremental costs),
- EU ETS allowances,
- CORSIA offsets.

Computations with the tool have been made for three airlines with different profiles. These airlines are anonymised in this report and are referred to as the network carrier, the low-cost carrier and the cargo carrier respectively.

For flights between the EEA and countries that do not participate in CORSIA, the EU ETS may be re-introduced from 2027 onwards (chapter 2).[66] Following the current list of countries which have signed up to CORSIA, the re-introduction of the EU ETS may take place between the EEA

[66] Flights to Least Developed Countries (LDCs) and Small Island Developing States (SIDS) are exempted from the reintroduction.

and 33 countries.[67] Hence, the demand for allowances in the tool (assessed for 2030 and 2035) is based on the current scope (intra EEA and flights to UK/CH) plus the flights for which the EU ETS may be reintroduced.

From 2026 onwards, no free allowances will be allocated anymore and hence in 2030 and 2035 airlines need to purchase allowances for all CO_2 emissions on flights which are subject to the EU ETS. The flights subject to CORSIA in 2030 and 2035 are the flights between the 127 countries that had signed up to CORSIA by July 2024 plus the five major aviation countries for which CORSIA becomes mandatory from 2027 onwards. Flights which are subject to the EU ETS will not be subject to CORSIA offset obligations.

The computations do not include possible impacts from the maximum of 20 million EU ETS allowances to be allocated to the aviation sector in the period 2024-2030 to cover part of the price difference between SAF and fossil kerosene (section 2.2). This is because the details of this support mechanism are currently still under development. Moreover, the computations are made for years 2030 and 2035; by 2030, the additional 20 million allowances to be allocated might already be depleted.

The input data for the tool include generic data and airline specific data. Generic data include the following data for 2030 and 2035:

- ReFuelEU Aviation SAF blending mandate for flights departing from airports in the EEA (source: ReFuelEU Aviation Regulation);
- CORSIA Sector Growth Factor (SGF)[68] (source: AERO-MS);
- Emission Reduction Factor for SAFs under CORSIA (source: CORSIA eligible fuels document);
- Price of EU ETS allowances (source: literature review by Oeko-Institut);
- Price of CORSIA offsets (source: literature review by Oeko-Institut);
- Fossil fuel price (source: ReFuelEU Aviation impact assessment study);
- SAF price[69] (source: ReFuelEU Aviation impact assessment study).

The average SAF prices in 2030 and 2035 are expected to be EUR 751 and EUR 978 higher per tonne of fuel compared to fossil fuel prices. Hence, if SAF-related emission reductions are claimed under the EU ETS the SAF-related incremental costs are EUR 238 and EUR 310 per tonne of CO_2. Expected EU ETS allowances prices are EUR 137 and EUR 167 in 2030 and 2035 respectively. This is lower compared to the incremental costs per tonne of CO_2 for SAFs. This implies the currently expected prices do not provide an economic incentive for airlines to use SAFs beyond the blending mandate in order to further reduce the number of EU ETS allowances to be surrendered.

Airline specific data included in the tool relate to total fuel use and CO_2 emissions for the base year. For the network carrier and the low-cost carrier, data are taken from airline-specific

[67] Algeria, Andorra, Argentina, Belarus, Bolivia, Brunei Darussalam, Chile, Colombia, Congo Brazzaville, Egypt, Eswatini, Ethiopia, Iran, Jordan, Kyrgyzstan, Lebanon, Libya, Mongolia, Morocco, Nicaragua, North Korea, Pakistan, Panama, Paraguay, Peru, South Africa, Sri Lanka, Syria, Tajikistan, Tunisia, Turkmenistan, Uzbekistan and Venezuela.

[68] According to the CORSIA Resolution in 2030, 100% of the offset obligation for airlines is based on the SGF. In 2035, 85% of the offset obligation is based on the SGF and 15% on the airline Individual Growth Factor (IGF). The spreadsheet tool calculates the IGF for the airline under consideration.

[69] The tool uses the weighted average price across different types of SAF. Both the underlying prices for different types of SAF and the ratio between different types of SAFs are taken from the ReFuelEU Aviation impact assessment study.

sustainability reports. For the cargo carrier, data are taken from the CCR and from the Union Registry. Moreover, for the airlines, the distribution of CO_2 emissions across relevant market segments and the expected average annual percentage growth of CO_2 emissions for period from the base year to 2035 have been taken from various sources including the AERO-MS. Demand and related number of flights and emissions for the network carrier and the low-cost carrier (passenger demand) and the cargo carrier (cargo demand) are assumed to grow in line with the overall demand on the route groups operated by these airlines. This basically means that the market shares of the airlines on various route groups are assumed to remain constant over time.

5.2 Results

The computational results of the tool for the three airlines are presented in Table 12 (network carrier), Table 13 (cargo carrier) and Table 14 (low-cost carrier). The first part of the tables presents the fuel use and CO_2 emissions by segment of flights. The first segment relates to the flights subject to EU ETS, the second segment to routes that may be subject to the EU ETS from 2027 onwards (see section 2.1.4). The third segment relates to the flights subject to CORSIA. The final segment of flights relates to flights that are subject to neither the EU ETS nor CORSIA. These are the flights to/from countries which have not signed to CORSIA and which are to/from LDCs and SIDS.

For the network carrier in both 2030 and 2035, it is expected that the flights under the EU ETS comprise 34% of total CO_2 emissions of the network carrier, whereas flights under CORSIA comprise 65% of these total CO_2 emissions. For the cargo carrier, flights under the EU ETS in 2030 and 2035 are expected to cover 61% of the airline's total CO_2 emissions, with flights under CORSIA comprising 38% of total CO_2 emissions. For the low-cost carrier, a much larger share of CO_2 emissions relates to flights under the EU ETS (94%); only 4% of emissions relate to flights under CORSIA. For all three airlines, the emissions from flights not subject to the EU ETS nor CORSIA comprise only about 1% to 2% of the airline's total CO_2 emissions.

The tables also present the fuel use and CO_2 emissions on the flights which are subject to the ReFuelEU Aviation. This is the fuel use and emissions related to all intra EEA flights + EEA to UK/CH (2024 scope of EU ETS) and half of the flights on intercontinental routes (i.e. intercontinental flights departing from airports in the EEA are subject to the ReFuelEU Aviation regulation but intercontinental flights arriving at airport in the EEA are not). Table 12 shows that flights subject to the ReFuelEU Aviation Regulation are expected to comprise 64% of total fuel use of the network carrier (in both 2030 and 2035). For the cargo carrier, the flights subject to the ReFuelEU Aviation regulation are expected to comprise 77% of the airline's total fuel use, and 96% of the emissions are subject to the regulation for the low-cost carrier.

To comply with the ReFuelEU Aviation blending mandate of 6% in 2030 and 20% in 2035, the demand for SAFs of the network carrier is expected to be 208 Kt and 750 Kt in 2030 and 2035 respectively. For the cargo carrier, the demand amounts to 27 Kt and 100 Kt (Table 13), and for the low-cost carrier 44 Kt and 158 Kt (Table 14).

The second and third part of Table 12 and Table 13 present the results for the three options to allocate emission reductions from the ReFuelEU Aviation related use of SAF to the EU ETS and CORSIA for respectively the year 2030 and 2035. The following observations and conclusions from these parts of Table 12 and Table 13 can be made:

Fuel costs

- Fuel costs are the same in all three options and are calculated as EUR 6,746 million in 2030 and EUR 8,343 million in 2035 for the network carrier. For the cargo carrier and the low-cost carrier, fuel costs are calculated as EUR 735 million and EUR 957 million in 2030 respectively and to EUR 932 million and EUR 1215 million in 2035 respectively.

- For the network carrier, the costs for SAFs as a percentage of total fuel costs increases from 6% in 2030 to 20% in 2035. For the cargo carrier and especially the low-cost carrier, these percentages are higher (7% in 2030 and 24% in 2035 for the cargo carrier and 9% in 2030 and 29% in 2035 for the low-cost carrier).

Option 0 – demand allowances and policy-induced costs

- For option 0 (no SAF-related reductions of EU ETS allowances and CORSIA offsets), the demand for allowances is higher compared to the demand for CORSIA offsets for all three airlines. For the network carrier, emissions on flights subject to CORSIA are about twice as high compared to the emissions on flights subject to the EU ETS. Under CORSIA, however, only part of the emissions needs to be offset, whereas under the EU ETS in 2030 and 2035 allowances need to be purchased for all emissions.

- In case no SAF-related reductions are allocated to the EU ETS and CORSIA (option 0), total policy-induced costs for the network carrier are calculated as EUR 1,019 million in 2030 and EUR 1,908 million in 2035. For 2030, 79% of these costs is related to purchasing EU ETS allowances, 15% to the incremental costs of SAFs and 6% to purchasing CORSIA offsets. For 2035, 55% of the overall policy-induced costs are related to purchasing EU ETS allowances, 38% to the incremental costs of SAFs and 6% to purchasing CORSIA offsets. For the cargo carrier, total policy-induced costs for option 0 are calculated as EUR 181 million in 2030 and EUR 314 million in 2035. For 2030, 87% of these costs is related to purchasing EU ETS allowances, 11% to the incremental costs of SAFs and 2% to purchasing CORSIA offsets. For 2035, 66% of the overall policy-induced costs are related to purchasing EU ETS allowances, 31% to the incremental costs of SAFs and 2% to purchasing CORSIA offsets. For the low-cost carrier, the policy-induced costs related to CORSIA are very limited, which is mainly related to the limited share of flights which fall under CORSIA. For all three airlines, the incremental costs for SAFs increase most over time which is mainly related to the blending mandate becoming stricter over time.

Option 1 – demand allowances and policy-induced costs

- For option 1 (SAF-related reduction proportionally allocated to flights), both the demand for EU ETS allowances and CORSIA are reduced relative to option 0. This results in a reduction of policy-induced costs for the network carrier by EUR 54 million in 2030 and EUR 244 million in 2035. For the cargo carrier, the reduction of policy-induced costs for option 1 relative to option 0 is EUR 10 million and EUR 44 million in 2030 and 2035 respectively, and for the low-cost carrier the reduction is EUR 19 million and EUR 81 million in 2030 and 2035 respectively. For all three airlines, most of the cost reductions relate to the lower number of EU ETS allowances to be surrendered.

Option 2 – demand allowances and policy-induced costs

- For option 2 (SAF-related reduction maximally allocated to the EU ETS), there is a further reduction in policy-induced costs. Relative to option 0, the reduction of policy-induced costs for the network carrier is EUR 90 million in 2030 and EUR 395 million in 2035. The additional reduction in policy-induced costs for option 2 relative to option 1 for the network carrier are EUR 36 million in 2030 and EUR 151 million in 2035 respectively. These are in fact the potential benefits for the network carrier if they used different fuel blends for flights covered by EU ETS and CORSIA.

- For the cargo carrier, the reduction of policy-induced costs for option 2 relative to option 0 are EUR 12 million in 2030 and EUR 53 million in 2035 respectively. The additional reduction in policy-induced costs for option 2 relative to option 1 for the cargo carrier are EUR 2 million in 2030 and EUR 9 million in 2035 respectively, and for the low-cost carrier the additional reductions are even much smaller. Hence, financial benefits for the cargo carrier and the low-cost carrier if they used different fuel blends for flights covered by EU ETS and CORSIA are much smaller compared to the potential benefits for the network carrier. This is related to the larger size the network carrier and a difference in the ratio between traffic covered by the EU ETS and traffic covered by CORSIA. Compared to the two other carriers, the network carrier has a larger share of emissions on flights covered by CORSIA; thus, the potential financial benefits of shifting the use of SAFs from CORSIA flights to EU ETS flights are higher.
- For option 2, relative to option 0, the demand for EU ETS allowances in 2030 is reduced by 11% and 8% for the network carrier and the cargo carrier respectively. For the low-cost carrier, the reduction in 2030 amounts to 6%. For 2035, the demand for allowances can be reduced by 37% (the network carrier), 25% (the cargo carrier) and 21% (the low-cost carrier) if the SAF-related reductions are maximally allocated to the EU ETS. The larger percentage reduction for the network carrier is again related to the larger share of emissions on flights covered by CORSIA, and thereby a larger potential to shift the use of SAFs from CORSIA flights to EU ETS flights.

Table 12: Impacts for the network carrier of allocating SAF-related emission reductions to the EU ETS and CORSIA

Fuel use and CO_2 emissions in 2030 and 2035

	2030	2035	
Fuel use by segment of flights (fossil fuel and SAFs)			
Flights subject EU ETS (2024 scope: Intra EEA+ EEA to UK/CH)	1,483	1,593	Kt fuel
Flights subject to possible reintroduction of EU ETS from 2027 onwards*	376	408	Kt fuel
Flights subject to CORSIA	3,532	3,840	Kt fuel
Flights not subject to EU ETS nor CORSIA	56	61	Kt fuel
All flights	**5,448**	**5,903**	Kt fuel
Of which flights subject to ReFuelEU Aviation	3,465	3,748	Kt fuel
CO_2 emissions by segment of flights (without ER of SAFs)			
Flights subject EU ETS (2024 scope: Intra EEA+ EEA to UK/CH)	4,682	5,028	Kt emissions
Flights subject to possible reintroduction of EU ETS from 2027 onwards*	1,186	1,289	Kt emissions
Flights subject to CORSIA	11,152	12,124	Kt emissions
Flights not subject to EU ETS nor CORSIA	178	194	Kt emissions
All flights	**17,198**	**18,635**	Kt emissions
Flights subject to ReFuelEU Aviation	10,940	11,831	Kt emissions
ReFeulEU Aviation			
Use of SAFs	208	750	Kt fuel

Results for 2030 for different options to allocate emissions reductions from SAFs to EU ETS and CORSIA

		Option 0: No SAF-related reduction of EU ETS allowances and CORSIA offset	Option 1: SAF-related reduction proportionally allocated to flights	Option 2: SAF-related reduction maximally allocated to EU ETS
Fuel costs				
Costs fossil fuels	million $€_{2023}$	6,338	6,338	6,338
Costs SAFs	million $€_{2023}$	408	408	408
Total fuel costs	million $€_{2023}$	**6,746**	**6,746**	**6,746**
Demand for EU ETS allowances and CORSIA offsets				
Demand for EU ETS allowances	Kt	5,868	5,516	5212
Demand for CORSIA offsets	Kt	2,546	2,306	2,546
Policy-induced costs				
SAFs (incremental costs)	million $€_{2023}$	156	156	156
EU ETS allowances	million $€_{2023}$	803	755	713
CORSIA offset	million $€_{2023}$	59	54	59
Total policy-induced costs	million $€_{2023}$	**1,019**	**965**	**929**

Results for 2035 for different options to allocate emissions reductions from SAFs to EU ETS and CORSIA

		Option 0: No SAF-related reduction of EU ETS allowances and CORSIA offset	Option 1: SAF-related reduction proportionally allocated to flights	Option 2: SAF-related reduction maximally allocated to EU ETS
Fuel costs				
Costs fossil fuels	million $€_{2023}$	6,644	6,644	6,644
Costs SAFs	million $€_{2023}$	1,699	1,699	1,699
Total fuel costs	million $€_{2023}$	**8,343**	**8,343**	**8,343**
Demand for EU ETS allowances and CORSIA offsets				
Demand for EU ETS allowances	Kt	6,317	5,054	3951
Demand for CORSIA offsets	Kt	3,627	2,645	3,627
Policy-induced costs				
SAFs (incremental costs)	million $€_{2023}$	733	733	733
EU ETS allowances	million $€_{2023}$	1,055	844	660
CORSIA offset	million $€_{2023}$	121	88	121
Total policy-induced costs	million $€_{2023}$	**1,908**	**1,665**	**1,513**

Source: Own compilation, TAKS

Note: * Assuming possible re-introduction of the EU ETS to take place between the EEA and 33 countries (Algeria, Andorra, Argentina, Belarus, Bolivia, Brunei Darussalam, Chile, Colombia, Congo Brazzaville, Egypt, Eswatini, Ethiopia, Iran, Jordan, Kyrgyzstan, Lebanon, Libya, Mongolia, Morocco, Nicaragua, North Korea, Pakistan, Panama, Paraguay, Peru, South Africa, Sri Lanka, Syria, Tajikistan, Tunisia, Turkmenistan, Uzbekistan and Venezuela).

Table 13: Impacts for the cargo carrier of allocating SAF-related emission reductions to the EU ETS and CORSIA

Fuel use and CO_2 emissions in 2030 and 2035	**2030**	**2035**	
Fuel use by segment of flights (fossil fuel and SAFs)			
Flights subject EU ETS (2024 scope: Intra EEA+ EEA to UK/CH)	322	352	Kt fuel
Flights subject to possible reintroduction of EU ETS from 2027 onwards*	40	44	Kt fuel
Flights subject to CORSIA	223	246	Kt fuel
Flights not subject to EU ETS nor CORSIA	5	6	Kt fuel
All flights	**591**	**647**	Kt fuel
Of which flights subject to ReFuelEU Aviation	456	499	Kt fuel
CO_2 emissions by segment of flights (without ER of SAFs)			
Flights subject EU ETS (2024 scope: Intra EEA+ EEA to UK/CH)	1,018	1,110	Kt emissions
Flights subject to possible reintroduction of EU ETS from 2027 onwards*	125	138	Kt emissions
Flights subject to CORSIA	704	775	Kt emissions
Flights not subject to EU ETS nor CORSIA	17	19	Kt emissions
All flights	**1,864**	**2,042**	Kt emissions
Flights subject to ReFuelEU Aviation	1,441	1,576	Kt emissions
ReFeulEU Aviation			
Use of SAFs	27	100	Kt fuel

Results for 2030 for different options to allocate emissions reductions from SAFs to EU ETS and CORSIA		Option 0: No SAF-related reduction of EU ETS allowances and CORSIA offset	Option 1: SAF-related reduction proportionally allocated to flights	Option 2: SAF-related reduction maximally allocated to EU ETS
Fuel costs				
Costs fossil fuels	million $€_{2023}$	681	681	681
Costs SAFs	million $€_{2023}$	54	54	54
Total fuel costs	million $€_{2023}$	**735**	**735**	**735**
Demand for EU ETS allowances and CORSIA offsets				
Demand for EU ETS allowances	Kt	1,143	1,074	1057
Demand for CORSIA offsets	Kt	161	146	161
Policy-induced costs				
SAFs (incremental costs)	million $€_{2023}$	21	21	21
EU ETS allowances	million $€_{2023}$	156	147	145
CORSIA offset	million $€_{2023}$	4	3	4
Total policy-induced costs	million $€_{2023}$	**181**	**171**	**169**

Results for 2035 for different options to allocate emissions reductions from SAFs to EU ETS and CORSIA		Option 0: No SAF-related reduction of EU ETS allowances and CORSIA offset	Option 1: SAF-related reduction proportionally allocated to flights	Option 2: SAF-related reduction maximally allocated to EU ETS
Fuel costs				
Costs fossil fuels	million $€_{2023}$	705	705	705
Costs SAFs	million $€_{2023}$	226	226	226
Total fuel costs	million $€_{2023}$	**932**	**932**	**932**
Demand for EU ETS allowances and CORSIA offsets				
Demand for EU ETS allowances	Kt	1,248	998	932
Demand for CORSIA offsets	Kt	234	171	234
Policy-induced costs				
SAFs (incremental costs)	million $€_{2023}$	98	98	98
EU ETS allowances	million $€_{2023}$	208	167	156
CORSIA offset	million $€_{2023}$	8	6	8
Total policy-induced costs	million $€_{2023}$	**314**	**270**	**261**

Source: Own compilation, TAKS

Note: * Assuming possible re-introduction of the EU ETS to take place between the EEA and 33 countries (Algeria, Andorra, Argentina, Belarus, Bolivia, Brunei Darussalam, Chile, Colombia, Congo Brazzaville, Egypt, Eswatini, Ethiopia, Iran, Jordan, Kyrgyzstan, Lebanon, Libya, Mongolia, Morocco, Nicaragua, North Korea, Pakistan, Panama, Paraguay, Peru, South Africa, Sri Lanka, Syria, Tajikistan, Tunisia, Turkmenistan, Uzbekistan and Venezuela).

Table 14: Impacts for the low-cost carrier of allocating SAF-related emission reductions to the EU ETS and CORSIA

Fuel use and CO_2 emissions in 2030 and 2035	2030	2035	
Fuel use by segment of flights (fossil fuel and SAFs)			
Flights subject EU ETS (2024 scope: Intra EEA+ EEA to UK/CH)	700	753	Kt fuel
Flights subject to possible reintroduction of EU ETS from 2027 onwards*	13	14	Kt fuel
Flights subject to CORSIA	34	37	Kt fuel
Flights not subject to EU ETS nor CORSIA	17	18	Kt fuel
All flights	**764**	**823**	Kt fuel
Of which flights subject to ReFuelEU Aviation	732	788	Kt fuel
CO_2 emissions by segment of flights (without ER of SAFs)			
Flights subject EU ETS (2024 scope: Intra EEA+ EEA to UK/CH)	2,210	2,379	Kt emissions
Flights subject to possible reintroduction of EU ETS from 2027 onwards*	41	44	Kt emissions
Flights subject to CORSIA	108	118	Kt emissions
Flights not subject to EU ETS nor CORSIA	53	57	Kt emissions
All flights	**2,412**	**2,598**	Kt emissions
Flights subject to ReFuelEU Aviation	2,311	2,488	Kt emissions
ReFeulEU Aviation			
Use of SAFs	44	158	Kt fuel

Results for 2030 for different options to allocate emissions reductions from SAFs to EU ETS and CORSIA		Option 0: No SAF-related reduction of EU ETS allowances and CORSIA offset	Option 1: SAF-related reduction proportionally allocated to flights	Option 2: SAF-related reduction maximally allocated to EU ETS
Fuel costs				
Costs fossil fuels	million $€_{2023}$	871	871	871
Costs SAFs	million $€_{2023}$	86	86	86
Total fuel costs	million $€_{2023}$	**957**	**957**	**957**
Demand for EU ETS allowances and CORSIA offsets				
Demand for EU ETS allowances	Kt	2,251	2,116	2113
Demand for CORSIA offsets	Kt	25	22	25
Policy-induced costs				
SAFs (incremental costs)	million $€_{2023}$	33	33	33
EU ETS allowances	million $€_{2023}$	308	290	289
CORSIA offset	million $€_{2023}$	1	1	1
Total policy-induced costs	million $€_{2023}$	**342**	**323**	**323**

Results for 2035 for different options to allocate emissions reductions from SAFs to EU ETS and CORSIA		Option 0: No SAF-related reduction of EU ETS allowances and CORSIA offset	Option 1: SAF-related reduction proportionally allocated to flights	Option 2: SAF-related reduction maximally allocated to EU ETS
Fuel costs				
Costs fossil fuels	million $€_{2023}$	858	858	858
Costs SAFs	million $€_{2023}$	357	357	357
Total fuel costs	million $€_{2023}$	**1,215**	**1,215**	**1,215**
Demand for EU ETS allowances and CORSIA offsets				
Demand for EU ETS allowances	Kt	2,423	1,939	1925
Demand for CORSIA offsets	Kt	35	25	35
Policy-induced costs				
SAFs (incremental costs)	million $€_{2023}$	154	154	154
EU ETS allowances	million $€_{2023}$	405	324	321
CORSIA offset	million $€_{2023}$	1	1	1
Total policy-induced costs	million $€_{2023}$	**560**	**479**	**477**

Source: Own compilation, TAKS

Note: * Assuming possible re-introduction of the EU ETS to take place between the EEA and 33 countries (Algeria, Andorra, Argentina, Belarus, Bolivia, Brunei Darussalam, Chile, Colombia, Congo Brazzaville, Egypt, Eswatini, Ethiopia, Iran, Jordan, Kyrgyzstan, Lebanon, Libya, Mongolia, Morocco, Nicaragua, North Korea, Pakistan, Panama, Paraguay, Peru, South Africa, Sri Lanka, Syria, Tajikistan, Tunisia, Turkmenistan, Uzbekistan and Venezuela).

5.3 Conclusions

If SAF-related emission reductions are proportionally allocated to flights which fall under EU ETS and CORSIA, both the demand for EU ETS allowances and CORSIA offsets are reduced. For airlines, this implies a reduction in policy-induced costs. Due to the higher EU ETS prices, the reduction in costs mainly relates to a reduction of costs to purchase EU ETS allowances. For the different airlines considered in this analysis, total policy-induced costs (which contain the incremental costs of SAFs and the costs to purchase EU ETS allowances and CORSIA offsets) are reduced by about 5% in 2030 and 15% in 2035 if SAF-related emission reductions are proportionally allocated. If a blending strategy allows to maximally allocated SAF-related emission reductions to the EU ETS, network carriers can generally further reduce their EU ETS-related costs. The additional reduction of total policy-induced costs amounts to about 4% in 2030 and about 8% in 2035 for the network carrier considered in this analysis. Low-cost carriers generally have a limited share of emissions on flights covered by CORSIA and therefore these airlines have limited potential to further reduce their EU ETS-related costs.

6 Synthesis and further considerations

6.1 Synthesis

Overview of policies to incentivise SAF uptake

The uptake of sustainable aviation fuels is incentivised by policies at EU and global level. CORSIA and the EU ETS put a price on emissions from aviation but differ in terms of coverage and ambition. The use of sustainable aviation fuels is a means to reduce the obligation to surrender allowances in the EU ETS or to offset emission increases under CORSIA.

In the EU, the RED contains targets for renewable energy, including specifically for the transport sector, to which aviation contributes. It includes targets for biofuels and RFNBOs, with additional incentives if these fuels are used in aviation. ReFuelEU Aviation is the main policy instrument to accelerate the uptake of SAF by imposing blending obligations for fuel providers until 2050. Airlines are obliged to refuel at least 90% of the annually required fuel volume for outgoing flights at EU airports to avoid evasion.

The RED III defines sustainability criteria for different SAF types and is referred to in both the EU ETS directive and ReFuel EU Aviation. The main types of SAF are synthetic aviation fuels (RFNBOs like e-kerosene), (advanced) aviation biofuels and recycled carbon aviation fuels. There are, though, slight differences between the policies in terms of which types of aviation fuel are eligible to count towards specific targets. Furthermore, the transposition of the RED to national law may vary among Member States, adding complexity for both fuel providers and the airlines as consumers.

Stakeholders highlighted in the interviews that regulatory uncertainty – also due to policies not being fully clear at the time of writing – drives up the costs and drives down the investments in new production capacity for SAFs. A speedy implementation, including the technical infrastructure such as the UDB, was requested.

SAF certification and administrative requirements

The policies assessed include SAF certification and administrative requirements to monitor the environmental impacts of SAF usage and to prevent unintended negative impacts and fraud. Certification schemes establish rules and requirements for issuing certificates of conformity or compliance with regulatory regimes as the RED, CORSIA or voluntary schemes to economic operators. Although there are differences between the schemes, all cover the following aspects:

- Feedstock production sustainability including type of feedstock and indirect land use change (ILUC);
- traceability and chain of custody (CoC) of sustainable materials through the supply chain; and
- verified reduction of GHG emissions.

While the RED sets stricter limits on certain feedstocks and thus to conventional biofuels and UCO, CORSIA includes additional social and environmental criteria. Furthermore, they differ in the GHG reduction than can be achieved depending on the fuel type.

For each shipment along the supply chain, i.e. each batch of outgoing sustainable material, either raw material, an intermediate product or the end product SAF, an economic operator must provide a PoS documentation, which cannot be duplicated and can be used only once. If a fuel provider sells sustainable aviation fuel to an aircraft operator, the same fuel amount can rightfully be counted towards the fulfilment of the fuel providers' obligation under the ReFuelEU Aviation Regulation and the aircraft operators may use it to report zero-rated fuels under the EU ETS. The current PoS documentation has to be further developed in order to allow for such rightful use while continuing to ensure the same amount is not claimed twice by, for example, different airlines at the same time.

SAF supply chain and its interaction with chain-of-custody methodologies

The fuel supply chain to individual airports depends on their geographic location, whether they are connected to a kerosene pipeline system and whether there are unloading facilities for trains and/or barges available. At the airports, the fuel is either delivered directly by refuelling vehicles to the aircraft or using a hydrant system whereby fuel is pressured and transported via a fixed pipeline network from the airport fuel depot to hydrant pits at aircraft fuelling positions.

Neat SAFs are typically produced in dedicated facilities and then transported to be blended with fossil kerosene as close to the airport or the pipeline system as possible. In the case of co-processed fuels, renewable feedstocks are used with fossil fuels and thus processed simultaneously in the refinery, resulting in only one blend. In this case, no blending facilities are required, and the fuel is supplied to the airport as a mix.

The chain-of-custody requirements should, on the one hand, provide enough flexibility to enable the uptake of sustainable aviation fuels and, on the other hand, safeguard the scheme against fraud. We distinguish three methodologies: physical segregation, mass balance and book-and-claim. Requirements are the strictest in the case of physical segregation and imply a separate supply chain which is likely to lead to extra cost and efficiency losses. Book-and-claim methodologies, in contrast, do not require any changes to the current infrastructure but at the same time physical flows are not necessarily linked to where the use is claimed and may pose a greater risk for fraud. Mass balance schemes conserve the link to the physical SAF amounts on the one hand while reducing the requirements for parallel infrastructure. The ReFuelEU Aviation Regulation and the Renewable Energy Directive (RED) allow for a mass balance system. Under the ReFuelEU Aviation Regulation, a book-and-claim approach might be introduced in future.

Impacts of claiming SAF-related emission reductions under EU ETS or CORSIA

An assessment of the potential for airlines to strategically attribute SAF amounts to flights regulated under the EU ETS rather than CORSIA showed substantial financial incentives for doing so. This is because prices of EU ETS allowances are expected to be higher compared to prices of CORSIA offsets. Airlines that operate both intra-EEA and international flights have more scope for optimisation than those concentrated on the intra-EEA market. Whether they can untap the full potential depends both on the specific regulation and the infrastructure of the airports.

6.2 Further considerations for the evaluation of chain-of-custody requirements and recommendations

In this report, we have explored three types of methodologies for the chain of custody and assessed them with a view to their risk of fraud and infrastructural needs:

a) physical segregation

b) mass balance

c) book-and-claim.

Strict **physical segregation** comes with many challenges and is expected to lead to additional costs for transport and eventually additional truck transport and/or the build-up of infrastructure. The current EU legislation already includes **mass balance elements**. For example, the recognition of the CEPS pipeline as mass balance system reduces transport costs for SAF blends for all airports connected to the system. Also at airport level, a mass balance approach is followed under the ReFuelEU Aviation's flexibility mechanism. Furthermore, the regulation can include derogations for small airports that might struggle with less advanced infrastructure.

Book-and-claim systems may also refer to different geographical entities. One of the interview partners strongly advocated a global book-and-claim system that follows the GHG protocol, arguing that a global book-and-claim system would boost the uptake of sustainable aviation fuel. They felt that it did not matter in which country the fuels were taken up as the reduction of emissions contributes to the global effort to reduce emissions.

A **national book-and-claim system** would allow substantial flexibility; especially in the first years, all supplied SAFs could be concentrated on one airport, thereby reducing implementation costs. As SAF amounts increase, further airports could be added one-by-one. This would ensure that in every Member State, at least for one location, the fuel supply chain for SAFs is built up. Furthermore, the responsibility of the Member State to check the Proofs of Sustainability is maintained, national specifications in RED transposition can be reflected and fraud such as double claiming might eventually be detected. It can be better integrated in their strategies e.g. a sub-quota for RFNBOs for aviation. Finally, Member States would be sure that the SAF uptake would be reflected in their greenhouse gas inventories and thus would contribute to reaching national greenhouse gas reduction targets.

A **European book-and-claim system** would be more efficient but would most probably imply that not in every Member State SAF is physically delivered and thus neither local human capacity nor SAF supply chain is built up. The European book-and-claim would enable the EU to reflect SAF use in their progress to EU climate targets. In order to prevent fraud, the European level compliance elements (such as the UDB) have to be strengthened and ensured that all fuel amounts registered are scrutinised either by the EU or by a designated national authority.

A **global book-and-claim system** would not ensure that mitigation in the aviation sector is reflected in the EU climate targets or counts towards the fulfilment of ReFuelEU Aviation blending mandate. Besides, the risk of fraud increases and the possibility of imposing higher quality requirements decreases. This option is therefore not recommended.

SAFs reduce GHG emissions not only from aviation, but also pollutants. All book-and-claim approaches will most likely lead to the concentration of SAFs on a relatively small number of airports, thus limiting the health benefits to certain communities. Likewise, the capacity building and the improvements of infrastructure are expected to focus on selected airports only.

We conclude that neither strict physical segregation, nor the global book-and-claim approach seems desirable because of the unintended side effects. At this stage, when global production of SAF is still small and production in Germany is in its early stages, **a mass balance approach that might be combined with national book-and-claim until the market matures further** seems a better way to make sure the integrity of the scheme is protected. Local knowledge is thereby built up while keeping additional costs manageable and posing no unnecessary obstacles hinder the ramp-up of production facilities.

Many interview partners stressed their wish for a **common definition** of sustainable aviation fuels across schemes. Within EU regulation, this is the case: both the EU ETS and ReFuelEU Aviation refer to the RED in their definitions. European legislation is thus largely harmonised. There are slight differences, however, in terms of which fuels can count towards which target. The definitions under CORSIA or the GHG protocol – an important voluntary reporting framework – are not harmonised to match EU definitions. Applying a common definition comes with the risk of agreeing only to the lowest common denominator. Therefore, we believe that harmonisation with international definitions should only be pursued if it does not compromise environmental integrity.

Eligible fuels under the EU ETS and ReFuelEU Aviation are required to have **minimum GHG savings of 70%** over the entire life-cycle compared to fossil kerosene. However, SAFs that achieve higher GHG reductions (greater than the minimum threshold) are not incentivised. The EU or national implementation of the RED mandate could offer additional incentives for fuels with superior GHG savings, encouraging producers to innovate and develop fuels with deeper emission cuts and to secure these fuels for the European market. Also with a view to this aspect, harmonisation within the European Union would be beneficial to minimise market distortion, to align incentives and to stimulate investments.

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A Appendix

A.1 National legislation and implementation of international policies

National RED implementation

EU directives need to be implemented via national legislation. In Germany, there are several legislations which implement the requirements of the RED. To account for the renewable energy targets of the RED, Germany implemented the greenhouse gas quota (in German: "Treibhausgasquote")[70] which to date only covers fuels used in road transport and rail transport. SAFs could contribute to fulfilling the quotas. As part of the implementation of RED II, a national blending quota for Power-to-Liquid fuels (PtL, or RFNBOs) in aviation was adopted in 2021 (BImSchG 2022). The quota will increase from 0.5% (2026) to 1% (2028) and 2% (2030).

A revised RED (RED III, (EU) 2023/2413) entered into force on 20.11.2023. Also, ReFuelEU Aviation was adopted by the EU to create a level playing field for SAF in the EU to avoid the fragmentation of the market through various national mandates.[71] The German PtL quota will thus have to be reconsidered. Generally, the German greenhouse gas quota is more (environmentally) stringent than ReFuelEU Aviation in terms of the eligible fuels.

Further, RED II requirements on sustainability certification are transposed into national law by the Biomass Electricity Sustainability Regulation (in German: "Biomassestrom-Nachhaltigkeitsverordnung", BioSt-NachV) and the Biofuel Sustainability Regulation (in German: "Biokraftstoff-Nachhaltigkeitsverordnung", Biokraft-NachV[72]).

The German transpositions of RED will need to be amended now to account for the changes of the RED III and the new ReFuelEU Aviation. Member States have 18 months to implement the changes to RED in national legislation – i.e. until June 2025.

National EU ETS implementation

The EU ETS is implemented via a directive (2003/87/EC) and several EU regulations, implementing and delegated acts. Important aspects for the implementation of the EU ETS (such as reporting, verification and surrender obligation timelines) are specified on the EU level via the ETS Directive and, for example, the implementing regulation on the monitoring and reporting of greenhouse gas emissions (MRR, EU 2018/2066).

As for the RED, there is a need to adopt national legislation for the implementation of the ETS Directive. The Greenhouse Gas Emissions Trading Act (in German: "Treibhausgas-Emissionshandelsgesetz", TEHG[73]) constitutes the national implementation of the EU ETS Directive for Germany. The current amendments to the EU Directive are implemented nationally via changes to the TEHG. The amending act has not yet entered into force.

[70] §37 in BImSchG Germany: https://www.gesetze-im-internet.de/bimschg/BJNR007210974.html#BJNG011202116 §37 in BImSchG Germany: https://www.gesetze-im-internet.de/bimschg/BJNR007210974.html#BJNR007210974BJNG011202116

[71] ReFuelEU Aviation (EU 2023/2405), recital 15: "[..] *Such a framework should prevent divergent requirements across the Union that would exacerbate refuelling practices distorting competition between aircraft operators or putting some Union airports at competitive disadvantage with others*."

[72] https://www.gesetze-im-internet.de/biokraft-nachv_2021/ https://www.gesetze-im-internet.de/biokraft-nachv_2021/

[73] https://www.gesetze-im-internet.de/tehg_2011/BJNR147510011.html https://www.gesetze-im-internet.de/tehg_2011/BJNR147510011.html

Germany also has a national Emissions Trading Regulation (in German: "Emissionshandelsverordnung" 2030, EHV 2030[74]), which specifies details of the TEHG for the trading period 2021 to 2030. Among other things, it contains additional data requirements to apply for free allowances and the legal basis for exempting small emitters. It also continues existing regulations from the third trading period.

The administering authority for German airlines is the German Emissions Trading Authority (Deutsche Emissionshandelsstelle, DEHSt). DEHSt is responsible for the approval of monitoring plans and checking of annual emission reports as well as the compliance with the surrender obligation under the EU ETS.

In Germany, airlines are required to use a server-based application called "Formular Management System" (FMS). It implements the requirements for the content and structure of the annual emission reports as stipulated in the EU MRR (EU/2018/2066). The annual emission reports also include information on SAFs. If SAFs reported in the annual emission report shall be accounted for with an emission factor of zero, proofs of sustainability for aviation fuels need to be submitted in accordance with the German Biofuel Sustainability Regulation to DEHSt via the "Nachhaltige – Biomasse – Systeme" (Nabisy) database. Other EU countries might have similar online systems or can use the template[75] for annual emission reports provided by the European Commission.

A.2 List of Interviewees

- Lufthansa
- DHL
- Shell
- Neste
- SkyNRG

[74] https://www.gesetze-im-internet.de/ehv_2030/BJNR053800019.html https://www.gesetze-im-internet.de/ehv_2030/BJNR053800019.html

[75] https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/monitoring-reporting-and-verification-eu-ets-emissions_en https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/monitoring-reporting-and-verification-eu-ets-emissions_en

A.3 SAF categories in different policies

Table 15: Summary of SAF categories across different pieces of legislation

	Feedstock	Production pathway	Counting towards the target	Remarks
Synthetic aviation fuel (RFNBO)	Renewable hydrogen (at least 70% GHG reduction[76])	Electrolysis + synthesis	RED III, ReFuelEU aviation, EU ETS	Subtargets in ReFuel Aviation, RED III
Aviation biofuel	Annex IXa biomass feedstock (advanced biofuel)	Gasification and Fischer-Tropsch, pyrolysis	RED III, ReFuelEU aviation, EU ETS	Subtarget in RED III,
	Annex IXb biomass feedstock	Esterification, hydrotreatment	RED III, ReFuelEU aviation, EU ETS	Contribution to RED III targets capped
	Other feedstock, except food and feed and complying with RED sustainability criteria	Any	RED III, ReFuelEU aviation, EU ETS	Max 3% in ReFuelEU
	Food and feed crops and complying with RED sustainability criteria	Any	RED III, EU ETS	Not one percentage point higher than in 2020, and maximum 7%.
Synthetic low-carbon aviation fuel	Non-fossil hydrogen (at least 70% GHG reduction)	Electricity from nuclear energy + electrolysis and synthesis	ReFuelEU Aviation, EU ETS	
Low-carbon hydrogen	Non-fossil, non-renewable hydrogen (at least 70% GHG reduction)	Electricity from nuclear energy + electrolysis	ReFuelEU Aviation, EU ETS	
Recycled carbon fuel	liquid or solid waste streams of non-renewable origin which are not suitable for material recovery. At least 70% GHG savings.	Fermentation, lanzanol	RED III, ReFuelEU Aviation, EU ETS	

Source: Own compilation, CE Delft

[76] Compared to the fossil fuel comparator of 94 g CO_2eq/mj, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2023.157.01.0020.01.ENG&toc=OJ%3AL%3A2023%3A157%3ATOC Compared to the fossil fuel comparator of 94 g CO2eq/mj, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2023.157.01.0020.01.ENG&toc=OJ%3AL%3A2023%3A157%3ATOC