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ICAO State Action Plan on the Reduction of CO_2 Emissions from Aviation for Germany

Impressum

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Contents

List of Abbreviations

AAT - Aircraft Assignment Tool

ACARE – Advisory Council for Research and Innovation in Europe

ACA – Airport Carbon Accreditation

ACI – Airports Council International

ACMI – Aircraft, Crew, Maintenance, Insurance

ADV – Arbeitsgemeinschaft Deutscher Verkehrsflughäfen (German Airport Operators Association)

AIRAC - Aeronautical Information Regulation and Control

AIRE – The Atlantic Interoperability Initiative to Reduce Emissions

AkkL – Arbeitskreis klimaneutrale Luftfahrt (Working Group on Climate-neutral Aviation)

ANSP – Air Navigation Service Provider

AO - Aircraft Operator

APER TG - Action Plans for Emissions Reduction Task Group of the ECAC/EU Aviation and Environment Working Group (EAEG)

ASK – Available Seat Kilometres

ATM – Air Traffic Management

BDL – Bundesverband der deutschen Luftverkehrswirtschaft (German Aviation Association)

BDLI – German Aerospace Industries Association

CAEP – Committee on Aviation Environmental Protection

CCR – CORSIA Central Registry

CDO – Continuous Descent Operations

CNG – Carbon neutral growth

CO_2 – Carbon Dioxide

CORSIA - Carbon Offsetting and Reduction Scheme for International Aviation

COVID – Corona Virus Disease

CS - Certification Specifications

DEFIS – European Commission’s Directorate-General for Defence Industry and Space

DEHSt – Deutsche Emissionshandelsstelle (German Emissions Trading Authority)

DFS – Deutsche Flugsicherung GmbH (German Air Navigation Service Provider)

DWD - Deutscher Wetterdienst (German Weather Service)

EAER – European Aviation Environmental Report

EASA – European Aviation Safety Agency

EAT – European Air Transport

EC – European Commission

ECAC – European Civil Aviation Conference

EEA – European Economic Area

EFTA – European Free Trade Association

eGPU – Electric Ground Power Unit

EU – European Union

EU ETS – EU Emissions Trading System

EUROCONTROL - European Organisation for the Safety of Air Navigation

FABEC – Functional Airspace Block Europe Central

GHG – Greenhouse Gas

GWh – Gigawatt hour

ICAO – International Civil Aviation Organization

IFR – Instrument Flight Rules

IPCC – Intergovernmental Panel on Climate Change

IPR – Intellectual Property Right

ITZ - Innovation and Technology Center Hydrogen

JU – Joint Undertaking

LED – Light-emitting Diode

LTAG – Long-term Aspirational Goal for International Aviation

LuFo – Luftfahrtforschungsprogramm (Aeronautical Research Program)

MBM – Market-based Measure

Mt – Million tons

MTOM – Maximum take-off mass

MUAC – Maastricht Upper Area Control Center

MW – Megawatt

MWh – Megawatt hour

MWp – Megawatt peak power

NIP – National Innovation Program Hydrogen and Fuel Cell Technologies

PPA – Power Purchase Agreement

PRB – Performance Review Body of the Single European Sky

PRISME - Pan European Repository of Information Supporting the Management of EATM

PtL – Power-to-Liquid Fuels

RED – Renewable Energy Directive

RPK – Revenue Passenger Kilometre

RTK – Revenue Tonne Kilometre

RTD – Research and Technological Development

SAF – Sustainable Aviation Fuels

SES – Single European Sky

SESAR – Single European Sky ATM Research

SESAR JU – Single European Sky ATM Research Joint Undertaking

SESAR R&D – SESAR Research and Development

SMEs - Small and Medium Enterprises

TRL – Technology Readiness Level

TU – Technical University

UNFCCC – United Nations Framework Convention on Climate Change

Part I:

Preamble and Introduction

1. Overview, Outline and Executive Summary for Germany

Overview and Outline

This report summarizes the activities of aviation stakeholders to reduce CO_2 emissions from air traffic, following the ICAO "basket of measures" approach in the areas of technology and standards, sustainable aviation fuels, operational improvements, market-based measures and additional measures in the aviation system, primarily at airports. It contains a European common section, describing common European measures that apply to all ECAC States, alongside a national section, describing complementary national information and additional measures and actions in Germany.

The sections are structured as follows: In Part I, this overview and executive summary for Germany is followed by a common introduction for European States' Action Plans, followed by an introduction, brief overview and current state of air transport in Germany, its main stakeholders and its development in recent years. Part II contains the European common section, which outlines a description of common European measures that apply to all ECAC States along the impact modelling, including an emissions baseline and a scenario with/without the implementation of measures. The final Part III describes national measures, specifically proposed and implemented by German stakeholders.

For Part III, the description of national contributions to measures taken collectively throughout Europe is an illustration of the State's involvement in its implementation and any quantified benefits should not be added to the benefits presented in the European common section. The content of this action plan was finalised in December 2024 and shall be considered as subject to update after that date.

Executive Summary for Germany

After the COVID-19 pandemic, air transport has largely recovered. So far, international passenger kilometres in Germany reached 87% of 2019 levels in 2023. International freight traffic already surpassed the levels of the pre-COVID-19 traffic, reaching 101% of 2019 traffic in 2023 whereas domestic flights are below a 50% recovery rate.

Regarding fleet structure of German operators, Lufthansa as the largest German operator, intends to replace older long-haul aircraft types with the most modern aircraft types on the market. Once completed, this fleet rollover has the potential to reduce CO_2 emissions by 750,000 tons per year. For the short- and medium-haul fleet, the complete replacement of the Airbus A320ceo/A321ceo by the A320neo/A321neo will result in a further emission reduction potential of 380,000 tons per year in the long term. Condor, Germany's second largest aircraft operator, also has an ambitious fleet renewal plan for both its short-/medium and long-haul fleet. For the short-and medium-haul fleet, the CO_2 emissions reduction potential is approximately 210,000 tons per year. For the long-haul fleet, there is no absolute CO_2 reduction potential, but the replacement of the Boeing 767-300 and Airbus A330ceo with more seated Airbus A330neo will increase capacity while reducing CO_2 emissions per passenger-kilometre by approximately 20%. The entire long-haul fleet rollover was accomplished in 2024 in record time of 2 years.

Research and development in aeronautics is a key focus in Germany, driven by universities, research centres, and industry to maintain the competitiveness of its civil aeronautical sector, which employed over 73,000 people in 2022. The German Federal Government is focusing on technologies to minimize the climate impact of aviation, supported by several programs: the Aeronautical Research Program (LuFo), National Innovation Program for Hydrogen and Fuel Cell Technologies, Innovation and Technology Center Hydrogen, and institutional funding for the

German Aerospace Center (DLR). Launched in 2019, LuFo VI aims to significantly reduce the climate impact of aviation. The program focuses on alternative climate-neutral propulsion systems and reducing energy use and resources. LuFo VII, starting in 2025, will extend these efforts to larger aircraft, aiming for market maturity by 2035 and climate neutrality by 2045, with an annual budget of around €200 million. Hydrogen and fuel cell technologies are also a major focus under the National Innovation Program (NIP), which emphasizes besides the market activation measures for R&D and demonstration projects to achieve a high level of technology readiness with a focus on the integration of hydrogen fuel cells also in aviation. Since 2017, around €90 million in funding have been made available for the development of fuel cell components and systems for use in aviation. The planned Innovation and Technology Center Hydrogen (ITZ) will support stakeholders in the hydrogen ecosystem through testing, standardization, and industrialization efforts. Initial funding includes up to €290 million in upcoming years. DLR, Germany's national aeronautics research centre, received €239 million in 2022 to advance projects to reduce the climate impact of aviation. The EXACT project, completed in 2023, explored various electric aircraft concepts and demonstrated potential climate impact reductions of up to 90% with hydrogen-powered aircraft. EXACT's successor will focus on refining these concepts and economic analyses for future aircraft operations.

Germany is deeply committed to the decarbonization of aviation through the introduction of sustainable aviation fuels (SAF). In 2021, several federal ministries, together with the German Aviation Association (BDL), published a roadmap targeting 200,000 tons of Power-to-Liquid (PtL) kerosene production in 2030. The German Aerospace Center (DLR), supported by the Federal Ministry for Digital and Transport, is developing the Technology Platform Power-to-Liquid Fuels (TPP) in Leuna, Saxony-Anhalt, which will be the world's largest PtL research and demonstration facility, with an annual capacity of up to 10,000 tons. Initial funding includes €30 million in 2024 and an additional €100 million from 2025 to 2027. To further advance production of PtL fuels, the Federal Government is also establishing PtX labs to develop and industrialize these fuels, with the first lab opening in the Lausitz region of Brandenburg in 2021. Hydrogen is a critical resource for SAF production, recognised in Germany's national hydrogen strategy, which aims to increase domestic electrolysis capacity to 5 GW by 2030, and a further 5 GW by 2040, supported by renewable electricity generation. Recognising the need for global cooperation, Germany is also working to establish a global green hydrogen market through international partnerships.

DFS Deutsche Flugsicherung GmbH, the German air navigation service provider, operates four en-route control centres and 15 airport towers in Germany. In 2021, operations of DFS operations resulted in 30,929 tons of CO_2 emissions. To address this, DFS has set a target of halving energy-related CO_2 emissions by 2025 through various projects using renewable electricity, modernizing radio beacons, and increasing the number of low-emission vehicles. DFS is part of the Single European Sky initiative and is working to improve environmental performance, including direct flight routing and continuous descent operations (CDO) and reducing taxi-out times. Despite challenges, CDO procedures are being implemented at major German airports, and taxi-out times have improved compared to pre-COVID-19 levels. DFS cooperates with ANSPs from neighbouring countries within the Functional Airspace Block Europe Central (FABEC) to improve airspace management and environmental sustainability. Significant efforts include the expansion of the free-route airspace, resulting in estimated weekly CO_2 savings of 6,700 kg.

Market-based measures continue to play an important role in the basket of measures to reduce CO_2 emissions. Germany participates in the EU Emissions Trading System (EU-ETS) for flights within the European Economic Area (EEA) and the ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) for international flights. The EU-ETS was reformed in 2023 under the "Fit-for-55" policy, which aims to reduce overall emissions to an even greater extent. In 2022, Germany administered 72 aircraft operators under the EU-ETS, which reported 7.2 million tons of

CO_2 emissions, a 55% increase from 2021 but still below pre-pandemic levels. Operators received only 45% of required allowances for free, purchasing the rest from auctions or other sectors. Germany supports CORSIA implementation, actively participates in ACT CORSIA Buddy Partnerships and cooperates with countries through trainings on monitoring, reporting and verification requirements.

German airports are actively working to reduce CO_2 emissions, with the goal of achieving net-zero emissions by 2045. Between 2010 and 2019, they achieved a reduction from nearly 700,000 tons to 500,000 tons of CO_2. A four-pillar plan, including renewable energies, sustainable construction, sustainable mobility, and CO_2-optimized infrastructure, is being implemented to achieve these goals. Frankfurt Airport has reduced emissions by 50% since 2010 and plans a 78% reduction by 2030. Munich Airport is aiming for carbon neutrality by 2030, focusing on LED lighting and renewable energy vehicles. Berlin Airport is focusing on renewable electricity and efficient infrastructure, while Düsseldorf Airport is targeting a 65% reduction by 2030 through extensive energy and vehicle upgrades. Hamburg Airport plans to achieve carbon neutrality by 2035 with significant investments in wind power and hydrogen aviation, and Stuttgart Airport aims to achieve zero carbon emissions by 2040 through renewable energy and electric vehicles. The Federal Ministry for Digital and Transport is supporting these efforts with grants for environmentally friendly ground power supplies. This includes funding for alternative technologies to reduce emissions during aircraft turnarounds, with recent investments in battery-powered mobile ground power units and stationary systems at several airports.

2. Common Introductory Section for European State Action Plans

The ICAO Contracting State the Federal Republic of Germany is a member of the European Union (EU) and of the European Civil Aviation Conference (ECAC). ECAC is an intergovernmental organisation covering the widest grouping of Member States[1] of any European organisation dealing with civil aviation. It is currently composed of 44 Member States and was created in 1955.

ECAC States share the view that the environmental impacts of the aviation sector must be mitigated, if aviation is to continue to be successful as an important facilitator of economic growth and prosperity, being an urgent need to achieve the ICAO long-term aspirational goal (LTAG) for international aviation of net-zero carbon emissions by 2050, and to strive for further emissions reductions. Together, they fully support ICAO's on-going efforts to address the full range of those impacts, including the key strategic challenge posed by climate change, for the sustainable development of international air transport.

All ECAC States, in application of their commitment in the 2016 Bratislava Declaration, support CORSIA implementation and have notified ICAO of their decision to voluntarily participate in CORSIA from the start of its pilot phase and have effectively engaged in its implementation.

The Federal Republic of Germany, like all of ECAC's 44 States, is fully committed to and involved in the fight against climate change and works towards a resource-efficient, competitive and sustainable multimodal transport system.

The Federal Republic of Germany recognises the value of each State preparing and submitting to ICAO an updated State Action Plan for CO_2 emissions reductions as an important step towards the achievement of the global collective goals agreed since the 38th Session of the ICAO Assembly in 2013 and the monitoring of the long-term aspirational goal agreed at 41st Session of the ICAO Assembly in 2022.

In that context, it is the intention that all ECAC States submit to ICAO an action plan. This is the action plan of the Federal Republic of Germany.

The Federal Republic of Germany strongly supports the ICAO basket of measures as the key means to achieve ICAO's LTAG target and shares the view of all ECAC States that a comprehensive approach to reducing aviation CO_2 emissions is necessary, and that this should include:

- Emission reductions at source, including European support to CAEP work in this matter (standard setting process);
- Research and development on emission reductions technologies, including public-private partnerships;

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[1] Albania, Armenia, Austria, Azerbaijan, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Moldova, Monaco, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, San Marino, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Türkiye, Ukraine, and the United Kingdom.

- Development and deployment of sustainable aviation fuels, including research and operational initiatives undertaken jointly with stakeholders to meet the ICAO aspirational vision of reducing CO_2 emissions by 5% by 2030 through increased use of SAF worldwide;
- Improvement and optimisation of Air Traffic Management and infrastructure use within Europe, in particular through the Single European Sky ATM Research (SESAR), and also beyond European borders through participation in international cooperation initiatives;
- Market Based Measures, which allow the sector to continue to grow in a sustainable and efficient manner, recognising that the measures at (i) to (iv) above cannot, even in aggregate, deliver in time the emissions reductions necessary to meet the ICAO long term aspirational goal of net-zero carbon emissions by 2050.

In Europe, many of the actions which are undertaken within the framework of this comprehensive approach are in practice taken collectively, including many led by the European Union. They are reported in Part II of this Action Plan, where the involvement of the Federal Republic of Germany is described, as well as that of other stakeholders.

In the Federal Republic of Germany numerous actions are undertaken at the national level. These national actions are reported in Part III of this Action Plan.

In relation to European actions, it is important to note that:

- The extent of participation will vary from one State to another, reflecting the priorities and circumstances of each State (economic situation, size of its aviation market, historical and institutional context, such as EU/non-EU). The ECAC States are thus involved in different degrees and on different timelines in the delivery of these common actions. When an additional State joins a collective action, including at a later stage, this broadens the effect of the measure, thus increasing the European contribution to meeting the global goals.
- Acting together, the ECAC States have undertaken measures to reduce the region’s emissions through a comprehensive approach. Some of the measures, although implemented by some, but not all of ECAC’s 44 States, nonetheless yield emission reduction benefits across the whole of the region (for example research, SAF promotion or ETS).

3. Introductory Section and Current State of Aviation in the Federal Republic of Germany

Introduction

Climate change has become one of the greatest challenges of the century for the entire international community. Decarbonization of industrial processes, power generation and transport is advancing in many countries around the world. Aviation is no exception. For international civil aviation, the 41st ICAO Assembly adopted an ambitious long-term aspirational goal (LTAG) of net-zero carbon emissions by 2050. This goal is likely to be achieved only through the implementation of measures and initiatives by all stakeholders along the value chain. Increased collaboration is therefore a key requirement.

Recognising the critical role of air transport in both global connectivity and carbon emissions, as well as additional economic (e.g. gross value added), social (e.g. employment) and environmental (e.g. non-CO_2) impacts, Germany is at the forefront of progressive action in the aviation sector. Climate protection is high on the agenda of all German aviation stakeholders. Numerous initiatives, projects and technological innovations have been planned and implemented in recent years. Even more ambitious initiatives are envisaged for the future.

With this document, the Federal Republic of Germany presents these initiatives by aviation stakeholders to reduce CO_2 emissions from aviation. The document represents the fourth edition of the German ICAO State Action Plan on CO_2 Emissions Reduction. It aims to showcase the ambitions and achievements of aviation stakeholders and to report on best practices. With the State Action Plan on CO_2 Emissions Reduction, Germany reaffirms its commitment to achieving the ambitious climate goals set out at the international level, such as the ICAO Long-Term Aspirational Goal (LTAG).

General characteristics of Germany's aviation sector

The aviation sector plays an important role in the German economy and mobility. With a relatively high share of foreign trade in total GDP and a focus on high-tech industries such as machinery, automotive and pharmaceuticals, Germany is highly dependent on a well-functioning aviation system. In addition, Germany is both an attractive location for inbound tourism and has one of the highest propensities to travel for outbound tourism, as well as strong ties with other countries for traffic related to visiting friends and relatives.

The country's diverse, polycentric socio-geographic structure is also reflected in its airport landscape. In 2023, Germany had 23 airports with more than 100,000 passengers each. Approximately 100 additional airports/airfields were used for international departures of IFR flights, mostly by general aviation aircraft, but also for occasional passenger and cargo charter flights. Figure 3.1 shows the geographic location of each airport/airfield.

Figure 3.1: Location of airports/airfields in Germany with international traffic

Source: Based on EUROCONTROL data [1].

German airports have a diverse ownership structure. Frankfurt Airport, the country's largest, is partially privatized and listed as a public limited company on the stock exchange. Other airports are also partially privatized, such as Düsseldorf and Hamburg. The majority of airports are publicly owned, often with multiple ownership by the Federal Republic of Germany, the Federal States, counties and/or municipalities. Examples include the airports Berlin-Brandenburg (German states of Berlin and Brandenburg, Federal Republic of Germany) and Cologne/Bonn (City of Cologne, Federal Republic of Germany, German State of North Rhine – Westphalia, City of Bonn, and two counties). The operating companies of a small number of airports are fully privatized, such as Frankfurt-Hahn and Lübeck-Blankensee. Table 3.1 provides an overview of the traffic distribution at the major airports in Germany, as reported by the German Airports Operators Association (ADV) for the year 2023.

Table 3.1: Traffic at major German airports, 2023

Rank (by total passenger traffic)	Airport	Total Passenger Traffic (millions)	Total Cargo Traffic (thousand tons)	Total Flights Movements
1	Frankfurt	59.4	1,869.1	430,436
2	Munich	37.0	284.3	302,153
3	Berlin	23.1	37.5	176,649
4	Düsseldorf	19.1	29.2	151,577
5	Hamburg	13.6	17.9	120,316
6	Cologne/Bonn	9.8	858.9	118,191
7	Stuttgart	8.4	39.6	92,074
8	Hannover	4.6	29.3	63,127
9	Nuremberg	3.9	3.0	50,313
10	Dortmund	2.9	0	34,182
11	Memmingen	2.8	0	27,574
12	Leipzig/Halle	2.1	1,392.6	80,536
13	Bremen	1.8	0.3	27,045
14	Karlsruhe/Baden	1.7	1.8	40,938
15	Hahn	1.7	131.5	15,736
16	Weeze	1.6	0	19,464
17	Münster/Osnabrück	1.0	0.1	36,316
18	Dresden	0.9	0.1	20,093
19	Paderborn/Lippstadt	0.7	0.1	37,610
20	Friedrichshafen	0.3	0	28,352
21	Saarbrücken	0.3	0	7,127
22	Erfurt	0.1	0	5,805
23	Sylt	0.1	0	11,201

Source: German Airports Operators Association (ADV) [2].

As of April 2024, 102 German air carriers are licensed by the Luftfahrt-Bundesamt (Federal Aviation Authority), 42 of which operate aircraft with a maximum take-off mass of more than 10 tons. The aircraft operators are fully privatized and compete in a liberalized, common European market. Smaller operators include leisure and ACMI/charter airlines such as Sundair, German Airways or Leav Aviation, as well as various operators in the General and Business Aviation segments.

Table 3.2: Passenger traffic statistics for German aircraft operators, 2023

Rank (by passengers)	Operator	Passengers (millions)	ASKs (millions)	RPKs (millions)	Seat Load Factor	Number of Flights
1	Deutsche Lufthansa*	46.7	144,455	124,504	86.2%	303,609
2	Eurowings*1	14.4	22,149	18,498	83.5%	112,445
3	Condor	7.6	30,141	26,682	88.5%	38,897
4	Lufthansa Cityline*	6.8	5,448	4,168	76.5%	94,474
5	TUIfly GmbH	3.8	10,312	9,048	87.7%	23,308
6	Discover Airlines*	3.4	17,516	14,635	83.6%	16,757

*) Part of Lufthansa Group 1) Includes services operated by Eurowings Europe (Malta)

Source: Sabre Market Intelligence [3].

The air navigation service provider DFS Deutsche Flugsicherung was corporatized as a limited liability company in 1993 and remains wholly owned by the Federal Republic of Germany. It controls most of the upper airspace over Germany and provides terminal navigation services at all 15 international airports in Germany. The upper airspace in the northwest of Germany is controlled by EUROCONTROL's Maastricht Upper Area Control Centre (MUAC). Air traffic control in Germany is financed by user charges, which are integrated into the EUROCONTROL charging area. En-route charges are levied based on the great circle distance flown and the maximum takeoff mass (MTOM) of the aircraft, while terminal air navigation charges are levied only on the basis of the MTOM.

Table 3.3 shows the development of the most important en-route traffic indicators of DFS. The recovery rate for the number of civil IFR movements in German airspace after the COVID-19 pandemic was at 78.5% for the year 2022 compared to 2019. The recovery rate for service units, which form the basis for user charging, was slightly better at 82.7% for 2022 compared to 2019, reflecting the trend towards the use of larger aircraft.

Table 3.3: Development of key traffic indicators of DFS, 2017-2022

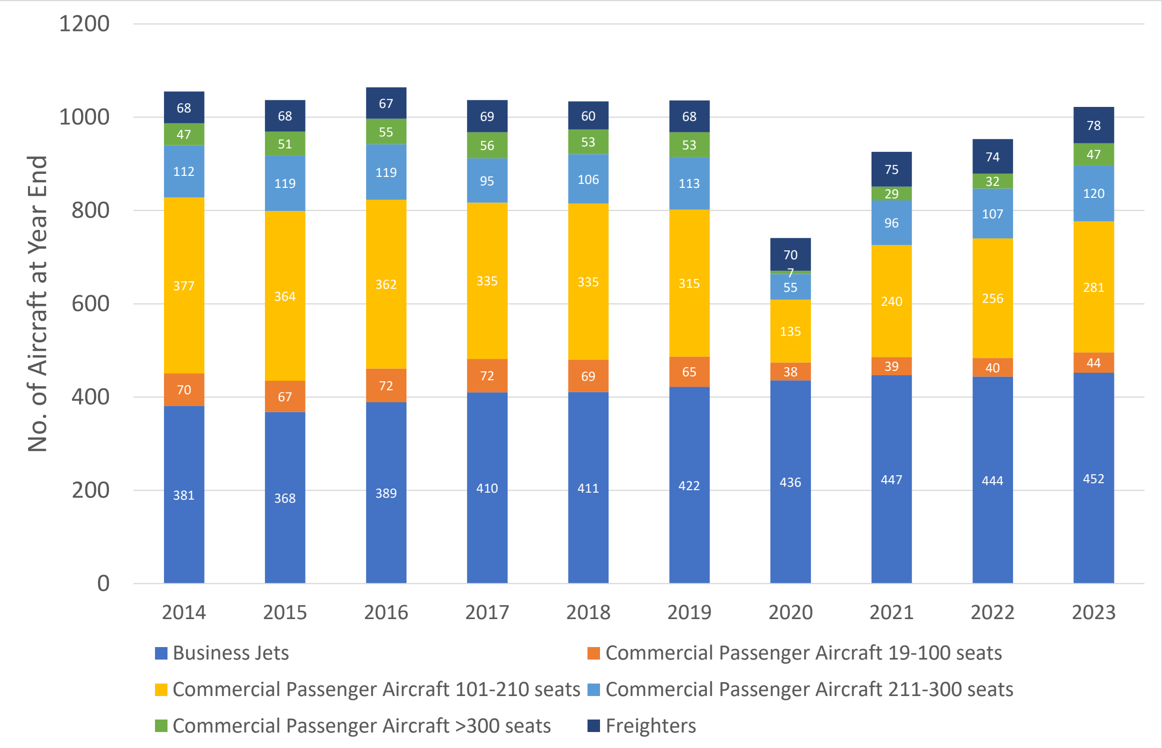
	2017	2018	2019	2020	2021	2022
Civil IFR Movements (thousands)	3,168	3,304	3,292	1,419	1,625	2,585
Civil IFR Movements (yearly variation in %)	+3.4%	+4.3%	-0.4%	-56.9%	+14.5%	+59.1%
Enroute service units (thousands)	14,303	14,932	15,132	6,793	7,679	12,519
Enroute service units (yearly variation in %)	+6.0%	+4.4%	+1.3%	-55.1%	+13.0%	+63.0%

Source: DFS Deutsche Flugsicherung, Annual Reports 2017-2022 [4].

Aircraft fleet of German operators

On 31st December 2023, 1022 business jets, commercial passenger aircraft with 19 or more seats and freighters were registered in Germany. Figure 3.2 provides an overview of the composition of the German aircraft fleet over time between 2014 and 2023, indicating a steady increase in fleet size only in the business jet segment (+19% from 381 units in 2024 to 452 units in 2023).

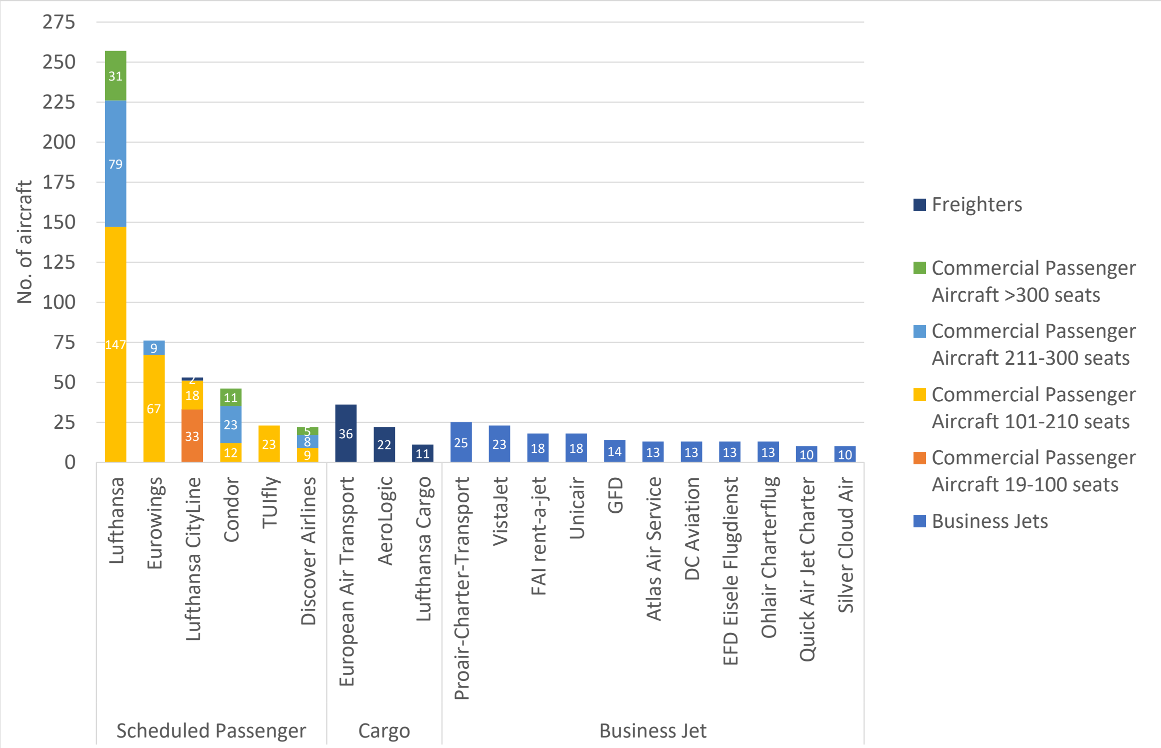
Figure 3.2: Development of Germany-registered aircraft fleet 2014-2023



Source: Cirium Fleets Analyzer [5].

The largest operators in the passenger, cargo and business jet market segments at the end of 2023, in terms of fleet size, are shown in Figure 3.3. The Lufthansa Group operators Lufthansa, Eurowings and Lufthansa Cityline occupy the top three positions, with Discover Airlines and Lufthansa Cargo adding to the group's total of 419 aircraft. After restructuring in recent years, Condor operates 46 aircraft, followed by TUIfly with 23 aircraft. The largest German cargo airline by number of aircraft operated is European Air Transport, which operates on behalf of DHL with 36 aircraft, followed by Aerologic (a joint venture between DHL and Lufthansa) with 22 aircraft. The business jet market is by far more fragmented with 11 operators with 10 or more aircraft on the German register.

Figure 3.3: Overview of largest German aircraft operators (operating ten or more aircraft)



Source: Cirium Fleets Analyzer [5].

Passenger and cargo traffic from Germany

Table 3.4 provides an overview of the development of passenger and freight traffic from Germany. In the period prior to the COVID-19 pandemic (2014-2019), international passenger traffic, measured in passenger kilometres, grew by an average of 3.8% per year, while international freight traffic increased by 1.5% per year.

Table 3.4: Development of passenger and freight traffic from Germany, 2014-2023

Year	Departing Passengers (millions)			Passenger-km (billions)			Freight (tons) (thousands)			Freight ton km (millions)		
	Domestic	International	Total	Domestic	International	Total	Domestic	International	Total	Domestic	International	Total
2014	23.0	81.9	104.9	10.0	202.1	212.1	101	2,236	2,338	36.2	11,032	11,068
2015	23.3	85.4	108.8	10.2	210.1	220.2	105	2,252	2,357	37.5	11,090	11,127
2016	24.0	88.5	112.4	10.4	215.5	225.9	113	2,323	2,436	40.4	11,402	11,442
2017	24.0	94.1	118.1	10.4	228.8	239.2	122	2,472	2,594	43.6	12,133	12,177
2018	23.8	99.3	123.0	10.3	237.6	247.9	124	2,508	2,632	44.3	12,392	12,437
2019	23.3	101.6	124.9	10.1	244.1	254.2	123	2,401	2,524	43.9	11,906	11,950
2020	6.0	25.6	31.5	2.6	59.1	61.7	116	2,307	2,423	41.4	10,866	10,907
2021	4.9	34.6	39.5	2.1	76.8	78.9	124	2,731	2,856	44.4	13,143	13,188
2022	9.5	72.8	82.3	4.1	172.7	176.8	121	2,580	2,701	43.3	13,060	13,103
2023	11.6	86.8	98.4	4.9	212.9	217.8	113	2,415	2,528	40.3	12,475	12,515

Source: German Air Transport Statistics [6].

The COVID-19 pandemic caused a significant decrease in passenger traffic also in Germany. Subsequently, the recovery took place, with international passenger traffic reaching 87% of 2019 traffic in 2023. International freight traffic, which experienced a strong boom during the pandemic, reached 101% of 2019 traffic in 2023. The market for domestic flights in Germany peaked in 2017, the year in which Air Berlin ceased operations, and has not fully recovered since then. In contrast to the international markets, only about 50% of pre-COVID-19 domestic traffic has recovered so far.

International air transport development of energy consumption and emissions from Germany
Data on energy consumption and CO_2 emissions from international air transport are reported annually as part of the UNFCCC national inventory reports.

Table 3.5: Development of traffic and CO_2 emissions from international aviation, 2000-2021

Year	Passenger -km (billions)	Cargo ton km (millions)	Total ton km (millions)*	Jet Fuel Consumption TJ	Jet Fuel Consumption (million t)**	Specific Energy Consumption (MJ/tkm)	CO_2 Emissions (kt)***	Specific CO_2 Emissions (kg / tkm)
2000	132.2	5,585	18,805	265,259	6.20	14.11	19,448	1.034
2001	129.1	5,571	18,479	258,455	6.04	13.99	18,948	1.025
2002	126.5	5,956	18,604	257,396	6.01	13.84	18,868	1.014
2003	129.9	5,905	18,895	261,951	6.12	13.86	19,201	1.016
2004	149.4	6,632	21,574	270,834	6.33	12.55	19,851	0.920
2005	159.3	7,128	23,060	313,919	7.33	13.61	23,007	0.998
2006	165.8	7,952	24,535	330,575	7.72	13.47	24,227	0.987
2007	175.7	8,494	26,060	342,795	8.01	13.15	25,122	0.964
2008	178.2	8,525	26,347	346,377	8.09	13.15	25,384	0.963
2009	171.2	8,175	25,299	337,164	7.88	13.33	24,709	0.977
2010	182.1	10,651	28,866	331,794	7.75	11.49	24,315	0.842
2011	189.7	11,505	30,479	315,851	7.38	10.36	23,146	0.759
2012	195.1	11,186	30,693	341,744	7.98	11.13	25,042	0.816
2013	196.9	11,211	30,899	348,620	8.15	11.28	25,545	0.827
2014	202.1	11,249	31,458	335,519	7.84	10.67	24,584	0.781
2015	210.1	11,338	32,344	334,227	7.81	10.33	24,491	0.757
2016	215.5	11,653	33,200	361,443	8.44	10.89	26,481	0.798
2017	228.8	12,366	35,247	398,413	9.31	11.30	29,189	0.828
2018	237.6	12,587	36,351	410,244	9.59	11.29	30,055	0.827
2019	244.1	12,087	36,497	406,043	9.49	11.13	29,747	0.815
2020	59.1	10,967	16,873	186,896	4.37	11.08	13,691	0.811
2021	76.8	13,216	20,897	247,665	5.79	11.85	18,144	0.868

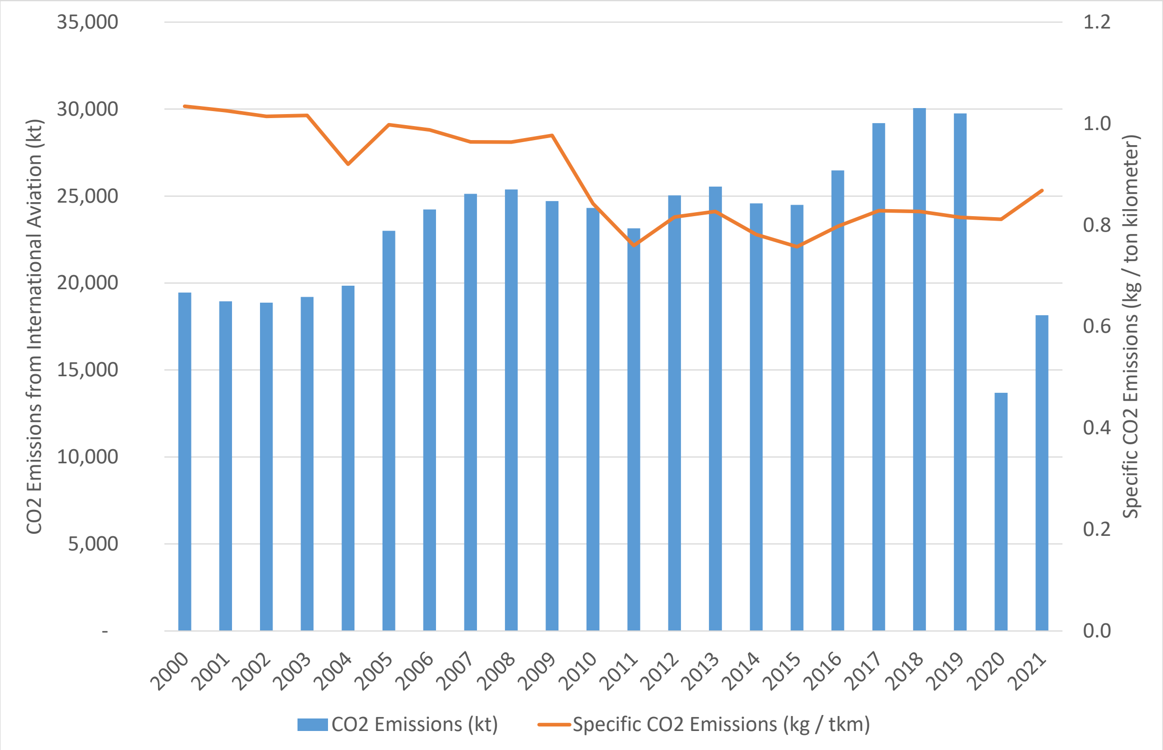
*) Assuming a total mass per passenger including carry-on and checked baggage of 100 kg
**) Assuming an energy density of 42.8 MJ/kg jet fuel
***) Includes CO_2 emissions from Avgas

Source: German Air Transport Statistics [6], UNFCCC National Inventory Reports, own calculations.

The most recent data available from this source is for the year 2021, which was heavily impacted by the COVID-19 pandemic. Therefore, the year 2019 is used as the basis for subsequent comparisons.

As shown in Table 3.5, jet fuel consumption for international air transport from Germany has increased by 2.3% per year between 2000 and 2019, while the transport performance of all traffic segments (passenger, freight and mail), measured in revenue ton-kilometres, increased by 3.6% per year over the same period. The decoupling of transport growth and emissions is therefore evident, with an improvement in specific energy consumption / CO_2 emissions of around 1.25% per year over the last two decades.

Figure 3.4: Absolute and specific CO_2 emissions from international aviation, 2000-2021

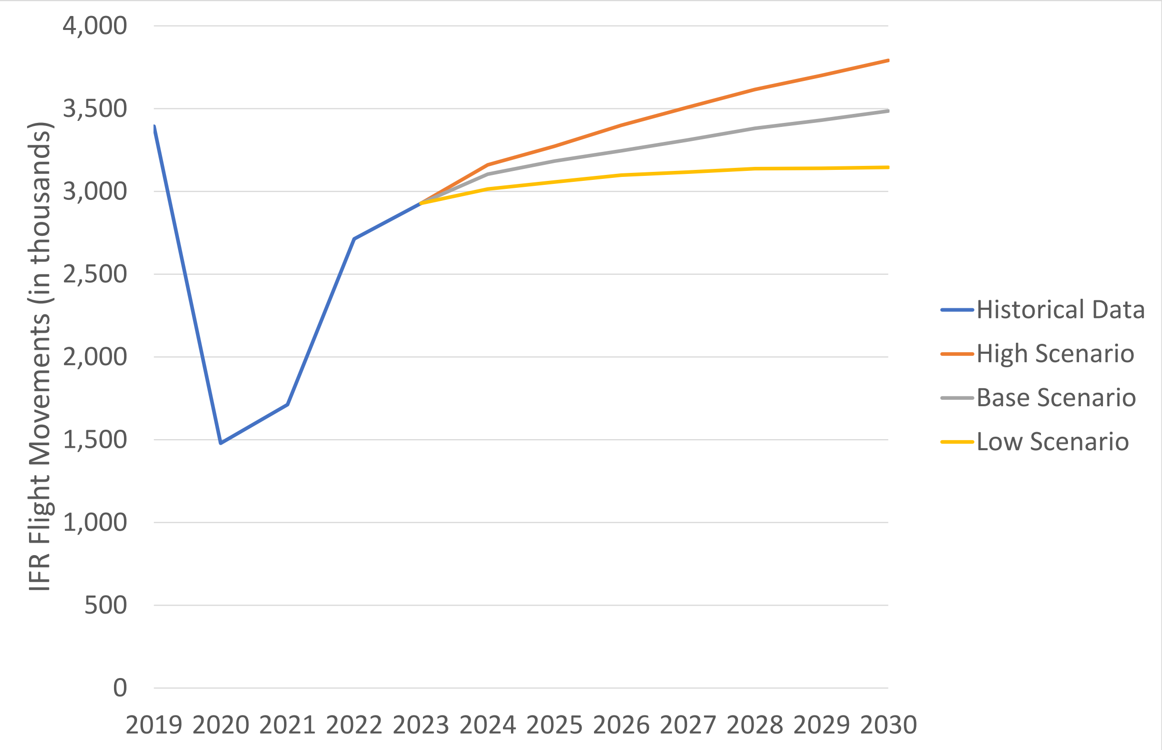


Source: German Air Transport Statistics [6], UNFCCC National Inventory Reports, own calculations.

Forecast

It is expected that the German aviation sector will further recover from the steep decline experienced during the COVID-19-pandemic. In its most recent seven-year forecast, published in February 2024, EUROCONTROL expects an average annual growth in IFR movements in German airspace of between 1.0% and 3.8%. The forecast for Germany is in line with the expectations for the aggregated development in all ECAC states, where growth rates depending on the scenario (low, base, high) are expected to be between 0.9% and 4.0%.

Figure 3.5: EURCONTROL seven-year forecast, spring 2024 – IFR movements in Germany



Source: EUROCONTROL (2024) [7].

List of References and Data Sources for Chapter 3:

[1] EUROCONTROL Aviation Data for Research, https://www.eurocontrol.int/dashboard/rnd-data-archive

[2] German Airports Operators' Association (ADV) Air Traffic Statistics, https://www.adv.aero/aktuelle-verkehrszahlen/

[3] Sabre Market Intelligence, https://www.sabre.com/products/suites/pricing-and-revenue-optimization/market-intelligence/

[4] DFS Deutsche Flugsicherung, Annual Reports 2017-2022, https://www.dfs.de/homepage/de/medien/publikationen/

[5] Cirium Fleets Analyzer, https://www.cirium.com/solutions/fleets-analyzer/

[6] German Air Transport Statistics, https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Transport-Verkehr/Personenverkehr/Publikationen/_publikationen-innen-luftverkehr.html

[7] EUROCONTROL (2024): EUROCONTROL Forecast 2024-2030 Update - Spring 2024, https://www.eurocontrol.int/publication/eurocontrol-forecast-2024-2030 [Last Access 16 August 2024].

Part II:

The ECAC/EU Common Section for European State Action Plans

4. Executive Summary of the European Common Section

The European Section of this action plan, which is common to all European State Action Plans, presents a summary of the actions taken collectively in the 44 States of the European Civil Aviation Conference (ECAC) to reduce CO_2 emissions from the aviation system.

Aviation is a fundamental sector of the European economy, and a very important means of connectivity, business development and leisure for European citizens and visitors. For over a century, Europe has led the development of new technologies, and innovations to better meet society’s needs and concerns, including addressing the sectorial emissions affecting the climate.

Since 2019, the COVID-19 pandemic has generated a world-wide human tragedy, a global economic crisis and an unprecedented disruption of air traffic, significantly changing European aviation’s growth and patterns and heavily impacting the aviation industry. The European air transport recovery can nevertheless be an opportunity to accelerate its contribution to the achievement of the global climate ambitions.

In 2023, the number of flights in Europe reached 92% of the 2019 (pre-COVID) levels, owing to the continuous recovery since the outbreak and the strengthening volumes during summer. Ukraine's airspace has remained closed since February 2022, with neighbouring airspace absorbing more traffic (and diverted flights overloading the busy South-East axis). The start of the conflict in the Middle East (October 2023) has affected various flows that were unable to overfly the zone. Geopolitical crises have also had an impact on flows in the South Caucasus, especially overflights. At the moment of drafting this plan, the level of uncertainty of how these crises will impact international air traffic in the long-term is still high, so the assessments made might be revised in the next update, as more accurate data of such impacts are expected to be available. EUROCONTROL is publishing regular comprehensive assessments of the latest traffic situation in Europe, and such best-available data have been used for the preparation of the European common section of this action plan.

The common section includes an updated description and assessment of the collective European efforts taken to mitigate the climate impacts of aviation, as well as the description of future measures driving to additional CO_2 savings.

Aircraft related technology

European members have worked together to best support the progress in the ICAO Committee on Aviation Environmental Protection (CAEP). This contribution of resources, analytical capability and leadership has undoubtedly facilitated leaps in global certification standards that have helped drive the markets demand for technology improvements. Europe is now fully committed to the implementation of the 2016 ICAO CO_2 standard for newly built aircraft and on the need to review it on a regular basis in light of developments in aeroplane fuel efficiency.

Environmental improvements across the ECAC States are knowledge-led and at the forefront of this is the Clean Sky EU Joint Technology Initiative (JTI) that aims to develop and mature breakthrough “clean technologies”. The second joint undertaking (Clean Sky 2 – 2014-2024) had the objective to reduce aircraft emissions and noise by 20 to 30% with respect to the latest technologies entering into service in 2014. The European Partnership for Clean Aviation (EPCA) will follow in the footsteps of Clean Sky2.

This activity recognises and exploits the interaction between environmental, social and competitiveness aspects with sustainable economic growth. Funding and its motivation are critical to research and the public private partnership model of the EU Research and Innovation programme underpins much that will contribute to this and future CO_2 action plans across the ECAC region.

The main efforts under Clean Sky 2 include demonstrating technologies: for both large and regional passenger aircraft, improved performance and versatility of new rotorcraft concepts, innovative airframe structures and materials, radical engine architectures, systems and controls, and consideration of how we manage aircraft at the end of their useful life. This represents a rich stream of ideas and concepts that, with continued support, will mature and contribute to achieving the goals on limiting global climate change.

Sustainable Aviation Fuels (SAF)

ECAC States are embracing the introduction of SAF in line with the 2050 ICAO Vision and are taking collective actions to address the many current barriers for SAF widespread availability or use in European airports. It has been proven fit for purpose and the distribution system has demonstrated its capacity to handle SAF. At European Union level, the ReFuelEU Aviation Regulation, which applies since 1 January 2024 will boost the supply and demand for SAF in the EU, while maintaining a level playing field in the air transport market. ReFuelEU Aviation aims to put air transport on the trajectory of the EU's climate targets for 2030 and 2050, as SAF are one of the key short- and medium-term tools for decarbonising aviation.

The common European section of this action plan also provides an overview of the current sustainability and life cycle emissions requirements applicable to SAF in the European Union's States as well as estimates of life cycle values for several technological pathways and feedstock. Collective work has also been developed through EASA on addressing barriers of SAF penetration into the market. The European Research and Innovation programme is also giving impulse to innovative technologies to overcome such barriers as it is highlighted by the number of recent European research projects put in place and planned to start in the short-term.

Improved Air Traffic Management

The Single European Sky (SES) policy of the European Union is designed to overhaul Air Traffic Management (ATM) across Europe. This initiative is geared towards digitising services, enhancing capacity, cutting ATM costs, and boosting safety, alongside reducing the environmental impact by 9.3% by 2040. The SES framework includes multiple elements, such as the development and implementation of cutting-edge technical and operational ATM solutions.

The SESAR programme, divided into three phases—SESAR 1 (2008-2016), SESAR 2020 (starting in 2016), and the ongoing SESAR 3 (2021-2031)—is central to advancing these solutions. By the end of the SESAR 3 Wave 2, the solutions developed and validated are expected to yield fuel savings per flight within the ECAC area between 3.6% (180.9 kg, at V3 maturity level only) to 4.6% (227.8 kg, with full and partial V3 maturity benefits considered), translating directly into comparable CO_2 reductions.

Market Based Measures (MBM)

Recognising the need for a global, market-based measure for aviation emissions (to incentivise and reward good investment and operational choices), ECAC Member States have been strong supporters of the Carbon Offsetting and Reduction Scheme for

International Aviation (CORSIA). Pursuant to their 2016 Bratislava Declaration, ECAC member States have voluntarily participated in the scheme since its pilot phase in 2021 and have encouraged other States to follow suit.

To implement CORSIA while preserving the environmental integrity of EU law, the EU ETS Directive was amended in 2023. It extended the restriction of the EU ETS geographical scope to flights between States of the European Economic Area (EEA)[2] and departing flights to the United Kingdom and Switzerland until the end of 2026. EEA States apply the EU Emissions Trading System (EU ETS), while both Switzerland and the United Kingdom implement their own emissions trading systems.

Overall, 500 aircraft operators are regulated under these cap-and-trade market-based measures aimed at limiting CO_2 emissions. In the period 2013 to 2020, the EU ETS has saved an estimated 200 million tonnes of intra-European aviation CO_2 emissions.

ECAC Scenarios for Traffic and CO_2 Emissions

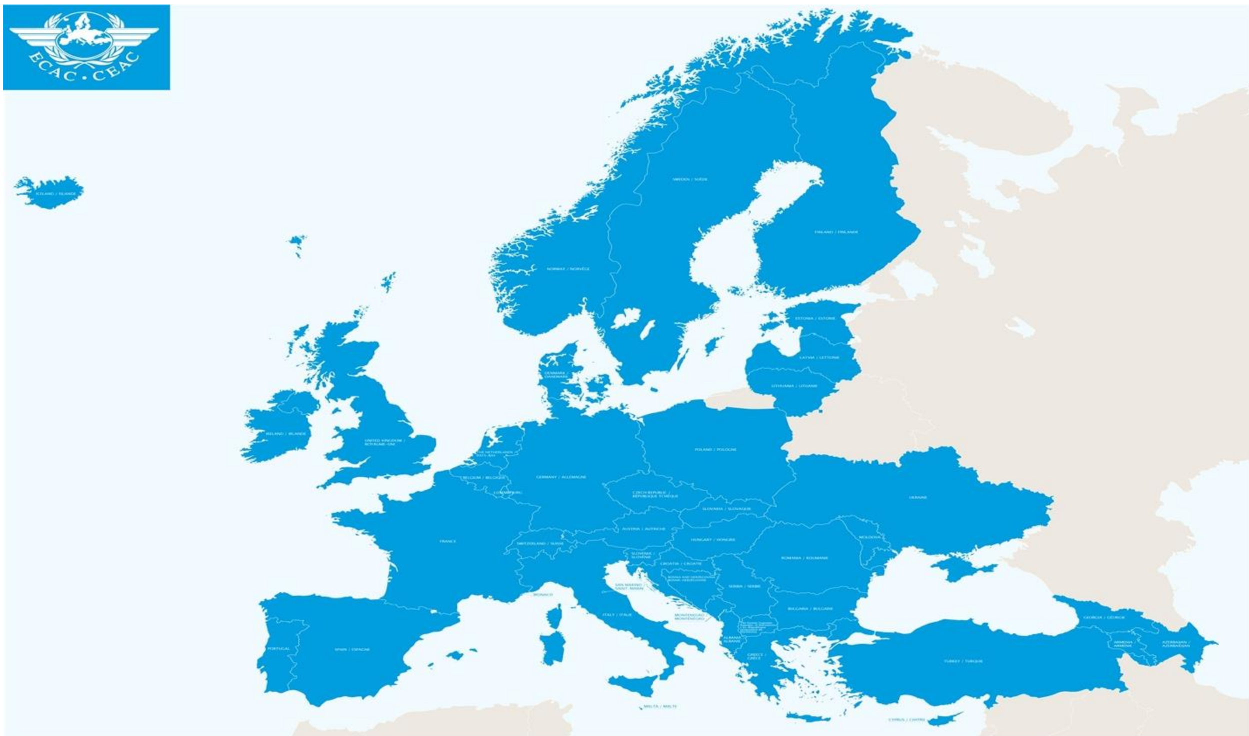
Despite the current extraordinary global decay on passengers' traffic due to the COVID-19 pandemic, hitting the European economy, tourism and the sector itself, aviation is expected to continue to grow in the long-term, develop and diversify in many ways across the ECAC States. Air cargo traffic has not been impacted as the rest of the traffic and thus, whilst the focus of available data relates to passenger traffic, similar pre-COVID forecasted outcomes might be anticipated for cargo traffic both as belly hold freight or in dedicated freighters. Analysis by EUROCONTROL and EASA have identified the most likely scenario of influences on future traffic and modelled these assumptions out to future years. Based on this traffic forecast, fuel consumption and CO_2 emissions of aviation have been estimated for both a theoretical baseline scenario (without any mitigation action) and a scenario with implemented mitigation measures that are presented in this action plan.

Under the baseline assumptions of traffic growth and fleet rollover with 2023 technology, CO_2 emissions would significantly grow in the long-term for flights departing ECAC airports without mitigation measures. Modelling the impact of improved aircraft technology for the scenario with implemented measures indicates an overall 21% reduction of fuel consumption and CO_2 emissions in 2050 compared to the baseline. Whilst the data to model the benefits of ATM improvements may be less robust, they are nevertheless valuable contributions to reduce emissions further. Overall CO_2 emissions, including the effects of new aircraft types and ATM-related measures, are projected to improve to lead to a 29% reduction in 2050 compared to the baseline.

The potential of market-based measures and their effects have been simulated in detail in the common section of this action plan (Chapter 6.4), but they will help reach the goal of carbon-neutral growth. As further developments in policy and technology are made, further analysis will improve the modelling of future emissions.

[2] Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden.

5. ECAC Baseline Scenario and Estimated Benefits of Implemented Measures



1. ECAC Baseline Scenario

The baseline scenario is intended to serve as a reference scenario for CO_2 emissions of European aviation in the absence of any of the mitigation actions described later in this document. The following sets of data (2010, 2019, 2023) and forecasts (for 2030, 2040 and 2050) were provided by EUROCONTROL for this purpose:

- European air traffic (includes all commercial and international flights departing from ECAC airports, in number of flights, revenue passenger kilometres (RPK) and revenue tonne-kilometres (RTK));
- its associated aggregated fuel consumption; and
- its associated CO_2 emissions.

The sets of forecasts correspond to projected traffic volumes in a 'Base' scenario, corresponding to the most-likely scenario, while corresponding fuel consumption and CO_2 emissions assume the technology level of the year 2023 (i.e. without considering reductions of emissions by further aircraft related technology improvements, improved ATM and operations, sustainable aviation fuels or market-based measures).

Traffic Scenario 'Base'

As in all forecasts produced by EUROCONTROL, various scenarios are built with a specific storyline and a mix of characteristics. The aim is to improve the understanding of factors that will influence future traffic growth and the risks that lie ahead. The latest EUROCONTROL Aviation Long-Term Outlook to 2050[3] has been published in 2024 and inspects traffic development in terms of Instrument Flight Rule (IFR) movements to 2050.

In the latter, the scenario called 'Base' is constructed as the 'most likely' scenario for traffic, most closely following the current trends. It considers a moderate economic growth with regulation reflecting environmental, social and economic concerns to address aviation sustainability. This scenario follows both the current trends, and what are seen as the most likely trends into the future.

Amongst the models applied by EUROCONTROL for the forecast the passenger traffic sub-model is the most developed and is structured around five main groups of factors that are taken into account:

- Global economy factors represent the key economic developments driving the demand for air transport.

- Factors characterizing the passengers and their travel preferences change patterns in travel demand and travel destinations.

- Price of tickets set by the airlines to cover their operating costs influences passengers' travel decisions and their choice of transport.

- More hub-and-spoke or point-to-point networks may alter the number of connections and flights needed to travel from origin to destination.

- Market structure considers a detailed analysis of the fleet forecast and innovative projects, hence the future size of aircraft used to satisfy the passenger demand (modelled via the Aircraft Assignment Tool).

Table 5.1 below presents a summary of the social, economic and air traffic related characteristics of three different scenarios developed by EUROCONTROL. The year 2023 served as the baseline year of the 30-year forecast results[4] (published in 2024 by EUROCONTROL). Historical data for the year 2010 and 2019 are also shown later for reference.

[3] EUROCONTROL Long-Term Aviation Outlook to 2050, EUROCONTROL, December 2024. (link to the report https://www.eurocontrol.int/publication/eurocontrol-forecast-2024-2050)

[4] EUROCONTROL Long-Term Aviation Outlook to 2050, EUROCONTROL, December 2024. (link to the report https://www.eurocontrol.int/publication/eurocontrol-forecast-2024-2050)

Table 5.1. Summary characteristics of EUROCONTROL scenarios

	High	***Base***	*Low*
7-year flight forecast 2024-2030	High ↗	Base →	Low ↘
Passenger			
Demographics (Population)	Aging UN Medium-fertility variant	Aging UN Medium-fertility variant	Aging UN Zero-migration variant
Routes and Destinations	Long-haul ↗	No Change →	Long-haul ↘
High-Speed&Night trains (new & improved connections)	32 HST/29 NT city-pairs faster implementation	31 HST/29 NT city-pairs	26 HST city-pairs later implementation.
Economic conditions			
GDP growth	Stronger ↗	Moderate →	Weaker ↘↘
EU Enlargement	+7 States, Later	+7 States, Earliest	+7 States, Latest
Free Trade	Global, faster	Limited, later	None
Price of travel			
Operating cost	Decreasing ↘↘	Decreasing ↘	No change →
Price of CO_2 in Emission Trading Scheme	Moderate, increasing ↗	Moderate, increasing ↗	Moderate, Increasing ↗
Price of oil/barrel	Moderate	Moderate	High
Price of SAF	Relatively High ↗	Relatively High ↗	Highest ↗↗
Structure Network	Hubs: Mid-East ↗↗ Europe ↘ Türkiye ↗ Point-to-point: N-Atlantic. ↘	Hubs: Mid-East ↗↗ Europe & Türkiye ↗ Point-to-point: N-Atlantic ↗, European Secondary Airports. ↗	No change →
Market Structure	Industry fleet forecast, Clean Aviation and STATFOR assumptions	Industry fleet forecast, Clean Aviation and STATFOR assumptions	Industry fleet forecast, Clean Aviation and STATFOR assumptions
Fuel mix	In line with ReFuelEU Aviation (2%SAF in 2025 to 70% in 2050)	In line with ReFuelEU Aviation (2% SAF in 2025 to 70% in 2050)	5 years behind ReFuelEU Aviation (0.5%SAF in 2025 to 42% in 2050)

Update of the EUROCONTROL Aviation Long-Term Outlook to 2050

In November 2023, EUROCONTROL started to work on an update of its EUROCONTROL Aviation Long-Term Outlook to 2050 (EAO). It is an update of the previously published EAO[5] (April 2022), covering the long-term flights and CO_2 emissions forecast to 2050, which was based on 2019 historical flight data. The 2024 edition of the EAO forecast is now based on the latest available actual flight data (2023) and uses the EUROCONTROL

[5] EUROCONTROL Aviation Outlook to 2050, EUROCONTROL, April 2022.

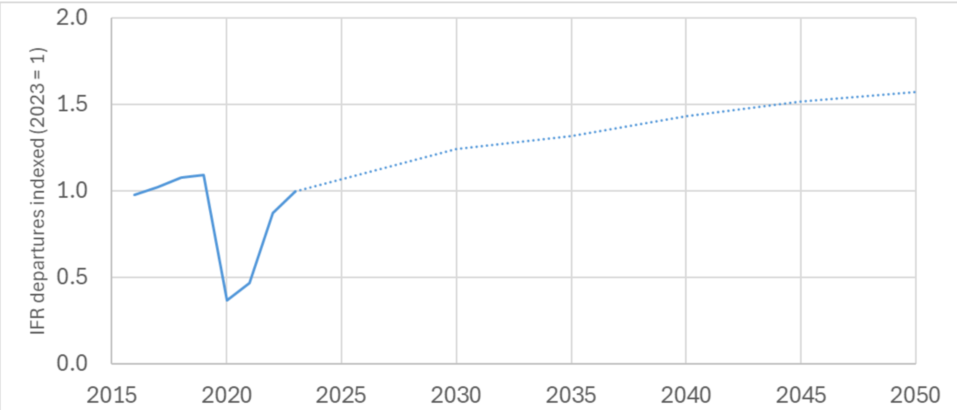
seven-year forecast (2024-2030). It includes a complete review of the fleet forecast assumptions as well as a review of other inputs: high-speed rail network development, impact of Sustainable Aviation Fuels (SAF) mandate, jet fuel and CO_2 allowances on ticket prices, as well as future airport capacity constraints.

EUROCONTROL also provides an update of its modelling framework and traffic environmental assessment with the IMPACT model including:

- an updated technological freeze baseline operations forecast using only growth and replacement in-production aircraft in the baseline year (traffic and fleet baseline scenario) from 2023 to 2050;
- an updated baseline passenger data (Eurostat). Additional data sources may be required to cover the ECAC region;
- Latest versions of the Aircraft Noise and Performance (ANP) database, BADA, ICAO Aircraft Engine Emissions Database (AEEDB), - versions of March 2024;
- Updated assumptions on future technologies, operational efficiency, SAF (e.g. based on the CAEP/13 Environmental Trends complemented with information on emerging technologies).

Figure 5.1 below shows the ECAC scenario of the passenger flight forecasted international departures for both historical (solid line) and future (dashed line) years.

Figure 5.1. Updated EUROCONTROL 'Base' scenario of the passenger flight forecast for ECAC international departures from 2024 to 2050.



Further assumptions and results for the baseline scenario

The ECAC baseline scenario was generated by EUROCONTROL for all ECAC States. It covers all commercial international passenger flights departing[6] from ECAC airports, as forecasted in the aforementioned traffic 'Base' scenario. The number of passengers per flight is derived from Eurostat data.

EUROCONTROL also generates a forecast for all-cargo flights in its baseline scenario.

[6] International departures only. Domestic flights are excluded. A domestic is any flight between two airports in the State, regardless of the operator or which airspaces they enter en-route. Airports located in overseas are attached the State having the sovereignty of the territory. For example, France domestic include flights to Guadeloupe, Martinique, etc.

However, no information about the freight tonnes carried is available. Hence, historical and forecasted cargo traffic have been extracted from another source (ICAO[7]). This data, which is presented below, includes both belly cargo transported on passenger flights and freight transported on dedicated all-cargo flights.

Historical fuel burn and emission calculations are based on the actual flight plans from the PRISME[8] data warehouse used by EUROCONTROL, including the actual flight distance and the cruise altitude by airport pair. These calculations were made with a subset of total passenger traffic (with available and usable information in the flight plans) covering 98% in 2010, and 99% in 2019 and 2030. Determination of the fuel burn and CO_2 emissions for historical years is built up as the aggregation of fuel burn and emissions for each aircraft of the associated traffic sample characteristics. Fuel burn and CO_2 emission results consider each aircraft's fuel burn in its ground and airborne phases of flight and are obtained by use of the EUROCONTROL IMPACT environmental model (https://www.eurocontrol.int/platform/integrated-aircraft-noise-and-emissions-modelling-platform), with the aircraft technology level of each year.

Forecast years (until 2050) fuel burn and modelling calculations use the 2023 flight plan characteristics as much as possible, to replicate actual flown distances and cruise levels, by airport pairs and aircraft types. When not possible, this modelling approach uses past years traffics too, and, if needed, the ICAO CAEP forecast modelling. The forecast fuel burn and CO_2 emissions of the baseline scenario for forecast years use the technology level of 2023. The usable forecast passenger traffic for calculation represents 99.7% of the total available passenger traffic.

For each reported year, the revenue per passenger kilometre (RPK) calculations use the number of passengers carried for each airport pair multiplied by the great circle distance between the associated airports and expressed in kilometres. Because of the coverage of the available passenger estimation datasets (Scheduled, Low-cost, Non-Scheduled flights, available passenger information, etc.) these results are determined for 96% of the historical passenger traffic in 2010, 97% in 2019, 99% in 2023, and around 99% of the passenger flight forecasts.

From the RPK values, the passenger flights RTK can be calculated as the number of tonnes carried by kilometres, assuming that one passenger corresponds to 0.1 tonne.

The fuel efficiency represents the amount of fuel burn divided by the RPK for each available airport pair with passenger data, for the passenger traffic only. Therefore, the fuel efficiency can only be calculated for city pairs for which the fuel burn and the RPK values exists[9].

The following tables and figures show the results for this baseline scenario, which is intended to serve as a reference case by approximating fuel consumption and CO_2 emissions of European aviation in the absence of mitigation actions.

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[7] ICAO Long-Term Traffic Forecasts, Cargo, Europe, International (excluding Russian Federation, Belarus and Greenland), 2021.

[8] PRISME is the name of the EUROCONTROL data warehouse hosting the flight plans, fleet and airframe data.

[9] Dividing the Fuel by the RPK results of the tables presented in this document is not suitable to estimate the fuel efficiency (traffic coverage differences). The presented result has been calculated on an airport pair basis.

Table 5.2. Baseline forecast for international traffic departing from ECAC airports

Year	Passenger Traffic (IFR movement) (million)	Revenue Passenger Kilometres[10] RPK (billion)	All-Cargo Traffic (IFR movements) (million)	Freight Tonne Kilometres transported[11] FTKT (billion)	Total Revenue Tonne Kilometres[12] RTK (billion)
2010	4.71	1,140	0.198	41.6	155.6
2019	5.88	1,874	0.223	46.9	234.3
2023	5.38	1,793	0.234	49.2	228.5
2030	6.69	2,176	0.262	55.9	273.5
2040	7.69	2,588	0.306	69.0	327.8
2050	8.46	2,928	0.367	86.7	379.5

Table 5.3. Fuel burn and CO_2 emissions forecast for the baseline scenario

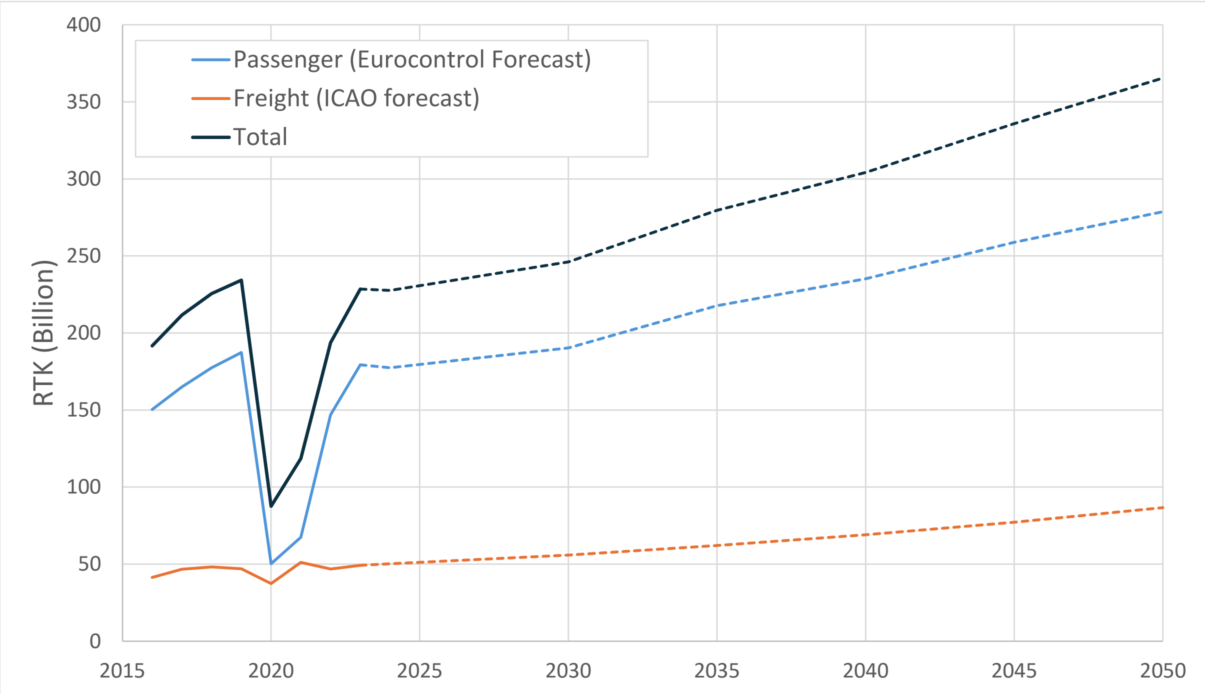
Year	Fuel Consumption (10^9kg)	CO_2 emissions (10^9kg)	Fuel efficiency (kg/RPK)	Fuel efficiency (kg/RTK)
2010	38.08	120.34	0.0327	0.327
2019	53.30	168.42	0.0280	0.280
2023	48.41	152.96	0.0268	0.268
2030	54.46	172.10	0.0250	0.250
2040	62.19	196.52	0.0240	0.240
2050	69.79	220.54	0.0238	0.238
For reasons of data availability, results shown in this table do not include cargo/freight traffic.				

10 Calculated on the basis of Great Circle Distance (GCD) between the airports of the available passenger reports (subset of the global traffic; from 97% in 2010 up to 99% for the forecast years).

11 Includes passenger and freight transport (on all-cargo and passenger flights).

12 A value of 100 kg has been used as the average mass of a passenger incl. baggage (ref: ICAO).

Figure 5.2. Forecasted traffic until 2050 (assumed both for the baseline and implemented measures scenarios)



Although data are not shown in Table 5.2, the number of flights between 2019 and 2023 in Figure 5.2 is reflecting the impact of the COVID-19 starting in 2020. If the passenger segment has been drastically affected by the outbreak, the freight segment seemed more immune.

As detailed by the Table 5.3, from 2010 to 2019, the CO_2 emissions increased from 120 to 168 million tonnes, corresponding to an annual growth rate of 3.8%. In 2023, due to the impact of the COVID-19 crisis on the traffic, the CO_2 emissions were lower than the 2019 level, with 153 million tonnes. For the forecast years, the estimated CO_2 emissions of the ECAC Baseline scenario would increase from 172 million tonnes in 2030 to 220 million tonnes in 2050 (corresponding to annual growth rate of 1.25%).

The fuel efficiency improvement is expected to be less important in the forecast years (annual growth rate of 0.4% between 2023 and 2050) than between 2010 and 2023 (1.5% per year), mainly due to the entry into service of the new generation aircraft families (e.g. MAXs, NEOs).

2. ECAC Scenario with Implemented Measures: Estimated Benefits

To improve fuel efficiency and to reduce future air traffic emissions beyond the projections in the baseline scenario, ECAC States have taken further action. Assumptions for a top-down assessment of the effects of mitigation actions are presented here, based on modelling results by EUROCONTROL and EASA. Measures to reduce aviation's fuel consumption and emissions will be described in the following chapters.

For reasons of simplicity, the scenario with implemented measures is based on the same traffic volumes as the baseline case, i.e. updated EUROCONTROL's 'Base' scenario described earlier. Unlike in the baseline scenario, the effects of aircraft-related technology development and improvements in ATM/operations as well as SAF are considered here for a projection of fuel consumption and CO_2 emissions up to the year 2050.

Effects of **improved aircraft technology** are captured by simulating fleet roll-over and considering the fuel efficiency improvements of the expected future aircraft types with conventional engines (e.g. Boeing 777X, reengineered Airbus A321Neo, etc..) and powered by hybrid electric and hydrogen engines. The simulated future fleet of aircraft has been generated using the Aircraft Assignment Tool[13] (AAT) developed collaboratively by EUROCONTROL, EASA and the European Commission. The retirement process of AAT is performed year by year, allowing the determination of the number of new aircraft required each year.

This technical improvement is modelled by a constant annual improvement of fuel efficiency of 1.16% per annum is assumed for each aircraft type, with entry into service from 2024 onwards. This rate of improvement corresponds to the 'Advanced' fuel technology scenario used by CAEP to generate the fuel trends for the Assembly. This modelling methodology is applied to the years 2030 to 2050. In addition, the entry into service of hybrid electric and hydrogen aircraft types in the traffic induce a percentage of baseline fuel consumption reduction ramping up from 0% in 2035 to 5% in 2050.

The effects of improved **ATM efficiency** are captured in the Implemented Measures Scenario based on the European ATM Master Plan, managed by SESAR 3. This document defines a common vision and roadmap for ATM stakeholders to modernise and harmonise European ATM systems, including an aspirational goal to reduce average CO_2 emission per flight by 5-10% (0.8-1.6 tonnes) by 2035 through enhanced cooperation. Improvements in ATM system efficiency beyond 2023 were assumed to bring reductions in full-flight CO_2 emissions gradually ramping up to 5% in 2035 and 10% in 2050. These reductions are applied on top of those coming from aircraft/engine technology improvements.

The yet un-estimated benefits of Exploratory Research projects[14] are expected to increase the overall future fuel savings.

While the effects of **introduction of SAF** were modelled in previous updates on the basis of the European ACARE goals[15], the expected SAF supply objectives for 2020 were not met. In the current update, the SAF benefits are modelled as a European regional common measure applied to the EU27+EFTA international traffic. It assumes that the minimum shares of SAF laid down in ReFuelEU Aviation Regulation would be met in the base scenario. According to the Regulation, the percentage of SAF used in air transport gradually ramps from 2% in 2025, up to 20% in 2035 and 70% in 2050. A decarbonation factor value of 70% of CO_2 emissions is expected for synthetic aviation fuels and 65% for aviation biofuels. As the SAF-related calculations can only be applied for countries that are expected to implement regional regulations (e.g. ReFuelEU Aviation), the tank-to-wake Net CO_2 emissions are reported in the Appendix of this document for EU27+EFTA international traffic only.

However, numerous initiatives related to SAF (e.g. ReFuelEU Aviation) are largely described in Chapter 6 within the SAF-part and it is expected that future updates will

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[13] https://www.easa.europa.eu/domains/environment/impact-assessment-tools

[14] See SESAR Exploratory Research projects - https://www.sesarju.eu/exploratoryresearch.

[15] https://www.acare4europe.org/sria/flightpath-2050-goals/protecting-environment-and-energy-supply-0

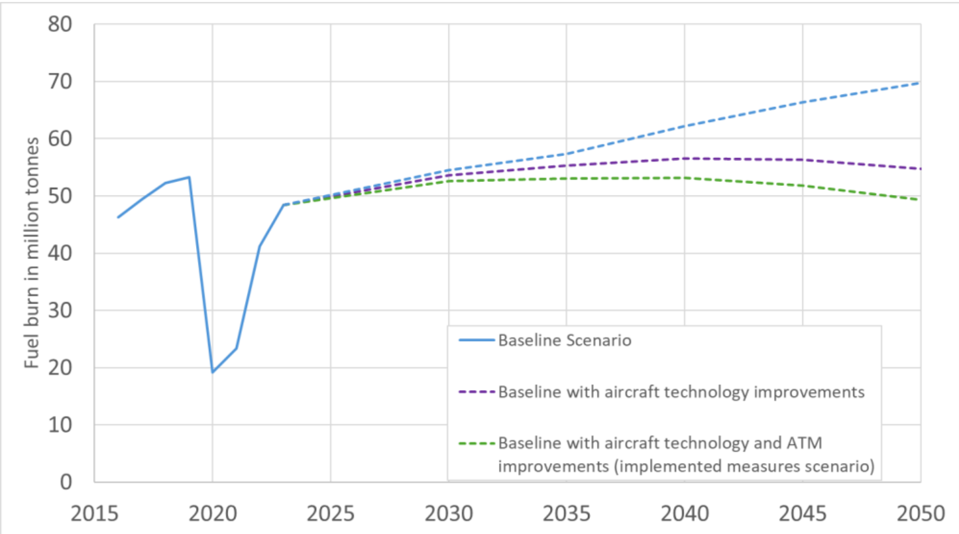
include an assessment of its benefits as a collective measure.

Effects on aviation's CO_2 emissions of **market-based measures** including the EU Emissions Trading System (ETS) with the linked Swiss ETS, the UK ETS and the ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) have not been modelled explicitly in the top-down assessment of the implemented measures scenario presented here. CORSIA aims for carbon-neutral growth (CNG) of aviation, and this target is therefore shown in Figure 5.4[16].

The EU ETS quantifications are described in more details in Chapter 6 within the MBM-part.

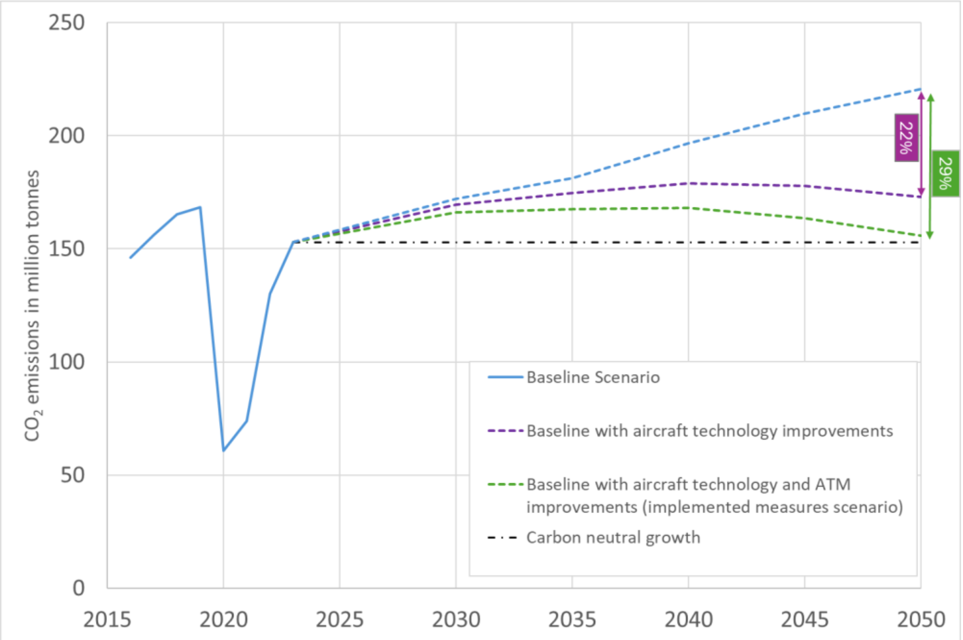
Tables 5.4-5.6, Figure 5.3 and Figure 5.4 summarize the results for the scenario with implemented measures. It should be noted that Table 5.4 and Table 5.6 show direct combustion emissions of CO_2 (assuming 3.16 kg CO_2 per kg fuel). More detailed tabulated results are found in the Appendix, including results expressed in equivalent CO_2 emissions on a well-to-wake basis (for comparison purposes of SAF benefits).

Figure 5.3. Fuel consumption forecast for the baseline and implemented measures scenarios (international passenger flights departing from ECAC airports).



[16] Note that in a strict sense the CORSIA target of CNG is aimed to be achieved globally (and hence not necessarily in each world region).

Figure 5.4. CO_2 emissions forecast for the baseline and implemented measures scenarios



As shown in Figure 5.3 and Figure 5.4, the impact of improved aircraft technology indicates an overall 22% reduction of fuel consumption and CO_2 emissions in 2050 compared to the baseline scenario. Overall CO_2 emissions, including the effects of new aircraft types (conventional, hybrid electric and Hydrogen) and ATM-related measures, are projected to lead to a 29% reduction in 2050 compared to the baseline.

Table 5.4. Fuel burn and CO_2 emissions forecast for the Implemented Measures Scenario (new aircraft technology and ATM improvements only)

Year	**Fuel Consumption (10^9kg)**	**CO_2 emissions (10^9kg)**	**Fuel efficiency (kg/RPK)**	**Fuel efficiency (kg/RTK)**
2010	38.08	120.34	0.0327	0.327
2019	53.30	168.42	0.0280	0.280
2023	48.41	152.96	0.0268	0.268
2030	52.57	166.11	0.0241	0.241
2040	53.20	168.11	0.0205	0.205
2050	49.29	155.75	0.0168	0.168
For reasons of data availability, results shown in this table do not include cargo/freight traffic.				

As detailed in Table 5.5, under the currently assumed aircraft and ATM improvement scenarios, the fuel efficiency is projected to lead to a 37% reduction from 2023 to 2050.

The annual rate of fuel efficiency improvement is expected to be at 1.5% between 2023 and 2030 and reach 2% between 2040 and 2050. However, aircraft technology and ATM improvements alone will not be sufficient to meet the post-2020 carbon neutral growth objective of ICAO, nor will the use of alternative fuels, even if Europe's ambitious targets for alternative fuels (SAF) are met. This confirms that additional action, particularly market-based measures, are required to fill the gap.

Table 5.5. Average annual fuel efficiency improvement for the Implemented Measures Scenario (new aircraft technology and ATM improvements only)

Period	Average annual fuel efficiency improvement (%)
2010-2023	-1.50%
2023-2030	-1.51%
2030-2040	-1.60%
2040-2050	-1.98%

The Table 5.6 below summarises the cumulated effects of each implemented measure. It identifies the weight of the technical improvement on the reduction of CO_2 emissions (from 2% in 2030 to 22% in 2050 compared to the Baseline scenario). The overall impact of the implemented measures (aircraft technology improvements and ATM) shows a reduction of CO_2 emissions by 29% in 2050 compared to the Baseline scenario.

Table 5.6. Summary of CO_2 emissions forecast for the scenarios described in this chapter

Year	CO_2 emissions (10^9 kg)			% improvement by Implemented Measures (full scope)
	Baseline Scenario	Implemented Measures Scenario		
		Aircraft technology improvements only	Aircraft technology and ATM improvements	
2010	120.34			
2019	168.42			
2023	152.96			
2030	172.10	169.50	166.11	-3%
2040	196.52	178.84	168.11	-14%
2050	220.54	173.06	155.75	-29%
For reasons of data availability, results shown in this table do not include cargo/freight traffic.				

The Appendix of this document provides the detailed results for each scenario, Baseline, and by implemented measure, as well as the CO_2 equivalent and EU27+EFTA Net CO_2 emissions.

6. Actions Taken Collectively in Europe

1. **TECHNOLOGY AND DESIGN**
2. **SUSTAINABLE AVIATION FUELS (SAF)**
3. **AIR TRAFFIC MANAGEMENT AND OPERATIONAL IMPROVEMENTS**
4. **MARKET-BASED MEASURES**
5. **ADDITIONAL MEASURES**

1. TECHNOLOGY AND DESIGN

- There have been a limited number of new certified large transport aircraft and engine types over the last few years with marginal environmental improvements, while deliveries of the latest generation of aircraft continue to penetrate the European fleet.
- Certification of all in-production aircraft types against the ICAO CO_2 standard is required by 1 January 2028, which is leading to an increase in activities within this area.
- Environmental technology standards will be important in influencing new aircraft-engine designs and contributing to future sustainability goals.
- In February 2025 the ICAO CAEP is aiming to agree on new aircraft noise and CO_2 limits that would become applicable in the next five years.
- ICAO independent experts medium-term (2027) and long-term (2037) technology goals were agreed in 2019 and are becoming outdated.
- Emissions data measured during the engine certification process acts as an important source of information to support modelling of operational emissions in cruise.
- There have been further developments within the low carbon emissions aircraft market (e.g. electric, hydrogen), with support from the Alliance for Zero-Emissions Aircraft to address barriers to entry into service and facilitate a potential reduction in short / medium-haul CO_2 emissions of 12% by 2050.
- EASA has published noise measurement Guidelines and Environmental Protection Technical Specifications in order to respond to the emerging markets of Drones and Urban Air Mobility.
- EASA has launched a General Aviation Flightpath 2030+ program to accelerate the transition of propulsion technology, infrastructure and fuels to support sustainable operations.
- Horizon Europe, with a budget of €95 billion, is funding collaborative and fundamental aviation research, as well as partnerships (e.g. Clean Aviation, Clean

Hydrogen) who are developing and demonstrating new technologies to support the European Green Deal.

The European Union Aviation Safety Agency (EASA) develops and implements aircraft environmental certification standards [1, 2, 3, 4] that manufacturers have to comply with in order to register their products within the EU and EFTA States.

The recent certification of new types of large transport aircraft and engines has continued to be focused on performance improvement packages for aircraft certified in the 2010s (e.g. Airbus A350, A330neo and A320neo; Boeing 737MAX and 787). The penetration of these aircraft types into the European fleet has slowed due to reduced annual deliveries following the COVID crisis and the average margin to the latest noise standard of the new deliveries is levelling off. In contrast, there has been increased research and certification activity in emerging markets such as zero carbon emission aircraft (e.g. electric and hydrogen powered aircraft).

1.1 Aircraft environmental standards

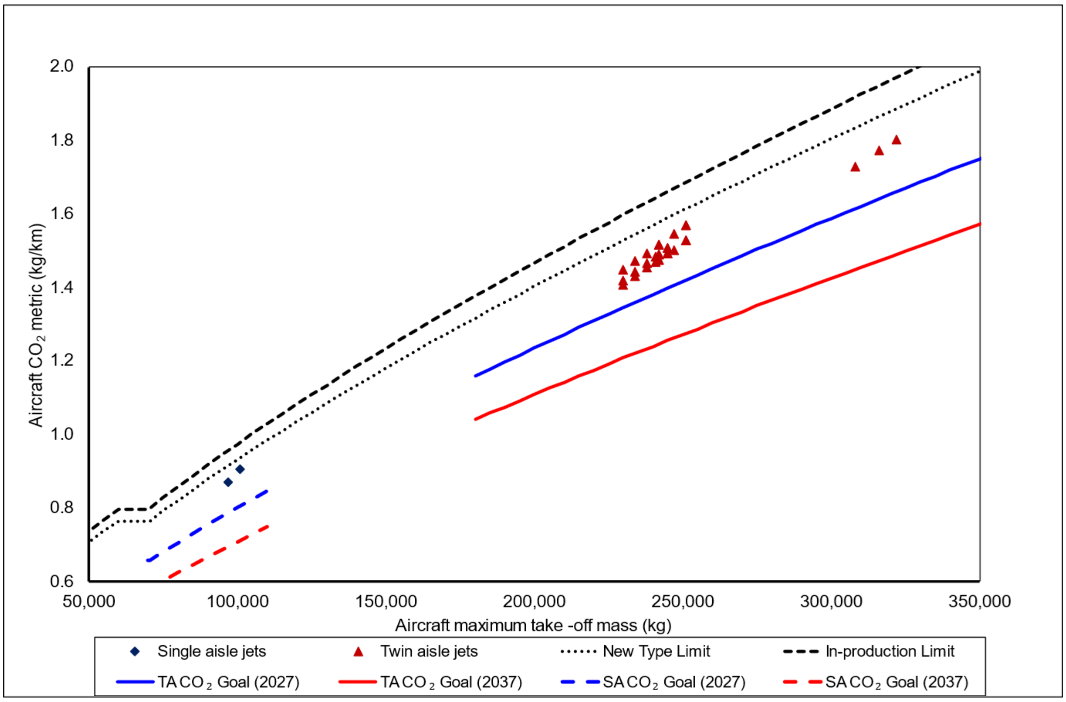
1.1.1 Aircraft CO_2 emissions

Since 1 January 2020, new aircraft types have to comply with a new type CO_2 standard[17], although no aircraft has been certified against this standard as of the start of 2025. The focus thus far has been on certifying in-production aircraft types against a less stringent in-production CO_2 standard as all aircraft have to be certified against this new requirement if they wish to continue to be produced beyond 1 January 2028.

As of the end of 2024, Airbus continues to be the only manufacturer to have certified in-production aircraft types, such as the A330-800neo and -900neo variants, and so the availability of certified CO_2 data remains limited [5]. In light of the approaching production cut-off deadline in 2028, certification of other aircraft types is ongoing by EASA and other regions of the world have also implemented the CO_2 standard into their legislation with it becoming effective in the US on 16 April 2024. The 2019 ICAO Independent Experts Panel goals for leading edge CO_2 emissions performance in 2027 and 2037 would need to be reviewed soon for them to remain relevant.

[17] ICAO Annex 16, Volume III to the Chicago Convention contains international aircraft CO_2 standards. The CO_2 metric is a specific air range-based metric (kg fuel per km flown in cruise) adjusted to take into account fuselage size.

Figure 6.1.1 Certified aircraft CO_2 emissions performance



ICAO dual Noise / CO_2 standard setting

A revision of the ICAO Annex 16 standards for aircraft noise and CO_2 emissions is currently being considered by the ICAO Committee on Aviation Environmental Protection (CAEP). This is the first time that CAEP standard setting has reviewed two standards at the same time in the form of an integrated dual stringency process taking into account design trade-offs at the aircraft level. The environmental benefits and associated costs of a broad range of options for more stringent new type standards have been assessed for an applicability date in the next 5 years. A recommendation by CAEP on new noise and CO_2 limits is due at the CAEP/13 meeting in February 2025.

Considering the long-term development and in-service timescales of new aircraft types, it will be important to set an updated new type CO_2 standard that will influence the fuel efficiency of future designs and effectively contribute to the ICAO Long-Term Aspirational Goal of net zero carbon emissions from international aviation by 2050 [6].

1.2 Low carbon emissions aircraft

In recent years, EASA has received an increasing number of enquiries with regard to the certification of novel aircraft configurations and sources of propulsion with zero carbon emissions in operation when produced with renewable energy.

1.2.1 Electric propulsion

Regarding Vertical take-off and landing Capable Aircraft (VCA – otherwise known as Urban Air Mobility or Advanced Air Mobility vehicles), EASA has recently published two Environmental Protection Technical Specifications (EPTS), which both underwent public consultation. The first EPTS, published in 2023, addresses VCA with non-tilting rotors [7], covering designs such as the Volocopter VoloCity or Airbus CityAirbus. The second EPTS, published in 2024, was for VCA powered, at least partially, by tilting rotors [8], covering designs such as the Lilium Jet. These two EPTS cover the majority of VCA designs currently envisioned and will be utilized in the corresponding noise certification programs. They were derived from legacy noise standards for large helicopters and tilt rotors, adapted to the VCA characteristics and expanded on to include hover condition measurement points. The same noise limits as for large helicopters are being used until more data can be collected. Ultimately, an EU Delegated Act will aim at incorporating the content of these EPTS into EASA noise regulations.

While applications to EASA for electric powered aircraft have increased, there have been few completed general aviation programs since the noise certification of the Pipistrel Velis Electro in 2020, aside from the LAK-17 self-launching sailplane in 2023, due to continuing challenges in increasing battery energy density to reduce weight and increase range. For both products, the legacy noise standards of ICAO Annex 16, Chapter 10 were used with small adjustments. This technology can lead to a 10-decibel noise reduction compared to equivalent piston-engine aircraft, which is perceived as 50% quieter.

EASA Innovative Air Mobility Hub

The EASA Innovative Air Mobility (IAM) Hub [9] is a unique digital platform, developed by a dedicated Task Force that brings together all actors in the European system including cities, regions, National authorities, the EU, operators and manufacturers. The primary goal is to facilitate the safe, secure, efficient, and sustainable implementation of IAM (e.g. Drones, UAMs) practices.

The platform currently comprises of five modules, including Drone and eVTOL Design, Rules and Regulations, Knowledge and Info Cards, Operational Information and Geographical Data such as population data. Various strategies have been deployed to mitigate the environmental impacts from UAS and VCA (e.g. regulations, no-fly zones, geofencing, altitude restrictions, remote identification) with a goal to balance the benefits of these new technologies with the need to protect EU citizens. A

methodology to underpin a full life-cycle environmental assessment of IAM aircraft, known as Environmental Footprint Aviation, is also being developed [10].

1.2.2 Hydrogen-powered Aircraft

The potential of hydrogen to power carbon-free flight has rekindled interest in this alternative fuel, with green hydrogen being relatively easy to produce, provided sufficient renewable energy is available. In particular, there has been a strong interest in the potential of hydrogen used in conjunction with fuel cells and electric motors for regional / short-haul aviation, where the weight of batteries needed for energy storage is currently seen by many as restrictive.

Pioneers in the field have advanced their flight test activity, with H2FLY conducting the world's first piloted flight of a liquid hydrogen powered electric aircraft in September 2023, using their HY4 demonstrator aircraft, operating from Maribor in Slovenia. Other notable flights include ZeroAvia's flight test campaign using a Dornier 228 with the left side propeller powered by their ZA600 prototype engine and, most recently, Beyond Aero achieved France's first manned fully hydrogen-electric flight, using a retrofit model G1 SPYL-XL to demonstrate their technology.

Although the headlines have primarily been related to these aforementioned flight tests using fuel cells, there has also been demonstrable progress on hydrogen combustion technology with Rolls Royce, Safran and GE all successfully running ground tests in this field.

1.2.3 Alliance for Zero Emission Aviation

The Alliance for Zero Emission Aviation (AZEA) was launched in June 2022 and aims to prepare the aviation ecosystem for the entry into service of hydrogen and electric aircraft [10]. It contains 181 Members representing industry, standardisation and certification agencies, research bodies, environmental interest groups and regulators. AZEA members jointly work to identify barriers to entry into commercial service of these aircraft, establish recommendations and a roadmap to address them, promote investment projects and create synergies and momentum amongst members.

In June 2023, AZEA published an overview of the current aviation regulatory landscape for hydrogen and electric aircraft [11], which describes the activities that EASA is doing to adapt the aviation regulatory framework to facilitate the entry into the market of aircraft that use electric or hydrogen propulsion. To support the introduction of disruptive technologies, innovative concepts (including ground and air operations) or products, whose feasibility may need to be confirmed, and for which an adequate regulatory framework does not yet exist or is not mature, EASA is engaging with future applicants through various Innovation Services [12].

With performance-based regulations there is a higher need for supporting industry standards for regulatory compliance and interoperability. As such, AZEA has also published a document mapping existing standards and committees working in this area, including EUROCAE, SAE and ASTM [13]. Further work to identify where new standards are needed is on-going and will serve as a resource for Standards Development Organizations and industry stakeholders to identify opportunities for collaboration and harmonization of activities.

In January 2024, AZEA published its Concept of Operation (CONOPS) for the introduction of electric, hybrid-electric and hydrogen powered aircraft [14]. This addresses the challenges and opportunities arising from the integration of these new market segments into the European aviation system, covering all components of the European Air Traffic Management network, in particular airports. The CONCOPS is expected to reassessed once robust aircraft performance data becomes available.

The AZEA vision "Flying on Electricity and Hydrogen in Europe" published in June 2024 [15] has developed a baseline scenario that, while recognising that long-haul flights relying on these power sources cannot be anticipated before 2050, predicts approximately 5000 electric and hydrogen aircraft (excluding urban air mobility vehicles and helicopters) will be delivered to European operators between now and 2050, leading to a reduction in short and medium-haul CO_2 emissions of 12%. While there are considerable challenges requiring the collaboration of all stakeholders, beyond these hurdles is an opportunity to reshape the aviation sector and to pioneer a sustainable future.

Figure 6.1.2 ATAG indicative overview of where low- and zero-carbon energy could be deployed in commercial aviation alongside that of SAF [16]

	2020	2025	2030	2035	2040	2045	2050
Commuter » 9-19 seats » < 60 minute flights » <1% of industry CO_2	SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF
Regional » 50-100 seats » 30-90 minute flights » ~3% of industry CO_2	SAF	SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF
Short haul » 100-150 seats » 45-120 minute flights » ~24% of industry CO_2	SAF	SAF	SAF	SAF potentially some Hydrogen	Hydrogen and/or SAF	Hydrogen and/or SAF	Hydrogen and/or SAF
Medium haul » 100-250 seats » 60-150 minute flights » ~43% of industry CO_2	SAF	SAF	SAF	SAF	SAF potentially some Hydrogen	SAF potentially some Hydrogen	SAF potentially some Hydrogen
Long haul » 250+ seats » 150 minute + flights » ~30% of industry CO_2	SAF	SAF	SAF	SAF	SAF	SAF	SAF

1.3 Supersonic aircraft

Following the retirement of Concorde in 2003, several manufacturers have been looking into developing supersonic business jets, with some currently looking at an entry into service date of around 2030. Key environmental challenges to address include the use of significantly more fuel on a per passenger kilometre basis compared to subsonic commercial aircraft [17], and noise, specifically the impact of the sonic boom generated when flying at supersonic speed.

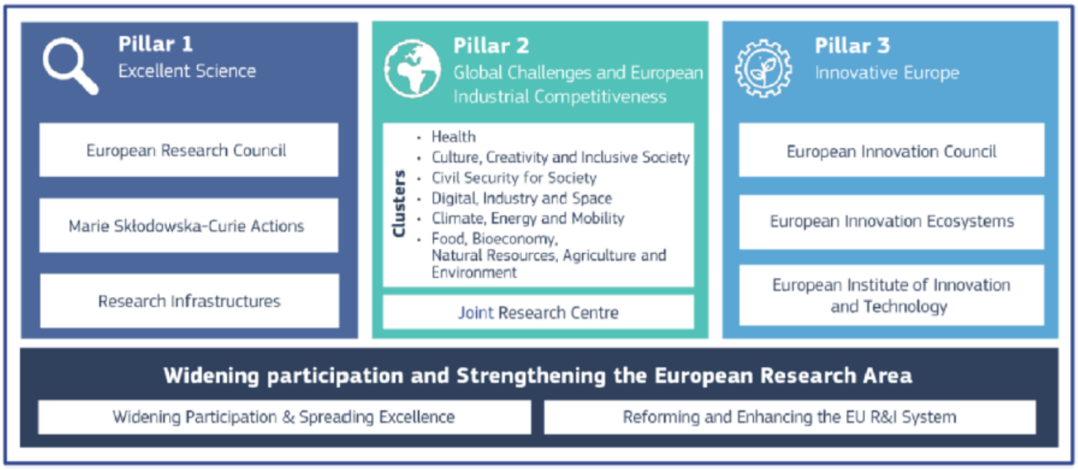
1.4 General Aviation Sustainability Roadmap

EASA is dedicated to making General Aviation (GA) more sustainable. Building on the success of the past GA Roadmap, the Agency has launched the new GA Flightpath 2030+ program in 2024 [18]. GA is seen as a cradle for development, testing, and industrialization of innovations that, when tested and implemented operationally, can drive improvements across the entire aviation sector in safety and sustainability.

The 'Greener Faster' initiative is designed to achieve sector-wide agreement on what sustainable GA means and how everyone can work together to accelerate the transition of GA propulsion technology, infrastructure and fuels to support sustainable operations and the objective of carbon-free aviation by 2050. This will be complemented by the 'Fly Direct' initiative that aims to optimize GA operations in the airspace by removing unnecessary operational restrictions, allowing aircraft to safely navigate the most efficient and environmentally friendly routes.

1.5 Research and Innovation Programmes

Aviation environmental research is embedded in European, National and industry research programmes. At EU level, most research is currently funded through 'Horizon Europe' (2021-2027) with an initial budget of €95.5 billion [19]. Aviation specific research contributes primarily to the European Green Deal and the EU's digital and competitiveness strategies across all three Horizon Europe pillars.



- **Pillar I**: European Research Council science, which often advances the limits of science and technology (e.g. new materials, breakthrough physical processes, artificial intelligence and quantum computing, sensor technologies);
- **Pillar II**: Cluster 5 aviation programme has been the foundation of aeronautics research for over 35 years, including relevant partnerships (e.g. Clean Aviation, Clean Hydrogen and SESAR), industry-led technology demonstrators and Cluster 4 synergies (Digital, Industry and Space); and
- **Pillar III**: European Innovation Council research actions, with emphasis on supporting and connecting SMEs and the aviation supply chain.

The collaborative and fundamental Pillar II Cluster 5 aviation environmental research develops and derisks technologies up to a Technology Readiness Level (TRL) 4, to be taken further by Horizon Europe partnerships, national or industry programmes. The current research is focused on:

- lightweight, multifunctional and intelligent airframe and engine parts
- holistic digital framework for optimized design, manufacturing and maintenance
- uncertainties quantification for design, manufacturing and operation
- ultra-efficient aircraft propulsion
- electrified and hydrogen-enabled propulsion
- fuel-flexible combustion systems and cryogenic liquid hydrogen storage
- better understanding and mitigating non-CO_2 emissions, with emphasis on contrails
- reduction of NO_X, and particulate matter emissions
- noise reduction technologies and abatement procedures

One such Horizon Europe project is HESTIA [20] that focuses on increasing the scientific knowledge of the hydrogen-air combustion of future hydrogen-fuelled aero-engines. Another example is BeCoM [21] which addresses the uncertainties related to the forecasting of persistent contrails and their weather-dependent individual radiative effects, in order to develop recommendations on how to implement strategies that enable air traffic management to reduce aviation's climate impact. Further information on the extensive projects funded under Horizon Europe research programme can be found on the European Commission website [22].

Clean Sky 2 (part of 'Horizon 2020' – 2014 to 2020)

The Clean Sky 2 projects (2014-2024) had a combined public and private budget of around €4 billion, with EU funding up to €1.75 billion [23]. Its objectives were to develop, demonstrate, and accelerate the integration of technologies capable of reducing CO_2, NO_X and Noise emissions by 20 to 30% compared to 'state-of-the-art' aircraft in 2014.

The benefits and potential impact from Clean Sky 2 research at the aircraft, airport and fleet level are evaluated through a dedicated Technology Evaluator function with key assessment and reporting duties. The final assessment by the Technology Evaluator was performed in 2024 [24] and the results are summarised in Table 6.1.1.

Table 6.1.1 Final Clean Sky 2 Technology Evaluator Assessment Results

Mission Level Assessment				
Concept Model	**Assessment**	**CO_2[1]**	**NOx[1]**	**Noise[2]**
Long Range (LR+)	1st	-13%	-38%	<-20%
	2nd	**-18.2%**	**-44.9%**	**-20.1%**
Short-Medium Range (SMR+ & SMR++)	1st	-17% to -26%	-8% to -39%	-20% to-30%
	2nd	**-25.8% to -30.4%**	**-2.3% to -5.1%**	**-11.5% to -16.3%**
Regional (TP90 -TP130 - MM TP70)	1st	-20% to -34%	-56% to -67%	-20% to -68%
	2nd	**-25% to -32.5%**	**-44% to -60%**	**+14% to -44%**
Commuter[3] & BJ	1st	-21% to -31%	-27% to -28%	-20% to-50%
	2nd	**-17.3% to -19.6%**	**-16.5% to -51.5%**	**-19% to -31%**

(1) CO_2 and NO_X values per passenger-kilometre.
(2) Averaged Perceived Sound Volume Reduction (EPNLdB) according to ICAO Annex 16 conditions for fixed-wing aircraft (Chapter 10 for CS-23 aircraft and Chapter 14 for CS-25 aircraft). 20% noise reduction is equivalent to 3dB reduction. 30% of noise reduction is equivalent to 5dB reduction.
(3) Only fossil fuel concepts, excluding the innovative E-Short Take-Off and Landing (STOL) hybrid-electric commuter concept.

Airport Level Assessment			
Assessment	CO_2	NO_x	Noise Area
1st	-8% to-13.5%	-6.5% to -10.5%	-10% to-15%
2nd	**-11.5 to -15%**	**-10.5 to -14.5%**	**-8% to -17% (Lden[1])**

(1) Surface area Reduction of Lden contours for 60-65 dB(A) noise levels at the European airports considered.

Fleet Level Assessment			
Assessment	CO_2	NO_x	Fleet Renewal
1st	-14% to-15%	-29% to -31%	70% to 75% (ASK)
2nd	**-14.5%**	**-29%**	**71.4% (ASK) 61.6% (a/c)**

Clean Aviation (part of 'Horizon Europe' – 2021 to 2027)

Clean Aviation was established in November 2021 under EU Horizon Europe to support the EU ambition of climate neutrality by 2050 [25]. The Clean Aviation programme aims to develop disruptive aircraft technologies that will deliver net greenhouse gas (GHG) reductions of no less than 30%, compared to 2020 state-of-the-art aircraft. The targets have been extended to CO_2 and non-CO_2 effects (nitrogen oxides, water vapour, particulates, contrails, etc.) and EASA is working with Clean Aviation to convey these benefits in the context of the ICAO Annex 16 environmental certification requirements. The technological and industrial readiness aims to allow deployment of these new aircraft no later than 2035, enabling 75% of the world's civil aviation fleet to be replaced by 2050.

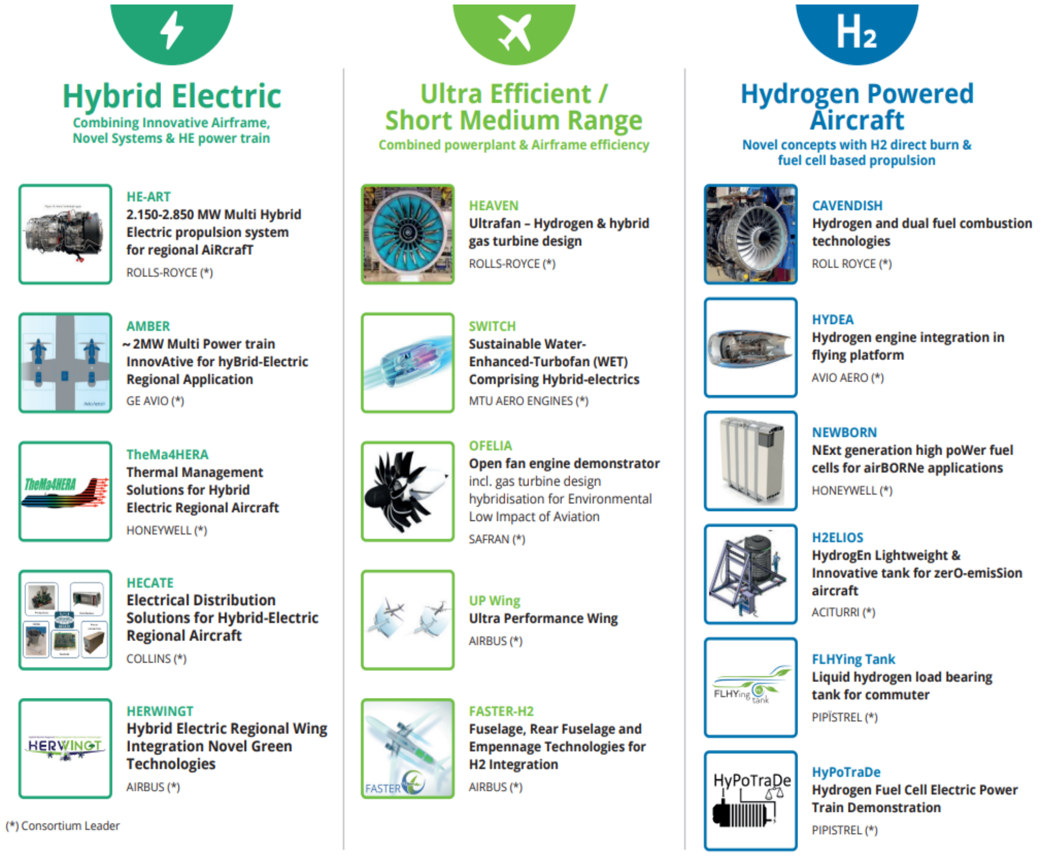
Clean Aviation will focus on three key areas of hybrid electric and full electric architectures, ultra-efficient aircraft architectures and disruptive technologies to enable hydrogen-powered aircraft. The targeted performance levels are summarised in Table 6.1.2 [26].

Table 6.1.2 Clean Aviation Targets

Aircraft Category	Key technologies and architectures to be validated at aircraft level in roadmaps	Entry Into Service Feasibility	CO_2 Emissions reduction (technology based)[28]	Net CO_2 Emissions reduction (i.e. including SAF effect)[29]	Current share of air transport system emissions
Regional Commercial Aircraft	> Hybrid-electric (SAF + Batteries) coupled with highly efficient aircraft configuration	~2035	-30%	-86%	~5%
	> Same with H2-electric power injection (Fuel Cells electric generation)	Beyond 2035	Up to -50%	Up to -90%	
Short-Medium Range Commercial Aircraft	Advanced ultra-efficient aircraft configuration and ultra-efficient gas turbine engines	~2035	-30%	-86%	~50%
Hydrogen-Powered Commercial Aircraft	Full hydrogen-powered aircraft (H2 Fuel Cells or H2-combution)	~2035	-100%	N/A	N/A

28. Improvement targets are defined as CO2 reduction compared to 2020 state-of-the-art aircraft available for order/delivery.
29. Assumes full use of SAF at a state-of-the-art level of net 80% carbon footprint reduction (and where applicable, zero-carbon electric energy for batteries charging and green hydrogen production).

Figure 6.1.3 Initial projects launched in 2023 to deliver important technology bricks in all three areas



STAKEHOLDER ACTIONS

AeroSpace and Defence Industries Association of Europe (ASD)

ASD includes 25 major European companies and 25 National Associations as our members, with an overall representation of up to 4,000 companies across 21 European countries. In 2022, ASD Members employed 921,000 people and generated a turnover of €261 billion.

UltraFan® Technology Demonstrator

Rolls-Royce has successfully run its UltraFan® technology demonstrator to maximum power during 2023. The initial stage of the test was conducted using 100% Sustainable Aviation Fuel (SAF). UltraFan® delivers a 10% efficiency improvement over the Trent XWB engine and a 25% efficiency gain since the launch of the first Trent engine. Testing has been supported by various partners, including the EU Clean Sky programmes.

Hydrogen Fuel Cells

Airbus has performed ground testing to achieve the milestone of running a fuel cell engine concept at full power (1.2 MegaWatts). This is the most powerful fuel cell test ever in the aviation sector, coupling 12 fuel cells to reach the output needed for commercial use. In addition, the Non-Propulsive Energy demonstrator, HyPower, will use a fuel cell containing ten kilograms of gaseous hydrogen generated from renewable sources to produce electricity when tested on board an Airbus A330 in standard operating conditions. It aims to reduce the emissions of CO_2, NO_X and noise levels associated with a traditional APU.

RISE Open Fan

SAFRAN is developing the CFM RISE Open Fan engine demonstrator combining lightweight equipment and advanced technologies such as hybrid electric systems. An open fan architecture has the potential to reduce fuel consumption and CO_2 emissions by more than 20% compared to today's most efficient engines. This advanced, new generation open fan architecture is expected to be able to fly at the same speed as current single-aisle aircraft (up to Mach 0.8) with a noise signature that will meet anticipated future regulations.

Flight testing of the RISE Open Fan is being done in collaboration with Airbus using their A380 Flight Test Demonstrator that aims to mature and accelerate the development of advanced propulsion technologies. The programme objectives include enhanced understanding of engine/wing integration and aerodynamic performance as well as propulsive system efficiency gains, evaluating acoustic models, and ensuring compatibility with 100% Sustainable Aviation Fuels.

List of References for Chapter 6.1:

[1] EU (2018), Regulation (EU) 2018/1139 of the European Parliament and of the Council of 4 July 2018 on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency.

[2] ICAO (2023), Annex 16 to the Convention on International Civil Aviation — Environmental Protection, Volume I, 8th Edition, Amendment 14 — Aircraft Noise.

[3] ICAO (2023), Annex 16 to the Convention on International Civil Aviation — Environmental Protection, Volume II, 5th Edition, Amendment 11 — Aircraft Engine Emissions.

[4] ICAO (2023), Annex 16 to the Convention on International Civil Aviation — Environmental Protection, Volume III, 1st Edition, Amendment 1 — Aeroplane CO_2 Emissions.

[5] EASA (2025), EASA Aeroplane CO_2 Emissions Database.

[6] ICAO (2025), ICAO Long Term Global Aspirational Goal (LTAG) for International Aviation.

[7] EASA (2023), Environmental Protection Technical Specifications applicable to VTOL-capable aircraft powered by non-tilting rotors.

[8] EASA (2024), Environmental Protection Technical Specifications applicable to VTOL-capable aircraft powered by tilting rotors.

[9] EASA (2025), Environmental Footprint Aviation Study for Drones & eVTOLs.

[10] AZEA (2025), Alliance for Zero Emission Aircraft.

[11] AZEA (2023), Current aviation regulatory landscape for aircraft powered by hydrogen or electric propulsion.

[12] EASA (2025), Innovation Services.

[13] AZEA (2023), Current Standardisation Landscape.

[14] AZEA (2024), Concept of Operation for the Introduction of Electric, Hybrid-electric and Hydrogen powered Zero Emission Aircraft.

[15] AZEA (2024), Flying on electricity and hydrogen in Europe.

[16] ATAG (2021), Waypoint 2050 Second Edition.

[17] ICCT (2022), Environmental limits on supersonic aircraft in 2035.

[18] EASA (2025), General Aviation Flightpath 2030+.

[19] EU (2025), Horizon Europe.

[20] EU (2025), HESTIA Horizon Europe project.

[21] EU (2025), BeCoM Horizon Europe project.

[22] EU (2025), EU Research Projects.

[23] Clean Sky 2 (2014), Council Regulation (EU) No 558/2014 of 6 May 2014 establishing the Clean Sky 2 Joint Undertaking.

[24] Clean Sky 2 (2024), Technology Evaluator.

[25] Clean Aviation (2021), Council Regulation (EU) 2021/2085 establishing the Joint

Undertakings under Horizon Europe.

[26] Clean Aviation (2024), Strategic Research & Innovation Agenda.

2. SUSTAINABLE AVIATION FUELS

- ReFuelEU Aviation sets minimum supply mandate for Sustainable Aviation Fuels (SAF) in the EU, starting with 2% in 2025 and increasing to 70% in 2050.
- A sub-mandate for synthetic aviation fuels, starting at 0.7% in 2030 and increasing to 35% in 2050, underlines their significant potential for emissions reductions.
- All SAF supplied under the ReFuelEU Aviation mandate must comply with the sustainability and greenhouse gas emissions saving criteria as set out in the Renewable Energy Directive (RED) and the revised Gas Directive.
- The ICAO CAAF/3 conference agreed in 2023 on a global aspirational vision to reduce CO_2 emissions from international aviation by 5% in 2030 through the use of SAF, low-carbon aviation fuels and other aviation cleaner energies.
- As of 2024, SAF production represented only 0.53% of global jet fuel use. Significant expansion of production capacity is required to meet future mandates and goals.
- SAF must meet international standards to ensure the safety and performance of aviation fuel. Various types of SAF have been approved, with ongoing efforts to increase blending limits and support the use of 100% drop-in SAF by 2030.
- SAF have the potential to offer significant CO_2 and non-CO_2 emissions reductions on a lifecycle basis compared to conventional jet fuels, primarily achieved during the production process using sustainable feedstock. However, various factors such as land use changes can negatively impact the overall lifecycle emissions.
- The upscaling of SAF has generated concerns about potential fraudulent behaviour whereby products labelled as meeting RED sustainability requirements are not compliant.
- Various measures have been put it place to support the achievement of European and ICAO goals on SAF, including a European Clearing House, financial incentives, research programmes and international cooperation.
- SAF production capacity currently under construction could supply the 3.2 Mt of SAF required under ReFuelEU Aviation in 2030, but would be required to ramp up quickly thereafter.

- SAF prices are currently 3 to 10 times more expensive than conventional fuel although they are expected to reduce substantially as production technologies scale up.

2.1 SAF Developments

The last few years have seen significant developments in the European sustainable aviation fuels landscape. With the adoption of the ReFuelEU Aviation Regulation [1], European legislators are ensuring a level playing field for sustainable air transport by establishing minimum mandates for fuel suppliers starting in 2025, including sub-mandates for e-fuels. Together with a growing number of initiatives and mandates outside of Europe, the market is now at a pivotal point and an ambitious increase of production capacity will be required to meet this mandate.

2.2 What are Sustainable Aviation Fuels?

A Sustainable Aviation Fuel (SAF) is a sustainable, non-conventional, alternative to fossil-based jet fuel. Several definitions and terminology apply, depending on regulatory context, feedstock basis, and production technology.

According to the ReFuelEU Aviation Regulation, SAF are defined as various types of drop-in aviation fuels (Table 6.2.1). For instance, aviation biofuels mean biofuels as defined in the Renewable Energy Directive (RED) [2] and excluding fuels produced from food and feed crops as well as other feedstock specified in Article 4 of the Regulation. Finally, for synthetic aviation fuels, a variety of terminologies are used, such as liquid Renewable Fuels of Non-Biological Origin (RFNBO) in ReFuelEU Aviation, but also Electrofuels, e-Fuels and Power-to-Liquid (PtL).

Both ReFuelEU Aviation and the EU Emission Trading System (ETS) use the RED as their basis and all eligible fuels need to comply with the sustainability and greenhouse gas (GHG) emissions reduction criteria set out in the RED.

Table 6.2.1 ReFuelEU Aviation aviation fuel categories

Type of ReFuelEU Aviation fuel	Definition in RFEUA Article	Comments
Categories of sustainable aviation fuels (SAF)		
Synthetic aviation fuels	Art 3(12)	Renewable fuel of non-biological origin in Directive (EU) 2018/2001
Advanced aviation biofuels	Art 3(8)(a)	Produced from the feedstock listed in Part A Annex IX of Directive (EU) 2018/2001
Aviation biofuels	Art 3(8)(b)	Produced from feedstock listed in Part B Annex IX of Directive (EU) 2018/2001
Other aviation biofuels	Art 3(8)(c)	Produced from feedstock not listed in Annex IX of Directive (EU) 2018/2001 and except for those produced from food and feed crops
Recycled carbon aviation fuels	Art 3(9)	Produced from waste streams of non-renewable origin which are not suitable for material recovery
Categories of other eligible renewable and low-carbon aviation fuels under RFEUA		
Low-carbon hydrogen for aviation	Art 3(15)	Produced from non-fossil non-renewable sources
Renewable hydrogen for aviation	Art 3(16)	Renewable fuel of non-biological origin in Directive (EU) 2018/2001
Synthetic low-carbon aviation fuels	Art 3(13)	Produced from non-fossil non-renewable sources
Other aviation fuels under RFEUA		
Conventional aviation fuel	Art 3(14)	Aviation fuels produced from fossil non-renewable sources of hydrocarbon fuels (e.g. crude oil)

Standardisation process for qualification of new SAF production pathways

The reliable performance of aviation fuel is essential to the safe operation of aircraft and is a matter of airworthiness requiring harmonised international practices. What is commonly referred to as "aviation turbine fuel", is a highly specified technical material, characterised by many chemical and physical properties defined by technical specifications, such as the ASTM D1655 and DEF STAN 91-091 [3, 4]. These specifications are developed and maintained by ASTM International and United Kingdom Ministry of Defence (UK MOD) respectively, with support from stakeholder groups such as Original Equipment Manufacturers (OEMs), fuel producers, fuel suppliers, airline operators and regulatory bodies. These fuel standards list the requirements for Jet A/Jet A-1, which is aviation turbine fuel for use within gas turbine engines.

Qualified production pathways are listed in ASTM D7566 [5], which sets out the standard specification for “aviation turbine fuel containing synthesized hydrocarbons”, meaning fuels that are of non-conventional origin. Each type of production pathway is defined in terms of feedstock, conversion technology, fuel specification properties, and maximum blending fraction. After fulfilling blending requirements in ASTM D7566 Table 1 the fuel is redeclared and treated as an ASTM D1655 Jet A/Jet A-1 fuel.

As of October 2024, eight SAF production processes have been standardized by ASTM and consequently been adopted by other fuel standards [5]. In addition, three pathways for the co-processing of renewable feedstocks in petroleum refineries are qualified [3] with a feedstock blending limit of up to 24% (see Table 6.2.2).

Table 6.2.2 Drop-in SAF qualified production pathways

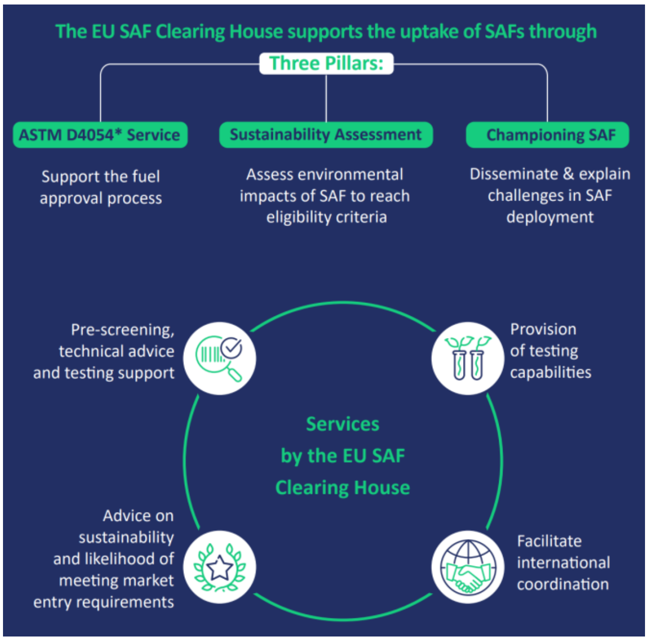
Production pathway	Feedstocks[18]	Certification name	Maximum SAF share
Biomass Gasification + Fischer-Tropsch (Gas+FT)	Energy crops, lignocellulosic biomass, solid waste	FT-SPK[19]	50%
Hydroprocessed Esters and Fatty Acids (HEFA)	Vegetable and animal fat	HEFA-SPK	50%
Direct Sugars to Hydrocarbons (DSHC)	Conventional sugars, lignocellulosic sugars	HFS-SIP[20]	10%[21]
Biomass Gasification + FT with Aromatics	Energy crops, lignocellulosic biomass, solid waste	FT-SPK/A[22]	50%
Alcohol to Jet (AtJ)	Sugar, starch crops, lignocellulosic biomass	ATJ-SPK	50%
Catalytic Hydro-thermolysis Jet (CHJ)	Vegetable and animal fat	CHJ or CH-SK[23]	50%
HEFA from algae	Microalgae oils	HC-HEFA-SPK[24]	10%
AtJ with Aromatics	Sugar, starch crops, lignocellulosic biomass	ATJ-SKA	50%
FOG Co-processing	Fats, oils, and greases	FOG	5%
FT Co-processing	Fischer-Tropsch (FT) biocrude	FT	5%
Hydroprocessed Lipids Co-processing	Hydroprocessed vegetable oils, animal fats, used cooking oils	Hydroprocessed Lipids Co-processing	10%

[18] The listed feedstocks are technologically feasible for the specific production pathway, but not necessarily applicable under certain regulations (e.g. ReFuelEU Aviation).
[19] FT-SPK: Fischer-Tropsch synthesised paraffinic kerosene.
[20] HFS-SIP: hydroprocessed fermented sugars to synthetic iso-paraffins.
[21] TRL 7-8 for conventional sugar feedstock; TRL 5 for lignocellulosic sugar feedstock.
[22] FT-SPK/A: Fischer-Tropsch synthesised paraffinic kerosene with Aromatics.
[23] CH-SK: catalytic hydrothermolysis synthesised kerosene.
[24] HC-HEFA-SPK: Synthesised paraffinic kerosene from hydrocarbon-hydroprocessed esters and fatty acids.

In order to be included in ASTM D7566, novel SAF production pathways need to go through a thorough qualification process specified in ASTM D4054 [6]. This process includes the testing of fuel samples, ranging from small-scale laboratory tests with a limited amount of fuel to full rig- and engine-testing that requires thousands of litres. The resulting research reports are then reviewed and approved by the OEMs before being proposed as ballot for inclusion of a new Annex to ASTM D7566. This is both expensive and time-consuming for all involved stakeholders, which has led to the setup of several SAF Clearing Houses to support this process (see Textbox).

EU SAF Clearing House

The EU SAF Clearing House [7], which is funded by the EU and managed by EASA, is a 'one stop' knowledge centre providing all the information, data and stakeholder connections needed by fuel producers seeking to advance through the ASTM qualification process described above and contribute to the production and supply of sustainable aviation fuels.



Each of the approved SAFs within the ASTM D7566 Annexes has its own characteristics and is tapping into certain categories of feedstock. To be able to produce enough SAF to meet the future needs of the aviation sector, more pathways that tap into new feedstock that have good sustainability characteristics and are economically viable, are required.

There is substantial work being done within fuel standard committees to increase the blending limits for both SAF and the co-processing of renewable feedstock in conventional refineries. For the latter, there are ambitions to increase the limit to 30% by 2025 as the existing infrastructure can be immediately deployed to increase the sustainable share in aviation fuels and support fulfilling the mandates without requiring major investments. The research work required to remove the blending limit and enable the use of 100% SAF is ongoing (see textbox).

Two Options for 100% SAF: Drop-in and Non-Drop-in

Approved SAF currently have associated maximum blending ratios (Table 6.2.2) that may limit the ability to use larger amounts of SAF in the future. As such, dedicated task groups within fuel standard committees are assessing two options to facilitate the use of 100% SAF in aircraft with an initial timeline of having fuel standards ready by latest 2030:

a. 100% Drop-In SAF: Jet Fuel Fully Comprised of Synthesized Hydrocarbon as a drop-in replacement which is identical to Jet A/Jet A-1

b. 100% Non-Drop-In SAF: Non-Drop-In Fully Synthetic Aviation Jet Fuel is aromatic free fuel, which is close to Jet A/Jet A-1 but would be a different fuel.

The 100% Drop-In SAF will be a modification to the existing ASTM D7566. One option to realize such a fuel is to blend two or more SAFs to produce a fuel with characteristics that are fit for purpose in terms of 100% use. Another option is the adaptation of currently used raw materials and production processes to produce a fully formulated 100% SAF in a single process stream (e.g. AtJ, FT- SPK/A and CHJ) or the use of new raw materials and processes yet to be developed and approved. In the last two years, the successful use of 100% Drop-In SAF was demonstrated in experimental flights by different commercial airlines in tight cooperation with OEMs and airworthiness authorities.

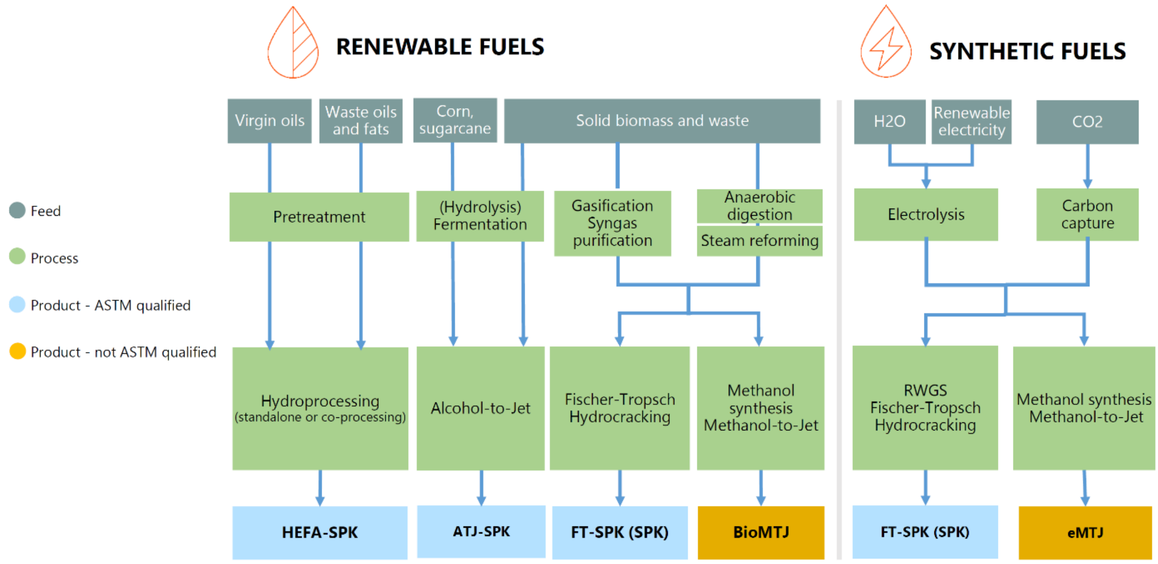
The 100% Non-Drop-In SAF would be a new fuel standard specification. It could be used in designated aircraft/engines only and would require a separate supply chain. A major motivation for this new fuel type would be to significantly reduce emissions that contribute to non-CO_2 climate impacts and local air quality. For (non-aromatic) 100% Non-Drop-In SAFs a series of research and test flights proved their positive effects on emissions and contrail formation. Furthermore, valuable data was collected that will support the specification of a 100% Non-Drop-In SAF.

A collaborative effort across the aviation ecosystem aims to maximize global impact, with standardization and technical readiness currently in progress. Ongoing impact analysis focuses on fuel production, while further studies are necessary to address infrastructure challenges associated with 100% Non-Drop-In SAF.

With a variety of feedstock categories that can be used to produce SAF, the production can be tailored to the specific circumstances of a country and thereby support diversification of fuel supplies. Four of the production pathways that are expected to play a major role in the future are Hydroprocessed Esters and Fatty Acids (HEFA) (TRL[25] 8-9), Alcohols to Jet (AtJ) (TRL 7-8), Biomass Gasification with Fischer-Tropsch (Gas+FT) (TRL 6-8) and Power-to-Liquid (PtL) (TRL 5-8). New production pathways and suitable feedstocks are being developed. Methanol-to-Jet is one promising technology that is being worked on by several companies and is currently going through the qualification process. The advantage of this pathway is that it can be used both with biomass feedstock as well as a conversion technology for Power-to-Liquid fuels.

[25] Technology Readiness Level.

Figure 6.2.1 Main SAF production pathways with similar building blocks [8]



Hydroprocessed Esters and Fatty Acids (HEFA). Currently the most viable option to produce SAF due to its commercial and technical maturity. Feedstocks include waste and residue fats, such as vegetable oil, used cooking oil, and animal fats, as well as purpose-grown crops like jatropha and camelina. These feedstocks are processed with hydrogen to remove oxygen and create hydrocarbon fuel components. However, supply will be limited by the availability of sustainable feedstock and competition from other sectors, such as road. In addition, with growing demand there is a risk of potential fraud from the use of feedstock that does not comply with the sustainability criteria (see Textbox on Sustainable Certification Schemes).

Alcohols to Jet (AtJ) and Biomass Gasification with Fischer-Tropsch (Gas+FT). AtJ fuels can be produced from agricultural residues and crops and the renewable fraction of municipal waste via an alcohol synthesis. Gas+FT converts biogas or syngas from similar feedstocks into fuel. Both methods can be produced with or without aromatics. Aromatics are essential for the performance of certain aircraft engine components (e.g. seals) but have environmental drawbacks in terms of particulate matter emissions. On the other hand, the production with aromatics would enable future 100% drop-in SAF production (see textbox) once the two pathways develop and are commercially available in the EU for aviation fuel production.

Power-to-Liquid (PtL). These fuels offer one of the highest potentials to scale-up production capacity in the future. While not being limited by sustainable biomass availability, they are reliant on access to sufficient additional renewable energy electricity, and an energy efficient conversion process, to achieve significant CO_2 emission reductions. Water and electricity are used in an electrolyser to generate hydrogen, which is then combined with CO_2 to create syngas. This syngas can then be further converted to SAF via the Fischer-Tropsch (FT) pathway or the Methanol-to-Jet pathway (currently in the ASTM D4054 qualification process). The CO_2 required for the PtL process can be obtained from industrial waste gases, biomass, or direct air capture (DAC). With DAC, the CO_2 is directly captured from the air through filters. As the concentration of CO_2 in the air is low, this process is very energy intensive but offers high CO_2 emission reduction potential, once the technology has further matured.

2.3 How sustainable are SAF?

Sustainability criteria

Table 6.2.3 provides an overview of the sustainability criteria used within both the RED [2] and the ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) [9].

Table 6.2.3 SAF sustainability criteria

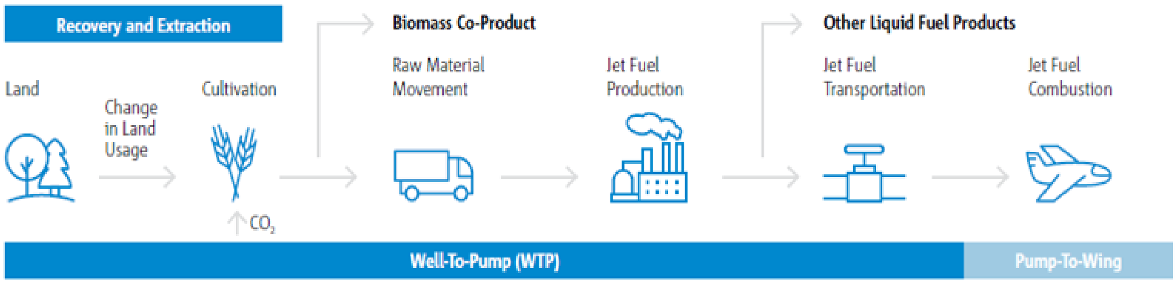
Scheme	**Sustainability criteria**
Renewable Energy Directive (2023), Article 29	• *GHG reductions* – GHG emissions on a life cycle basis from biofuels must be lower than from the fossil fuel they replace (fossil fuel baseline = 94 g CO_2e/MJ): at least 50% lower for installations older than 5 October 2015, 60% lower for installations after that date and 65% lower for biofuels produced in installations starting operation after 2021. For renewable fuels from non-biological origin, and recycled carbon fuels, the savings shall be at least 70%. • *Land use change* – Carbon stock and biodiversity: raw materials for biofuels production cannot be sourced from land with high biodiversity or high carbon stock (i.e., primary and protected forests, highly biodiverse grassland, wetlands and peatlands). Other sustainability issues covered by the reporting obligation are set out in the Governance regulation [10] and can be covered by certification schemes on a voluntary basis. There are also constraints on forest management. • There are additional criteria that are applicable and ensure that electricity used for the production of renewable hydrogen and RFNBOs is of renewable and additional origin. • There are also limitations on biomass production from feedstocks with high indirect land use change (ILUC) risk and using feedstock that could otherwise be used for food, in order to prevent inappropriate land usage and risk to food security.

CORSIA Sustainability Criteria for CORSIA eligible fuels (November 2022)	For batches produced on or after 1 January 2024, the following Sustainability Criteria are applicable: • *GHG reductions* – CORSIA eligible fuel / SAF must achieve net GHG emissions reductions of at least 10% compared to the baseline life-cycle emissions values for aviation fuel on a life cycle basis (fossil fuel baseline = 89 g CO_2e/MJ), including an estimation of ILUC and/or DLUC emissions. • *Carbon Stock* - CORSIA eligible fuel / SAF will not be made from biomass obtained from land converted after 1 January 2008 that was primary forest, wetlands, or peat lands and/or contributes to degradation of the carbon stock in primary forests, wetlands, or peat lands as these lands all have high carbon stocks. • *Permanence* – The emissions reductions attributed to CORSIA SAF should be permanent. Practices will be implemented that monitor, mitigate and compensate any material incidence of non-permanence resulting from carbon capture and sequestration (CCS) activities. There are additional criteria that are applicable and are addressing the following themes: Water, Soil, Air, Conservation (biodiversity), Waste and chemicals, Human and labour rights, Seismic and Vibrational Impacts, Land use rights and land use, Water use rights, Local and social development and Food security.

GHG emissions reductions

The emissions reductions from drop-in SAF in a lifecycle analysis (LCA) are predominately achieved during the production process and more precisely through the use of sustainable feedstock. The greenhouse gases (GHG) emissions in terms of gCO_2e/MJ from its combustion in an aircraft engine are effectively the same as that those of fossil fuels. Many variables can influence the overall results of the LCA (Figure 6.2.2), but given historic concerns surrounding biofuel sustainability, it is encouraged to calculate actual life cycle emission values rather than applying a default value.

Figure 6.2.2 Components of typical well-to-wing LCA for biofuel-based jet fuel



Overestimations of GHG emissions reductions can occur if potential land use changes are not properly considered. Direct Land Use Changes (DLUC) occur when existing land is converted for the growth of feedstock for biofuel, while Indirect Land Use Change (ILUC) occurs when agricultural land used for food or feed is converted to biofuel production and the displaced production shifts to previously non-agricultural land, such as forests or grasslands [11]. Land use change, both direct and indirectly caused by crop displacements, can potentially negate any GHG savings from biofuels, or even release more CO_2-equivalent emissions than what the biomass subsequently grown on that land is able to reduce. Wastes and residues are conventionally considered as having zero DLUC or ILUC associated emissions.

The update to the RED in 2023 has tightened the rules around land use, emphasizing the protection of biodiverse areas and placing stricter controls on land conversion, and imposing restrictions on feedstocks with the higher ILUC risk. Bioenergy production is restricted on lands with high biodiversity value, such as primary forests, highly biodiverse grasslands, and areas designated for nature protection purposes. ReFuelEU Aviation is more stringent than RED by excluding feed and food crops, palm and soy-derived materials, palm fatty acid distillate (PFAD), soap stock and its derivatives as eligible.

Figure 6.2.3 provides an overview of modelled emissions under CORSIA for approved SAF production pathways as of March 2024, separated into Core LCA and ILUC values. Work is ongoing to approve the methodology for calculating the GHG emissions reductions for Power-to-Liquid fuels, where the main lever for emission reductions is the source of electricity to obtain the hydrogen and the source of carbon, which are both required for PtL fuels.

SAF and non-CO_2 emissions

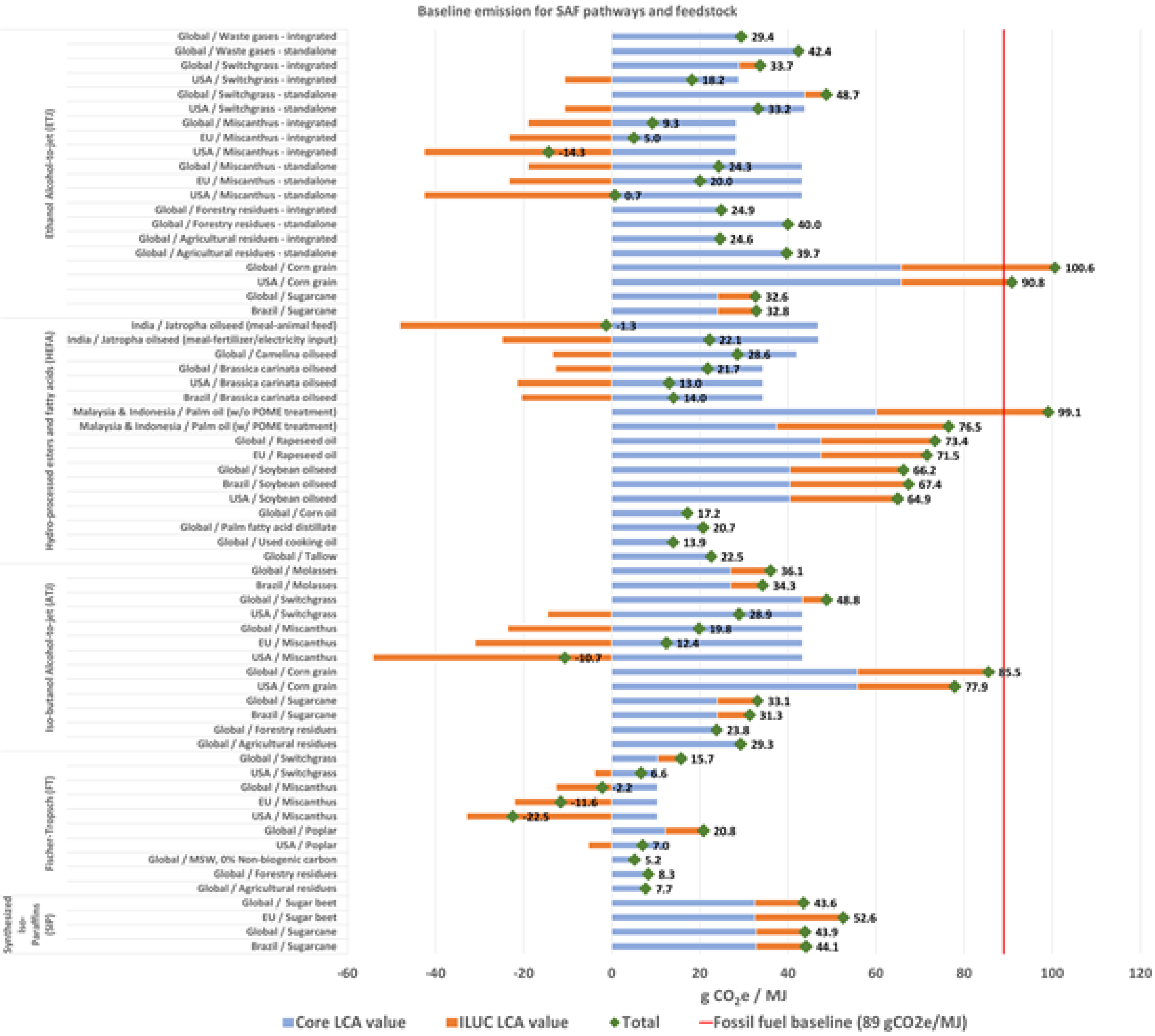
Aviation non-CO_2 emissions refer to pollutants other than carbon dioxide (CO_2) that have a climate impact, including nitrogen oxides (NO_X), aerosol particles (soot and sulphur-based) and water vapour. Some types of SAF have the potential to offer significant non-CO_2 emissions reductions [12, 13].

While it is recognised that aviation non-CO_2 emissions contribute to the overall climate impact, these non-CO_2 effects are currently only estimated with low confidence and substantial uncertainties. The revised EU ETS Directive requires aircraft operators to monitor and report once a year on the non-CO_2 aviation effects.

Research projects, such as AVIATOR and RAPTOR [14, 15] have shown that the use of certain types of SAF could have positive impacts on local air quality [16] due to lower levels of sulphur and aromatic content which contribute to volatile and non-volatile particulate matter (nvPM) emissions. Evidence of contrail reduction when using SAF has been collected and scientifically acknowledged since 2015 (ECLIF I) and further substantiated in the ECLIF II and ND-MAX projects (2018) [17].

In-flight measurements between 2021 and 2024 during the European ECLIF III and VOLCAN I and II research projects extended the studies by using 100% Drop-In and 100% Non-Drop-In SAF in both modern rich-burn and learn-burn combustors. These tests demonstrated a significant contrail reduction due to lower nvPM emissions and ice crystal formations, thereby indicating positive effects on climate change mitigation through the use of SAF [18].

Figure 6.2.3 LCA emissions for CORSIA eligible SAF pathways and feedstock compared to CORSIA fossil fuel reference value (89 g CO_2e/MJ) [19][26]



[26] Two different ATJ conversion plant layouts can be considered. The integrated plant layout assumes co-locating the ATJ process with ethanol production and emissions reductions as a result of heat integration. The standalone configuration assumes that ethanol is taken from the market or a separate ethanol production facility.

Sustainability Certification Schemes – Combatting fraudulent practices.

With so much emphasis being placed on SAF to help reduce aviation emissions, the 'S' in SAF needs to live up to its promise and ensure the effective delivery of emission reductions while avoiding unintended negative environmental and social impacts of its production, thus contributing to the credibility of the sector.

Major regulatory frameworks, such as the EU RED and CORSIA, therefore make use of Sustainability Certification Schemes (SCS). The objective of SCS is to ensure that SAF meet the required sustainability criteria by controlling the compliance with the sustainability requirements along the SAF value chain on a lifecycle basis. Audits are performed by ISO-accredited third-party certification bodies along the complete value chain, from raw material extraction to delivery of SAF to its point of use. In these audits, the auditor focuses on checking each economic operator's compliance with a defined set of sustainability criteria as well as traceability (Chain of Custody) and life cycle emissions criteria, thus ensuring that SAF is produced in accordance with the relevant regulatory requirements (e.g. as per the EU RED or CORSIA).

In recent years, SAF and biofuels upscaling has generated growing concerns about the fraudulent trading of non-sustainable feedstock or biofuels in the EU [20, 21]. Fraudulent behaviour may ensue whereby products are labelled as meeting sustainability requirements even when they are non-compliant. This is highly problematic insofar as these practices threaten both the effectiveness and credibility of climate and renewable energy policies.

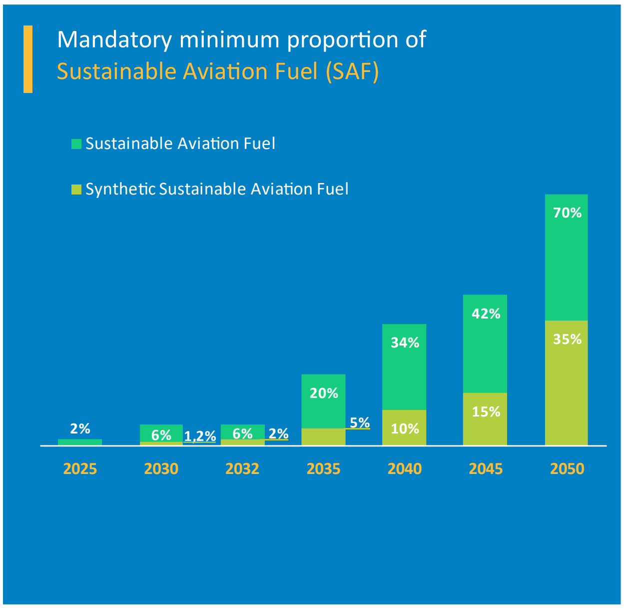
NGOs and European biofuel producers have repeatedly warned against dubious imports and raised concerns about the effectiveness of the certification schemes, which in part led to the development of the EU Union Database that will increase the transparency and reliability of the tracking system of renewable fuels along their supply chains. The Union Database is appropriately integrated in the reporting process of SAF supplied to EU airports under the ReFuelEU Aviation Regulation and the EU ETS Directive.

In response to these concerns, certification schemes have generally increased their efforts to enhance the credibility of the system, including unannounced integrity audits at randomly selected plants and economic operators. As a result, some sustainability certificates were withdrawn or temporarily suspended. They have also put in place a transaction database that is linked with the EU Union Database to prevent the relabelling of sustainability declarations, a mapping tool to support risk identification for auditors, specific guidance materials for waste and residue materials and evaluations of the technical feasibility of processing plants to deal with low-grade advanced waste/residue material [22].

2.4 SAF Policy Actions

ReFuelEU Aviation

The ReFuelEU Aviation Regulation sets out EU-level harmonised obligations on aviation fuel suppliers, aircraft operators and Union airports for scaling up SAF used for flights departing from all EU airports above a certain annual traffic thresholds (passenger traffic above 800,000 or freight traffic above 100,000 tons). Starting in 2025, aviation fuel suppliers are required to supply a minimum of 2% blend of SAF with conventional fossil-based fuels to Union airports and this gradually increases to at least 70% by 2050. Synthetic aviation fuels are subject to an ambitious sub-mandate, starting with 1.2% in 2030, 2% in 2032 and reaching 35% in 2050 [1]. Aircraft operators departing from EU airports must also refuel with the aviation fuel necessary to operate the flight. This avoids the excessive emissions related to extra weight and minimises the risks of carbon leakage caused by so-called 'economic tankering' practices. Between 2025 and 2034, aviation fuel suppliers can supply the minimum shares of SAF as an average over all the aviation fuel they have supplied across Union airports for that reporting period. This flexibility mechanism allows the industry to develop the production and supply capacity accordingly and the fuel suppliers to meet their obligations in the most cost-effective way without reducing the overall ambition. The Commission's Report will identify and assess the developments on SAF production and supply on the Union aviation fuel market, as well as assess possible improvements or additional measures to the existing flexibility mechanism, such as setting a potential accounting and trading mechanism for SAF (a so-called 'book and claim' system). [27]



In order to support the achievement of the ReFuelEU Aviation supply mandate, the EU has put in place various regulatory, financial and other supporting measures, including:

- A zero emissions rating of RED-compliant SAF used under the EU Emissions Trading System (ETS);
- A maximum of 20 million extra ETS (with an estimated value of €1.6 billion) allowances will be allocated to aircraft operators during 2024 to 2030 for the uplifting of SAF to also cover part of, or all of the price difference with fossil kerosene, depending on the type of SAF and the uplift location;
- A fuel tax structure under the proposed revision of Energy Taxation Directive that would incentivise SAF over fossil kerosene through preferential tax rates;
- A flight emissions label laying down harmonized rules for the estimation of airline emissions taking into account SAF uptake;
- The inclusion in the EU Taxonomy of SAF production and uptake to improve

access to green finance;

• R&D and deployment financing support under Horizon Europe, Innovation Fund, InvestEU programmes to de-risk SAF production at all technology maturity stages;

• The accelerated qualification of new SAF technologies and approval of new production plants through creation of EU SAF Clearing House and inclusion of SAF in the Net Zero Industry Act proposal;

• Cross-sectoral cooperation in the Renewable and Low-Carbon Fuels Value Chain Industrial Alliance (RLCF Alliance). The RLCF Alliance, as the industrial pillar of ReFuelEU Aviation to support SAF supply, and emergence of SAF projects and match-making with potential fuel offtakers, is open to all stakeholders;

• EU-funded international cooperation SAF projects with partner States in Africa, Asia, Latin America and the Caribbean. This includes a €4 million ACT-SAF project to conduct feasibility studies and capacity building activities;

• Designation of SAF as a 2024 Global Gateway Flagship initiative, supporting the development, production and use of SAF by de-risking SAF investments outside Europe via different types of funding;

• International cooperation at ICAO level, including the EU's role in the negotiations to reach an agreement at CAAF/3 in November 2023.

ICAO Conference on Aviation Alternative Fuels (CAAF/3)

The third ICAO Conference on Aviation Alternative Fuels (CAAF/3) was held in November 2023, during which ICAO Member States agreed on the ICAO Global Framework for SAF, Lower Carbon Aviation Fuels (LCAF) and other Aviation Cleaner Energies. This includes a collective global aspirational vision to reduce CO_2 emissions from international aviation by 5% in 2030 with the increased production of SAF, LCAF and other initiatives [23]. Building blocks in terms of policy and planning, regulatory framework, implementation support and financing will be key in achieving this goal. The vision will be continually monitored and periodically reviewed, including through the convening of CAAF/4 no later than 2028, with a view to updating the ambition on the basis of market developments in all regions.

The ReFuelEU Aviation Regulation also foresees a thorough monitoring and reporting system of SAF supply and usage that will provide an overview of the European SAF market and form part of future editions of this report. This reporting is linked with an enforcement mechanism consisting of penalties imposed by Member States for the cases of non-compliance from fuel suppliers and aircraft operators.

First in 2027 and every four years thereafter, the European Commission will present a detailed assessment of the SAF market and the possible need to revise the scope of the Regulation, the eligible fuels, the minimum shares and the level of fines for non-compliance. It will also include an assessment of possible support mechanisms for production and uptake of SAF.

ECAC States policy actions

Switzerland set out a SAF strategy with the goal that SAF shall contribute a minimum of 60% to net CO_2 reductions in Swiss civil aviation by 2050, contributing to the Swiss goal of reaching net-zero CO_2 emissions in 2050. It is accompanied by a legislative proposal that includes a blending mandate and provision of funding for the development of SAF production pathways, planned to enter into force in 2025. To avoid market distortion, the mandate shall be aligned with ReFuelEU Aviation. Türkiye is also planning to develop dedicated SAF regulations to incentivize its uptake [24]. The United Kingdom SAF policy includes a SAF Mandate to drive an ambitious ramp-up of SAF in the aviation fuel supply, starting with 2% in 2025, increasing linearly to 10% in 2030 and reaching 22% in 2040. The Mandate includes a cap on the amount of HEFA SAF used to meet obligations, and there is a separate obligation for power-to-liquid fuels, starting in 2028 with 0.2% of the total fuel supply and reaching 3.5% in 2040. [25].

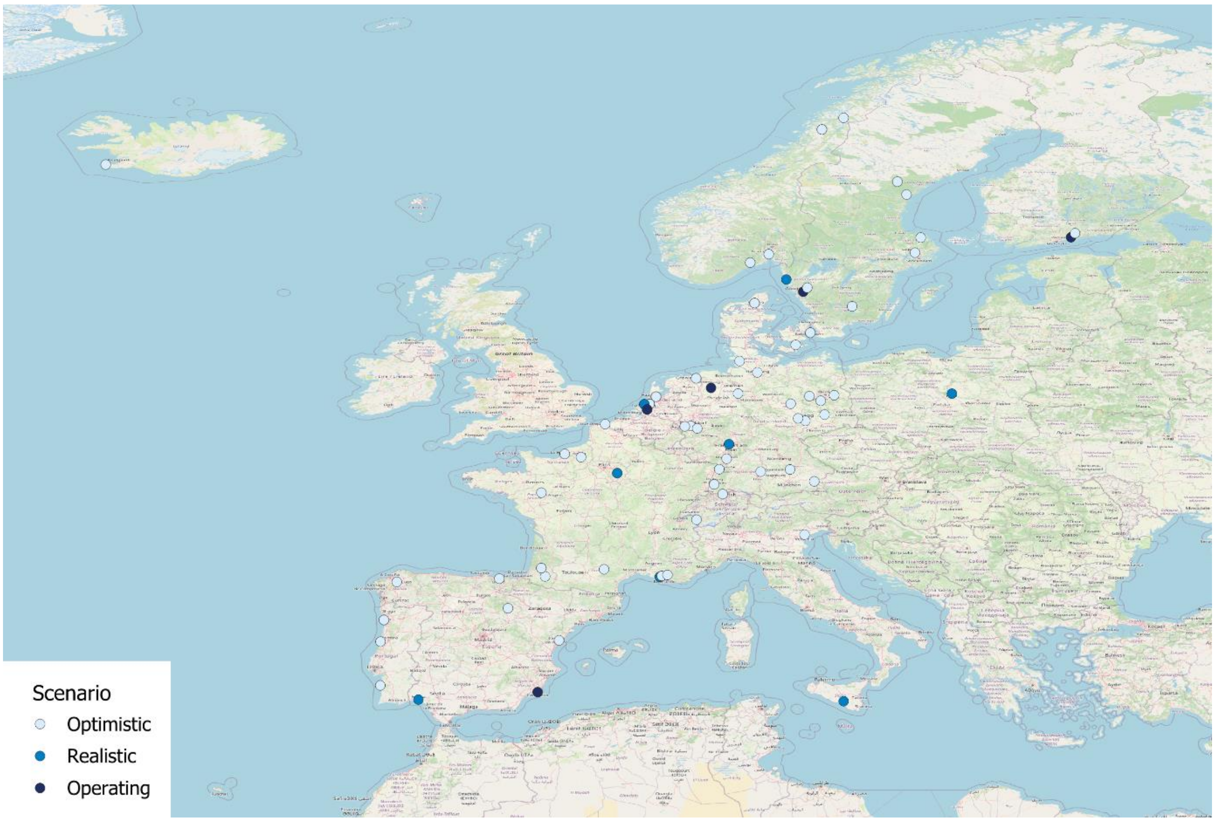
2.5 SAF Market

Global SAF production represented only 0.53% of jet fuel use in 2024, up from 0.2% in 2023 [26, 27, 28]. The EU SAF market, incentivized following the adoption of the ReFuelEU Aviation Regulation and the revision of the EU ETS and the RED, is now in a transition phase. The regulation requires a significant expansion of the production capacity in order to avoid the EU market becoming overly reliant on imports. Starting in 2025, fuel suppliers are mandated to supply a growing amount of SAF to Union airports. EASA is tasked with monitoring and reporting under the regulation and will produce annual reports, which will include a status of the evolving SAF market.

Current and future SAF production capacity

According to information collated with the support of ReFuelEU Aviation Member State Network (Figure 6.2.5), established by EASA to support the implementation of the Regulation, the current annual SAF production capacity in the EU is just above 1 million tonnes (Mt). Almost all this SAF production is HEFA and does not account for co-processing production using sustainable feedstock in fossil fuel plants, for which there is not enough reliable information. This could be considered to be an ‘operating scenario’.

Figure 6.2.5 Projected EU SAF facilities in 2030 under the Optimistic scenario

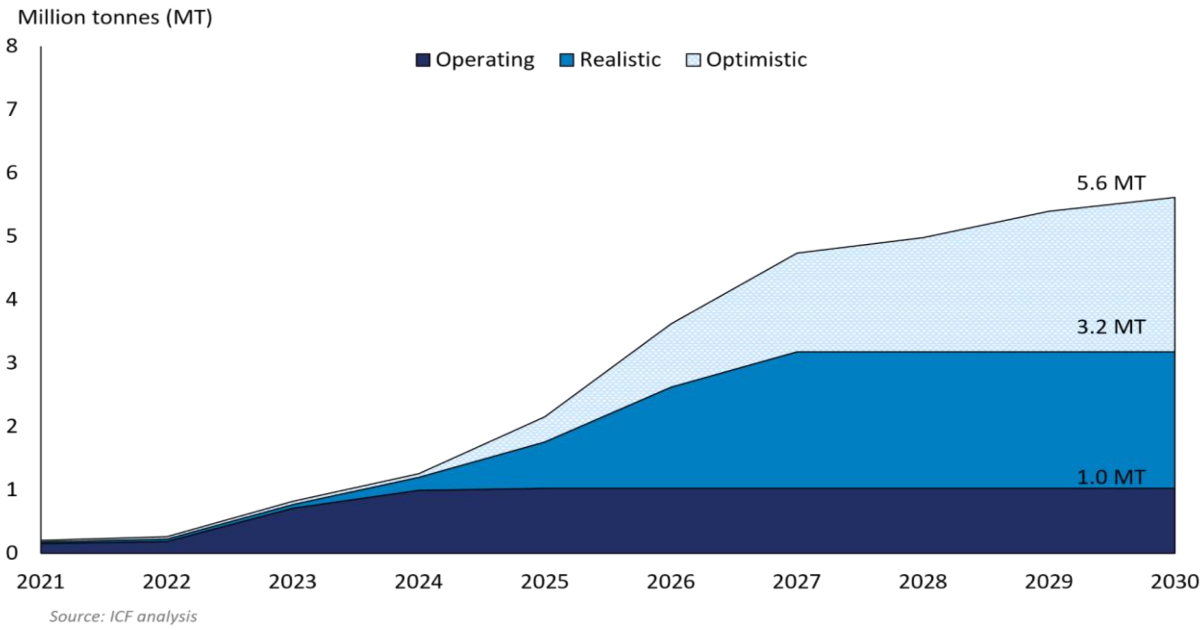


If facilities that are currently under construction are taken into account, the amount of SAF production capacity in 2030 could reach 3.5 Mt. This could be considered a 'realistic scenario'. Again, almost all this production would be dominated by the HEFA production pathway and does not include any Power-to-Liquid (PtL) production, as no plant has yet evolved beyond a pilot stage. Other studies come to different conclusions, mostly due to a different set of assumptions and methodologies. The recent SkyNRG Market Outlook from June 2024 [29] estimates 3.8 Mt by 2030, including 0.3 Mt of PtL as well as some co-processing production, while IEA predicts roughly 3.8 Mt by 2038 [30]. In both cases, a significant acceleration in the construction of PtL plants will be needed to meet the first sub-mandate of 0.7% in 2030.

In addition to the operating and realistic scenarios, both the ReFuelEU Aviation Member State Network and the SkyNRG Market Outlook collected information to build up an 'optimistic scenario'. This includes all projects in the pipeline to be in operation by 2030 and includes PtL projects, leading to a projected SAF capacity of 5.9 Mt and 5.5 Mt respectively.

Figure 6.2.6 illustrates all of the above scenarios out to 2030. While the realistic scenario (3.5 Mt) would be able to meet the projected demand of the 6% mandate by 2030 (2.8 Mt), significant growth in production capacity is required to fulfil the very ambitious ramp-up to 20% in the subsequent 2030-2035 period.

Figure 6.2.6 Projected EU SAF capacity in 2030 by scenario



Beyond 2030, projections of production capacity are more challenging and the potential SAF production will depend on the availability of feedstocks (e.g. HEFA, green hydrogen, renewable energy). The aviation industry will be competing with other sectors as part of the economy wide decarbonization efforts where these feedstocks could be used to directly decarbonize the primary energy supply. As a result, securing these sources of renewable energy will be critical to ensure the ramp-up of PtL SAF production within Europe. There are positive signals in particular from the solar industry, where the growth of global installation capacity is accelerating faster than anticipated and becoming the largest source of new electricity, with solar capacity doubling every three years and hence growing ten-fold every decade [31]. Overall, renewable energy passed 30% of the total global energy supply for the first time in 2023 [32]. By the 2030s, solar energy is likely to become the biggest source of electrical power and by the 2040s it may be the largest source of all energy [31].

Another limiting factor for SAF deployment towards 2050 is the capital expenditure required to build the production facilities. It is estimated that between 500-800 SAF facilities[27] will be needed globally by 2050, which, assuming €1.8 billion per facility, would result in around €36 billion capital expenditure annually between 2025 and 2050 [29].

Estimations of the future SAF landscape have concluded that indeed PtL fuels have the potential to cover 50% of the global SAF production capacity by 2050. Whereas HEFA production will be around 7% and AtJ / FT the remaining 43%. Projections by region also highlight the varying availabilities for feedstocks in the different parts of the world [33].

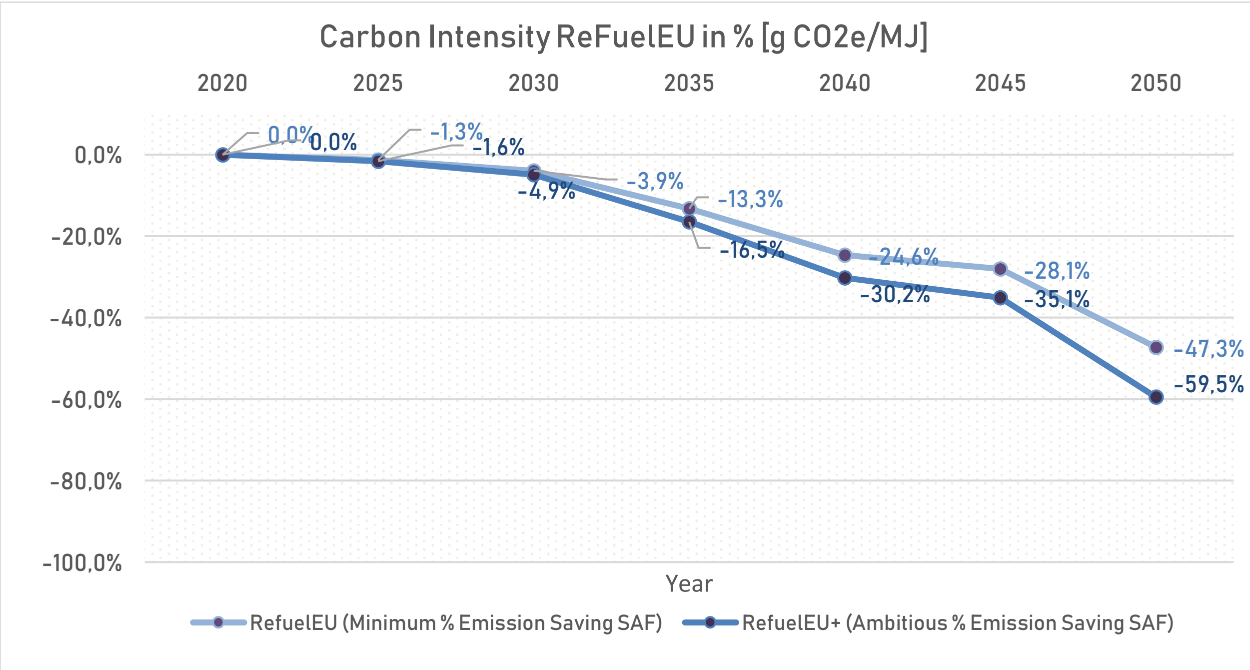
[27] Assuming 0.3 – 0.5 Mt average SAF output per year per facility.

CO_2 emissions reductions

To estimate the potential CO_2 emission savings from the ReFuelEU Aviation Regulation, a comparison has been made between the carbon intensity reduction of global aviation fuel taking into account the SAF supplied and the EU RED fossil fuel baseline intensity of 94 gCO_2e/MJ.

Two scenarios were assessed, a 'minimum' emissions saving and a more 'ambitious' scenario. The scenarios differ in the assumed emission reductions achieved by the (advanced) biofuels mandate and the RFNBO (PtL) fuel sub-mandate. The minimum scenario assumes a 65% and 70% emission reduction for biofuels and RFNBOs over their lifecycle respectively, which aligns with the minimum requirements set out in the ReFuelEU Aviation Regulation [1]. The second, more ambitious scenario assumes 80% and 90% emission reductions respectively for the two SAF types.

Figure 6.2.8 % CO_2eq emissions reductions from the uptake of SAF under ReFuelEU Aviation scenarios



SAF Price

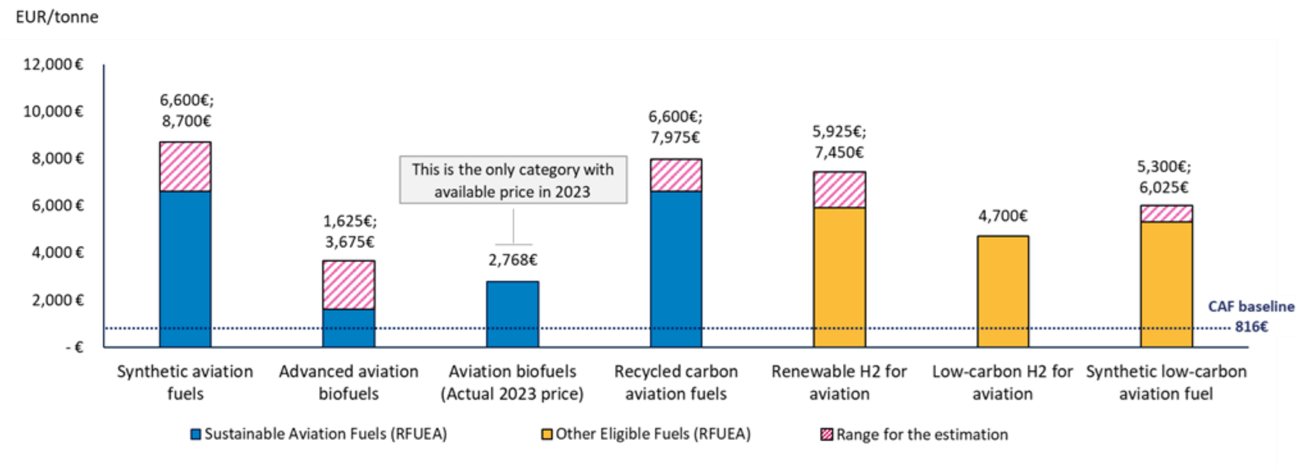
The price of SAF is one of the most critical factors when it comes to its uptake, as fuel costs currently represent a large share of the operational cost of aircraft operators (approx. 30%). In 2023, the price of conventional jet fuel averaged around €816 per tonne and is a figure that is readily available from Price Reporting Agencies (PRA) indexes

[34].[28, 29] When assessing the prices for ReFuelEU Aviation eligible SAF, a differentiation was made with SAF that are currently available on the market, and SAF for which only production cost estimations can be performed due to the market not being mature enough yet. For the former, only aviation biofuels that are produced from feedstock listed in Part B Annex IX of the Renewable Energy Directive have a market availability in 2023. The average price for these SAF was around €2768 per tonne in 2023, using as a reference the relevant indexes from the PRAs.

For fuels that had no market availability in 2023, production cost estimations were developed based on feedstock, energy and technology deployment costs resulting in prices that range from €1600 per tonne for advanced aviation biofuels to €8700 per tonne for PtL fuels. Figure 6.2.9 illustrates the estimated price ranges for the different eligible fuels under ReFuelEU Aviation in 2023. These production costs are expected to reduce substantially as emerging SAF and hydrogen production technologies scale up, and associated costs reduce.

Especially for PtL fuels, for which the energy price is a key cost driver, the differences in energy prices across Europe may play a role in where the production is most attractive and competitive for such fuels in the future [35, 36].

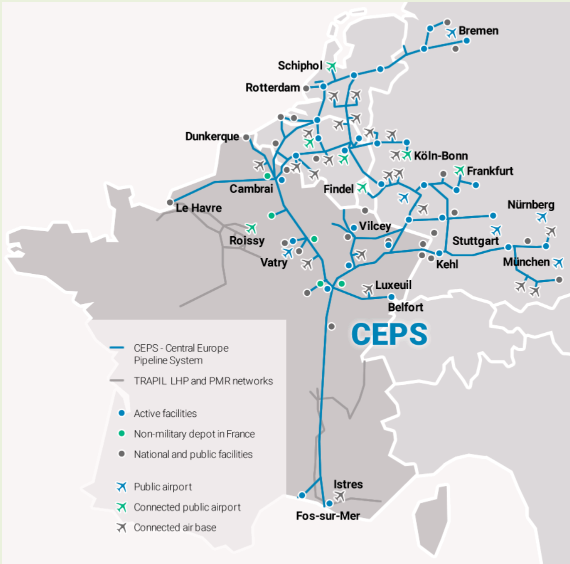
Figure 6.2.9 Estimated prices and production costs in 2023 for ReFuelEU Aviation eligible fuels



[28] Price Reporting Agencies (PRA) used as data source: S&P Global Commodity Insights (Platts), Argus Media and General Index.
[29] With the density of kerosene of around 0.8 g/cm3, this results in a price of around €1.02/l.

STAKEHOLDER ACTIONS

Central Europe Pipeline System: First delivery of SAF



The Central Europe Pipeline System (CEPS) [37] is the largest fuel supply system in NATO and crosses Belgium, France, Germany, Luxemburg and the Netherlands and comprises of approx. 5,300 km of pipeline. It delivers jet fuel to major civil airports such as Frankfurt, Brussels, Luxembourg, Zurich and Schiphol (Amsterdam). Following the permission of NATO, the connected airports have been able to receive SAF blends through CEPS since 2023.

Neste cooperated with Brussels Airlines to deliver sustainable aviation fuel to the airline at Brussels Airport on January 1, 2023. This marked the first time that SAF was supplied to an airline at a European airport using the NATO CEPS. It showcases how existing fuel infrastructure can be used to supply SAF to airports.

Delivering CORSIA certified SAF to airlines [38]

In July 2022, Neste delivered the first ever CORSIA certified batch of SAF (Neste MY Sustainable Aviation Fuel™) to American Airlines at San Francisco International Airport in July 2022. This was part of a pilot to certify SAF as a CORSIA Eligible Fuel that can be used by an airline to meet its emissions obligation under the Carbon Offsetting and Reduction Scheme for International Aviation ('CORSIA'), which is a market-based measure to lower CO_2 emissions for international flights and reduce aviation's contribution to climate change.

First flight in history with 100% sustainable aviation fuel on a regional commercial aircraft [39]

Regional aircraft manufacturer ATR, Swedish airline Braathens Regional Airlines and Neste have collaborated to enable the first ever 100% SAF-powered test flight on a commercial regional aircraft.

The flight took place in Sweden in July 2022 and is part of the 100% SAF certification process of ATR aircraft that started in September 2021.

Bringing together airlines and corporates [40]

Project Runway is an initiative launched by SkyNRG in June 2024 and brings together airlines and corporates to provide easy access to SAF. The project will support airlines in navigating the complexities of SAF procurement and provide an effective way to reduce their greenhouse gas emissions. Project Runway facilitates airlines access to SAF and allows them to share the SAF price premium with ambitious corporates aiming to reduce their own Scope 3 aviation emissions.

Modular Power-to-X plants [41]

The modular chemical plants for power-to-X and gas-to-liquid applications developed by INERATEC use hydrogen from renewable electricity and greenhouse gases such as CO_2 to produce, among other products, Power-To-Liquid fuels. The modular approach is being used for the first time in a pioneer plant and large-scale industrial PtL project in Germany. The modular concept of the plants allows scalability over several stages, keeping the planning and construction efforts manageable and improving the cost-benefit ratio.

First trans-Atlantic flight on 100% Drop-In Sustainable Aviation Fuel [42]

In 2023, Virgin Atlantic Flight 100 flew on 100% SAF from London to New York, marking the culmination of a year of collaboration to demonstrate the capability of SAF as a safe drop-in replacement for fossil derived jet fuel that is compatible with today’s engines, airframes, and fuel infrastructure. Flown on a Boeing 787, using Rolls-Royce Trent 1000 engines, the flight marked a world first on 100% Drop-In SAF by a commercial airline across the Atlantic. The SAF used was 88% HEFA (Hydroprocessed Esters and Fatty Acids) made from waste fats and 12% SAK (Synthetic Aromatic Kerosene) made from plant sugars. It is estimated that the use of SAF reduced nvPM emissions by 40% and CO_2 emissions by 64%, as well as an overall improvement in fuel burn efficiency as the SAF produced 1% more energy compared to the same mass of fossil fuel.

List of References for Chapter 6.2:

[1] European Commission (2023), Regulation (EU) 2023/2405 of the European Parliament and of the Council of 18 October 2023 on ensuring a level playing field for sustainable air transport (ReFuelEU Aviation)

[2] EU (2018),Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (Text with EEA relevance.).

[3] ASTM (2021) D1655, 2021, Standard Specification for Aviation Turbine Fuels. DOI: 10.1520/D1655-21C.

[4] Ministry of Defence (2024), DefStan 91-091 Issue 17

[5] ASTM (2021), D7566, 2021, Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons. DOI: 10.1520/D7566-21.

[6] ASTM (2021), ASTM D4054, 2021, Standard Practice for Evaluation of New Aviation Turbine Fuels and Fuel Additives. DOI: 10.1520/D4054-21A.

[7] European Union (2024), EU SAF Clearing House

[8] Renewable and Low-Carbon Fuels Value Chain Industrial Alliance (2024)

[9] ICAO (2021), CORSIA Sustainability Criteria for CORSIA Eligible Fuels.

[10] EU (2018), Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action.

[11] European Court of Auditors (2023), The EU's support for sustainable biofuels in transport. An unclear road ahead.

[12] Teoh, Roger et al (2022), Targeted Use of Sustainable Aviation Fuel to Maximize Climate Benefits

[13] Märkl, Raphael Satoru et all (2024), Powering aircraft with 100 % sustainable aviation fuel reduces ice crystals in contrails

[14] AVIATOR Project (2024), Assessing aViation emission Impact on local Air quality at airports: TOwards Regulation.

[15] RAPTOR (2024), Research of Aviation PM Technologies, modelling and Regulation

[16] Lukas Durdina, Benjamin T. Brem, Miriam Elser, David Schönenberger, Frithjof Siegerist, and Julien G. Anet (2021), Reduction of Nonvolatile Particulate Matter Emissions of a Commercial Turbofan Engine at the Ground Level from the Use of a Sustainable Aviation Fuel Blend.

[17] Voigt, C. et all (2021), Cleaner burning aviation fuels can reduce contrail cloudiness | Communications Earth & Environment (nature.com)

[18] Euractiv (2024), European ECLIF3 flight test study shows significant contrail reduction with 100% SAF

[19] ICAO (2021), CORSIA Supporting Document "CORSIA Eligible Fuels - Life Cycle Assessment Methodology" (Version 3 – March 2021).

[20] Euractiv (2024), Biofuel certification schemes slammed for failing to halt fraud

[21] Argus (2024), Norway says Esso misclassified animal fat biofuels

[22] ISCC (2023), Biodiesel and EU Imports from China

[23] ICAO (2023), ICAO Global Framework for SAF, LCAF and other Aviation Cleaner Energies

[24] ECAC Guidance on Sustainable Aviation Fuels (SAF) (2023), European Civil Aviation Conference

[25] Department for Transport (2024), Aviation fuel plan

[26] Simple Flying (2024), IATA Says SAF Production Will Reach 0.53% of Aviation 2024 Fuel Usage

[27] EUROCONTROL (2024), Use of sustainable aviation fuels in European States (ECAC) and airports

[28] Transport and Environment (2024),How is e-kerosene developing in Europe?

[29] SkyNRG (2024), Sustainable Aviation Fuel Market Outlook – June 2024 Update

[30] International Energy Agency (2023), Renewables 2023 Analysis and forecast to 2028

[31] The Economist (2024), The exponential growth of solar power will change the world

[32] The Guardian (2024), Renewable energy passes 30% of world's electricity supply

[33] ICF (2021), Fueling Net Zero – How the aviation industry can deploy sufficient sustainable aviation fuel to meet climate ambitions. An ICF Report for ATAG Waypoint 2050

[34] IATA (2024), Unveiling the biggest airline costs

[35] EASA (2024), ReFuelEU Aviation Market Report

[36] Politico (2024), Franco-German energy cash splash strains EU single market

[37] CIM&CCMP (2024), The CEPS network

[38] Neste (2022), Delivering CORSIA certified SAF to airlines

[39] Neste (2022), First flight in history with 100% sustainable aviation fuel on a regional commercial aircraft

[40] SkyNRG (2024), SkyNRG launches Project Runway with Microsoft as a founding member

[41] INERATEC (2023), Groundbreaking for e-fuel production plant in Frankfurt

[42] The Guardian (2023), First transatlantic flight using 100% sustainable jet fuel takes off

3. AIR TRAFFIC MANAGEMENT AND OPERATIONAL IMPROVEMENTS

- The Single European Sky (SES2+) proposal of the Commission was formally adopted by the Council and the European Parliament in 2024, although only modest progress was made and various issues were left unresolved.
- Implementation of SES2+, and a focus on continuous improvement to address unresolved issues, is critical to enhance capacity, efficiency and sustainability.
- RP4 (2025-2029) SES performance targets reflect the ambition to enhance environmental performance, as does the desire to develop improved environmental monitoring indicators while building up resilience and strengthening capacity.
- It is recognised that the SES performance scheme needs to be improved in terms of the ATM-related performance indicators for environment. Work is ongoing to identify a more robust KPI which, after a period of monitoring and analysis during RP4, will be ready for performance target setting in RP5.
- Updated SES ATM Master Plan has been aligned with the RP4 ambitions such that ANSPs invest in technologies to provide greener, smarter and more effective air traffic.
- Ambitious environmental performance targets cannot be achieved unless the ATM system supports and incentivises all stakeholders to optimize the efficiency of their operations.
- 400 million tonnes of CO_2 emissions (9.3% less CO_2 per flight) could be saved with the completion of the SES ATM Master Plan vision by 2050.
- The war in Ukraine and the Middle East conflict, and the subsequent impact on EU airspace, has made it more difficult to assess whether ATM actions towards improving environmental performance indicators have resulted in tangible benefits.
- During busy periods, Air Traffic Controllers may need to use alternative procedures to maintain required aircraft separation, thereby limiting the capacity to accommodate fuel efficient Continuous Descent Operations.
- Total gate to gate CO_2 emissions broken down by flight phase indicates that highest

emissions originate from cruise phase (62.9%) and climb phase (23.2%).

- The implementation of cross-border, free route airspace (FRA) significantly improves en-route environmental performance. Up to 94,000 tonnes of annual CO_2 emissions are estimated to be saved by 2026 through the Borealis Alliance FRA implementation among 9 States.
- Air traffic control strikes in 2023 had a significant environmental impact with an additional 96,000 km flown and 1,200 tonnes of CO_2 emissions due to knock-on effects across neighbouring States and the wider SES Network.
- SESAR study estimated that €1 invested in Common Project 1 (CP1) ATM functionalities during 2023 resulted in €1.5 in monetizable benefits and 0.6 kg of CO_2 savings, and these benefits are expected to increase overtime as CP1 is fully implemented.

3.1 Single European Sky

In the last few years, air traffic has continued to recover following the COVID pandemic and the number of flights to or from EU27+EFTA airports was 8.35 million during 2023. This is an 8.5% increase compared to 2022 (7.69 million) but still 9.1% below the level of 2019 (9.19 million). Growth rates at the State level have been unevenly distributed due to changes in traffic flows resulting from the war in Ukraine since 2022, changes in holiday traffic and less domestic traffic in several States.

The closure of Ukraine's airspace to commercial traffic was amplified by reciprocal airspace bans for Russian and many Western operators. While most of the European traffic is not directly affected by the airspace closures, east-west flights between Europe and Asia that previously travelled through Russian airspace need to divert, which adds travel time and fuel burn thereby lowering flight efficiency.

In 2004, the Commission launched the Single European Sky (SES) [1] representing a holistic framework to harmonise and improve the performance of Air Traffic Management (ATM) in terms of safety, capacity, cost-efficiency and the environment. The SES builds on five interrelated pillars: economic regulation, airspace organisation/network management, technological innovation, safety and Human Dimension. The SESAR (Single European Sky ATM Research and Development) project is the technological innovation pillar of the SES aiming to modernise ATM through the innovation cycle of defining, developing and deploying innovative technological systems and operational procedures. The goal is to achieve the 'digital European sky' defined in the European ATM Master Plan [2], which is a common roadmap to establish Europe as the most efficient and environmentally friendly sky in the world. It includes the goal to reduce the average CO_2 emission per flight by 9.3% (600 kg) by 2050. A key element in achieving that is goal is the deployment of Common Project One (CP1) [25], which facilitate service provision along optimized routes from gate to gate and thereby reduce both CO_2 and non-CO_2 emissions.

The SES has evolved over time and has significantly benefited ATM in Europe. Nevertheless, a profound reform of the SES was considered necessary to more effectively reach the above-mentioned objectives, which led to the Commission launching the 'SES2+' proposal in 2020. The process for adopting the SES2+ was challenging and heavily discussed, but a political agreement was finally reached between the European Parliament and the Council and the new Regulation was adopted in 2024.

While the SES2+ outcome strengthens economic performance regulation and incentivises environmental performance by establishing the Performance Review Body (PRB) on a permanent basis, only modest progress was made and many issues were left unresolved. For example, the Network Manager[30] lacks the means to ensure that ANSPs deliver the promised and much needed capacity to the network when demand from airlines is high. In addition, while SESAR has enhanced coordination between stakeholders through the ATM innovation cycle, the transition from development to deployment of SESAR solutions by ANSPs, airport operators and airspace users across Europe has proven difficult and subsequently led to insufficient progress in modernising the ATM system. This may be due to national requirements in airspace design and security issues, thereby making it complex in identifying universal solutions for monopolistic and state-owned Air Navigation Service Providers (ANSPs). All these points could contribute to challenges in terms of adopting technological innovation, responsiveness to demand and cost base adjustments, and cooperation between ANSPs.

The goal of climate neutrality by 2050 calls for the EU to ensure decarbonisation of the air transport sector. Likewise, the Zero Pollution Action Plan includes goals for reducing impacts from noise and air quality. Ambitious targets such as these cannot be achieved unless the ATM system supports and incentivises air navigation service providers (ANSPs), airport operators and aircraft users to optimize the efficiency of their operations and thus reduce excess fuel burn and emissions to a minimum.

Enhanced airspace organisation that minimises the inefficient use of available airspace, primarily through improved airspace and air traffic control sector design and effective airspace management procedures (civil-military coordination), are additional ATM tools to enable and allow for fuel efficient flight trajectories. Continuous improvement should be fostered at both local and network level.

While a significant progress has already been made in the ATM domain, it is important to now implement the SES2+ reform and focus on continuous improvements in infrastructure and operational procedures, notably through closer cooperation between all stakeholders and faster deployment of SESAR solutions.

[30] Commission Implementing Decision (EU) 2019/709 [4] renewed the appointment of EUROCONTROL as Network Manager (NM) for the period 2020-2029. EASA continues to act as the competent authority that certifies and oversees the NM. The NM coordinates operational stakeholders in order to manage demand through flow and capacity management, thereby optimising the network performance to limit unnecessary fuel burn and emissions.

3.2 SES environmental performance and targets

Overall context

Reference Period 2 (RP2)	2015-2019
Reference Period 3 (RP3)	2020-2024
Reference Period 4 (RP4)	2025-2029
Reference Period 5 (RP5)	2030 -2034

The SES Performance and Charging Scheme [6] defines key performance indicators (KPIs) for air navigation services and network functions, which are used for performance target setting at Union-wide and local levels in the key performance areas (KPAs) of environment, safety, cost efficiency and capacity. SES Performance Scheme Reference Periods (RP) are divided into five-year periods. This report captures the results of RP2 and RP3, while highlighting intentions for RP4 and preparations for future RP5 changes (e.g. safety monitoring but no KPA, climate and environmental KPA). The environmental performance dimension of SES involves both target setting to drive improvements as well as and the monitoring and reporting on environmental performance indicators.

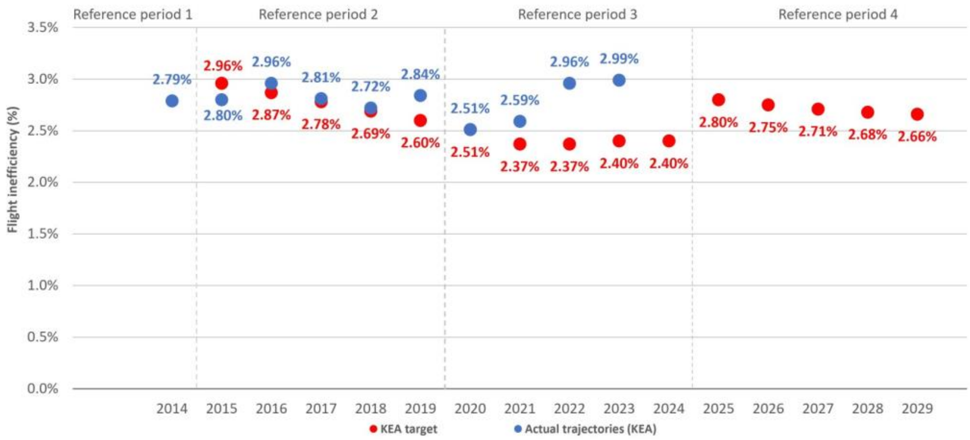
Key Performance Indicator for environment (with targets)

During RP3, environmental performance has been measured through one KPI, namely horizontal en-route flight efficiency of the actual flight path (KEA). KEA measures the additional distance flown in comparison to the great circle distance (shortest distance between two airports).

The higher the KEA inefficiency value, the worse the performance. However, other factors such as wind, weather, airspace structures, and network constraints influence the optimum trajectory. One of the objectives of the SES2+ proposal from the Commission was to develop a more suitable KPI on environmental performance for RP4. However, due to the duration of the negotiations and adoption of the SES2+ legislation, this was not possible and is now planned for RP5.

Following the COVID pandemic, environmental performance measured against the KEA KPI deteriorated significantly in 2022 and 2023 (Figure 6.3.1). EU Member States were not able to meet, by a wide margin, the Union-wide environmental performance targets set for 2022 (2.37%) and for 2023 (2.40%). Unfortunately, the impact of the war in Ukraine and the subsequent restrictions in parts of EU airspace made it more difficult to assess whether ATM actions towards improving the KEA actually resulted in tangible benefits. The PRB estimates that over 26 million kilometres of additional distance was flown in 2022 as a result of missing the Union-wide target by 0.59%. This equates to approximately 118 million kilograms of excess fuel burnt (375 million kilograms of CO_2).

Figure 6.3.1 KEA horizontal en-route flight inefficiency and targets for 2014 to 2029



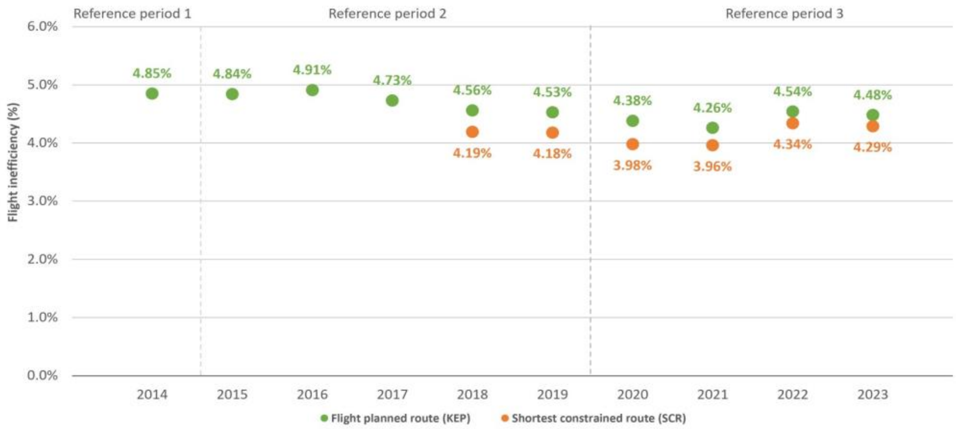
Performance Indicators for monitoring (without targets)

The Performance Scheme includes various indicators that are only monitored at either EU-level or local level but with no binding targets. These include the average horizontal en-route flight efficiency of the last filed flight plan trajectory (KEP)[31] and the shortest constrained trajectory (KES/SCR)[32]. As with all other indicators, KEP and KES/SCR (Figure 6.3.2) have been significantly affected by the war in Ukraine leading to general increases of inefficiency during 2022 and 2023, although there has been a reduction in the delta between KES/SCR and KEP. As with KEA, it is recognised that more suitable indicators are needed to give a clearer indication on the effectiveness of ANSP and Network Manager actions.

[31] The difference between the length of the en-route part of the last filed flight plan trajectory and the corresponding portion of the great circle distance, summed over all IFR flights within or traversing the European airspace.

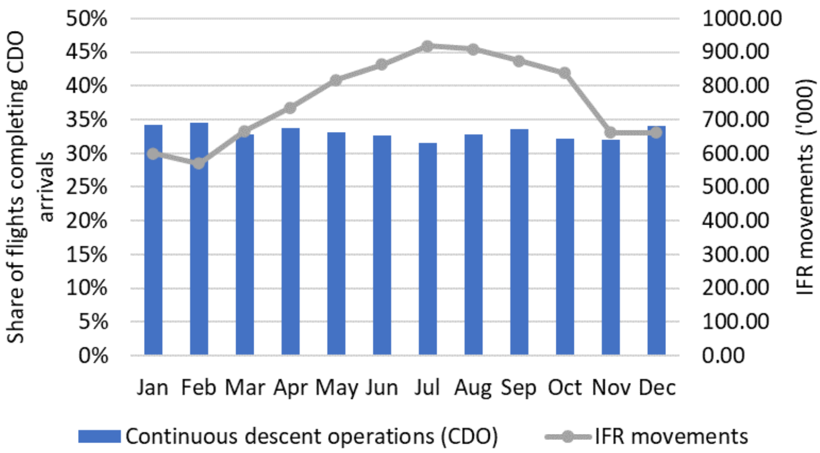
[32] The difference between the length of the en-route part of the shortest constrained route available for flight planning, as calculated by the path finding algorithms and flight plan validation systems of the Network Manager, measured between the exit and entry points of two terminal manoeuvring areas, and the corresponding portion of the great circle distance summed over all IFR flights within or traversing the European airspace.

Figure 6.3.2 KEP horizontal en-route flight inefficiency and KES/SCR for 2014 to 2023



The share of flights completing Continuous Descent Operations (CDOs) in 2023 fell by only 0.03% compared to 2022 data. The trend in terms of monthly share of CDO flights during 2023 (Figure 6.3.3) was fairly steady at around 30-35%, even during the summer period with a significantly higher number of flights. Air Traffic Controllers (ATCOs) will endeavour to clear aircraft for a CDO when they can guarantee safe separation all the way to final approach. However, during busy periods, ATCOs may need to use alternative ATC procedures to maintain the required separation, such as radar vectoring and speed control, which are not compatible with CDOs. As such, Figure 6.3.3 illustrates that there is a limited capacity to accommodate CDOs during busier periods.

Figure 6.3.3 CDO vertical flight efficiency indicator for 2023



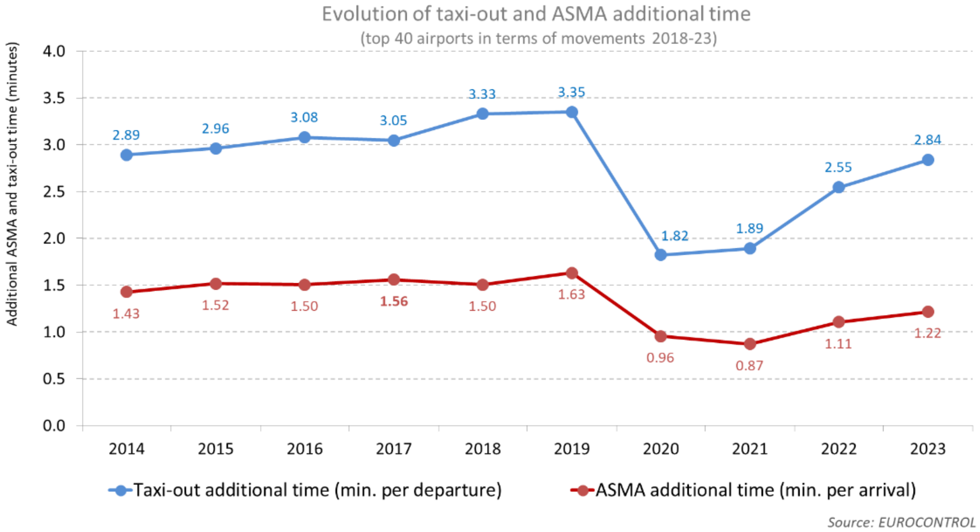
Restrictions on the number of CDOs are linked to the current ATM system. It is expected that with future Time-Based Operations (TBO), more CDOs would be facilitated by embedding them in aircraft fuel efficient trajectories.

Additional time in the Arrival Sequencing and Metering Area (ASMA time)

Additional ASMA time, otherwise known as airborne holdings, has a direct impact in terms of increased fuel burn. There is a clear interest in finding a balance between regulating arrivals by absorbing delays on the ground and airborne delays during the approach phase. Airborne delays allow for tactical management of the arrival flow, potentially optimizing the approach sequence and maximizing runway throughput. However, excessive airborne delays are unnecessary and have a clear impact on emissions. As per ASMA, extended taxi-out durations contribute to higher fuel consumption and CO_2 emissions. Recognising that establishing a departure sequence enhances runway efficiency and that airports may occasionally need to clear stands for arriving flights, striking a balance between ATC pre-departure delays to regulate runway traffic and added taxi-out times is essential for minimizing environmental impacts.

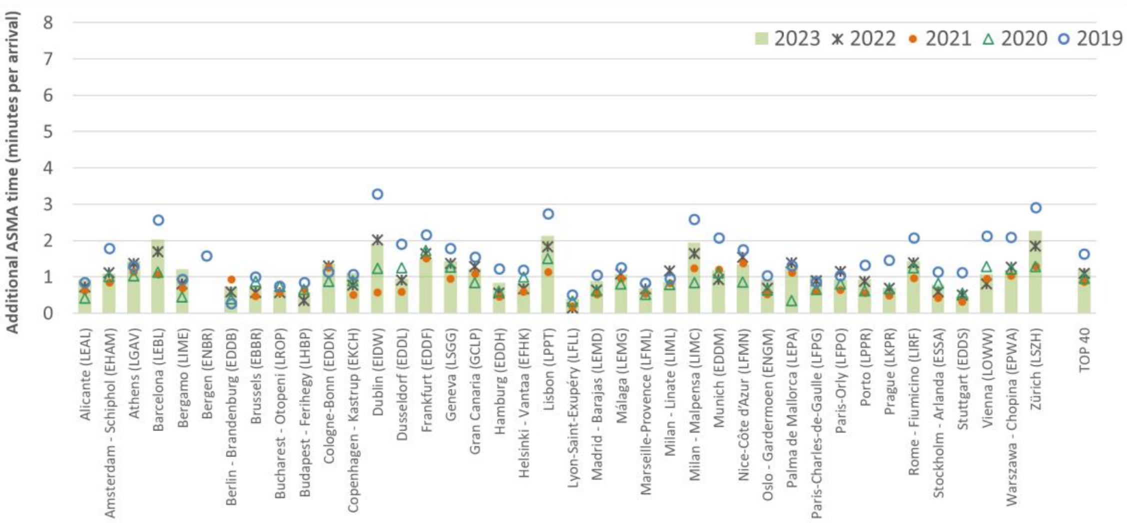
The evolution of both indicators follows a similar trend (Figure 6.3.4) with a slight increase during 2014-2019 followed by a significant decrease due to the drastic reduction in traffic during COVID. Traffic has since recovered such that it is only 10% below 2019 at the 40 busiest EU27+EFTA airports in 2023, while additional ASMA and taxi-out times are also increasing at the same time.

Figure 6.3.4 Average additional ASMA and taxi-out times for the busiest EU27+EFTA 40 airports in terms of flight movements



Significant variations exist between the top 40 busiest EU27+EFTA airports in terms of additional ASMA time (Figure 6.3.5).

Figure 6.3.5 ATM related inefficiencies on the arrival flow (AMSA) at the 40 busiest EU27+EFTA airports (2019-2023)



Forthcoming Reference Period 4 (2025-2029)

It remains essential for the ATM industry to maintain and even strengthen its commitment to contribute to the achievement of the European Green Deal goals and a more sustainable future of the aviation. The RP4 Union-wide performance targets [42] reflect the ambition of enhancing environmental performance and sustainability while building up resilience and strengthening capacity as well as reducing costs. It is also should be noted that PRB has developed a Traffic Light System to assess Member States environmental performance [43].

The PRB advice to the European Commission regarding the performance indicators for RP4 placed a focus on improving the ATM environmental performance by prioritising actions which enable airspace users to fly the most fuel-efficient trajectories, and thus reduce the fuel burn gate-to-gate [41]. In the interest of better flight efficiency in European airspace, all efforts need to be made by ANSPs and the Network Manager to support fuel-efficient trajectories, avoiding detours and delays due capacity hotspots.

Given the interdependency between the environment and capacity KPAs, it is crucial to address the long-term capacity shortages faced by certain ANSPs in order to enable the required environmental performance improvements. Such capacity issues have been observed since the second SES Reference Period (2015-2019), and they have re-emerged during the recovery from the COVID-19 crisis due to insufficient ATCOs in the core area of Europe to adequately meet traffic demand.

Recognising the forecasted traffic growth during RP4, which may impact the complexity of operations, and the continued consequences of the war in Ukraine, the future RP4 environmental targets improve following a step-wise approach with KEA targets reducing from 2.80% for 2025 to 2.66% for 2029. Progress has also been made in the development of new and revised performance monitoring indicators (PIs), including within the environmental area, that draw on the results of a study conducted by the

Commission. These are currently being discussed by the Single Sky Committee with a view to their possible use during RP4.

Preparations for Reference Period 5 (2030-2034)

The new rules to be developed for the performance and charging scheme on the basis of the SES2+ Regulation will start to apply during RP5. This includes a single key performance area that would cover both environmental and climate aspects, as well as a requirement for binding targets for terminal air navigation services provided that adequate environmental indicators are identified and put in place.

The SES performance and charging scheme aims to capture the relationship between flight routing and environmental impacts, and existing indicators were previously regarded as reasonable proxy measures to incentivise ANSP efficiency. However, limitations with the current environmental KPI/PIs have been identified and were confirmed during the COVID pandemic, when some Member States were unable to meet their environmental targets despite a dramatic reduction in traffic. These weaknesses should be borne in mind when drawing conclusions on the basis of the existing KEA KPI, especially when considering the performance achieved at the level of an individual EU Member State's airspace.

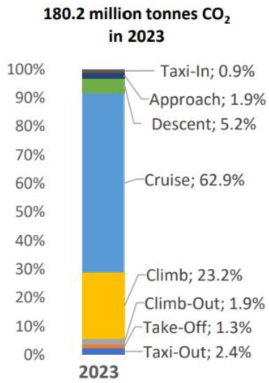
It is recognised that the SES performance scheme needs to be improved in terms of the ATM-related performance indicators for environment. KEA does not provide the needed granularity at national level to specifically assess the contribution of ATM to environmental efficiency. However, while this main KPI is not considered fit for purpose, gaining agreement on alternative has proved complicated. Work is now ongoing to find a more robust KPI which, after a period of monitoring and analysis during RP4, will be ready for performance target setting in RP5 and beyond.

3.3. Operational performance indicators

Total gate to gate CO_2 emissions

The total gate to gate CO_2 emissions within the EUROCONTROL area [39], or the part of the trajectory within the airspace for flights to and from the area, were 180.2 million tonnes in 2023, which represents an increase of 14% over 2022. Figure 6.3.6 illustrates the breakdown of these CO_2 emissions by flight phase and, as expected, the cruise and climb phases have the highest share of emissions with 63% and 23% respectively. While much less inefficiencies are detected in the climb phase than in the descent phase, and consequently more attention was given to the descent phase, it is important to note that even a small percentage of inefficiency during the climb can result in a significant amount of additional CO_2.

Figure 6.3.6 Total CO_2 emissions by flight phase within the EUROCONTROL area during 2023

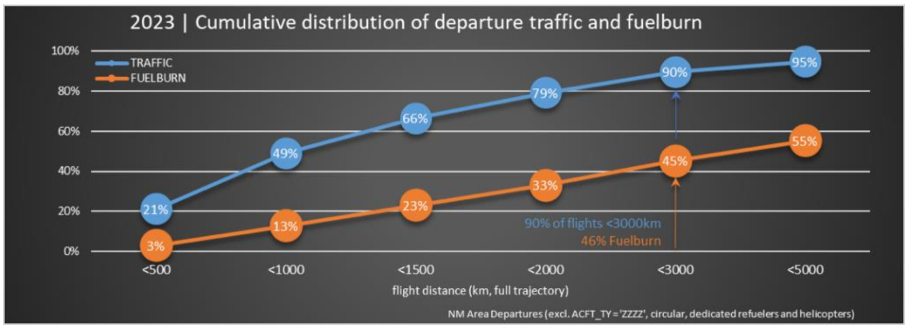


Network Fuel Burn

The SES Network Manager (NM) has developed an Excess Fuel Burn (XFB) metric as a measure of the fuel inefficiency on a particular route for a particular aircraft type, compared to a reference based on the best performer on that city pair / aircraft type combination.

Subsequently, the NM has enhanced its fuel burn dataset with fuel profiles for all flights, including fuel burn at specific points along the flight profile, and presents it in different ways on the NM's CO_2MPASS dashboard [30]. Figure 6.3.7 highlights that 95% of NM departures fly less than 5,000km and represent 55% of total fuel burn, meaning that just 5% of departures representing long-haul flights greater than 5,000km burn 45% of total fuel.

Figure 6.3.7 Cumulative distribution of departure and fuel burn in 2023



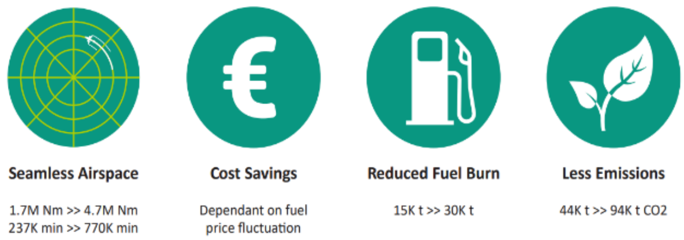
Free Route Airspace

Free Route Airspace (FRA) is a SESAR solution that is defined as a volume of airspace within which users may freely plan a route between any defined entry and exit points, subject to airspace availability [15]. The continuous implementation of FRA in Europe over the past years has been an enabler for improved flight efficiency, as it provides airlines with greater flexibility to file more efficient flight plans. However, FRA must not only be implemented but also applied by airlines to reap the benefits.

In line with the European ATM Master Plan and EC Regulation No. 2021/116, FRA implementation with cross-border dimension and connectivity to Terminal Manoeuvring Areas (TMA) should be completed by 31 December 2025. Cross-border FRA areas have been implemented between the following States:

- BALTIC FRA: Poland and Lithuania.
- BOREALIS FRA: Denmark, Estonia, Ireland, Iceland, Finland, Latvia, Norway, Sweden and United Kingdom.
- SECSI FRA: Albania, Austria, Bosnia and Herzegovina, Croatia, Montenegro, North Macedonia, Serbia and Slovenia.
- SEE FRA: Bulgaria, Czech Republic, Hungary, Republic of Moldova, Romania and Slovakia.
- BALTIC FRA and SEE FRA.
- SECSI FRA and FRA IT

The Borealis Alliance (a collaboration of ANSPs from Denmark, Estonia, Finland, Iceland, Ireland, Latvia, Norway, Sweden and the United Kingdom) is a pioneer in the implementation of a cross-border FRA among its nine national airspaces. Whilst implementation has been slowed down by the COVID crisis, full implementation is still planned by the end of 2026. The above figure illustrates the actual benefits of FRA achieved in 2018 and the estimated annual gains in 2026 with full FRA implementation.



Impact of strikes on European Aviation

Between 1 March and 9 April 2023, there were 34 days with industrial action impacting air transport in Europe, mostly in France but also, to a lesser extent, in Germany. As context, for the whole of 2022, there were 5 days of industrial action in France. The 34 days of strikes in 2023 potentially impacted 237,000 flights (flights to, from or across the countries mentioned above, mainly France). By comparison, the airspace closures in Europe resulting from the eruption of the Eyjafjallajökull volcano in 2010 (15-22 April) led to the disruption of some 100,000 flights.

In addition to the impact on passengers, strikes can also have a large environmental footprint. EUROCONTROL estimates that an extra 96,000 km were flown each strike day in 2023, with an average additional 386 tons of fuel burnt and 1,200 tons of CO_2 emissions [31]. The average cost to aircraft operators of cancellations and delays was €14 million per day.

Each Strike Day (during 7 March - 9 April)
96,000 additional km flown
386 tons of additional fuel burnt
1,200 additional tons of CO_2 emissions

As an example, on 12 March, around 40 flights had to extend their path by at least 370 km in order to avoid French airspace (when compared to their flight plans on 5 March, a non-strike day). These strikes also impacted up to 30% of flights across the continent, highlighting the disproportionate impact that disruptions in one country can have on neighbouring countries and the European Network as a whole. Although France does have minimum service provisions, preventing the complete closure of its ATC operations, these do not protect overflights. Minimum service regulations across Europe that protect overflights (such as are seen in, for example, Italy and Spain) would go some way to protect the flying public from the type of disruption as well as the associated environmental impact.

3.4 SESAR: Towards the digital European sky

SESAR Research and Development

The first SESAR Joint Undertaking was established in 2007 as the EU body responsible for the research and development phase of the SESAR innovation cycle. It has produced over 100 solutions with an estimated combined benefit that could enable a 4% reduction in CO_2 emissions per flight. The online SESAR solutions catalogue contains technical information on these solutions and their level of deployment as reported by European states [32].

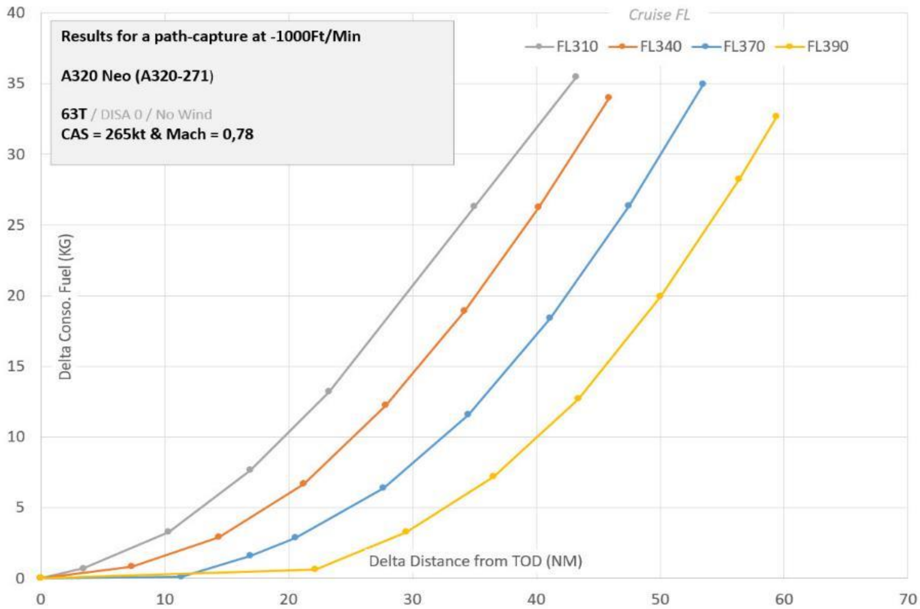
The current SESAR 3 Joint Undertaking [36] has a 10-year mandate (2021-2031) to continue this work. During 2024, the European ATM Master Plan was updated to define the critical path for establishing Europe as the most efficient and environmentally friendly sky to fly in the world. It defines the Strategic Deployment Objectives and Development Priorities, providing a framework to facilitate the roll out of SESAR solutions and shaping the European position to drive the global agenda for ATM modernisation at ICAO level.

The implementation of a first critical sub-set of SESAR solutions is mandated by the Common Project 1 (CP1), ensuring a coordinated and timely deployment of key enablers for Trajectory-Based Operations (TBO) and for establishing a digital backbone for the Single European Sky (SES).

Improvements in all phases of flight SESAR addresses the full scope of aviation's environmental impacts, from CO_2 and non-CO_2 emissions to noise and air quality at every phase of flight.

- **TAXI phase**. During the ground part of the trajectory, a key objective is to reduce the engine-on time. Increasing the predictability of the take-off clearance time avoids waiting time at the runway holding point. In addition, single-engine taxi and engine-off taxi, where aircraft are towed by a sustainable taxi vehicle, can reduce overall engine emissions. The expected reduction of emissions from an engine-off taxi initiative can be over 50% that also was showed cased in ALBATROSS project [34].
- **CLIMB and DESCENT phases**. The focus in this phase is to leverage the availability of the optimum profile for each individual flight through the Extended Projected Profile (EPP), where aircraft tend to start their descent on average 35-70 nautical miles (nmi) before what would be their optimum Top-of-Descent (ToD) point[33]. This leads to long thrust descent, which is inefficient even if it does not include intermediate level-offs (Figure 6.3.8). The EPP provides visibility of the optimum top-of-climb and top-of-descent points on the ground, making it possible for air traffic controllers to facilitate a better trajectory. In addition, SESAR advocates a transition from conventional fixed arrival routes commonly used today, towards a more dynamic deployment of RNP (Required Navigation Performance) route structures within the Terminal Manoeuvring Area. Utilizing these dynamic routes increases capacity during peak periods, optimizes fuel consumption during off-peak hours, and decreases the noise footprint particularly during nighttime operations. Moreover, the adoption of these dynamic routes enables agile responses to fluctuations in operational conditions.

Figure 6.3.8 Increased fuel consumption as a function of the distance before the optimum Top of Descent that the descent phase is started, without intermediate level-offs (e.g. when a descent from cruise at FL370 is started 50nmi early, the additional fuel burn is 30 kg).



CRUISE phase. Free route in the horizontal domain is already widely available in Europe. As such, the enhancement of vertical flight efficiency is a priority through the provision of sufficient airspace capacity for aircraft to fly at their optimum altitude. While the exact

33 SESAR Optimised Profile Descents Demonstration Report.

increase in emissions varies based on aircraft type and specific flight conditions, studies suggest that flying at lower altitudes can increase fuel consumption by approximately 6-12% compared to optimal cruising altitudes [21;22]. An increase in capacity can be achieved via digital and automation support for all ATM processes, including air traffic controllers, such as Dynamic Route Availability Document (RAD) that results in fewer vertical restrictions both at flight-planning and during the flight [33]. ATM may also evolve to support the deviation of flights to avoid cruising within airspace where non-CO_2 impacts are disproportionately high (referred to as eco-sensitive volumes).

The SESAR 3 Joint Undertaking has also provided support to operational stakeholders in the monitoring and management of their environmental performance in the planning, execution, and post-operation phases. At the airport level, this includes the full integration of environmental performance monitoring with the Airport Operations Plan (AOP) [35].

Trajectory optimisation in a digital environment

The deviation from the flight plan during the execution of the flight, for example by allowing an unplanned shortening of the flight path, allows fuel savings and reduced emissions for the flight concerned and its specific flight phase. However, this can have a negative impact on the predictability of the air traffic network, which in turn could have a negative impact on the environment. Trajectory-Based Operational (TBO) concepts ensure the free flow of information between air traffic management units and the Network Manager, allowing rapid sharing of trajectory information across the network and increased flexibility in the execution of the flight for airspace users.

The updated ATM Master Plan has defined the European TBO roadmap for the 2025–2045 period with the ambition of guaranteeing continuous and precise optimisation of all aircraft trajectories throughout their life cycle, from planning to execution, from gate to gate, even in congested airspace. With the potential introduction of zero emissions aircraft beyond 2035, their specific performance characteristics will also need to be considered in terms of any impact on the Network.

SESAR Deployment

sesar DEPLOYMENT MANAGER

The SESAR Deployment Manager [36] plans, synchronises, coordinates and monitors the implementation of the 'Common Projects' that mandate the synchronised deployment of selected ATM functionalities (AF) based on SESAR solutions. The current Common Project (CP1) [EU 2021/116] has 6 AF (Figure 6.3.9) aiming to reduce inefficiencies and thus generate fuel and CO_2 savings in different phases of the flight, especially cruise. The SESAR Deployment Programme [38] defines how the operational stakeholders will implement CP1 AF, which is due to be completed by 31 December 2027. The expected performance benefits from CP1 AF represent approximately 20% of the European ATM Master Plan performance ambitions for 2035 [40] and will be a critical step towards sustainable ATM-related aviation in

Europe. 65% of CP1 CO_2 savings are expected to be found in the cruise phase, 25% in the descent phase and 10% in the taxi-out phase. By the end of 2023, [CP1] already delivered €4.6bn worth of cumulative benefits. This value is set to reach €19.4bn by 2030, once [the CP1] is fully deployed, whilst in a longer timespan [CP1] is expected to bring €34.2bn worth of cumulative benefits by 2035 and €52.3bn by 2040.

Figure 6.3.9 Overview of Common Projects 1 (CP1) ATM Functionalities

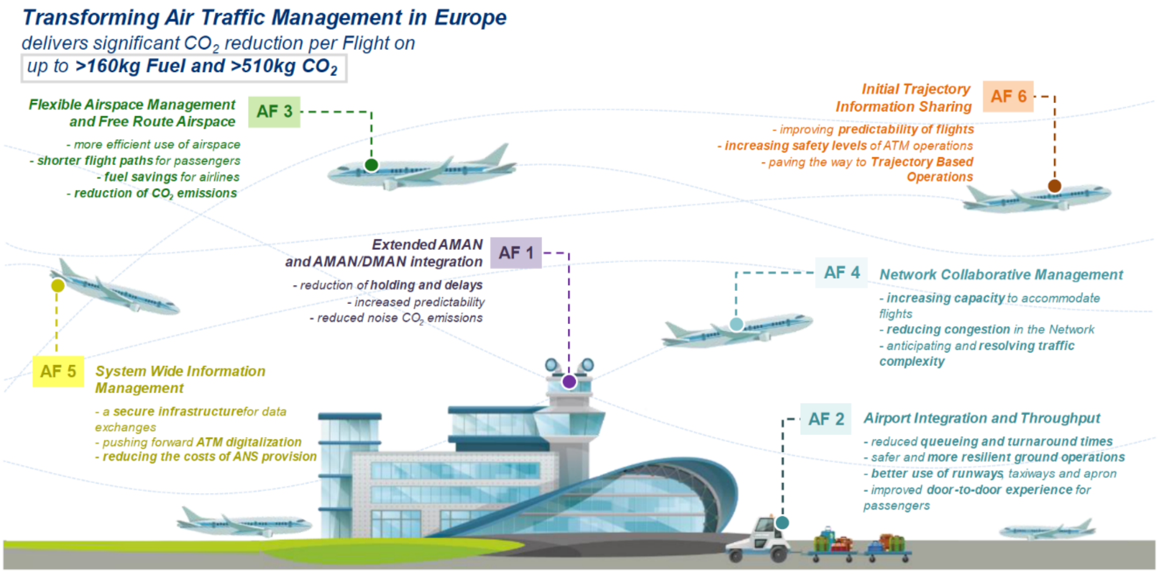


Table 6.3.1 below details the total CO_2 savings potential of concerned flights, that could be expected should all CP1 sub-AF concepts be deployed in the future ATM system with all technologies mature and realising their full benefits. The values in the table below represent an order of magnitude of CO_2 savings that can be expected from different sub-functionalities, and which highly depend on the specific conditions of the flight and the local situation.

Table 6.3.1 CO_2 savings per Common Project 1 ATM Functionality

CP1 Functionality		Fuel saving per flight concerned	CO2 savings per flight concerned	Time saving per flight concerned	% of ECAC flights concerned	Flight phase concerned
AF1	Departure Management Synchronised with Pre-departure sequencing	[2.9 – 10 kg]	[9.2 - 31.5 kg]	[0.5 – 1 min]	30%	Taxiing phase
	Initial/ extended AOP	[0.4 – 0.8 kg]	[1.2 - 2.5 kg]	[0.1 – 0.1 min]	70%	Taxiing phase
AF2	Airport Safety Nets	[0.1 – 3.1 kg]	[0.3 - 9.7 kg]	[0.01 – 0.01 min]	30%	Taxiing phase
AF3	ASM and A-FUA	[8 – 41.7 kg]	[25.2 - 131.3 kg]	[0.15 – 0.55 min]	10%	Cruising phase
	Enhanced Free Route Airspace Operations	[35 – 58 kg]	[110.2 - 182.7 kg]	[1 – 2 min]	75%	Cruising phase
AF4	Enhanced Short Term ATFCM Measures	n/a		[0.3 – 0.4 min]	5%	Pre departure phase
	Interactive rolling NOP	n/a		[0.2 – 0.3 min]	50%	Pre departure phase
AF5	Automated Support for Traffic Complexity Assessment and Flight Planning interfaces	n/a		[0.1 – 0.2 min]	70%	Pre departure phase
AF6	Initial AirGround Trajectory Information Sharing	[8 – 12 kg]	[25.2 - 37.8 kg]	[0.05 – 0.1 min]	90%	Cruising phase

The benefit-cost ratio (BCR) of the investment in CP1 AF shows the value of the investment by comparing the costs of a project with the benefit that it generates. In this case, it has been estimated that every € invested into CP1 deployment brought €1.5 in return during 2023 to the stakeholders in terms of monetizable benefits, as well as 0.6 kg of CO_2 savings (Table 6.3.2). Furthermore, the BCR and CO_2 savings are expected to increase overtime as CP1 AF are fully implemented (Table 6.3.3).

Table 6.3.2 Benefit-Cost Ratio and CO_2 savings from CP1 AF implementation

	Already achieved			
Metric	**2023**	**2030**	**2035**	**2040**
Benefit-cost ratio[13]	**1.5**	3.8	5.9	8.0
CO_2 kg saved per € invested[14]	**0.6**	2.2	4.0	6.0

Table 6.3.3 Savings in fuel and CO_2 emissions per flight in 2023 and the forecast out to 2040

	Already achieved			
Metric	**2023**	**2030**	**2035**	**2040**
Fuel kg saved	**7.0 kg**	42.3 kg	47.0 kg	47.8 kg
CO_2 kg saved	**22.1 kg**	133.2 kg	147.9 kg	150.5 kg

STAKEHOLDER ACTIONS

Improving flight efficiency in Skyguide's airspace

Skyguide introduced Free Route Airspace (FRA) within the area under its responsibility at the end of 2022 (Switzerland and parts of France, Italy, Germany and Austria). One of the objectives of Skyguide's FRA project was to optimise flight trajectories between Switzerland and Germany, independent of airspace boundaries. A post-implementation analysis confirmed significant improvements in horizontal flight efficiency. Compared with the pre-COVID period, planned flight paths within Swiss airspace have been improved by 22%. As a result of cross-border FRA, horizontal flight efficiency performance at the Skyguide-DFS interface has also improved significantly, with planned and flown trajectories at the entry points improving by 16% and 19% respectively. In 2023, despite a 5% increase in traffic compared with 2022, planned and flown trajectories improved by 13% and 2% respectively, thanks mainly to Skyguide's cross-border FRA.

CiCERO – Citizen and Community Empowerment in Route Optimization

Austro Control, in collaboration with the Federal Government, is enhancing transparency and public involvement regarding air traffic noise in Austrian airspace. In 2024, an innovative public participation process was launched, inviting citizens to engage and actively shape instrument flight rules (IFR) arrival and departure procedure changes in Austria. Through this initiative, citizens can propose enhancements to existing IFR routes and provide valuable feedback on new or modified routes. Submissions are reviewed by an expert panel, ensuring every input is considered and assessed. In the first two months of operation, more than 500 inputs were recorded and processed. The entire process is transparently documented, with Austro Control keeping the public informed every step of the way. It aims to enhance quality of life by reducing noise and fostering a safer, punctual, and environmentally friendly air traffic system.

CONCERTO – Dynamic Collaboration to Generalize Eco-friendly Trajectories

The CONCERTO project aims to make eco-friendly trajectories an everyday occurrence in order to reduce the CO_2 and non-CO_2 impact of aviation. The project will look to integrate green air traffic control capacity into the system, and support stakeholders in balancing regularity and environmental performance at local and network levels. The project will do so by leveraging state-of-the-art climate science and data to allow ATM stakeholders to take their "eco-responsibility" to the next level. At the same time the project aims to demonstrate that mitigation measures can be deployed progressively at network level, in sync with scientific progress.

List of References for Chapter 6.3:

[1] EC (2004), Regulation (EC) No 549/2004 laying down the framework for the creation of the Single European Sky; Regulation (EC) No 550/2004 of the European Parliament and of the Council of 10 March 2004 on the provision of air navigation services in the Single European Sky; Regulation (EC) No 551/2004 of the European Parliament and of the Council of 10 March 2004 on the organisation and use of the airspace in the single European sky (the airspace Regulation)

[2] SESAR (2020), European ATM Master Plan.

[3] EU (2019), Regulation (EU) 2019/123 of 24 January 2019 laying down detailed rules for the implementation of air traffic management (ATM) network functions.

[4] EU (2019), Decision (EU) 2019/709 of 6 May 2019 on the appointment of the Network Manager for air traffic management (ATM) network functions of the Single European Sky.

[5] EU (2021), Regulation (EU) 2021/2085 of 19 November 2021 establishing the Joint Undertakings under Horizon Europe.

[6] EU (2019), Regulation (EU) 2019/317 of 11 February 2019 laying down a performance and charging scheme in the single European sky.

[7] PRB (2019), PRB Monitoring Report 2020.

[8] EU (2005), Regulation (EC) No 2150/2005 of 23 December 2005 laying down common rules for the flexible use of airspace.

[9] EU (2020), Regulation (EU) 2020/1627 of 3 November 2020 on exceptional measures for the third reference period (2020-2024).

[10] EUROCONTROL (2022), Route Availability Document (RAD).

[11] EUROCONTROL (2021), Environmental Assessment: European ATM Network Fuel Inefficiency Study.

[12] EUROCONTROL (2019), Fuel Tankering: Economic Benefits and Environmental Impact.

[13] ICAO (2014), Operational Opportunities to Reduce Fuel Burn and Emissions (Doc 10013).

[14] EUROCONTROL Network Manager (2022), Optimised operational performance.

[15] EUROCONTROL (2022), Free route airspace.

[16] EUROCONTROL (2021), European Route Network Improvement Plan (ERNIP) - Part 2.

[17] EUROCONTROL (2020), European Continuous Climb and Descent Operations Action Plan.

[18] EUROCONTROL (2022), Vertical flight efficiency at airports.

[19] SESAR Dreams Project (2020), Initial Trajectory Information Sharing.

[20] EUROCONTROL (2022), EUROCONTROL learning zone.

[21] SESAR (2021), SESAR Solutions Catalogue charting progress towards the Digital European Sky.

[22] SESAR (2020), Albatross Project.

[23] SESAR (2021), SESAR 3 Joint Undertaking Multiannual Work Programme 2022-2031.

[24] SESAR Deployment Manager (2022), SESAR Deployment Manager.

[25] EU (2021), Regulation (EU) 2021/116 - Common Project 1 Regulation.

[26] SESAR (2022), SORT - Improving runway throughput in one airport.

[27] SESAR (2022), ADSCENSIO - ADS-C Enables and supports improved ATM operations.

[28] SESAR (2021), Airbus - Fello'fly.

[30] EUROCONTROL (2024), CO_2MPASS Interactive Dashboard.

[31] EUROCONTROL (2023), Impact of strikes on European Aviation.

[32] SESAR (2021), SESAR Solutions Catalogue.

[33] SESAR (2024), Dynamic Route Availability Document (RAD).

[35] SESAR (2024), Airport Operations Plan (AOP).

[36] EU (2021), SESAR Single Basic Act.

[37] EU (2013), SESAR Deployment Framework.

[38] SESAR (2022), SESAR Deployment Programme 2022.

[39] EUROCONTROL (2025), EUROCONTROL Area.

[40] SESAR (2025), SESAR Deployment Manager.

[41] PRB(2024), PRB report -https://eu-single-sky.transport.ec.europa.eu/news/prb-advice-union-wide-targets-rp4-feedback-period-draft-commission-implementing-decision-opened-2024-03-25_en

[42] EC (2024), Commission Implementing Decision (EU) 2024/1688 of 12 June 2024 setting Union-wide performance targets for the air traffic management network for the fourth reference period from 1 January 2025 to 31 December 2029.

[43] PRB (2024), Traffic light system for environmental performance 2023.

4. MARKET-BASED MEASURES

- Market-based measures incentivise 'in-sector' emissions reductions from technology, operational measures and sustainable aviation fuels, while also addressing residual emissions through 'out-of-sector' measures.
- Emissions trading systems (e.g. ETS) have a greenhouse gas emissions cap covering various economic sectors, while offsetting schemes (e.g. CORSIA) compensate for emissions via reductions in other sectors but without an associated cap.
- During 2013 to 2023, the EU ETS led to a net CO_2 emissions reduction in aviation of 206 Mt through funding of emissions reductions in other sectors, of which 47 Mt in 2021-2023.
- EU ETS allowance prices have increased in the recent years, reaching an average annual price of more than €80 per tonne of CO_2 in 2022 and 2023.
- Revisions were agreed to the EU ETS in 2023, including a gradual phase-out of free allowances to airlines and a reduction to the aviation emissions cap from 2024 onwards.
- Monitoring, reporting and verification of CO_2 emissions under CORSIA began in 2019. As of 2025, 128 out of 193 ICAO States have volunteered to participate in the CORSIA offsetting scheme.
- Offsetting under the CORSIA scheme is expected to start in 2024. A total of 19Mt of CO_2 emissions are forecast to be offset for flights departing from Europe during CORSIA's first phase in 2024-2026.
- The first emissions units have now been authorized for use in CORSIA, complying with the UNFCCC rules on avoidance of double-counting of emissions reductions.
- Technology to capture carbon from the air and store it underground is being developed to support the broader decarbonisation efforts of the aviation sector.
- The EU Taxonomy System sustainable finance initiative has been amended to

include aviation activities.

- No agreement has been reached on proposals to revise the Energy Taxation Directive to introduce minimum rates of taxation for intra-EU passenger flights.

Future goals to address the climate impact of the aviation sector are expected to be achieved by in-sector measures (technology, operations, fuels) that are incentivised by Market-based Measures (MBMs) through pricing of carbon emissions. This chapter provides an overview of the key MBMs that have been put in place for the aviation sector, including the EU's Emissions Trading System (ETS) and ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), as well as other sustainable finance initiatives.

4.1 EU Emissions Trading System

The cornerstone of the EU’s policy to combat climate change is the EU Emissions Trading System. Various economic sectors (e.g. power, heat, manufacturing industries, maritime, aviation) have been included within this cap-and-trade system to incentivise CO_2 reduction within each sector, or through trading of allowances with other economic sectors included in the EU ETS where emission reduction costs are lower.

Aviation and the EU ETS

The EU decided to include aviation activities within the EU ETS in 2008 [1], and the system has been applied to aviation activities since 2012. As such, they are subject to the EU's greenhouse gas emissions reduction target of at least minus 55% by 2030 compared to 1990. The initial scope of the EU ETS covered all flights arriving at, or departing from, airports in the European Economic Area (EEA)[34]. However, flights to and from airports in non-EEA countries or in the outermost regions were subsequently excluded until the end of 2023 through a temporary derogation. This exclusion facilitated the negotiation of a global market-based measure for international aviation emissions at the International Civil Aviation Organisation (ICAO).

In July 2021, the European Commission adopted the ‘Fit for 55’ Legislative Package to make the EU's climate, energy, transport and taxation policies fit for achieving the 2030 greenhouse gas emissions reduction target. This included proposed amendments to the EU ETS Directive for aviation activities, which entered into force on 5 June 2023 [2]. The main changes to the aviation ETS are applicable from 2024 onwards, and include the following:

- Applying EU ETS for flights within and between countries in the European Economic Area, as well as departing flights to Switzerland and to the United Kingdom, while applying CORSIA for flights to and from third countries.
- Applying EU ETS for flights between countries in the European Economic Area and the outermost regions, as well as between the outermost regions, unless they connect to

[34] The European Economic Area includes EU27, Norway, Iceland and Liechtenstein.

the respective Member State's mainland. EU ETS also applies to flights from the outermost regions to Switzerland and the United Kingdom.

- Gradual phase-out of the free ETS allocation to airlines as follows: 25% in 2024; 50% in 2025; and 100% from 2026, meaning full auctioning of EU Allowances to the aviation sector from 2026. The free allocation for the years 2024 and 2025 is distributed according to the aircraft operators' share of verified emissions in the year 2023.
- Applying an annual linear reduction factor of 4.3% to the EU Allowances issued for aviation from 2024 onwards.
- Creation of a new incentive scheme for Sustainable Aviation Fuels (SAF). For the period from 2024 to 2030, a maximum of 20 million ETS allowances will be allocated to aircraft operators for the uplifting of SAF to cover part or all of the price difference between SAF and fossil kerosene, depending on the type of SAF used.
- Setting up a monitoring, reporting and verification system for non-CO_2 aviation effects
- Assessment of CORSIA's environmental performance after the 2025 ICAO Assembly. The Commission will report in 2026 on the progress at ICAO negotiations every three years, accompanied by legislative proposals, where appropriate.

More detailed amendments to the ETS Directive are implemented though various delegated and implementing acts, which are referenced in the Directive itself.

Linking the EU ETS to other emissions trading systems is permitted provided that these systems are compatible, mandatory and have an absolute emission cap. An agreement to link the systems of the EU and Switzerland entered into force on 1 January 2020. Accordingly, flights from the EEA area to Switzerland are subject to the EU ETS, and flights from Switzerland to the EEA area fall under the Swiss ETS. Allowances from both systems can be used to compensate for emissions occurring in either system.

The Environmental Management Information Service (EMIS) of EUROCONTROL, which superseded the EU ETS Support Facility in 2023, continues to provide 28 States with access to EU ETS and ICAO CORSIA related data, as well as traffic and emissions data to over 400 aircraft operators.

Historic and forecasted aviation emissions under EU ETS

The initial total amount of aviation allowances within the EU ETS in 2012 was 95% of the average annual emissions between 2004 and 2006 of flights within the full ETS applicability scope (all flights departing from or arriving in the European Economic Area), representing 221.4 million tonnes (Mt) of CO_2 per year. The EUAAs issued for aviation activities in the ETS's third phase (2013-2020) was adjusted for the applicability scope. While aircraft operators may use EUAAs as well as EU Allowances (EUAs) from the stationary sectors, stationary installations are not permitted to use EUAAs. In addition, aircraft operators were entitled to use certain international credits (CERs) until 2020 up to a maximum of 1.5% of their verified emissions. In 2023, there were 254 aircraft operators reporting a total of 53 million tonnes (Mt) of CO_2 emissions under the EU ETS.

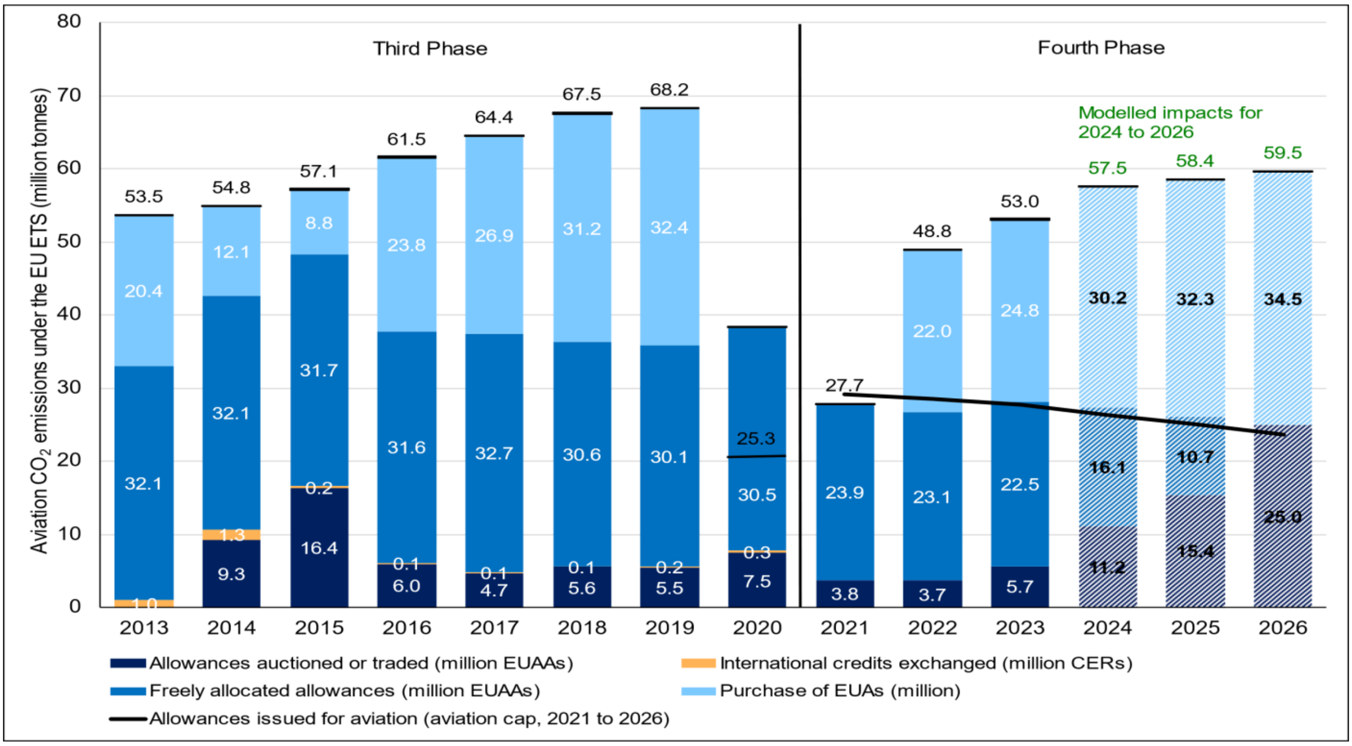
Aircraft operators are required to report verified emissions data from flights covered by the scheme on an annual basis. As is shown in Figure 6.4.1, total verified CO_2 emissions from aviation covered by the EU ETS increased from 53.5 Mt in 2013 to 68.2 Mt in 2019. This implies an average increase of CO_2 emissions of 4.15% per year. The impact of the COVID-19 pandemic on international aviation saw this figure fall to 25.3 Mt in 2020, representing a decrease of 63% from 2019 levels. From 2013 to 2020, the amount of annual EUAAs issued was around 38.3 Mt of which about 15% have been auctioned by the Member States, while 85% have been allocated for free. The purchase of EUAs by the aviation sector for exceeding the EUAAs issued went up from 20.4 Mt in 2013 to 32.4 Mt in 2019 contributing thereby to a reduction of around 155.6 Mt of CO_2 emissions from other sectors during 2013-2019. As a result of the COVID-19 pandemic, the verified emissions of 25.3Mt in 2020 were below the freely allocated allowances for the first time (see Figure 6.4.1).

Since 2021, a gradual recovery of aviation activities has been observed: total verified aviation CO_2 emissions covered by the EU ETS in 2021, 2022 and 2023 were 27.7Mt, 48.8Mt and 53.0Mt respectively. The free allowances allocated to the aviation sector were 23.9Mt in 2021, 23.1Mt in 2022 and 22.5Mt in 2023. Following the rebound of aviation sector's CO_2 emissions from the COVID-19 pandemic, the sector became a net purchaser of EUAs again in 2022 (22.0Mt) and in 2023 (24.8Mt). From 2021 until 2023, a linear reduction factor of 2.2% has been applied to the Allowances issued for aviation, and this factor will increase to 4.3% for the period of 2024-2027.

As also shown in Figure 6.4.1, the modelled CO_2 emissions under the aviation ETS are expected to grow to 59.5Mt in 2026. In line with the gradual phase out of the free allowances to the aviation sector, the annual amount of freely allocated EUAs for aviation is expected to reduce from 16.1 Mt in 2024 to 10.7Mt in 2025 and then become zero from 2026 onwards. Purchase of EUAs is expected to grow from 27.1Mt in 2024 to 28.7Mt in 2026. Emissions benefits from the claiming of Sustainable Aviation Fuels (SAF) could grow from 0.5Mt in 2024 to 1.7Mt in 2026, assuming a zero emissions factor of SAF as per the EU ETS Directive. Moreover, there could be a relative demand reduction within the aviation sector over the years 2024-2026 of 9.8Mt as a result of the carbon price incurred due to the EU ETS[35].

[35] Estimation from EASA AERO-MS model. See Appendix for more details.

Figure 6.4.1 Aviation CO_2 emissions under the EU ETS in 2013-2023 and modelled impact of the revised ETS Directive for years 2024-2026, where 1 EUAA / EUA equals 1 tonne of CO_2 emissions[36]



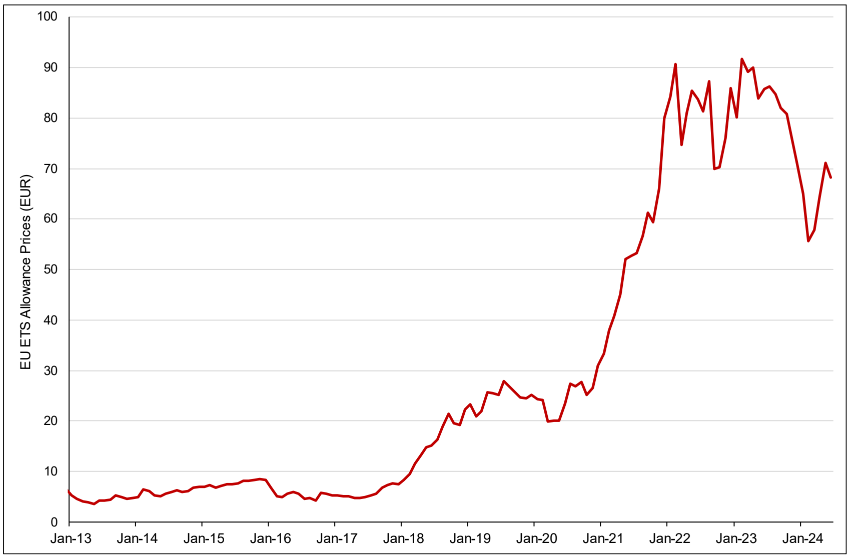
Note: Data in Figure 6.4.1 reflects the years in which the EUAAs were effectively released to the market. This applies especially for allowances attributable to years 2013, 2014 and 2015, which were all auctioned in 2015. The 2014 auctions of EUAAs relate to auctioning of EUAAs due to the postponement of 2012 auctions. Modelled data for years 2024-2026 from the updated AERO-MS model.

As shown in Figure 6.4.2, the annual average EU ETS carbon price varied between €4 and €30 per tonne of CO_2 during the 2013-2020 period. Consequently, total aircraft operator costs linked to purchasing EU Allowances (EUAs) have gone up from around €84 million in 2013 to around €955 million in 2019. Since 2021, the EUA price has increased significantly, reaching average annual EUA prices of more than €80 in 2022 and 2023, resulting in total aircraft operator cost of approximately €1.8 billion in 2022 and €2.1 billion in 2023. Peak EUA prices exceeding €90 per tonne of CO_2 were observed in early 2022 and again in 2023. For the period of 2024-2026, it is estimated that the ETS cost could represent 4-6% of airlines' total annual operating costs[37].

[36] In addition, the Swiss ETS is forecast to result in a purchase of ETS allowances by aviation sector as follows: 0.3 million in 2023; 0.4 million in 2024; 0.5 million in 2025 and 0.6 million in 2026.

[37] Estimation from EASA AERO-MS model.

Figure 6.4.2 EU ETS Allowance Prices (2013-2024)



From 2024 until 2030, airlines can apply for additional ETS allowances to cover part or all of the price differential between the use of fossil kerosene and SAF on their flights covered by the EU ETS. A maximum amount of 20 million allowances will be reserved for such a support mechanism, and airlines can apply for an allocation on an annual basis. The Commission will calculate the price differentials annually, taking into account information provided within the annual ReFuelEU Aviation report from EASA.

European Model for Impact Assessments of Market-based Measures

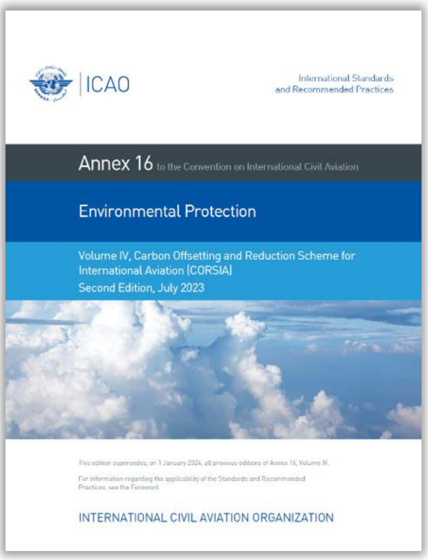
The EASA AERO Modelling System (AERO-MS) has been developed to assess the economic and environmental impacts of a wide range of policy options to reduce international and domestic aviation GHG emissions. These policies include taxes (e.g. fuel and ticket taxation), market-based measures (e.g. EU ETS, CORSIA), as well as the introduction of sustainable aviation fuels and air traffic management improvements. The model can provide insight into the effect of policy options on both the supply side and demand side of air travel due to higher prices, and the forecasted impact on emission reductions.

During the last 20 years, the AERO-MS has been a key part of more than 40 international studies where the model results have informed policy discussions and decisions. Beneficiaries of the AERO-MS include a wide range of organizations, including the European Commission, Member States, EASA, IATA, ICAO, aviation industry and NGOs. As a part of a project funded by the EU Horizon 2020 research programme, an update to AERO-MS was completed in 2024 to enhance its capabilities for future studies. This included a new base year of 2019 traffic and emissions, latest information on price elasticities, the addition of particulate matter emissions modelling and the inclusion of the impacts of SAF. Modelling results from AERO-MS have been used as input for various Figures included within this Chapter.

4.2 CARBON OFFSETTING AND REDUCTION SCHEME FOR INTERNATIONAL AVIATION (CORSIA)

Background

In 2016, the 39th ICAO General Assembly reconfirmed the 2013 aspirational objective of stabilising CO_2 emissions from international aviation at 2020 levels. In light of this, ICAO States adopted Resolution A39-3 which introduced a global market-based measure called the 'Carbon Offsetting and Reduction Scheme for International Aviation' (CORSIA). ICAO Assembly Resolutions are reassessed every three years, and the current Resolution A41-22 for CORSIA implementation was adopted by the 41st ICAO Assembly in 2022, following the outcome of the first CORSIA periodic review by the ICAO Council [3].



CORSIA is being implemented through the associated ICAO Standards and Recommended Practices (SARPs) contained in ICAO Annex 16, Volume IV, the 1st Edition of which became applicable on 1 January 2019. In March 2023, the 2nd Edition of Volume IV was approved by the Council and became applicable 1 January 2024. There were two main sources for the 2nd Edition updates: technical amendments arising from the 12th meeting of ICAO's Committee on Aviation Environmental Protection (CAEP) in February 2022, and consequential amendments to reflect the outcome of the 41 ICAO Assembly in October 2022.

12th ICAO CAEP Meeting

- Clarification on technical matters related to monitoring, reporting and verification provisions.
- Definition of an offsetting threshold of 3,000 tonnes of offsetting requirements per 3-year compliance cycle for aeroplane operators with low levels of international aviation activity.
- Clarification on the calculation of offsetting requirements for new aeroplane operators that do not qualify as new entrants.
- Alignment of verification-related contents with the latest applicable editions of International Organization for Standardization (ISO) documents referenced in Annex 16, Volume IV.

41st ICAO Assembly

- Use 2019 emissions as CORSIA's baseline emissions for the pilot phase years in 2021-2023; and 85% of 2019 emissions after the pilot phase in 2024-2035.
- Decision on the share of individual/sectoral growth factors: 100% sectoral growth factor until 2032; 85% sectoral / 15% individual growth factor in 2033-2035.

- Use of 2019 emissions for the determination of the new entrant operators threshold.

The SARPs are supported by guidance material included in the Environmental Technical Manual (Doc 9501), Volume IV and so called "Implementation Elements", which are directly referenced in the SARPs [4]. ICAO Member States are required to amend their national regulations in line with the amended SARPs, if necessary.

Europe's participation in CORSIA

In line with the 'Bratislava Declaration' signed on 3 September 2016, and following the adoption of the CORSIA SARPs by the ICAO Council, EU Member States and the other Member States of the European Civil Aviation Conference (ECAC) notified ICAO of their intention to voluntarily participate to CORSIA offsetting from the start of the pilot phase in 2021, provided that certain conditions were met, notably on the environmental integrity of the scheme and global participation. EU member states have implemented CORSIA's MRV provisions since 2019 and, as per the revised EU ETS Directive, are implementing CORSIA's offsetting requirements since 2021 for routes between the European Economic Area (EEA) and States that are participating in CORSIA offsetting, as well as for flights between two such States[38]. Implementation of CORSIA's monitoring, reporting and verification rules within the EU has been through the relevant ETS Regulations [5, 6, 7].

CORSIA scope and timeline

CORSIA operates on a route-based approach and applies to international flights, i.e. flights between two ICAO States. A route is covered by CORSIA offsetting requirements if both the State of departure and the State of destination are participating in the Scheme and is applicable to all aeroplane operators on the route (i.e. regardless of the administering State).

All aeroplane operators with international flights producing annual CO_2 emissions greater than 10,000 tonnes from aeroplanes with a maximum take-off mass greater than 5700 kg, are required to monitor, verify and report their CO_2 emissions on an annual basis from 2019. The CO_2 emissions reported for year 2019 represent the baseline for carbon neutral growth for CORSIA's pilot phase (2021-2023), while for the first and second phases in 2024-2035, the baseline is 85% of the CO_2 emissions reported for year 2019. The aviation sector is required to offset any international these baseline levels.

[38] As per the ETS Directive, EU ETS is being applied for flights within and between countries in the European Economic Area, as well as departing flights to Switzerland and to the United Kingdom.

CORSIA includes three implementation phases. During the pilot and first phases, offsetting requirements will only be applicable to flights between States which have volunteered to participate in CORSIA offsetting. There has been a gradual increase of States volunteering to join CORSIA offsetting, rising from 88 States in 2021 to 129 in 2025 [8]. The second phase applies to all ICAO Contracting States, with certain exemptions.

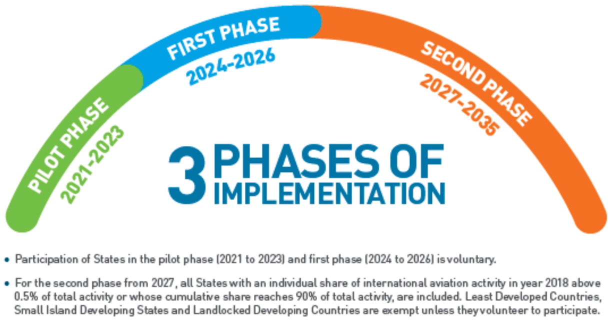
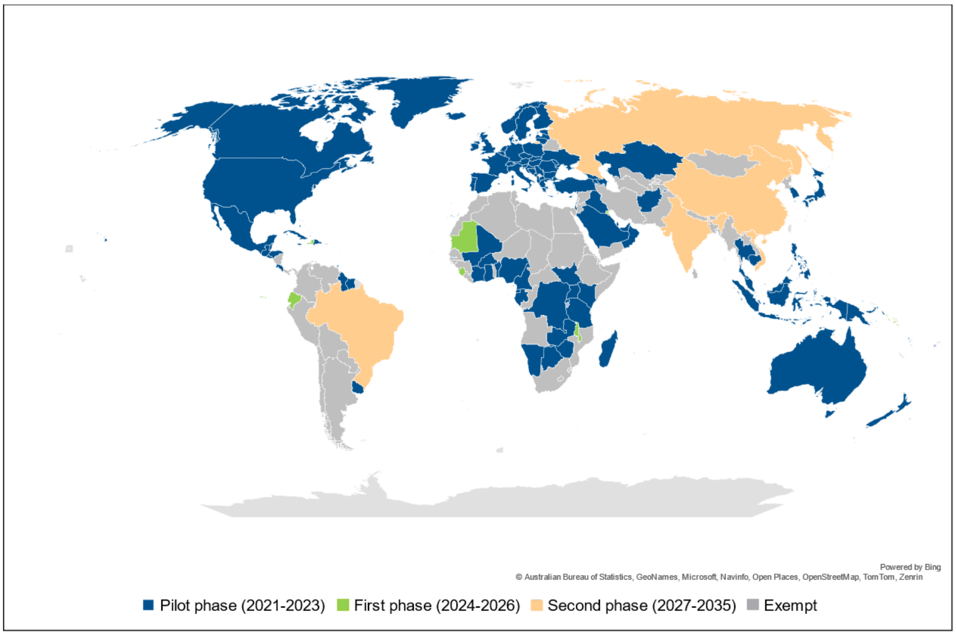
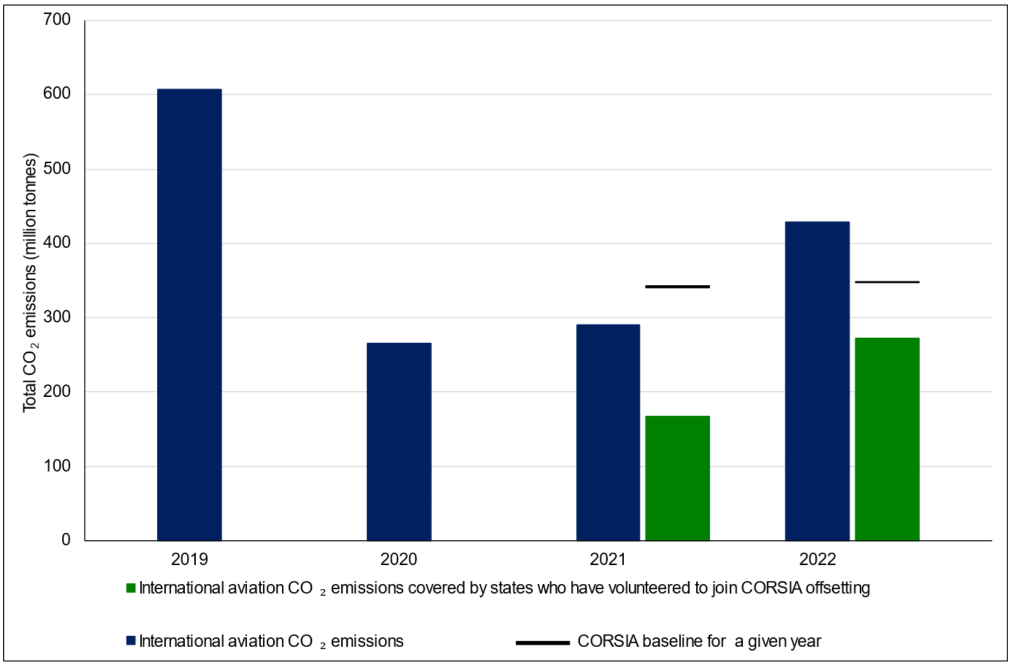


Figure 6.4.3 ICAO Member States participation in CORSIA offsetting in various phases



Due to the change in CORSIA baseline to 2019 emissions for years 2021-2023, and the fact that international aviation emissions covered by routes between two States that have volunteered to join CORSIA offsetting have not reached 2019 levels by 2023, there has not been any offsetting requirements to airlines from CORSIA during its pilot phase. Figure 6.4.4 illustrates the reported CO_2 emissions from all international flights (blue bars) and a subset of these emissions (green bars) between States that have volunteered to join CORSIA offsetting in respective years. For years 2021-2023, CORSIA's baseline emissions are the total CO_2 emissions covered by CORSIA offsetting in 2019. This baseline emissions will be re-calculated for every given year, based on the routes covered by CORSIA offsetting requirements in that given year.

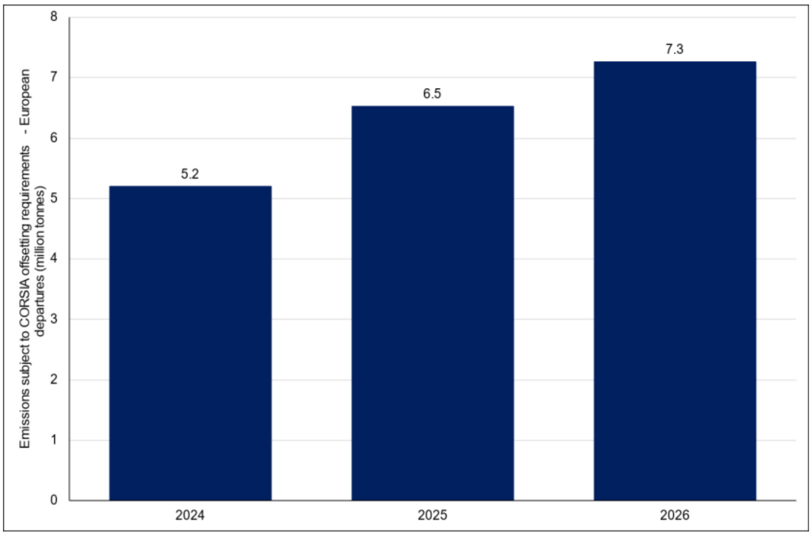
Figure 6.4.4 International aviation CO_2 emissions reported through the CORSIA Central Registry



The revised EU ETS will be applied to flights within and between countries in the European Economic Area, as well as departing flights to Switzerland and to the United Kingdom, while applying CORSIA offsetting for flights to, from and between third countries that participate in CORSIA offsetting. It is estimated that the offsetting requirements for flights departing from Europe will increase from 5.2 million tonnes in 2024 to 7.3 million tonnes in 2026[39] (Figure 6.4.5).

[39] Estimation by EASA AERO-MS model.

Figure 6.4.5 Estimated CORSIA offsetting requirements for departing flights from Europe[40]



CORSIA in practice

International flights within the scope of CORSIA are attributed to an aeroplane operator, and each operator is attributed to an administrating State to which it must submit an Emissions Monitoring Plan. Since 1 January 2019, an aeroplane operator is required to report its annual CO_2 emissions to the State to which it has been attributed, irrespective of whether it has offsetting obligations. As of 1 January 2021, the State calculates annual offsetting requirements for each operator that has been attributed to it by multiplying the operator's CO_2 emissions covered by CORSIA offsetting obligations with a Growth Factor. For years 2021-2032, the Growth Factor represents the percentage growth of the aviation sector's international CO_2 emissions covered by CORSIA's offsetting requirements in a given year compared to the sector's baseline emissions. For the period of 2033-2035, the Growth Factor is calculated by using 85% of the sector's growth against the baseline and 15% of individual aeroplane operator's growth against the baseline.

At the end of each 3-year compliance period (2021-2023, 2024-2026, etc.), an aeroplane operator must meet its offsetting requirements by purchasing and cancelling certified CORSIA eligible emissions units. Each emissions unit represents a tonne of CO_2 avoided or reduced. In order to safeguard the environmental integrity of offset credits used under CORSIA, the emission units must comply with the Emission Unit Criteria approved by the ICAO Council. The price of a CORSIA eligible emissions unit has varied greatly depending on the type of the project ($0.50 to $45/t$CO_2$e during 2020-2021 with a weighted average of $3.08/t$CO_2$eq in 2021) [9]. For the period 2024-2026, it is estimated that the cost of purchasing CORSIA offset credits could be limited at 0.07-0.15% of the total annual operating costs for airlines. Aeroplane operators can also reduce their offsetting requirements by using CORSIA eligible fuels (CEF) that meet the CORSIA sustainability

[40] Covers departing traffic for all airlines from EEA countries and Switzerland to third countries that participate in CORSIA offsetting, except for flights to the United Kingdom, which are covered by EU and CH ETS.

criteria, which includes at least 10% less CO_2e emissions on a life-cycle basis compared to a reference fossil fuel value of 89.1gCO_2e/MJ.

ICAO has established a Technical Advisory Body (TAB) to undertake the assessment of Emissions Unit Programmes against the approved Emissions Units Criteria, and to make annual recommendations on their use within CORSIA. To date, based on the TAB's recommendations, the ICAO Council has approved 11 emissions unit programmes to supply CORSIA Eligible Emissions Units for CORSIA's pilot phase in 2021-2023, and two programmes to supply Units for the first phase in 2024-2026 [10].

In addition to avoidance and reduction projects, removal projects that are designed to remove carbon from the atmosphere can include both natural (e.g., planting trees) and technological carbon removal processes (e.g. Direct Air Capture – DAC or Direct Air Carbon Capture and Storage – DACCS) and have a potential to produce high-quality carbon offsets in the future. Carbon capture and storage technologies can also potentially be utilized for the production of sustainable aviation fuels. The EU has put forward a carbon removal certification framework [11], which aims to scale up carbon removal activities by empowering businesses to show their action in this field. Such certified removals can potentially become eligible in schemes such as CORSIA or when offsetting internal aviation emissions.

In order to address concerns on double counting, rules for international carbon markets under Article 6 of the Paris Agreement were adopted at the UN COP26 meeting in 2021. These rules require a host country to authorize carbon credits for 'international mitigation purposes', such as CORSIA, and to ensure that these emission reductions are not used to achieve its National Determined Contribution (NDC) under the UNFCCC process. These rules are designed to guarantee that corresponding adjustments take place prior to these emission reductions being used to demonstrate compliance with CORSIA. First announcements of authorizations of carbon credits for CORSIA compliance purposes have been observed in early 2024 [12].

What are the differences and similarities between the EU ETS and CORSIA?

The EU ETS is a **cap-and-trade** system, which sets a limit on the number of emissions allowances issued, and thereby constrains the total amount of emissions of the sectors covered by the system. In the EU ETS, these comprise operators of stationary installations (e.g. heat, power, industry), maritime transport operators and aircraft operators. The total sum for aviation allowances in the EU ETS is 95% of the average emissions between 2004 and 2006, adjusted for the applicability scope and reduced by the linear reduction factor annually. The total number of emissions allowances is limited and reduced over time, thereby driving operators in need of additional allowances to buy these on the market from other sectors in the system – hence 'cap-and-trade'. This ensures that the objective of an **absolute decrease of the level of CO_2 emissions** is met at the system level. The revised EU ETS Directive is expected to lead to emission reductions of 61% in 2030 compared to 2005 levels for the sectors covered by the Directive. The supply and demand for allowances establishes their price under the ETS, and the higher the price, the higher the incentive to reduce emissions in order to avoid having to purchase more allowances. Aircraft operators can also use Sustainable Aviation Fuels to comply with their ETS obligations.

The ICAO CORSIA is an **offsetting** scheme with an objective of carbon neutral growth designed to ensure that CO_2 emissions from international aviation do not exceed 2019 levels in 2021-2023 and 85% of 2019 levels in 2024-2035. To that end, aeroplane operators will be required to purchase **offset credits** to compensate for emissions above the CORSIA baseline or use CORSIA Eligible Fuels. The observed spread of the cost of CORSIA eligible emission units has been high and dependent on the project category.

EU ETS allowances are not accepted under CORSIA, and international offset credits, including those deemed eligible under CORSIA, are not accepted under the EU ETS as of 1 January 2021.

Both the EU ETS and CORSIA include similar **Monitoring, Reporting and Verification (MRV) systems,** which are aimed to ensure that the CO_2 emissions information collected through the scheme is robust and reliable. The MRV system consists of three main components: first, an airline is required to draft an Emissions Monitoring Plan, which needs to be approved by a relevant Competent Authority. After the Plan has been approved, the airline will **monitor** its CO_2 emissions either through a fuel burn monitoring method or an estimation tool. The necessary CO_2 information will be compiled on an annual basis and **reported** from airlines to their Competent Authorities by using harmonised templates. A third-party **verification** of CO_2 emissions information ensures that the reported data is accurate and free of errors. A verifier must be independent from the airline, follow international standards in their work and be accredited to the task by a National Accreditation Body.

4.3 Sustainable Finance and Energy Taxation Initiatives

In addition to the EU ETS and CORSIA, there are recent regulatory developments in the area of sustainable finance and energy taxation that are relevant for the aviation sector, notably the introduction of aviation-related activities under the EU Taxonomy system, as well as proposal to introduce minimum rates of fuel taxation for intra-EU passenger flights.

EU Taxonomy

In order to direct investments towards sustainable products and activities, the EU has introduced a classification system, or "EU Taxonomy". This EU Taxonomy is expected to play a crucial role in scaling up sustainable investment and implementing the EU Green Deal by providing companies, investors and policymakers with definitions of which economic activities can be considered as environmentally sustainable. Under the Taxonomy Regulation [13], "Technical Screening Criteria (TSC)" have been developed for economic activities in various sectors. These TSC determine the conditions under which an economic activity qualifies as Taxonomy aligned and should be reviewed on a regular basis, and at least every 3 years.

On 9 December 2021, a first delegated act on sustainable activities for climate change mitigation and adaptation objectives of the EU Taxonomy ("Climate Delegated Act") was published in the Official Journal [14]. It included the activity on low carbon airport infrastructure as well as on manufacture of hydrogen and hydrogen-based synthetic fuels.

The Climate Delegated Act [15] was amended in 2023 to include the following additional aviation-related activities: manufacturing of aircraft, leasing of aircraft, passenger and freight air transport and air transport ground handling operations.

The new TSC focus on incentivising the development and market introduction of aircraft with zero direct (tailpipe) CO_2emissions, and best-in-class aircraft (See Figure 7.6 presenting a part of the Technical Screening Criteria for "best in class" aircraft). In addition, and as transitional activities, the TSC also incentivise the manufacturing and uptake of the latest generation aircraft that replace older, less fuel-efficient models without contributing to fleet expansion. The latest generation aircraft are identified by referring to a certain margin to the ICAO New Type Aeroplane CO_2 standard, several other requirements and 'do no significant harm' (DNSH) criteria, including on emissions and noise. In addition, the TSC also puts a strong emphasis on the replacement of fossil jet fuel with Sustainable Aviation Fuels (SAF) and the technical readiness of the aircraft fleet to operate with 100% SAF.

EU Energy Taxation Directive

Aviation fuel, other than in private pleasure-flying, is currently exempted from taxation under the EU Energy Taxation Directive. EU Member States could tax fuel used for domestic flights or for intra-EU transport if agreed between the Member States concerned on a bilateral basis, although none currently do so. As part of the 'Fit for 55' Legislative Package, the European Commission has proposed to introduce minimum rates of taxation for intra-EU passenger flights that would encourage a switch to sustainable fuels as well as more fuel-efficient aircraft [16]. According to the proposal, the tax for aviation fuel would be introduced gradually over a period of 10 years before reaching the final minimum rate of €10.75/GJ (approximately €0.38 per litre). In comparison, sustainable aviation fuels would incur a zero-tax rate during this same period and after that benefit from a lower minimum tax rate. No agreement on a final Directive has been achieved to date.

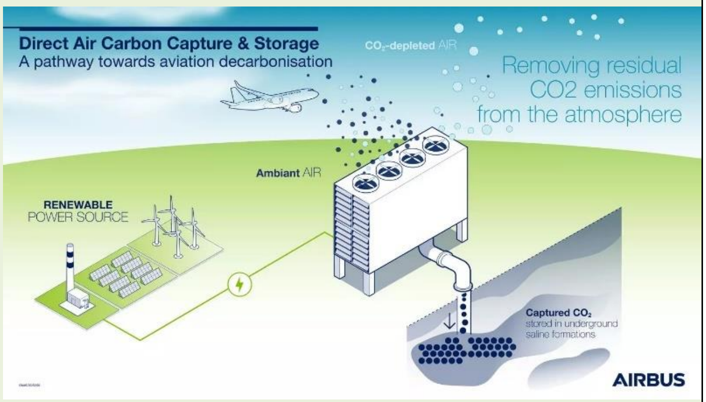
Voluntary Offsetting

In recent years, some airlines have introduced voluntary offsetting initiatives aimed at compensating, partly or in full, those CO_2 emissions caused by their operations that are not mitigated by other measures. Such voluntary initiatives have the potential to contribute to a more sustainable aviation sector, assuming that investments are channelled to high quality offset credits that meet certain quality criteria, e.g. are additional[41.] However, there has been some criticism of the quality of offset credits in this unregulated voluntary market, as well as scepticism of such voluntary activity enhancing aviation sustainability [17, 18, 19].

[41] "Additionality" means that that the carbon offset credits represent greenhouse gas emissions reductions or carbon sequestration or removals that exceed any greenhouse gas reduction or removals required by law, regulation, or legally binding mandate, and that exceed any greenhouse gas reductions or removals that would otherwise occur in a conservative, business-as-usual scenario. [20]

STAKEHOLDER ACTIONS

Airbus Carbon Capture Offer (ACCO)



Airbus developed ACCO with the aim to bring to the aviation industry high-environmental integrity, scalable and affordable carbon dioxide removal credits. [21]. ACCO looks to support the management of the remaining and residual CO_2 emissions of aircraft with the latest carbon removal technologies.

As a first step, Airbus partnered with 1PointFive for exploring direct air carbon capture and storage solutions for the aviation industry. In particular, 1PointFive is developing a large-scale facility expected to capture 0.5 million tonnes of CO_2 per year starting in 2025. Airbus has committed to purchase 400,000 tonnes of CO_2 removals. This initiative aims to support efforts for decarbonising and mitigating Airbus' Scope 3 emissions from the use of its sold product, and also contributes to the larger efforts already underway across the aviation industry.

List of References for Chapter 6.4:

[1] EC (2008), Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008 amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community.

[2] EU (2023), Directive (EU) 2023/958 of the European Parliament and of the Council of 10 May 2023 amending Directive 2003/87/EC as regards aviation's contribution to the Union's economy-wide emission reduction target and the appropriate implementation of a global market-based measure.

[3] ICAO (2022), Resolution A41-22: Consolidated statement of continuing ICAO policies and practices related to environmental protection — CORSIA.

[4] ICAO (2024), ICAO CORSIA Implementation Elements: CORSIA Implementation Elements (icao.int)

[5] EU (2024), Implementing Regulation (EU) 2018/2066 on the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC and amending Commission Regulation (EU) No 601/2012.

[6] EU (2018), Implementing Regulation (EU) 2018/2067 on the verification of data and on the accreditation of verifiers pursuant to Directive 2003/87/EC.

[7] EU (2019), Commission Delegated Regulation (EU) 2019/1603 supplementing Directive 2003/87/EC of the European Parliament and of the Council as regards measures adopted by the International Civil Aviation Organisation for the monitoring, reporting and verification of aviation emissions for the purpose of implementing a global market-based measure.

[8] ICAO (2024), CORSIA States for Chapter 3 State Pairs.

[9] Ecosytem Marketplace (2024), CORSIA Carbon Market Data.

[10] ICAO (2024), CORSIA Eligible Emissions Units.

[11] EC (2022), Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing a Union certification framework for carbon removals.

[12] Government of Guyana (2024), World's First Carbon Credits for Use in UN Airline Compliance Programme, CORSIA.

[13] EU (2020), Regulation (EU) 2020/852 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088.

[14] EU (2021), Commission Delegated Regulation (EU) 2021/2139 of 4 June 2021 supplementing Regulation (EU) 2020/852 of the European Parliament and of the Council by establishing the technical screening criteria for determining the conditions under which an economic activity qualifies as contributing substantially to climate change mitigation or climate change adaptation and for determining whether that economic activity causes no significant harm to any of the other environmental objectives.

[15] EU (2023), Delegated Regulation (EU) 2023/2485 of 27 June 2023 amending Delegated Regulation (EU) 2021/2139 establishing additional technical screening criteria for determining the conditions under which certain economic activities qualify as contributing substantially to climate change mitigation or climate change adaptation and for determining whether those activities cause no

significant harm to any of the other environmental objectives.

[16] EC (2021), Proposal for a COUNCIL DIRECTIVE restructuring the Union framework for the taxation of energy products and electricity.

[17] Bloomberg (2024), Inside the Controversy That's Divided the Carbon Offsets Market - BNN Bloomberg.

[18] Washington Post (2023), Airlines want you to buy carbon offsets. Experts say they're a 'scam.' - The Washington Post.

[19] De Mello, Fabiana Peixoto (2024), Voluntary carbon offset programs in aviation: A systematic literature review, Transport Policy, Volume 147, Pages 158-168.

[20] ICAO (2019), CORSIA Emissions Unit Eligibility Criteria.

[21] Airbus (2024), Airbus Carbon Capture Offer.

5. ADDITIONAL MEASURES

- Significant airport initiatives are being taken forward to invest in onsite production of renewable energy to electrify ground support equipment, thereby mitigating noise and emissions.
- Airport infrastructure will need to be adapted to accommodate SAF and zero emissions aircraft (electric, hydrogen) to meet ReFuelEU Aviation requirements. Various research projects and funding mechanisms are leading the way.
- Some airports are supporting the uptake of SAF through investment in production, supply chain involvement, raising awareness, financial incentives and policy engagement.
- 132 airports in Europe have announced a net zero CO_2 emissions target by 2030 or earlier, and 13 airports have already achieved it.
- In 2023, a new Level 5 was added to the Airport Carbon Accreditation programme requiring 90% CO_2 emissions reductions in Scopes 1 and 2, a verified carbon footprint and a Stakeholder Partnership Plan underpinning the commitment of net zero CO_2 emissions in Scope 3.
- Global environmental challenges require global cooperation to achieve agreed future goals.
- International Cooperation is a key element to reach the global objective of net-zero CO_2 emissions by 2050 including the aim to achieve a 5% reduction of CO_2 emissions from the use of Sustainable Aviation Fuels (SAF), Low Carbon Aviation Fuels and other aviation cleaner energies by 2030.
- Since 2022, EU entities (e.g. States, Institutions and Stakeholders) have committed more than €20M to support environmental protection initiatives in civil aviation across Africa, Asia, Latin America and the Caribbean.
- Collaboration with Partner States has contributed to the sound implementation of

CORSIA-Monitoring Reporting and Verification in more than 100 States and facilitated new States joining its voluntary pilot and first phases.

- Technical support contributed to the development of a first or updated State Action Plan for CO_2 emissions reduction within 18 States, and to an enhanced understanding of SAF and the associated opportunities worldwide.
- Future efforts with Partner States in Africa, Asia, Latin America and the Caribbean are expected to focus on the implementation of CORSIA offsetting and building capacity to increase SAF production.
- SAF, which has the biggest potential to significantly reduce the carbon footprint of air transport in the short- and long-term, are also an opportunity for States to develop their green economy and to boost job creation. Hence, initiatives like the EU Global Gateway are providing financial support (initially on feasibility studies) to help realise viable SAF production projects in Partner States.
- Awareness, coordination, and collaboration in International Cooperation initiatives among supporting partners are essential factors to maximise the value of the resources provided to Partner States.
- The Aviation Environmental Protection Coordination Group (AEPCG) provides a forum to facilitate this coordination of European action with Partner States.

5.1 Airport Measures

5.1.1 Aircraft Operations

Performance Based Navigation (PBN)

The use of Performance Based Navigation (PBN) enables an optimum aircraft flight path trajectory to mitigate environmental impacts, particularly in the vicinity of airports, without having to overfly ground-based navigation aids. Implementation of the PBN Regulation [1] has shown a positive trend since the last report. As of July 2024, 75% of instrument runways are now fully compliant with the requirements and the implementation of PBN has respectively started for 81% Standard Instrument Departures (SIDs) and 82% Standard Terminal Approach Routes (STAR) at these runways. Completion is due by 2030.

The implementation of the PBN Regulation is expected to result in a number of environmental benefits, although neither their evaluation nor their quantification is mandated. As such, it has proven challenging to identify relevant data for this report. Stakeholders responsible for putting in place the required PBN routes and procedures are encouraged to optimise airspace design and the potential environmental benefits, in particular for flight efficiency and route placement flexibility.

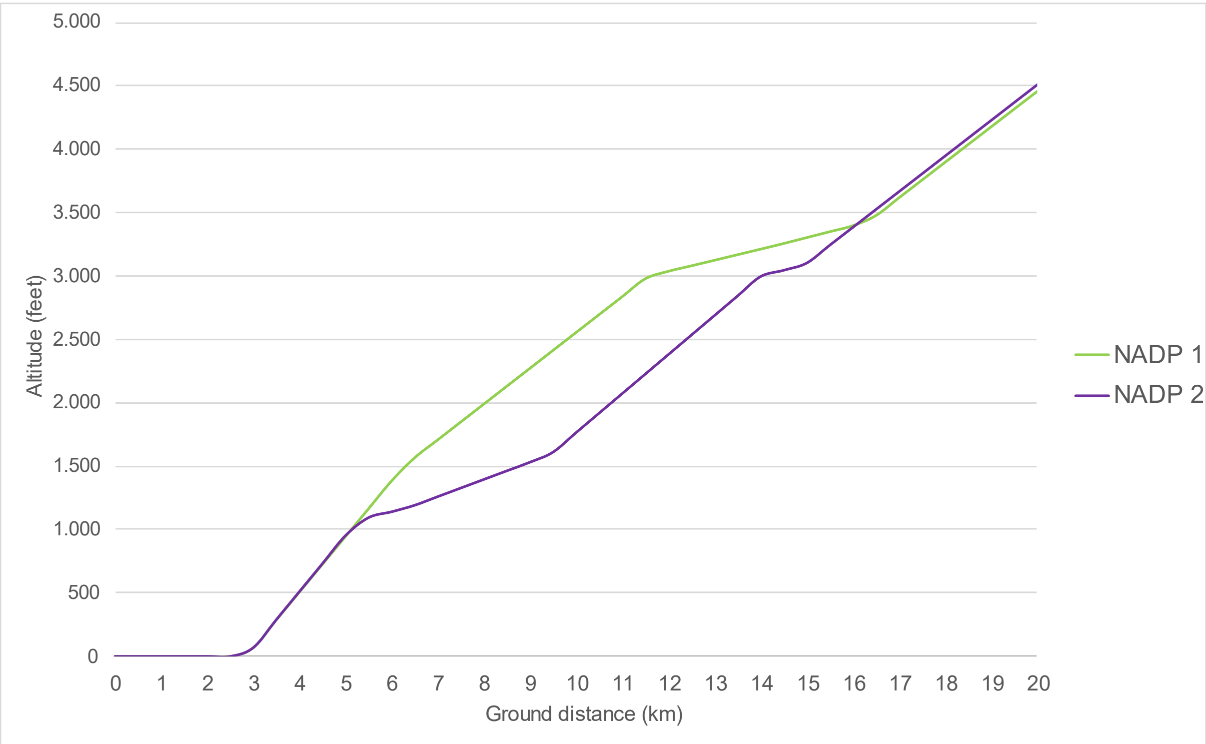
Green Operational Procedures

Building on the previous ALBATROSS research project [2], the goal of the SESAR project HERON launched in 2023 is to reduce the environmental impact from aviation through the deployment of already-mature solutions that range from more efficient aircraft operations to optimised management of air traffic during flights [3]. This includes the Green Apron Management demonstration, which uses sensors and artificial intelligence for more predictable and efficient aircraft handling during airport stopovers.

Noise Abatement Departure Procedures (NADPs)

NADPs aim to reduce the noise impact of departing aircraft by selecting the appropriate moment to clean the aircraft (i.e. retract flaps), which has an impact on the flown vertical profile. NADP1 results in noise reductions close to the airport, while NADP2 reduces noise further away and has lower fuel consumption (Figure 6.5.1). Depending on the operational context (aircraft type, take-off weight, weather, etc) and on the location of the noise sensitive areas, the best balance between noise and emission reductions needs to be determined.

Figure 6.5.1 Example of the difference between NADP 1 and 2 for a wide body aircraft with thrust reduction at 1,000ft.



A study performed by EUROCONTROL highlighted that in many cases a fixed NADP procedure for all aircraft types and runways is advised or mandated by the airport authorities, but that this is not always the optimal solution to balance noise and emission reductions. Noise sensitive areas vary from airport to airport, and from departure runway to runway. As such, airports should identify key noise sensitive areas in each Standard Instrument Departure procedure. By taking the local operational context into consideration and allowing the flight crew to determine the best NADP, additional noise or emission reductions could be achieved.

The study concluded that in some cases where NADP1 procedures are applied, using NADP2 procedures could reduce fuel burn by 50kg to 200kg while only marginally increasing noise by 1dB close to the airport.

Sustainable Taxiing

Trials linked to sustainable taxiing are ongoing at various airports (e.g. Amsterdam Schiphol, Eindhoven, Paris Charles-de-Gaulle and Brussels) through various SESAR research projects as well as national projects. To incentivise implementation and to synchronize developments, a EUROCONTROL / ACI-EUROPE Sustainable Taxiing Taskforce developed a Concept of Operations in 2024 [4].

The Concept of Operations (CONOPS) addresses the potential fuel burn reductions of several sustainable taxiing solutions, which could be up to 400kg CO_2 from a single aisle aircraft taxi-out phase. In addition, there are noise and air quality benefits as the aircraft engine start-up and shut-down procedures occur away from the gate area.

These benefits are mainly the result of operational improvements, such as single engine taxing, combining engine start-up while taxiing, or combining pushback and taxi clearances by air traffic control, thereby reducing total taxi and engine running times that still take into consideration engine thermal stabilization and some additional complexity in ground operations. Research is also looking into limiting Auxiliary Power Units (APU) use to outside certain temperature above a certain threshold. On-going trials are expected to further clarify how to integrate the different taxi operational solutions and quantify their benefits by end of 2025.

5.1.2 Airport Infrastructure

Various EU research projects, including TULIPS [5], OLGA [6] and STARGATE [7], are currently demonstrating innovative environmental solutions at airports, which can be replicated on a European scale.

Ground Support Equipment

Sustainable ground operations at airports have received growing attention in the last few years as a way to address concerns regarding health and working conditions of airport operational staff, as well as the impact on communities in the vicinity of airports. States are already in the process of adopting more stringent regulations to address these concerns resulting in airports looking to fully electrify their ground operations [8].

To advance carbon neutrality of ground operations, Skytanking and Brussels Airport have been developing electric hydrant fuel dispensers, which deliver aviation fuel from the underground hydrant system into the aircraft. After a successful test period in 2023 during which two diesel fuel dispensers were retrofitted to run on electricity, Skytanking commissioned two custom made fully electric hydrant fuel dispenser, which were delivered in 2024 leading to a significant reduction in noise and exhaust gases, which is important for both the local environment and for the ground handling staff. As part of the same research project, DHL Express has replaced a third of its ground handling fleet (tractors, container lifts, belly loaders and pushbacks) with fully electric equivalents.

In 2024, Frankfurt Airport commissioned an expansion to its vertical photovoltaic solar energy system beside Runway 18 West in order to supply renewable energy to power electrified ground support equipment [9]. This facility has provided such encouraging results that its gradually expanded from 8.4kW to 17.4MW, and is now considered the world's largest facility of its kind at an airport. The airport is also using charging infrastructure bidirectionally, which means it's possible to turn electric vehicles into mobile power storage units [10].

Zero Emission Aircraft

The European Commission has established the Alliance for Zero Emission Aircraft (AZEA) to prepare the aviation ecosystem for the entry into service of hydrogen and electric aircraft (see Technology-Design chapter). This will require major investment in energy infrastructure is required to prepare for the introduction of zero-emission aircraft with electric and hydrogen propulsion. The large-scale introduction of zero-emission aircraft will be a crucial pillar in reaching net zero carbon emissions by 2050.

GOLIAT is an EU project that brings together all relevant aviation stakeholders to demonstrate small-scale liquid hydrogen aircraft ground operations at three European airports [11]. Launched in 2024, the group will support the aviation industry's adoption of liquid hydrogen (LH2) transportation and energy storage solutions by:

- Developing and demonstrating LH2 refuelling technologies scaled-up for future large aircraft;
- Demonstrating small-scale LH2 aircraft ground operations at airports;
- Developing the standardisation and certification framework for future LH2 operations; and
- Assessing the sizing and economics of the hydrogen value chains for airports.

New airport pavement bearing strength calculation to optimise maintenance works

In order to ensure safe aircraft operations, airports need to continuously monitor the lifetime and life cycle of critical pavement infrastructure (runways, taxiways and aprons) based on the impact caused by different types of aircrafts with different weights, tyre geometry and tyre pressure. In 2024 EASA published guidance to European airports and competent authorities that changed the Aircraft Classification Rating - Pavement Classification Rating (ACR-PCR) methodology used to calculate pavement bearing strength [12]. These changes are expected to optimise the use of pavement, reduce maintenance needs and costs and also reduce greenhouse gas emissions through a well-managed and better targeted pavement life cycle management by airports.

Sustainable Aviation Fuels

The European policy framework for the deployment of SAF is ReFuelEU Aviation Regulation, which sets out a supply mandate for aviation fuel suppliers and an obligation on Union airports to facilitate this supply of aviation fuels containing the minimum shares of SAF to aircraft operators. European airports are also taking voluntary actions to support the uptake of SAF through various means (Table 6.5.1). A detailed overview of these types of SAF incentive initiatives by European airports has been compiled by ACI EUROPE [13].

Table 6.5.1 Overview of airport initiatives to support the uptake of SAF

Supply Chain Investment
• Support airlines on logistic issue to facilitate the delivery of SAF. • Engage in joint negotiations with SAF suppliers, carriers and other airports to develop SAF projects. • Invest in SAF production facilities.
Raise Awareness
• Inform passengers and corporations on opportunities to purchase SAF for their flights and/or support SAF projects to compensate for their CO_2 emissions.
Financial Incentives
• Provide airlines with SAF incentive programmes (e.g. cost sharing of SAF price premium, differentiated landing and take-off fees based on SAF use, free SAF storage).
Policy Engagement
• Engage with government and local stakeholders to support SAF development and financial incentives for airlines, but not through any kind of minimum shares of SAF other than those of ReFuelEU Aviation.

The EU ALIGHT research project, led by Copenhagen airport, is looking into how to address the barriers to the supply and handling of SAF at major airports by improving the logistics chain in the most efficient and cost-effective manner [14].

Greening Aviation Infrastructure

As the aviation sector evolves to address environmental challenges, this transition is being supported through Member State actions and EU support, notably the Trans-European Transport Network [15], the Alternative Fuels Infrastructure Regulation [16] and their 'financial arm' in the form of the Connecting Europe Facility [17].

Trans-European Transport Network (TEN-T)

The revision of the TEN-T Guidelines [18] introduces requirements on Member States that include the improvement of airport connections to the trans-European railway network, air traffic management infrastructure to enhance the performance and sustainability of the Single European Sky, alternative fuels infrastructure and pre-conditioned air supply to stationary aircraft.

Alternative Fuels Infrastructure Regulation (AFIR)

The AFIR introduces mandatory targets for Member States on the provision of electricity to stationary aircraft at TEN-T network airports and requires Member States to define national strategies on deployment of ground infrastructure for electric and hydrogen aircraft.

Connecting Europe Facility (CEF)

Under CEF Transport Alternative Fuel Infrastructure Facility, 20 projects representing 63 airports from across the EU were selected since 2021, with a total EU Grant support exceeding €160 million [19, 20]. The support has been directed to electricity and pre-conditioned air supply to stationary aircraft, electric charging of ground support equipment, electricity grid connections and green electricity generation.

5.2 Net Zero CO_2 Emissions

The ACI EUROPE Sustainability Strategy was launched in 2019 [21], which included the Net Zero Resolution that has been updated in 2024 [22]. 303 European airports have since committed to net zero[42] carbon emissions from airport operations within their control by 2050 and provided a roadmap detailing how this will be achieved [23].

This net zero commitment covers Scope 1 direct airport emissions and Scope 2 indirect emissions (e.g. consumption of purchased electricity, heat or steam). 132 airports have announced a net zero target by 2030 or earlier, and 13 airports have already achieved net zero. In 2022, guidance on reducing Scope 3 emissions from others operating at the airport which are the largest share of emissions (e.g. aircraft, surface access, staff travel) was published [24] and this was followed in 2023 with guidance on developing Net Zero carbon roadmaps [25].

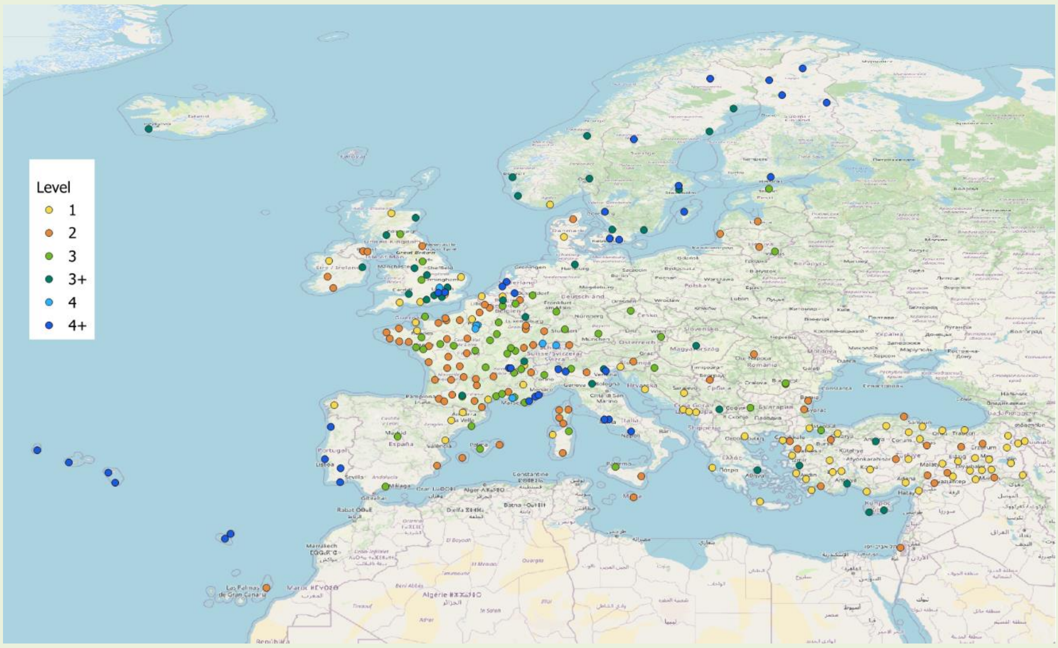
[42] Net zero carbon dioxide (CO_2) emissions are achieved when CO_2 emissions from human activities are balanced globally by CO_2 removals from human activities over a specified period. Net zero CO_2 emissions are also referred to as carbon neutrality.

STAKEHOLDER ACTIONS

Airport Carbon Accreditation Programme

The Airport Carbon Accreditation (ACA) programme [40] was launched in 2009 by the Airports Council International Europe and, as of June 2024, now includes 564 airports on a global basis. The ACA is a voluntary industry led initiative, overseen by an independent Administrator and Advisory Board, that provides a common framework for carbon management with the primary objective to encourage and enable airports to reduce their CO_2 emissions. All data submitted by airports is externally and independently verified. As of the latest 2022-2023 reporting period, there were **290 European airports** participating in the programme corresponding to 77.8% of European passenger traffic (Figure 6.5.2).

Figure 6.5.2 – European airports participating in the ACA programme



The ACA programme was initially structured around four levels of certification (Level 1: Mapping, Level 2: Reduction, Level 3: Optimisation; Level 3+: Neutrality) with increasing scope and obligations for carbon emissions management (Scope 1: direct airport emissions, Scope 2: indirect emissions under airport control from consumption of purchased electricity, heat or steam and Scope 3: emissions by others operating at the airport such as aircraft, surface access, staff travel).

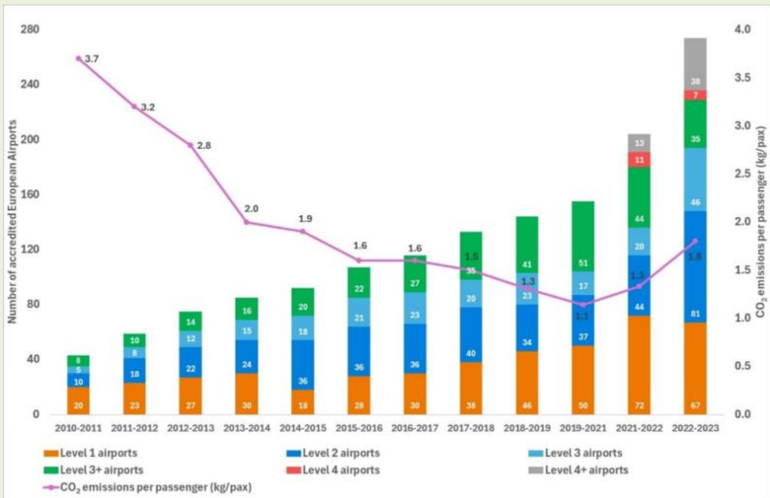
In 2020, Levels 4 (Transformation[43]) and 4+ (Transition[44]) have been added as interim steps towards the long-term goal of achieving net zero CO_2 emissions and to align it with the objectives of the Paris Agreement. Guidelines were also published to inform airports about offsetting options, requirements and recommendations, as well as dedicated guidance on the procurement of offsets.

In 2023, a new Level 5 was added to the ACA programme. When applying for Level 5 airports are required to reach and maintain ≥ 90% absolute CO_2 emissions reductions in Scopes 1 and 2 in alignment with the ISO Net Zero Guidelines, as well as commit to achieving net zero CO_2 emissions in Scope 3 by 2050 or sooner. Any residual emissions need to be removed from the atmosphere through investment in credible carbon removal projects. To support airports in this endeavour, an update to the Airport Carbon Accreditation Offset Guidance Document [26] was published on carbon removal options and most effective removal strategies. Level 5 accredited airports need to outline detailed steps to achieve their emissions reduction targets, as part of their Carbon Management Plan.

Level 5 also requires airports to submit a verified carbon footprint for Scopes 1 and 2, and all relevant categories of Scope 3 as per the requirements of the GHG Protocol Guidance [27], notably covering all significant upstream and downstream activities from third parties, including airlines. Finally, airports must establish a Stakeholder Partnership Plan underpinning their commitment to net zero CO_2 emissions in Scope 3, by engaging with the entire airport ecosystem and actively driving third parties towards delivering emissions reductions with regular milestone to gauge progress.

Ten airports were certified against Level 5 at launch, including 9 European airports (Amsterdam Schiphol, Eindhoven, Rotterdam-The Hague, Beja, Madeira, Ponta Delgada, Göteborg Landvetter, Malmö and Toulon-Hyères). Ivalo, Kittilä, Kuusamo and Rovaniemi airports were also subsequently accredited to Level 5 in 2024.

Figure 6.5.3 – Increasing number of accredited European airports and decreasing CO_2 emissions per passenger



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[43] Definition of a long-term carbon management strategy oriented towards absolute emissions reductions and aligned with the objectives of the Paris Agreement. Demonstration of actively driving third parties towards delivering emissions reductions.
[44] All Levels 1 to 4 plus offsetting of the residual carbon emissions over which the airport has control.

The carbon emission per passenger travelling through European airports at all levels of Airport Carbon Accreditation has increased to **1.8 kg CO_2/passenger** (Figure 5.4). A total reduction in Scope 1 and 2 emissions compared to a three year rolling average[45] of **452,893 tonnes of CO_2** for all accredited airports in Europe was also reported (Figure 6.5.3). This represents about 20% reduction compared to the three-year rolling average.

Figure 6.5.4 – Scope 1 and 2 emissions reductions in airport CO_2 emission

Further developments in the ACA programme are envisaged in 2025 that will focus on the efforts of airport supply chains to reduce their CO_2 emissions.

45 Emissions reductions have to be demonstrated against the average historical emissions of the three years before year 0. As year 0 changes every year upon an airport's renewal/upgrade, the three years selected for the average calculation do so as well. Consequently, airports have to show emissions reductions against a three-year rolling average.

STAKEHOLDER ACTIONS

Airport Council International Europe (ACI EUROPE)

ACI EUROPE represents over 500 airports in 55 countries, which accounts for over 90% of commercial air traffic in Europe. It works to promote professional excellence and best practice amongst its members, including in the area of environmental sustainability.

Digital Green Lane

The Digital Green Lane [28] was launched in 2023 and is a fully digital system for the delivery and collection of goods between freight forwarders and ground handlers, facilitated using cloud-based applications. This process offers numerous benefits, including shorter waiting times for the trucks that deliver and collect goods, a reduction in CO_2 emissions, increased transparency and less paper. The Digital Green Lane was further expanded by cargo community organisation Air Cargo Belgium and some 95% of all cargo in the Brussels Airport cargo zone is now processed via this system. A pilot programme incorporating this same system has also been launched at Athens airport.

Airport Regions Council (ARC)

ARC is an association of local and regional authorities hosting or adjacent to both major European hub airports and smaller airports. The organisation's expertise is at the intersection of airport operations and local/regional policies, and it supports maximising benefits and minimising environmental impact, ultimately striving to improve the well-being of residents in airport regions.

Digital Twin

Within the EU Horizon 2020 research project 'Stargate' [29], IES and Brussels Airport have developed a Digital Twin of the airport's 40 most energy-intensive buildings before modelling scenarios such as installing solar panels, electric vehicle chargers and replacing gas boilers with heat pumps to find the most effective routes to net zero carbon emissions by 2030. This marks a significant step up from the current use of digital twin technology, where it has most commonly been used to optimise commercial operations. Through rigorous modelling stages, it was verified that energy saving measures had the potential for up to 63% CO_2 savings against the 2019 baseline year. This approach will also be replicated at Athens, Budapest and Toulouse airports and promoted across ARC Members.

Non-Governmental Organisations (NGOs)

Environmental NGOs are actively involved in policy-making discussions to address the environmental impacts of aviation. They communicate civil society concerns and positions associated with noise, air pollution, climate change and social justice. They also contribute to raising awareness on aviation's environmental impact through transparency of data.

Tracking progress of business travel emissions savings

Travel Smart is a global campaign aiming at reducing corporate air travel emissions by 50% or more from 2019 levels by 2025, led by a coalition of NGOs in Europe, North America and Asia. The campaign ranks over 327 companies based on the sustainability of their business travel practices and holds them accountable through an Emissions Tracker [30]. This tool uses Carbon Disclosure Project [31] corporate emissions database and allows users to track the progress of a company's business air travel emissions reduction target.

The tracker shows through coloured bars whether companies have returned to levels of emissions above their targets or whether they have maintained reductions of -50% or more, thereby highlighting leaders and incentivising competition between companies. Through this Travel Smart campaign, various company best practices have highlighted that reducing flying is compatible with continued development of profitable business [32].

5.3 Areas of International Collaboration

The aviation sector has a long-standing history of making use of International Cooperation through technical cooperation programmes to grow the capabilities of States in the areas of safety, security and ATM, and EU entities are trusted and experienced partners in those initiatives.

During the last decade, the number of technical cooperation programmes dedicated to environmental protection has grown in line with the increasing ambitions of States to mitigate the environmental impact of aviation. European entities have been key contributors to this having collaborated with 112 Partner States and committed an estimated €20 million in civil aviation environmental protection projects since 2022. At global level, ICAO has developed technical capacity building programmes, such as ACT-CORSIA and ACT-SAF, which offer a common umbrella to the capacity building efforts in environment [33]. The contribution of the European Commission to these programmes amounts to €56.5 million[46], including €9.6 million in projects directly implemented by ICAO. The European States and the European industry are also contributing to these ICAO programmes.

These European projects, implemented by EASA, European States, European Industry or directly by ICAO with European funds, have supported capacity building in numerous regions covering various technical topics that are summarised in this section. Building on this, there is a commitment to continue engaging through International Cooperation initiatives to pursue sustainable aviation on a global basis.

5.3.1 CORSIA Implementation

The initiatives of EU entities, either through the ICAO ACT-CORSIA programme or through dedicated technical cooperation projects, have contributed to the increasing numbers of States volunteering to take part in CORSIA during the Pilot Phase (2021-2023) and First Phase (2024-2026) by facilitating the implementation of the Monitoring, Reporting and Verification (MRV) process and in some cases the development of their National accreditation process.

As described in detail within Chapter 6.4 on Market-Based Measures, CORSIA has now entered the First Phase (2024-2026) where, after the recovery of air traffic following the COVID-19 pandemic, the scheme is likely to lead to offsetting obligations for aeroplane operators flying between two volunteering States. CORSIA offers two ways to perform the offsetting, either by purchasing and cancelling CORSIA Emission Units (CEU) or by using CORSIA Eligible Fuels (CEF). In both cases, specific criteria and rules apply to CEU or to CEF production in order to deem them as eligible offsets. While CEU and CEF can be purchased worldwide, States are looking to benefit from the environmental and economic benefits of CORSIA by providing CEU and CEF on a domestic basis.

[46] Some of the projects covered environment among other activities but were not fully dedicated to environment matters.

Increasing commitments of States under the Paris Agreement through their National Determined Contributions (NDC) may result in greater competition for the use of CEU within international markets. As such, technical cooperation is also playing an important role to facilitate the understanding of the complementarity of CORSIA with other carbon markets, enabling positive synergies to maximise their intended goals and avoiding potential double-counting of emissions and emission cancellations. The cooperation between European entities and Partner States in the period 2025-2027 is expected to focus on the sound implementation of the offsetting mechanisms under CORSIA and facilitating an increase in the availability of carbon projects providing CEU.

Mr Jame E. Empeno

Director, Philippines Accreditation Bureau

"The Philippine Accreditation Board (PAB) has worked hand in hand with EASA and with the Thai Industrial Standards Institute (TISI) to develop and implement the CORSIA Accreditation Process. The combination of expertise between the three parties, sponsored by the EU-SEA CCCA CORSIA Project, has provided the necessary conditions for us to embark into this new area as an organisation, and to achieve the first accreditation of a Verification Body in the Philippines. This collaboration between PAB, EASA and TIITISI is an excellent example of sharing expertise and resources, thus enabling the growth of the accreditation and verification capabilities in ASEAN, which is a key area to ensure the sound and economical implementation of CORSIA within our region."

5.3.2 SAF Development

The development of Sustainable Aviation Fuels (SAF) is the most cost-effective measure and has the biggest potential to significantly reduce the carbon footprint of air transport in the short- and long-term. The carbon reduction of SAF is on a life cycle basis.

The 3rd ICAO Conference on Alternative Aviation Fuels (CAAF#3) in 2023, called as part of the efforts to achieve the LTAG, resulted in its Member States adopting the "Global Framework for Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other Aviation Cleaner Energies" which includes an objective to reduce the emission of air transport of 5% by 2030 thanks to SAF and other cleaner energies [34]. As part of this Framework, it was acknowledged that support to States and industry to develop end finance SAF initiatives is essential to ensure that "No Country is Left Behind" in the decarbonisation efforts. As such, the ICAO ACT-SAF Programme was established to support States in developing their full potential in SAF, through specific training activities, development of feasibility studies, and other implementation support initiatives.

A rapid and geographically balanced scaling up of SAF production requires both significant investments and well-informed decision-making. In this regard, EU entities are advocating and supporting the development of SAF within 42 Partner States in Africa, Asia and Latin America through different International Cooperation initiatives.

The first stage of this support is to raise awareness, to exchange best practices and to develop technical capabilities on SAF. The second stage involves supporting the development of local capabilities to enable local SAF production.

As part of the first stage, EU funded projects have been facilitating SAF workshops and webinars around the world and has also funded, via projects implemented by ICAO, 7 SAF Feasibility Studies - for Kenya, Trinidad and Tobago, Dominican Republic, Burkina Faso, Zimbabwe, Côte d'Ivoire and Rwanda [35, 36, 37, 38, 39, 40, 41]. Beyond Feasibility Studies, the technical cooperation initiatives from EU entities have facilitated bringing all relevant stakeholders together in order to develop a common understanding on SAF, the potential of SAF within their State and what their role could be in the development of local SAF production. This has covered the entire value chain of SAF including the different pathways for production, technoeconomic analyses, readiness studies and policy dialogues. Depending on the State profile, the support and collaboration has been tailored towards its specific potential for SAF production (e.g. analysing the activation of specific feedstocks, taking advantage of existing refining capabilities, potential use of electricity from renewable sources) and assessing at high level the technoeconomic viability of possible production pathways.

Similarly to the support provided on State Action Plans for CO_2 emissions, the most valuable contribution has been to facilitate a common understanding on SAF among the potential SAF actors in a State, and more crucially among different Governmental Departments (e.g. Ministries of Energy, Transport, Environment, Finance, Civil Aviation Authorities) and non-aviation stakeholders (e.g. gas and oil industry, feedstock producers).

In the framework of the EU Global Gateway strategy, EU entities have now reached the start of the second stage with the funding by the European Commission of SAF projects in 15 Partner States: Cameroun, Cote d'Ivoire, Egypt, Equatorial Guinea, Ethiopia, Kenya, India, Madagascar, Mauritania, Morocco, Mozambique, Nigeria, Rwanda, Senegal, South Africa. These projects will be implemented by ICAO and by EASA and aim to support them in achieving local SAF production projects.

The funds are being committed under the EU Global Gateway strategy and contribute to ICAO's ACT-SAF programme and other technical cooperation projects that follow a similar approach. The support initiatives are discussed and agreed with the Partner States in order to map out the main areas of potential collaboration:

- **Developing and managing the SAF programme at State level**, including the definition of the SAF Roadmap, organising the stakeholder engagement and launching communication campaigns to explain the need of SAF for decarbonisation of air transport.
- **Designing and deploying the most adequate SAF framework**, as a set of State initiatives providing favourable conditions for SAF production projects to become viable (e.g. SAF policies, financial initiatives, capacity building), starting with having a good understanding of the State's potential in the form of a feasibility study.
- **Defining viable Direct Supply Lines (SAF production and supply projects)**, assessing the technoeconomic viability of different scenarios, identifying challenges and defining actions at State level (e.g. SAF policies or regulations, incentive schemes, research on sustainability of feedstocks) or at project level (e.g. adjusting technologies, establishing partnerships, securing feedstocks) for those production projects to become viable.
- **Facilitating access to finance**, enabling the bankability of the SAF production project by derisking investment and accessing dedicated funds (e.g. Development Banks, EU Global Gateway).

The initiatives are following and contributing to the development of ICAO's ACT-SAF programme framework, templates and tools. This collaborative work is providing a common and harmonised toolkit that helps both the Partner States and relevant stakeholders match needs and supporting resources in a more agile manner, and allows for more efficient cooperation, even with multiple and concurrent partners.

This coordination is deemed essential to maximise the output of the resources dedicated to the upscale of SAF production worldwide.

Mr Emile Arao

Director General, KCAA, Kenya

"SAF will be a key element in the ability of the aviation sector to increase its sustainability in mid to long-term. It is also an opportunity for countries to develop their green economy and to gain greater independence in a strategic area. However, the complexity of the product, the interdependencies with other economic sectors and the strategic decisions that are required to start producing SAF locally, requires coordination across a wide range of expertise in order for a Government to make the right decisions. The collaboration with international partners, such as the European Union, European States and Organisations, is crucial to maximise the use of available resources that can facilitate Kenya in its ambition to be one of the first countries in Africa to produce SAF at a commercial scale. Under the SAF Steering Committee, Kenya ensures an orchestrated collaboration among all partners, establishes clear leadership and milestones and allows for transparency in achieving this ambitious but exciting endeavour."

5.3.3 Environmental Management Systems for Airports

As defined by ICAO, an Environmental Management System (EMS) provides a methodology and framework to systemically identify and cost-effectively manage significant environmental aspects in the operation of aviation organisations. It has been proven effective across a wide range of organisations, including airports, air carriers, manufacturers and government agencies. EMS is one of the tools available for managing environmental matters at an airport, along with sustainability plans, certifications and other processes.

Through the support from EU funded projects to the ASEAN Member States, Thailand, Laos PDR, Philippines, Indonesia and Vietnam have all developed technical capacity for the implementation of EMS in selected airports of their network. The support provided through a series of training sessions, and the exchange of experiences between airport officials, has facilitated the local implementation of the EMS and the progressive transformation of airport infrastructure to reduce its environmental impact.

As an example, Iloilo Airport in the Philippines was supported in developing and implementing their EMS, including associated manuals, processes and action plans, which led to certification against ISO14001 in 2023 [42]. This attested to a well-established system and the commitment from airport senior officials to mitigate the impact of the infrastructure and its operation on the environment and surroundings. The environmental team from Iloilo Airport, together with the Civil Aviation Authority of Philippines (CAAP) and the support of EU Projects, has subsequently developed an EMS implementation package to support CAAP in progressively rolling out the EMS across the airport network from 2024 onwards.

The implementation of EMS is location specific and faced different scenarios and environmental challenges at each airport. For example, Luang Prabang Airport in Laos PDR is an airport surrounded by UNESCO sites where the need to respect the local cultural heritage was essential during the implementation of their EMS.

All the expertise accumulated in the various EMS implementations is being shared among the ASEAN Member States in thematic workshops facilitated by EU funded projects, and in a dedicated workstream at ASEAN level led by the ASEAN Air Transport Working Group (ATWG).

5.4 Global Gateway

The European Commission is promoting the green transition externally, aiming to combat climate change and to minimise threats to the environment in line with the Paris Agreement together with Partner States. This includes notably the so-called Global Gateway strategy.

Global Gateway will foster convergence with European or international technical, social, environmental and competition standards, reciprocity in market access and a level playing field in the area of transport infrastructure planning and development. It will serve to enhance the recharging and refuelling infrastructure for zero-emission vehicles and foster the supply of renewable and low-carbon fuels. It will serve to strengthen aviation and maritime links with key partners, while also setting new standards to enhance environmental and social sustainability, create fair competition and reduce emissions in those sectors.

Air transport is acknowledged as a hard to decarbonise sector, while at the same time global air traffic is projected to continue growing, contributing to economic and social growth. This increase in air traffic will increase total aviation emissions if no action is taken. To face this challenge, acknowledging SAF as a cost-effective measure with the potential to significantly reduce the carbon footprint of air transport in the short- and long-term, increased availability and use of SAF outside of Europe has become a strategic objective for the EU. SAF also has a high potential to contribute to the economic development of States, notably in Africa, and to reduce their dependence on imported energy sources.

In December 2023, the European Council endorsed the list of Global Gateway flagship initiatives for 2024, including the global development and use of SAF [43], in line with the strategy's pledge to enhance sustainable transport connections. This will support achieving the objectives of both the Long-Term Aspirational Goal of net zero CO_2 emissions from international aviation by 2050 and the ReFuelEU Aviation Regulation mandate that 70% of fuel supplied by 2050 must be SAF.

The recognition of SAF as a strategic priority provides the opportunity to access dedicated funds that can help reduce the investment gap for sound SAF production projects in Partner States.

5.5 Aviation Environmental Project Coordination Group (AEPCG)

Mindful of the need to maximise the impact of the technical and financial resources made available to Partner States, the European Commission (EC) and the European Union Aviation Safety Agency (EASA) established the Aviation Environmental Project Coordination Group (AEPCG) in 2020 as a forum to raise awareness and facilitate the coordination of international cooperation support being delivered by EU Entities.

The AEPCG meets twice a year with an increasing number of participants[47] and initiatives being discussed. While the initial intent of the group was to raise awareness and facilitate coordination, the discussions among the group identified synergies in the implementation of CORSIA and the development of SAF. For example, following the provision of technical support to Cambodia that was coordinated between DGAC France and an EU funded project (EU-SEA CCCA CORSIA Project), the Partner State decided to join CORSIA during its voluntary phase. Looking forward, similar synergies are being developed in the concurrent support of the EU and the Government of the Netherlands to the SAF development in Kenya through the ACT-SAF Programme.

This close coordination and collaborative spirit among support partners will be a key factor in successfully meeting future environmental goals.

[47] AEPCG participants currently include DG MOVE, DG CLIMA, EEAS-FPI, EASA, A4E, ACI-Europe, AEF, Airbus, DGAC-France, ECAC, ENAC, GIZ, Leonardo, Neste, RSB, AESA/SENASA, SkyNRG and UBA.

List of References for Chapter 6.5:

[1] EU (2018), Regulation 2018/1048 laying down airspace usage requirements and operating procedures concerning performance based navigation.

[2] SESAR (2021), ALBATROSS research project.

[3] SESAR (2023), HERON research project.

[4] EUROCONTROL (2024), Sustainable Taxiing Operations – Concept of Operations and Industry Guidance.

[5] EU (2025), TULIPS Horizon 2020 research project.

[6] EU (2025), OLGA Horizon 2020 research project.

[7] EU (2025), STARGATE Horizon 2020 research project.

[8] Schiphol (2024), Emissions Free by 2030.

[9] Fraport (2024), Frankfurt Airport Vertical Photovoltaic System.

[10] Fraport (2024), Frankfurt Airport Using Charging Infrastructure Bidirectionally.

[11] EU (2024), GOLIAT (Ground Operations of LIquid hydrogen AircrafT) research project.

[12] EASA (2024), Guidance for the implementation of the new Aircraft Classification Rating (ACR) – Pavement Classification Rating (PCR) method for the EASA Member States.

[13] ACI-E (2024), European airports' initiatives to incentivise SAF.

[14] EU (2025), ALIGHT Horizon 2020 research project.

[15] EU (2025), Trans European Transport Network (TEN-T).

[16] EU (2023), Alternative Fuels Infrastructure Regulation.

[17] EU (2025), Connecting Europe Facility.

[18] EU (2024), Regulation (EU) 2024/1679 of 13 June 2024 on Union guidelines for the development of the trans-European transport network, amending Regulations (EU) 2021/1153 and (EU) No 913/2010 and repealing Regulation (EU) No 1315/2013.

[19] EC (2023), Transport infrastructure: over EUR 352 million of EU funding to boost greener mobility.

[20] EU (2024), CEF Transport Alternative Fuels Infrastructure Facility (AFIF) call for proposal.

[21] ACI-E (2020), Sustainability Strategy for Airports.

[22] ACI-E (2024), What is Net Zero? – ACI-E Net Zero Resolution 2024.

[23] ACI-E (2022), Repository for airport net zero CO_2 roadmaps.

[24] ACI-E (2022), Guidance on Airports' Contribution to Net Zero Aviation.

[25] ACI-E (2023), Developing an Airport Net Zero Carbon Roadmap.

[26] ACA (2023), Offset Guidance Document.

[27] GHG Protocol (2025), Scope 2 and 3 Calculation Guidance.

[28] Air Cargo Belgium (2024), Digital Green Lane.

[29] STARGATE (2025), Digital Twin project.

[30] Travel Smart (2025), Emissions Tracker.

[31] CDP (2025), Carbon Disclosure Project.

[32] Travel Smart (2025), Case Studies of company best practices.

[33] ICAO (2024), ACT-CORSIA and ACT-SAF.

[34] ICAO (2023), ICAO Global Framework for Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other Aviation Cleaner Energies.

[35] ICAO (2018), Kenya – Feasibility study on the use of SAF

[36] ICAO (2018), Trinidad and Tobago – Feasibility study on the use of SAF

[37] ICAO (2018), Dominican Republic – Feasibility study on the use of SAF.

[38] ICAO (2018), Burkina Faso – Feasibility study on the use of SAF.

[39] ICAO (2023), Zimbabwe – Feasibility study on the use of SAF.

[40] ICAO (2023), Cote d'Ivoire – Feasibility study on the use of SAF.

[41] ICAO (2023), Rwanda – Feasibility study on the use of SAF.

[42] CAAP (2023), award of ISO14001 Certificate to Iloilo International Airport

[43] EU (2022), Global Gateway flagship projects.

Part III:

National Actions in Germany

7. Activities in Working Groups and Committees

Germany is committed to the further development of regulatory standards in the environmental domain, and in particular to CO_2 reductions.

In ICAO, Germany is elected as one of 36 States to serve on the ICAO Council within Part I - *States of chief importance in air transport*. Furthermore, Germany is an active member of ICAO's Committee on Aviation Environmental Protection (CAEP). For the CAEP/13 cycle, Germany currently supports the work of CAEP with in total 39 nominations to almost all (10 out of 11) groups under CAEP. Nominated by the CAEP Member of Germany from the Federal Ministry for Digital and Transport, various stakeholders from government institutions, research and industry have participated in ICAO CAEP working groups to advance emissions standards and certification work.

AkkL
At the national level, a Working Group on Climate-neutral Aviation (Arbeitskreis klimaneutraler Luftverkehr, AkkL) was established in 2022. Recognising that the challenge of decarbonizing aviation - with long innovation cycles, high market entry barriers and international competition - is a task that requires close cooperation of all stakeholders, the working group was established on the initiative of Parliamentary State Secretary Oliver Luksic (Federal Ministry of Digital and Transport, BMDV) and the Federal Government's Aerospace Coordinator Dr. Anna Christmann (Federal Ministry of Economic Affairs and Energy, BMWK). Experts from aviation companies, industry associations, research organizations, trade unions and civil society met regularly to develop recommendations for climate-friendly aviation. The work was organized in three sub-groups:

- WG 1: Market ramp-up Sustainable Aviation Fuels & Power to Liquid.
- WG 2: Technologies for the climate-friendly commercial aviation of tomorrow.
- WG 3: Efficient air transport as a building block for climate-neutral aviation.

After two years of intensive collaboration, the results were presented at the Berlin Air Show 2024 ("Results of the working group on climate-neutral aviation - key fields of action on the way to an environmentally and climate-friendly air transport system of the future", see (Federal Ministry for Digital and Transport / Federal Ministry for Economic Affairs and Climate Action, 2024) [1].

The paper acknowledged, that worldwide production of SAF continuously increases but is still characterized by scarce availability and significant prices compared to fossil kerosene. However, for the flight display at Berlin Air Show SAF blends were used by German Airforce, Airbus A321XLR, DLR and others. It was also highlighted that innovations “made in Germany” make aviation more efficient and ensure industrial value creation for future generations of aircraft. The comprehensive technological stocktake identified both quick wins that are effective in the short term as well as necessary technological steps in the medium and long term, such as evolutionary and revolutionary engines or the upstretched wing. Since the measurability and comparability of climate protection measures is a basic prerequisite for using scarce resources with the greatest possible yield, a new tool was used for assessment. The ALICIA tool developed by DLR and funded by the German government makes it possible to quantify the reduction potential of new technologies, the use of SAF/PtL and innovative flight routes in terms of CO_2 emissions and non-CO_2 effects. The consistent application during the AkkL consultations showed the potential for climate protection measures in existing aircraft fleets. In the case of shark-skin technology, this even proved as a business case. The work in the AkkL raised awareness on the importance of non-CO_2 effects, recognising the need for further research into the quantification of these effects. This led to the initiative for a so-called 100-flights program, a Europe-wide unique field trial, which began with first flights on 7 March 2024.

The main recommendations can be summarized as follows [1]:

- Continuation of collaboration between the different branches of the Federal Government and aviation stakeholders on SAF research, market uptake and regulations;
- Avoiding distortions of competition and carbon leakage potentially resulting from SAF blending mandates;
- Implementing quick wins in aircraft technology and operations (e.g. shark skin, engine wash, improved wing tip devices, pilot assistance for low emission approaches, optimized wastewater management, provision of pre-conditioned air on the ground);
- Avoiding non-CO_2 effects through improved weather forecasts and implementation of “most capable – best served” approaches to incentivize equipping aircraft with the best technologies available.

Further results and recommendations of the sub-working groups (WG 1 to WG 3) can be found in the subsequent chapter and sections.

List of References and Data Sources for Chapter 7:

[1] Federal Ministry for Digital and Transport / Federal Ministry for Economic Affairs and Climate Action (2024): Ergebnisse des Arbeitskreises klimaneutrale Luftfahrt - Zentrale Handlungsfelder auf dem Weg zu einem umwelt- und klimaschonenden Luftverkehrssystem der Zukunft, https://bmdv.bund.de/SharedDocs/DE/Anlage/LF/mantelpapier-ergebnisse-akkl.pdf?__blob=publicationFile [Last Access 16 August 2024], https://bmdv.bund.de/SharedDocs/DE/Pressemitteilungen/2024/041-deutsche-innovationen-luftfahrt.html [Last Access 16 August 2024].

8. Actions and Measures in Germany

TECHNOLOGY AND STANDARDS

SUSTAINABLE AVIATION FUELS (SAF) AND ROADMAPS

OPERATIONAL IMPROVEMENTS

MARKET-BASED MEASURES (MBMs)

ADDITIONAL MEASURES

Technology and Standards

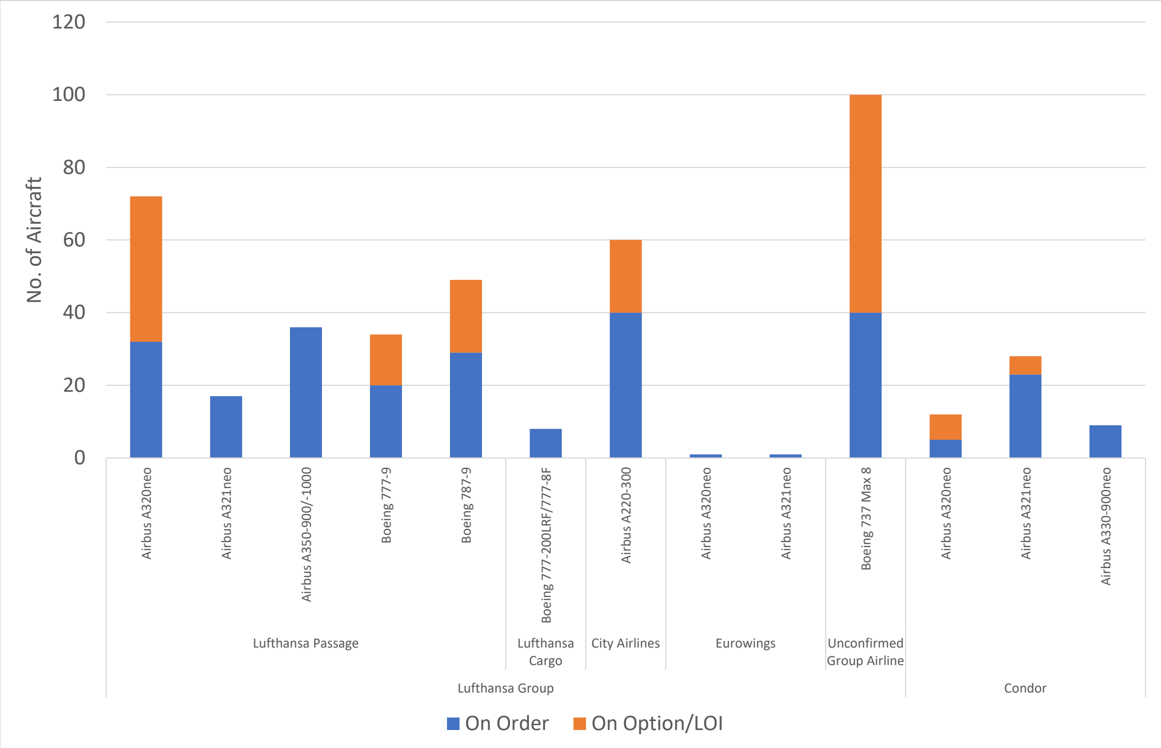
AkkL
As part of AkkL, Technology WG 2 aimed on highlighting the key technologies for climate-neutral aviation and what is needed to accelerate their implementation. An overview of the interim results was presented at the Berlin Air Show 2024 prioritized by means of a quantified potential assessment.

- As *Quick Wins*, measures to reduce the climate impact were identified that are expected to be implemented quickly and available for a large part of the world fleet. Some of the identified quick wins might be profitable for the aircraft operators without further incentives due to the associated lower consumption of aviation fuel, e.g. Shark skin (foil on airframe to reduce aerodynamic drag), Innovative engine compressor washing process, grey water use for onboard toilets etc.
- In order to achieve a massive increase in climate compatibility, specific *Enabler* can facilitate technological leaps in propulsion systems and for the airframe in the area of structure, aerodynamics but also systems engineering if implemented in the next generation of aircraft. As vast majority of climate impact of aviation comes from aircrafts with more than 100 seats, why focus on new technologies should be in this domain.

Next steps are preparation of an implementation plan and definition of the testing and integration platforms that serve research, development and manufacturing stakeholder in Germany to be in a position to visualise and shape future commercial aircraft.

Aircraft fleets
German aircraft operators are striving to improve the environmental performance of their fleets by introducing new aircraft. At the end of 2023, German operators had collectively a total of 439 business jets, freighters and passenger aircraft with 19 or more seats on order.

Figure 8.1: Order book of German aircraft operators at year end 2023



Source: Own analysis based on Cirium Fleets Analyzer [1].

A major impact of Lufthansa's fleet renewal will come from the long-haul fleet. In the medium term, the entire fleet of Boeing 747-400, Airbus A340-300 and Airbus A340-600 will be phased out [2]. Based on 2023 flight schedules with 13,000 flights of these aircraft types, the full replacement by Boeing 777-9, Boeing 787-9 and Airbus A350-900/A350-1000 has the potential to reduce CO_2 emissions in the order of 750,000 tons annually. Further CO_2 emissions reductions will come from the replacement of single-aisle aircraft (Airbus A320ceo/A321ceo) with Airbus A320neo/A321neo. The complete replacement of the A320ceo/A321ceo by the A320neo/A321neo will have a further emission reduction potential of 380,000 tons annually in the long term.

Condor, Germany's second largest airline, has undergone financial restructuring in recent years and is in the process of completely renewing its short-/medium- and long-haul fleet. The current single aisle fleet consisting of Airbus A320ceo/A321ceo and Boeing 757-300 will be replaced by Airbus A320neo/A321neo in the coming years. The replacement of the long-haul fleet of Boeing 767-300ER and Airbus A330ceo with Airbus A330neo has already been completed in 2024. Based on the 2023 flight schedule, Condor's fleet renewal has the potential to reduce CO_2 emissions by approximately 210,000 tons per year for the short- and medium-haul fleet. For the long-haul fleet, no notable absolute reduction in CO_2 emissions is expected, as the block fuel consumption of the Boeing 767-300ER and the Airbus A330-900 is very similar, but the result will be a significant reduction in specific emissions per passenger-kilometre. Condor's Airbus A330-900 has a seating capacity of 310, compared to 259 for the Boeing 767-300. As a result, CO_2 emissions per passenger-kilometre are expected to be reduced by about 20 %.

Research and development

Research and development in aeronautics plays an important role in Germany. Efforts are undertaken at universities, research centres and within industry. Progress in the research and development of aeronautical technologies is crucial for the competitiveness of the civil aeronautical industry, which employed more than 73,000 persons in Germany in 2022.

All of the aviation research instruments of the Federal Government of Germany are currently focussed on technologies that help reduce the climate impact. The main national research tools in this regard are:

- Aeronautical research program (Luftfahrtforschungsprogramm, LuFo);
- National innovation program hydrogen and fuel cell technologies;
- Innovation and technology centre hydrogen;
- Institutional funding of the German Aerospace Center (DLR).

Since 1995, the Federal Government has been supporting the aeronautical industry, universities and research organizations with the *aeronautical research program (Luftfahrtforschungsprogramm)*. In 2019, the sixth aeronautical research program with three program calls (VI-1 to VI-3) was launched.

The central objective of the LuFo VI-3 program call is to significantly reduce the climate impact of aviation. In order to meet the requirements and goals of international climate protection agreements and policies, as well as to strengthen social acceptance, intensive efforts are needed to achieve emission-free and climate-neutral aviation. The expected increase in air traffic volume and the future integration of new unmanned aerial vehicles into the airspace can only be coped with more efficient, emission-free and climate-neutral air transport and production systems.

The focus of LuFo is based on three pillars:

- Alternative climate-neutral propulsion systems;
- Reducing primary energy requirements and the use of resources by reducing weight and increasing the efficiency of drives, systems and aerodynamics;
- Reduction of production times and costs with the primacy of closed material cycle systems.

The following primary targets are being pursued in the medium term up to 2035:

- 40% reduction in weight;
- 50% reduction in energy requirements;
- 50% reduction in production costs and times.

Against this backdrop, technological developments are supported that make flying sustainable, climate-neutral and safe. Five time horizons in the priority aircraft classes serve as orientation markers.

Short implementation horizons are made possible for unmanned aerial vehicles.

- By 2028 - first passenger services on pre-defined tracks;
- By 2030 - regional aircraft;
- By 2035 - medium-haul;
- By 2045 - long-haul.

The sixth round of the German aeronautics research program has an annual budget of approximately €200 million from federal funding. The projects to be funded require substantial additional contributions from industry, so that the total project-related budget is significantly higher than this figure. Substantial financial contributions were already made in the previous program cycle. Between 2007 and 2018, 2,097 projects were approved with a total budget of €3,246 million and federal grants of €1,781 million.

The aeronautics research program will continue in its seventh round (LuFo VII) for projects to be funded from 2025 to 2030. The first calls for Lufo VII, launched in April 2024, will focus on alternative climate-neutral propulsion technologies, reduction of energy requirements and increasing competitiveness, resource efficiency, reducing the ecological footprint and improving social acceptance.

While LuFo VI focused on regional aircraft with less than 100 seats, LuFo VII aims to bring technologies for larger aircraft to the market with a time horizon of market maturity by 2035 and climate-neutrality by 2045. A key objective is to accelerate innovation, so demonstrator projects will also be supported.

The aeronautical industry and its products are international by definition. Accordingly, product innovations developed by the German aeronautical industry have positive spillover effects on a global scale. In 2023, the German Aerospace Center (DLR) evaluated the long-term effects of technologies developed in the aeronautics research program. The study took into account aviation growth as well as the relatively slow technology diffusion once aircraft equipped with advanced low emissions technologies enter the fleet. Table 8.1 provides information on the cumulative CO_2 emissions reductions under different geographical scopes. It displays reduction potentials of this national aeronautics research program under defined assumptions as outlined and analysed in the above mentioned study, and these analysis results are provided here in the national section of this State Action Plan as complementary information. An overarching quantification of effects of improved aircraft technology is provided in the ECAC/EU Common Section for European State Action Plans within the estimated benefits of implemented measures and further described in the actions taken collectively in Europe for technology and design. Reference is made to these sections of this State Action Plan for quantifications.

Table 8.1: Cumulative CO_2 emissions reduction potential due to the aeronautical research program in million tons (Mt)

	Geographical Scope		
Timeframe	Germany - domestic	Germany – departing international traffic	Global civil aviation
Cumulative Potential Emissions Reduction (Technologies TRL > 6) 2023-2030	0.85 Mt	15.18 Mt	500.68 Mt
Cumulative Potential Emissions Reduction (Technologies TRL > 6) 2023-2050	46.56 Mt	703.56 Mt	24,704.69 Mt
Cumulative Emissions Reduction - Realistic Market Diffusion 2023-2030	0.14 Mt	2.72 Mt	87.45 Mt
Cumulative Emissions Reduction - Realistic Market Diffusion 2023-2050	25.64 Mt	409.75 Mt	14,253.42 Mt

Source: Linke et al. (2023) [3].

The national innovation program hydrogen and fuel cell technologies (NIP), under the auspices of the Federal Ministry for Digital and Transport is currently in its second phase (2016-2026) and aims at the competitive establishment of hydrogen and fuel cell technologies in the transport sector. R&D funding focuses on demonstration, innovation and market preparation activities. In particular, projects aiming at a technology readiness level (TRL) of 5 to 8 will be supported. In the field of air transport, the focus is laid on fuel cell systems for use in smaller regional aircraft. Between 2017 and 2022, several projects in aviation have been funded, such as (NOW GmbH, 2023) [4]:

- BALIS – Fuel cell propulsion for aircraft 1.5+ MW, led by the German Aerospace Center (DLR) with a project volume of €28.9 million.
- BALIS 2.0 - Development of a fuel cell-based megawatt powertrain as basis for multi-megawatt (up to 10MW) drives in aviation, conducted by a consortium of H2Fly GmbH, the German Aerospace Center (DLR) and Diehl Aerospace, with a project volume of €16.7 million.
- BETA – Development of solutions for reliable and safe operation of fuel cells in aircraft, conducted by a consortium of Airbus Operations GmbH, University of the Bundeswehr Hamburg, ZAL Zentrum für Angewandte Luftfahrtforschung and the German Aerospace Center (DLR), with a project volume of €5.6 million.
- BILBO – fuel cell integration in aircraft and airports, conducted by a consortium of Airbus Operations GmbH, Diehl Aviation, ZAL Zentrum für Angewandte Luftfahrtforschung and the German Aerospace Center (DLR), with a project volume of €5.7 million.
- GO4H2 – pollutant-free 4-seater aircraft with hydrogen fuel cell propulsion, conducted by a consortium of Ulm University, Rolls-Royce Germany, Diehl Aerospace, H2Fly and the German Aerospace Center (DLR), with a project volume of €5.5 million.
- GO4HY2 – development of a fuel-cell/battery system for passenger aircraft (follow-up project of GO4H2), conducted by a consortium of Ulm University, Rolls-Royce Germany, Diehl Aerospace, H2Fly, the German Aerospace Center (DLR) and Deutsche Aircraft, with a project volume of €9.9 million.
- H2GA – Transfer of automotive hydrogen fuel cell technologies to the Antares E2 demonstrator, conducted by a consortium of Lange Research Aircraft, Fraunhofer-Institute for Chemical Technology and TU Dresden, with a project volume of €5.0 million.
- H2Sky – Development of a hydrogen fuel cell stack for the use as the main propulsion system in an aircraft, conducted by a consortium of Aerostack GmbH, Fraunhofer Institute for Solar Energy Systems, Center for Solar and Hydrogen Research, Technical University of Munich, EKPO Fuel Cell Technologies, Freiburg University and Hahn Schickard, with a project volume of €44.3 million.

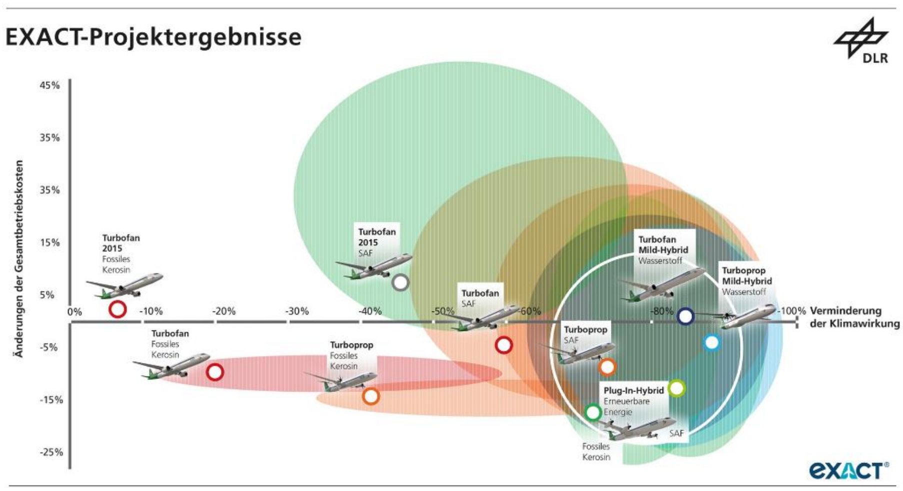
In 2021, the Federal Ministry for Digital and Transport commissioned a feasibility study on the establishment of an *Innovation and Technology Center Hydrogen (ITZ)* [5]. The centre, which is to be established in four decentralized locations in Germany, will facilitate the cooperation of stakeholders in the hydrogen ecosystem in the areas of testing and development, standardization, capacity building, networking, the support of start-up companies, increasing the visibility, certification and consulting. The ITZ location North (Hamburg, Bremen/Bremerhaven and Stade) will focus on aviation and maritime shipping applications. With a strategic co-location close to stakeholders working on aviation hydrogen technologies (Airbus at all three locations, the ZAL Zentrum für Angewandte Luftfahrtforschung in Hamburg-Finkenwerder and a wide range of other stakeholders in the area), the ITZ is expected to advance testing, certification, the development of regulations and further steps towards the industrialization of hydrogen technologies.

In addition to the presented activities in hydrogen research and development, the Federal Ministry for Digital and Transport intends to publish a roadmap on hydrogen and e-fuels in transport in 2025.

The *German Aerospace Center (DLR)* is Germany's national research centre for aeronautics and space. Its aeronautics research area received €239 million in funding from the Federal Government in 2022 [6]. A significant portion of the funding was used to work on projects aimed at reducing the climate impact of aviation.

EXACT (Exploration of Electric Aircraft Concepts and Technologies) is a DLR key project for the long-term development of the aviation system to reduce emissions. In EXACT, the expertise of 20 different DLR institutes was combined and several innovative aircraft concepts in the regional and short-/medium-haul sector were developed and evaluated with regard to their climate impact and change in operating costs compared to today's aircraft technologies. The project was completed in 2023.

Figure 8.2: EXACT aircraft concepts and results with regards to climate impact/operational costs



Source: DLR (CC BY-NC-ND 3.0).

Short-/medium-haul aircraft powered by advanced technology turboprop engines expected to enter service around 2040, could already achieve a 40% reduction in climate impact compared to a turbofan aircraft at a technology level of 2015. At the same time, operating costs will be reduced in the order of 15%. Using the same aircraft technology with sustainable aviation fuels could reduce the climate impact by 70%, but at higher operating costs. Hydrogen-powered aircraft, if available, could reduce the climate impact by 85-90%, at operating costs comparable to today's fossil-fuel powered turbofan aircraft. Surprisingly, a plug-in hybrid aircraft with batteries and a gas turbine range extender can achieve the highest cost savings (depending on key assumptions such as battery energy density and charge cycle degradation) and climate impact reductions in the order of 70-80%, depending on the fuel source (fossil jet fuel or SAF). On very short routes, the aircraft can be operated solely on battery-electric power with no local gaseous emissions and no operational CO_2 emissions when recharged with electricity from renewable sources.

EXACT will be succeeded by a project focusing on the most promising aircraft concepts, including long-haul air transport, and a more refined economic analysis including different operational and regulatory scenarios that will have an impact on the operation of future aircraft.

Sustainable Aviation Fuels (SAF) and Roadmaps

Germany is strongly committed to supporting the decarbonization of aviation through the introduction of sustainable aviation fuels.

In 2021, various departments of the German government (Federal Ministry for the Environment Nature Conservation and Nuclear Safety, Federal Ministry for Digital and Transport, Federal Ministry for Economic Affairs and Energy, Federal Ministry for Economic Cooperation and Development) together with the German Aviation Association (BDL) published a roadmap for the upscaling of power to liquid aviation fuels (PtL). The roadmap includes an ambition of 200,000 tons by 2030 [7].

AkkL
As part of the Working Group on Climate-neutral Aviation (AkkL), SAF WG 1 stakeholder identified 10 measures for the government to accelerate the market ramp-up of SAF:

1. Establishment of an Interministerial Steering Group on Renewable Fuels for close exchange towards stronger coordination within the Federal Government.

2. Continuation of the WG 1 as proven advisory body under the patronage of the Federal Government which is deemed crucial by the stakeholders for successful cooperation.

3. Price gap between SAF and fossil fuels needs to be evened out to avoid that the blending obligation for SAF for European airports will not lead to considerable competitive disadvantages and carbon leakage.

4. Create investment incentives for E-SAF production.

5. Preparation of an official guide for obligated companies and potential investors.

6. SAF production as an industrial policy instrument.

7. Pooling research on SAF and transferring it into practice.

8. Simplification and acceleration of the SAF ramp-up through further incentives or flexibility measures like introduction of a book & claim system (under consideration as flexibility mechanism within ReFuelEU Aviation regulation) while assuring strong objectives e.g. pragmatic design, high compliance standards etc.

9. Strategic development of the use of biogenic raw materials.

10. Investor conference on the initiative of the German government.

Co-ordinated by the Federal Ministry for Digital and Transport the respective Ministries dealing with SAF are currently working on a reply to the measures stated above.

SAF support
With funding from the Federal Ministry for Digital and Transport the German Aerospace Center (DLR) will build the Technology Platform Power-to-Liquid Fuels (TPP) in Leuna, Saxony-Anhalt, as a research and demonstration facility for PtL production. The facility will be the world's largest research and demonstration plant for PtL production, with a production capacity of up to 2,000 - 3,000 tons per year. Initial funding amounts to €30 million in 2024 and a further €100 million are planned to be invested between 2025 and 2027.

With the Funding Programme for Renewable Fuels, the Federal Ministry for Digital and Transport supports the development of renewable fuels. To date, 19 research and development projects have been funded with over €117 million most of them with a focus on SAF [8].

Together with the Hessian Ministry of Economics, Transport, Housing and Rural Areas the Federal Ministry for Digital and Transport is also supporting the SAF-Monitor, which provides an overview of announced SAF projects globally. The database is updated regularly and the SAF Monitor will be launched annually [9].

As a further measure, the Federal Government is supporting the implementation of PtX labs to develop production processes and the large-scale industrialization of PtL fuels. The first PtX Lab has been established in the Lausitz region in 2021 as part of the region's transition in the state of Brandenburg from lignite mining to green industries of the future.

The production of SAF requires hydrogen as a key resource in different conversion pathways (such as the hydrogenation of used cooking oil or the power-to-liquid production pathway). This is fully recognised in the national hydrogen strategy, published in 2020 and subsequently updated [10]. Key elements to support the supply of green hydrogen are the expansion of domestic electrolysis capacity to 5 GW including the required on- and offshore renewable electricity generation capacity, by 2030 and a further 5 GW by 2040 at the latest. It is acknowledged that not all green hydrogen can be produced domestically, so the implementation of a global green hydrogen market including partnerships with a variety of countries around the world is promoted.

Operational Improvements

AkkL
As part of the Working Group on Climate-neutral Aviation (AkkL), WG 3 on Efficient air transport as a building block for climate-neutral aviation deals with the following core challenges on the way to climate-neutral aviation:

- Avoiding non-CO_2 effects: Determination of ice-supersaturated air layers in a Deutscher Wetterdienst (DWD) forecast model.
- 100-flight trial: Feasibility study to determine whether it is possible to fly around ice-supersaturated air layers when taking existing traffic volumes into account.
- "Best equipped, best served": Feasibility study for targeted priority treatment of aircraft that take part in the trial and are given priority to new flight altitudes and landing procedures. In later regular operations, this will be an incentive system for aviation organizations to convert their fleets to new technologies more quickly.

Operations
DFS Deutsche Flugsicherung GmbH is the German state-owned air navigation service provider (ANSP), operating four en-route control centres and 15 airport towers.

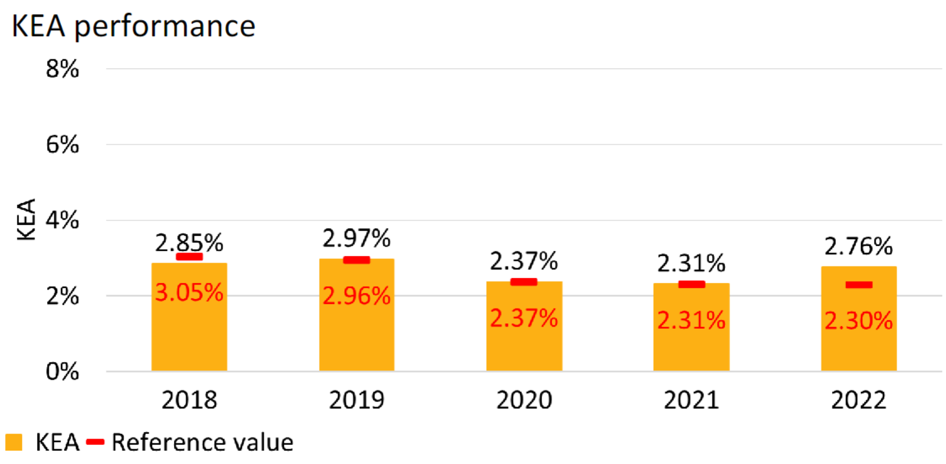
The operation of the ANSP infrastructure by DFS caused 30,929 tons of CO_2 in 2021 (Scope 1 & 2, which are the direct emissions of the company and the indirect emissions of suppliers, e.g. for purchased energy). To reduce these emissions, DFS has set up two objective areas with various individual projects:

The decarbonization of energy demand shall result in a 50% reduction of CO_2 emissions by 2025. Individual projects to achieve this goal include:

- Conception, planning and implementation for "Green Communication" using the example of the pilot site Brinkum;
- Conversion from natural gas to district heating at the Karlsruhe Centre and Nuremberg Tower;
- Purchasing of electricity from renewable sources via direct purchase "Power Purchase Agreements";
- Conversion and decommissioning of beacons;
- Achieve a quota of 50% low-emission pool vehicles.

The activities of DFS are embedded in the cooperation of air navigation service providers throughout Europe as part of the Single European Sky initiative of the European Union. One of the goals of this initiative is to continuously improve environmental parameters. The direct flight route has been regarded as a key indicator so far. Binding targets are set within the SES Performance Scheme for the efficiency of the actual flight path (KEA).

Figure 8.3: En-route flight efficiency performance for Germany, 2018-2022

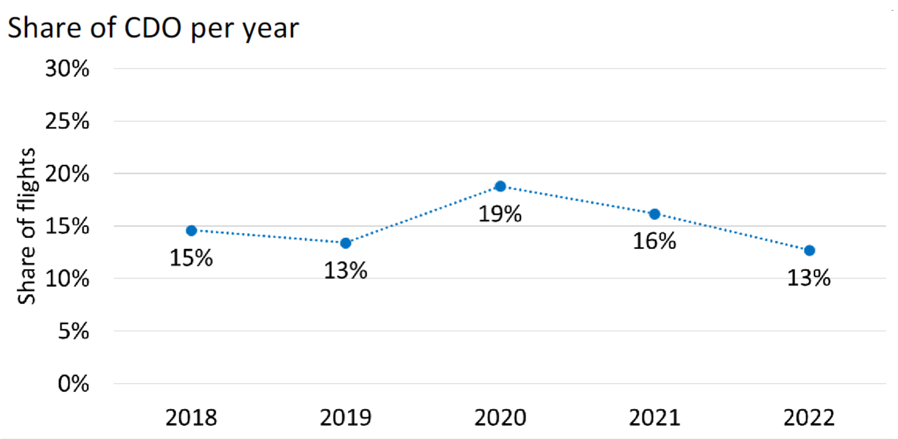


Source: PRB (2023) [11].

Horizontal flight efficiency improved over time and is at a relatively low level with 2.76%, although it missed the target of 2.3%.

Continuous descent operations (CDO) can help reduce fuel consumption and CO_2 emissions. In 2022, 13% of all flights in Germany operated under CDO conditions. Due to the traffic growth after the COVID-19 pandemic and the associated capacity constraints, the level is lower than in 2020/2021, but at the same level as in 2019, the year before COVID-19. The implementation of CDO procedures continues to evolve. Currently, they are in use at the airports Hanover, Braunschweig, Düsseldorf, Cologne/Bonn, Leipzig, Nuremberg, Stuttgart and Munich.

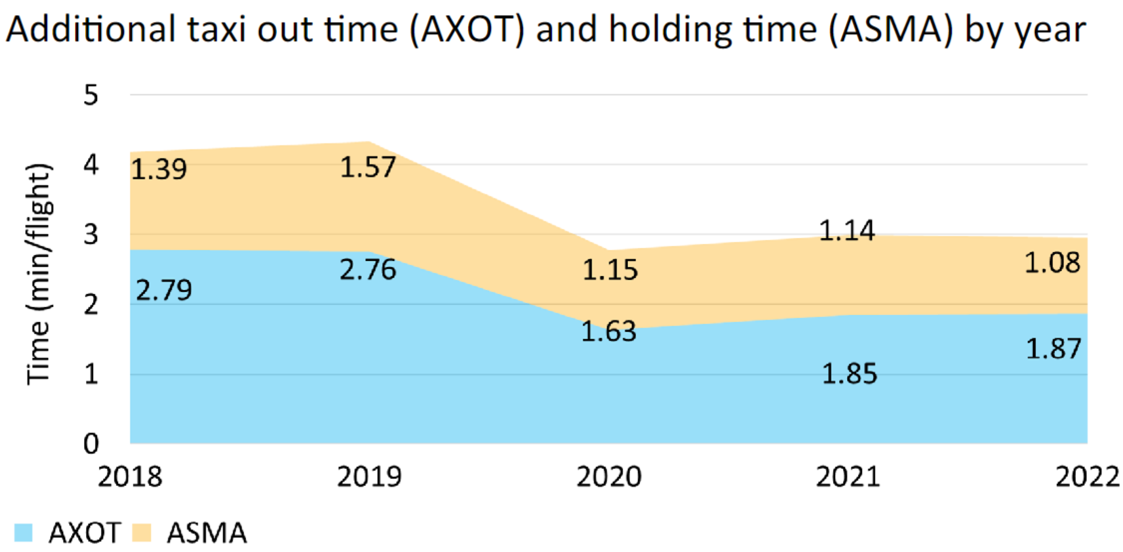
Figure 8.4: Development of Continuous Descent Operations in Germany, 2018-2022



Source: PRB (2023) [11].

The reduction of taxi-out time is another factor contributing to both the reduction of fuel consumption and CO_2 emissions. In 2022, terminal airspace users spent an additional 2.85 minutes per flight either taxiing and/or holding at German airports. A positive trend can be observed compared to the pre-COVID years, where an average of 4.18 minutes and 4.33 minutes were spent as additional taxi/holding times per flight in 2018 and 2019, respectively.

Figure 8.5: Development of additional taxi out time and holding time in Germany, 2018-2022



Source: PRB (2023) [11].

DFS cooperates with other ANSPs from Belgium, France, Luxembourg, the Netherlands and Switzerland in the Functional Airspace Block Europe Central (FABEC). The aim is to achieve optimum performance in terms of safety, environmental sustainability, capacity, cost-efficiency, flight efficiency and military mission effectiveness, through the design of airspace and the organization of air traffic management in the airspace concerned regardless of existing borders.

Within FABEC, both DFS and EUROCONTROL MUAC as providers of en-route air traffic control in the German airspace are focusing on the extension of free-route airspace [12]. Since 25 February 2021, the upper airspace in Germany under the responsibility of Karlsruhe UAC is completely transferred to free-route airspace.

In March 2024, MUAC revised its airspace sector layout, in order to better implement free-route airspace. The benefits of this measure are estimated to be in the order of 6,700 kg of CO_2 savings per week. Changes for airspace users have been communicated through the European Route Availability Document and further information on the potentials for route planning has been provided through MUAC AO AIRAC Briefs.

Further improvements for optimizing free-route airspace are ongoing together with the ANSPs of neighbouring states as Austria, Czech Republic, Poland, Switzerland, France and Belgium.

Market-Based Measures (MBMs)

Germany participates in the EU-ETS and in CORSIA.

Under the scope of the EU-ETS, Germany administers 72 aircraft operators that reported 7.2 million tons of CO_2 subject to the EU-ETS in 2022. Due to the recovery of the aviation sector after the COVID-19 pandemic, CO_2 emissions increased by 55% compared to 2021, but did not yet reach the levels of the pre-pandemic period, when an average of 9 million tons of CO_2 were emitted. Aircraft operators received only 45% of the allowances they required through the free allocation process in 2022. Most of the required allowances had to be purchased, to a lesser extent through auctions by Member States and to a greater extent by purchasing allowances from the emitters of other sectors or through the European Energy Exchange. Table 8.2 provides complementary information on the development of CO_2 emissions under the scope of the EU-ETS emitted by operators administered by Germany in the past years. Quantification of effects of market-based measures in future years, including the EU-ETS, are described in more details in the ECAC/EU Common Section for European State Action Plans, especially within the actions taken collectively in Europe for market-based measures. Within this national section, national developments in future years are not additionally modelled due to its dependency of overarching market development as well for consistency reasons.

Table 8.2: Development of CO_2 emissions under the scope of the EU-ETS emitted by operators administered by Germany.

Year	Number of operators	Allocation of allowances [1,000 EUA]	Emissions [kt CO_2 equivalent]	Free allocation percentage	Development of emissions (year-over-year in percent)
2013	63	5,160	8,610	59.9%	
2014	67	5,149	8,861	58.1%	2.9%
2015	67	5,101	8,929	57.1%	0.8%
2016	67	5,100	9,274	55.0%	3.9%
2017	72	5,098	9,105	56.0%	-1.8%
2018	67	3,577	9,391	38.1%	3.1%
2019	63	3,534	9,014	39.2%	-4.0%
2020	45	3,544	3,856	91.9%	-57.2%
2021	67	3,331	4,688	71.1%	21.6%
2022	72	3,247	7,245	44.8%	54.5%

Source: DEHSt (2023) [13].

The largest emitters among the aircraft operators administered by Germany in 2022 were Deutsche Lufthansa AG (3.15 million tons of CO_2), Eurowings GmbH (1.51 million tons), EAT Leipzig GmbH (0.98 million tons), Condor Flugdienst GmbH (0.47 million tons) and TUIfly GmbH (0.23 million tons). These five operators accounted for more than 87.5% of all operators administered by Germany.

Germany actively supports the implementation of CORSIA through ACT CORSIA Buddy Partnerships. In the third phase, which focuses on the implementation of the reporting and verification requirements under the CORSIA SARPs (Annex 16, Volume IV) with a particular emphasis on the use of the CORSIA Central Registry (CCR), Germany built buddy partnerships with Albania, Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, North Macedonia, the Republic of Moldova, Saudi Arabia, Serbia, Tajikistan and Turkmenistan [14].

Additional Measures

Airports
German airports are highly committed to reducing their CO_2 emissions. Between 2010 and 2019, CO_2 emissions were reduced from almost 700 thousand tons to 500 thousand tons of CO_2. This puts the airports on track to reduce CO_2 emissions by 65% in 2030 compared to 2010. The ultimate goal is to achieve net-zero CO_2 emissions by 2045. As defined by the German Airport Operators Association (ADV), the net-zero goal means reducing CO_2 emissions to an absolute minimum and removing any remaining CO_2 from the atmosphere.

To achieve this goal, German airports are currently implementing a four-pillar plan consisting of the following measures:

- Use of renewable energies;
- Sustainable construction and renovation;
- Increasing sustainable mobility;
- Investment in CO_2-optimized airport infrastructure.

Eight German airport operators participate in ACI's Airport Carbon Accreditation Program, as shown in Table 8.3. The program recognises the progress being made by airport operators in their efforts to become carbon neutral. This is represented by the awarding of one of seven levels, reflecting the progress from Level 1 (monitoring) to Level 5 (achieving net zero balance for Scope 1 & 2 emissions and actively addressing Scope 3 emissions). In Germany, Hamburg Airport has currently achieved the highest level, 3+, which represents carbon neutrality for direct emissions with emission reductions and offsets.

Table 8.3: Current status of ACI airport accreditation scheme for German airports

Airport	ACA Scheme Level	Current Status
Berlin Brandenburg	Level 3	Optimisation
Düsseldorf	Level 3	Optimisation
Hamburg	Level 3+	Neutrality
Cologne/Bonn	Level 2	Reduction
Memmingen	Level 2	Reduction
Munich	Level 3	Optimisation
Stuttgart	Level 3	Optimisation
Frankfurt	Level 3	Optimisation

Source: Airport Carbon Accreditation (2024) [15]

The following section provides an overview of the most important initiatives at German airports. Typically, airports report their direct emissions (Scope 1), emissions from supplied products and services such as electricity and heat (Scope 2), and emissions that cannot be directly influenced by the airport operator, but are still part of the value chain in which the airport operators are involved, such as emissions from commuters and passengers accessing the airport by ground transport (Scope 3).

Frankfurt Airport, Germany's main hub, has reduced its Scope 1 & 2 emissions to 113 thousand tons by 2022, a 50% reduction compared to 2010, and aims to reduce CO_2 emissions by 78% by 2030 compared to 2010. The airport is accredited by ACI's Airport Carbon Accreditation Program at Level 3, which represents the efforts to optimize infrastructure and processes with a significant reduction in carbon footprint. Key measures contributing to the CO_2 reduction include the introduction of battery-electric and hydrogen ground service equipment and other vehicles, power purchase agreements for renewable energy (electricity, district heating/cooling), the implementation of on-site photovoltaic power generation, energy storage, the construction of electric charging stations and the energy-efficient renovation of buildings. One of the highlights in 2022 was the start of the construction of a photovoltaic fence along runway 18, which will have a total peak power of 17.4 MWp when completed.

Munich Airport, as the second largest airport in Germany, plans to achieve carbon neutrality by 2030. In 2022, Scope 1 & 2 emissions amounted to 90 thousand tons, a reduction of 12% compared to 2017. Key measures include the conversion to LED lighting, which was 90% complete by 2022, the replacement of the airport's vehicle fleet with new vehicles that use renewable energies, and the expansion of rooftop and ground-mounted photovoltaic systems at and around the airport to 50 MWp by 2029. As part of its "Green IT" initiative, the airport plans to build a new construction of a corporate data centre with a waste heat recovery system. Aircraft operators are encouraged to use pre-conditioned air whenever possible to reduce APU use on the ground and promote single-engine taxiing.

Berlin Airport uses 50% renewable electricity. In the medium term, there are plans to use renewable energy sources for the combined heat and power plant, which already operates at an efficiency of 80% [16]. The BER terminal building was built to consume 30% less energy than required by building codes at the time of construction in 2007. The installation of heat exchangers, indirect air cooling with water and the use of geothermal energy will reduce CO_2 emissions by 11,000 tons per year compared to a conventional construction design.

Düsseldorf Airport, which is Germany's fourth busiest airport by passenger numbers in 2023, is also on track to achieve its ambitious net-zero strategy. In line with the goals of the German Airports Operators' Association, the airport aims to achieve net-zero CO_2 emissions by 2045. An interim goal is to reduce Scope 1&2 emissions by 65% by 2030. This corresponds to an absolute emissions reduction of more than 20,000 t CO_2 annually [17]. The measures contributing to this objective are in the three areas of building and systems engineering, energy supply and vehicle fleet management. In the area of building and systems technology, two combined heat and power plants are being operated, lighting is being replaced with LEDs and heating/cooling is being optimized. In the area of energy supply, the installation/operation of photovoltaic power generation is being expanded, the airport has been connected to the Düsseldorf district heating system and since January 2022, all externally purchased electricity has been sourced from certified renewable sources. While ground handling services at Düsseldorf Airport are provided exclusively by external service providers, the airport operator is renewing its own vehicle fleet with electric vehicles. The goal is to have 50% electric vehicles by 2030 and 100% by 2045. Overall, Düsseldorf Airport has achieved the third level ("Optimization") of the Airport Carbon Accreditation Program for the eighth time.

Hamburg Airport aims to achieve carbon neutrality by 2035 with zero carbon emissions and no need for offsets. A total of €250 million will be invested in the energy-efficient renovation of buildings, the generation of renewable energy and the replacement of the vehicle fleet is planned to amount to €250 million. A major contributor will be made by the construction of an onshore wind farm on land outside Hamburg that was originally earmarked as a new airport site. The investment will amount to €70 million and the energy generation capacity is expected to exceed

100 GWh per year. The project is expected to be completed by 2028. Hamburg Airport is also a pioneer in the implementation of hydrogen aviation. A detailed roadmap for the implementation of hydrogen infrastructure has been published in 2023. Hamburg airport participates in the Baltic Sea Region HyAirport project, in which stakeholders from the Baltic Sea region collaborate on an improvement of connectivity with hydrogen-powered regional aircraft. The aim is to prepare airports to receive hydrogen aircraft when they become available in the coming years.

Stuttgart Airport aims to achieve zero carbon emissions by 2040. The implementation of LED lighting in the terminal building, which was completed in 2022, reduces energy consumption by 26 MWh per year. Runway lighting has been replaced with LEDs, and the same is being done for the apron lighting. The airport operator has entered into a power purchase agreement, for all renewable energy (hydrogen power). By 2040, 90% of heating energy is expected to come from renewable sources. Electricity generation from photovoltaics is expected to increase from 2.6 GWh in 2022 to 20 GWh in 2040 and 30 GWh in 2050. New installations are planned for parking garages and open spaces. As peak power generation is expected to exceed on-site electricity demand, the airport will implement smart grids to balance supply and demand as well as thermal and electrical energy storage solutions. For apron operations, all passenger buses and baggage carts have been replaced with battery-electric vehicles. The next step will be the replacement of heavy-duty vehicles, such as fuel tank and de-icing vehicles. Between 2009 and 2012, emissions from ground operations were reduced by 83%. In addition, 38 out of 48 aircraft parking positions are equipped with fixed ground power supply. Total investment to achieve net-zero emissions by 2040 is expected to be €2 billion.

Furthermore, the Federal Ministry for Digital and Transport supports the environmentally friendly ground power supply of aircraft at airports with mobile or stationary systems through investment grants. The funding program for the market activation of alternative technologies for the climate- and environmentally-friendly ground power supply of aircraft at airports is intended to promote investments in alternative technologies and to reduce emissions. The use of alternative technologies for mobile ground power systems, such as those based on direct current, batteries or hydrogen, can reduce greenhouse gas emissions during the aircraft turnarounds. In the first call for funding from July 2023, 52 battery-powered mobile ground power units (eGPUs) and the associated charging infrastructure at a total of 7 commercial airports in Germany were funded with around €4.11 million. A second call for funding of ground power units took place in May 2024. Within this call 125 eGPUs, 16 stationary systems and the associated charging infrastructure at a total of 18 airports were funded with around €17.77 million [18].

Intermodal Access at Airports

Air-rail integration in Germany has made significant progress in recent years. By 2024, 26 German cities are connected to Frankfurt Airport by the Lufthansa Express Rail network. Lufthansa offers code-share connections in cooperation with Deutsche Bahn, allowing passengers to book a seamless connection between rail and air services. Features of this service include:

- Optimum coordination of train and Lufthansa flight with guaranteed transfers (or free rebooking in case a connection is missed);
- One ticket and one check-in for rail services and Lufthansa flights.

These services promote the use of long-distance trains as feeders to Lufthansa's Frankfurt Airport hub as an alternative to domestic flights or the use of private cars for travel to the airport.

In addition, Lufthansa also promotes Express Bus connections between Nuremberg and Augsburg and Munich Airport, and between Strasbourg and Frankfurt Airport, which are operated by subcontractors.

Figure 8.6: Lufthansa Express Rail Network in cooperation with Deutsche Bahn

Source: Deutsche Bahn (2024) [19].

Deutsche Bahn has long been selling its Rail&Fly product via airlines and tour operators in Germany, which includes flexible travel to and from the airport by any means of local and long-distance transport without a guaranteed connection. Over 50 airlines are currently (as of September 2023) cooperating with the rail transport sector in this way [20].

Improving the integration of airports into public transport networks remains a priority for stakeholders. Several projects to improve access to airports by light rail, metro and rail services are currently in the planning and construction stages. In Berlin, feasibility studies and cost-benefit analyses are being conducted to extend the U7 metro line beyond its current terminus at Rudow to Berlin Brandenburg Airport. Up to €890 million could be invested for a potential extension of the line by around 8 km.

In Düsseldorf, a light rail line is currently under construction that will connect the city centre to the airport via the trade fair/exhibition centre and football stadium. The line is expected to open in 2025, with an investment of more than €230 million. At a later stage, the line could be extended to connect the cities of Meerbusch (with a population of 57,000), Neuss (population 155,000) and Ratingen (population 87,000) directly to the airport. The light railway line will join an already operating regional train station in the terminal and a long-distance train station at the airport's outskirts.

In Stuttgart, the extension of the U6 metro line to the airport has opened in 2021. The 3.2-kilometre extension, which cost €130 million, provides an additional connection to the airport from various stations in the city centre via the trade fair grounds, in addition to regional train services.

At Munich Airport, several infrastructure measures have improved rail access. Since December 2018, there has been a direct regional train connection between Regensburg (population 160,000) and Munich Airport. By the end of 2024, the train line will be extended to Nuremberg (526,000 inhabitants). Further improvements in rail access between Munich Airport and the surrounding communities are expected in the future.

At Frankfurt Airport, a new 52-kilometre light rail line is under construction to connect the western outskirts of the city with the airport. The investment is estimated at more than €325 million. Partial opening is expected in 2026 and full completion in 2028.

All of these projects are expected to increase the overall share of climate-friendly public transport as an access mode at German airports, which has already been increasing over the past few years. On average, more than 37% of passengers at German airports participating in the German Airports Association's passenger survey arrive at the airport by bus, subway or train. However, the share of each airport depends very much on its infrastructure and integration into bus and train schedules.

List of References and Data Sources for Chapter 8:

[1] Cirium Fleets Analyzer, https://www.cirium.com/solutions/fleets-analyzer/

[2] Lufthansa (2023): Lufthansa Group orders 22 latest-generation long-haul aircraft – total list price of 7.5 billion US dollars, https://investor-relations.lufthansagroup.com/en/news/financial-news/investor-relations-financial-news/date/2023/03/02/lufthansa-group-orders-22-latest-generation-long-haul-aircraft-total-list-price-of-75-billion-us-dollars.html [Last Access 15 August 2024].

[3] Linke, Florian and Ehlers, Thorsten and Lütjens, Klaus and Lau, Alexander et al. (2023): Potenzial zur Treibhausgas-Emissionsminderung im Luftverkehr bis 2030. DLR-Internal Report. DLR-IB-LV-HA-2023-118.

[4] NOW GmbH (2023): Nationales Innovationsprogramm: Wasserstoff- und Brennstoffzellentechnologie, Programmüberblick 2023, https://www.now-gmbh.de/wp-content/uploads/2023/04/NOW_NIP_Programmueberblick-2023.pdf [Last Access 15 August 2024].

[5] Federal Ministry for Digital and Transport (2022): Machbarkeitsstudie zur Prüfung der Umsetzung eines Innovations- und Technologiezentrums für Wasserstofftechnologien, Zusammenfassung der Ergebnisse, https://bmdv.bund.de/SharedDocs/DE/Anlage/K/machbarkeitsstudie-wasserstofftechnologie.pdf?__blob=publicationFile [Last Access 16 August 2024].

[6] DLR (2023): Das DLR in Zahlen, https://www.dlr.de/de/das-dlr/ueber-uns/das-dlr-in-zahlen [Last Access 16 August 2024].

[7] The Federal Government (2021): PtL roadmap - Sustainable aviation fuel from renewable energy sources for aviation in Germany, accessible at: https://ptl-roadmap.de/roadmap/ [Last Access 2 October 2024].

[8] NOW GmbH (2024a): Gesamtkonzept für erneuerbare Kraftstoffe des Bundesministeriums für Digitales und Verkehr (BMDV), https://erneuerbarekraftstoffe.de/ [Last Access 10 October 2024].

[9] NOW GmbH (2024b): SAF-Monitor, https://erneuerbarekraftstoffe.de/saf-monitor/ [Last Access 10 October 2024].

[10] Federal Ministry for Economic Affairs and Energy (2020): The National Hydrogen Strategy, https://www.bmwk.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.pdf?__blob=publicationFile&v=1 [Last Access 15 August 2024].

[11] PRB (2023): Performance Review Body Monitoring Report 2022 Annex I – Member States' factsheets, https://eu-single-sky.transport.ec.europa.eu/document/download/33295be7-2823-454e-a3d9-1860adbdf8b9_en?filename=231009_AMR2022_AnnexI_published.pdf [Last Access 15 August 2024].

[12] FABEC (2022): Performance Plan FABEC Third Reference Period (2020-2024), https://www.fabec.eu/images/user-pics/pdf-downloads/performance_plan/2020-2024/F5860_RP3%20FABEC%20Performance%20Plan%20v2.pdf [Last Access 15 August 2024].

[13] DEHSt (2023): Greenhouse Gas Emissions in 2022 - Stationary Installations and Aviation Subject to Emissions Trading in Germany (2022 VET Report), https://www.dehst.de/SharedDocs/downloads/EN/publications/2022_VET-Report.pdf?__blob=publicationFile&v=3 [Last Access 15 August 2024].

[14] ICAO (2024): CORSIA Buddy Partnerships, https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Buddy-Partnerships.aspx [Last Access 15 August 2024].

[15] Airport Carbon Accreditation (2024): What is it?, https://www.airportcarbonaccreditation.org/about/what-is-it/ [[Last Access 20 December 2024].

[16] Berlin Airport (2021): Energieversorgung, https://corporate.berlin-airport.de/de/umwelt/klima/energieversorgung.html [Last Access 15 August 2024].

[17] Düsseldorf Airport (2024): Klimaneutraler Airport, https://www.dus.com/de-de/konzern/nachhaltigkeit/klimaneutraler-airport [Last Access 15 August 2024].

[18] NOW GmbH (2024c): Klima- und umweltfreundliche Versorgung von Luftfahrzeugen mit Bodenstrom an Flughäfen, https://www.now-gmbh.de/foerderung/foerderprogramme/bodenstrom-an-flughaefen/ [Last Access 10 October 2024].

[19] Deutsche Bahn (2024): Lufthansa Express Rail - bequem mit Umsteigegarantie zum Flug, https://www.bahn.de/service/informationen-buchung/bahn-flug/lufthansa-express-rail [Last Access 15 August 2024].

[20] Deutsche Bahn (2023): Rail&Fly Airline Partner, https://assets.static-bahn.de/dam/jcr:eb32951b-3636-4b79-b5c9-6af1464db07c/202309_Rail&Fly%20Airline%20Partner.pdf [Last Access 15 August 2024].

Appendix

The ECAC/EU Common Section - Detailed Results for ECAC Scenarios from Part II

1. BASELINE SCENARIO

a) Baseline forecast for international traffic departing from ECAC airports

Year	Passenger Traffic (IFR movement) (million)	Revenue Passenger Kilometres[48] RPK (billion)	All-Cargo Traffic (IFR movements) (million)	Freight Tonne Kilometres transported[49] FTKT (billion)	Total Revenue Tonne Kilometres[50] RTK (billion)
2010	4.71	1,140	0.198	41.6	155.6
2019	5.88	1,874	0.223	46.9	234.3
2023	5.38	1,793	0.234	49.2	228.5
2030	6.69	2,176	0.262	55.9	273.5
2040	7.69	2,588	0.306	69.0	327.8
2050	8.46	2,928	0.367	86.7	379.5
Note that the traffic scenario shown in the table is assumed for both the baseline and implemented measures scenarios.					

b) Fuel burn and CO_2 emissions forecast for the baseline scenario

Year	Fuel Consumption (10^9 kg)	CO_2 emissions (10^9 kg)	Fuel efficiency (kg/RPK)	Fuel efficiency (kg/RTK)
2010	38.08	120.34	0.0327	0.327
2019	53.30	168.42	0.0280	0.280
2023	48.41	152.96	0.0268	0.268
2030	54.46	172.10	0.0250	0.250
2040	62.19	196.52	0.0240	0.240

[48] Calculated on the basis of Great Circle Distance (GCD) between the airports of the available passenger reports (subset of the global traffic ; from 97% in 2010 up to 99% for the forecast years).

[49] Includes passenger and freight transport (on all-cargo and passenger flights).

[50] A value of 100 kg has been used as the average mass of a passenger incl. baggage (ref: ICAO).

2050	69.79	220.54	0.0238	0.238
For reasons of data availability, results shown in this table do not include cargo/freight traffic.				

c) Average annual fuel efficiency improvement for the Baseline scenario

Period	Average annual fuel efficiency improvement (%)
2010-2023	-1.50%
2023-2030	-1.01%
2030-2040	-0.40%
2040-2050	-0.08%

2. IMPLEMENTED MEASURES SCENARIO

2A) EFFECTS OF AIRCRAFT TECHNOLOGY IMPROVEMENTS AFTER 2023

d) Fuel consumption, CO_2, and CO_2 equivalent emissions of international passenger traffic departing from ECAC airports, with aircraft technology improvements after 2023 included. The well-to-wake emissions are determined by assuming 3.88 Kg of CO_2 equivalent emissions for 1 Kg of Jet-A fuel burn[51]:

Year	Fuel Consumption (10^9 kg)	CO_2 emissions (10^9 kg)	Well to Wake CO_2 equivalent emissions (10^9 kg)	Fuel efficiency (kg/RPK)	Fuel efficiency (kg/RTK)
2010	38.08	120.34	147.77	0.0334	0.334
2019	53.30	168.42	206.80	0.0284	0.284
2023	48.41	152.96	187.82	0.0270	0.270
2030	53.64	169.50	208.12	0.0246	0.246
2040	56.60	178.84	219.59	0.0218	0.218
2050	54.77	173.06	212.50	0.0187	0.187

[51] "Well-to-wake CO_2e emissions of fossil-based JET fuel are calculated by assuming an emission index of 3.88 kg CO_2e per kg fuel (see DIN e.V., "Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers)", German version EN 16258:2012), which is in accordance with 89 g CO_2e per MJ suggested by ICAO CAEP AFTF."

For reasons of data availability, results shown in this table do not include cargo/freight traffic.

e) Average annual fuel efficiency improvement for the Implemented Measures Scenario (new aircraft technology only)

Period	Average annual fuel efficiency improvement (%)
2010-2023	-1.50%
2023-2030	-1.22%
2030-2040	-1.19%
2040-2050	-1.55%

2B) EFFECTS OF AIRCRAFT TECHNOLOGY AND ATM IMPROVEMENTS AFTER 2023

f) Fuel consumption, CO_2 and CO_2 equivalent emissions of international passenger traffic departing from ECAC airports, with aircraft technology and ATM improvements after 2023. The well-to-wake CO_2 equivalent emissions are determined by assuming 3.88 Kg of CO_2 equivalent emissions for 1 Kg of Jet-A fuel burn:

Year	Fuel Consumption (10^9 kg)	CO_2 emissions (10^9 kg)	Well-to-Wake CO_2 equivalent emissions (10^9 kg)	Fuel efficiency (kg/RPK)	Fuel efficiency (kg/RTK)
2010	38.08	120.34	148.02	0.0327	0.327
2019	53.30	168.42	207.16	0.0280	0.280
2023	48.41	152.96	188.14	0.0268	0.268
2030	52.57	166.11	204.31	0.0241	0.241
2040	53.20	168.11	206.78	0.0205	0.205
2050	49.29	155.75	191.58	0.0168	0.168
For reasons of data availability, results shown in this table do not include cargo/freight traffic.					

g) Average annual fuel efficiency improvement for the Implemented Measures Scenario (new aircraft technology and ATM improvements)

Period	Average annual fuel efficiency improvement (%)
2010-2023	-1.50%
2023-2030	-1.51%
2030-2040	-1.60%
2040-2050	-1.98%

h) *Equivalent CO_2e emissions forecasts for the scenarios described in this common section, assuming 3.88 Kg of CO_2 equivalent emissions for 1 Kg of Jet-A fuel burn:*

Year	Well-to-wake CO_2e emissions (10^9 kg)			% improvement by Implemented Measures (full scope)
	Baseline Scenario	Implemented Measures Scenario		
		Aircraft techn. improvements only	Aircraft techn. and ATM improvements	
2010	147.77			
2019	206.80			
2023	187.82			
2030	211.32	208.12	203.95	-3%
2040	241.30	219.59	206.41	-14%
2050	270.79	212.49	191.24	-29%
For reasons of data availability, results shown in this table do not include cargo/freight traffic.				

2C) EFFECTS OF AIRCRAFT TECHNOLOGY, ATM IMPROVEMENTS AND SAF AFTER 2023 ON EU27+EFTA INTERNATIONAL DEPARTURES

The Net CO_2 emissions and expected benefits of SAF use are calculated where regional measures are taken (e.g. ReFuelEU Aviation) in the European scenario with measures.

i) *Fuel consumption, CO_2, Net CO_2 emissions of international passenger traffic departing from EU27+EFTA airports, with aircraft technology and ATM improvements after 2023 The tank-to-wake Net CO_2 emissions are based on the use of Sustainable Aviation Fuels (ReFuelEU Aviation, 70% decarbonation factor for the synthetic aviation fuels, and 65% for aviation biofuels).*

Year	Fuel Consumption (10^9 kg)	CO_2 emissions (10^9 kg)	Tank-to-Wake Net CO_2 emissions (10^9 kg)
2010	27.84	87.97	87.97
2019	38.19	120.69	120.69
2023	34.08	107.71	107.71
2030	36.97	116.84	112.21
2040	35.63	112.60	87.15
2050	32.80	103.63	54.67
For reasons of data availability, results shown in this table do not include cargo/freight traffic.			