EASA
European Union Aviation Safety Agency

EUROPEAN AVIATION ENVIRONMENTAL REPORT

2025

European Environment Agency

EUROCONTROL

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Foreword

Written by Paul Goodenough in collaboration with Bertrand Piccard. Illustration by Hector Trunnec. Lettering by Bernardo Brice.

References

Information originating from work not performed as part of this report is referenced in square brackets and detailed in the List of Resources (Appendix A) along with other relevant sources.

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EUROPEAN AVIATION ENVIRONMENTAL REPORT

2025

WELCOME MESSAGES

Magda Kopczyńska

Director-General for Mobility
and Transport
European Commission

This report, like its predecessors, is indispensable for its assessment of progress made and identification of challenges ahead. Through its comprehensive data and analysis, it supports informed decision-making and helps stakeholders evaluate the impact of current policies. For aviation, achieving environmental targets while maintaining connectivity and economic growth will require continued collaboration between government, industry, and civil society.

In recent years, Europe's aviation sector has continued to navigate a challenging yet crucial path towards sustainability. We are on the verge of a major change, affecting the entire sector – from technological, energy and operational perspectives. The recent milestone developments, both in Europe and globally, give aviation a clear path towards significantly lowering its climate footprint.

With the European Green Deal legislation now fully adopted, EU aviation is set to help Europe become the first carbon-neutral continent. The ReFuelEU Aviation mandate, aiming for 70% Sustainable Aviation Fuels (SAF) usage by 2050, is pivotal, supported by the Flight Emissions Label, fuel quality improvements, a clearing house, and financial incentives to scale SAF adoption.

Further measures include revised emissions reduction frameworks, such as the updated EU Emissions Trading System, and a plan to monitor non-CO_2 emissions. The airport sector is also advancing, with 130 airports committed to net-zero CO_2 emissions by 2030, bolstered by EU-supported renewable energy expansions.

Globally, ICAO's 2050 net-zero carbon emissions goal for aviation has strengthened the sector's climate commitments, and a 5% CO_2 reduction target for 2030 using SAF and cleaner energy has emerged as a short-term goal. Europe is also extending its environmental leadership, with over €20 million pledged to support aviation sustainability projects in Africa, Asia, Latin America, and the Caribbean.

However, the path ahead is far from straightforward. Europe is warming faster than any other continent, and the need for resilience in the aviation sector is increasingly apparent. Airports, airlines, and regulators need to prioritise preparedness for the impacts of climate change, while ensuring that the sector continues to meet its sustainability obligations.

As we move towards 2050, the European Commission is confident that the ongoing transformation of the sector, underpinned by robust policy frameworks and sustained innovation, will allow European aviation to not only meet its environmental obligations, but to lead the way in global efforts towards sustainability.

Florian Guillermet

Executive Director
European Union Aviation
Safety Agency (EASA)

This report would not have been possible without the expertise, dedication and hard work of all contributors, who have worked tirelessly to bring it to fruition. Heartfelt thanks, and congratulations on this achievement!

This is the fourth European Aviation Environmental Report (EAER) and, when I compare it with past editions, it is clear that the urgency to address the sustainability challenges facing the aviation sector has intensified. This has been acknowledged within Europe and there are significant new initiatives in place under the European Green Deal, with the aim of achieving the agreed environmental goals at both the European and ICAO level.

To meet the 2050 goals of EU climate neutrality and ICAO net-zero carbon emissions, aviation will need to significantly reduce its current contribution every single year from 2025 onwards. European citizens expect the aviation industry to be proactive in this, as people judge climate change, and the associated impacts on nature and biodiversity, to be one of the most serious problems facing the world today. In addition, airports are facing operational challenges due to the impact of noise and air quality on local communities, and this has been recognised through new 2030 targets that have been set under the Zero Pollution Action Plan.

The challenge for the aviation sector is to turn these sustainability goals into concrete action. Having made environmental protection a key strategic priority, we are now in a decisive period where we will be judged on how the industry comes together to solve a range of issues that cannot be resolved by any one organisation alone.

Much has been achieved in recent years to set us on the right path. However, we need to move faster. A concerted effort is required now. By addressing the issues within this report, we will be able to manage an orderly transition to cleaner aviation while maintaining a high uniform level of safety and connectivity. Honest, transparent and effective communication is critical to securing the trust of European citizens that aviation is indeed acting to become more sustainable and will meet the future goals.

Europe is positioning itself to make the most of this new green economy and to create an aviation sector fit for future generations. I invite you to engage with this EAER for an overview of the progress to date and the way forward.

CONTENTS

ACKNOWLEDGMENTS

The fourth European Aviation Environmental Report has been prepared by the European Union Aviation Safety Agency (EASA) with support from the European Environment Agency (EEA) and EUROCONTROL. Its development was coordinated by a Steering Group[1] made up of representatives from the following organisations:

European Aviation Environmental Report website

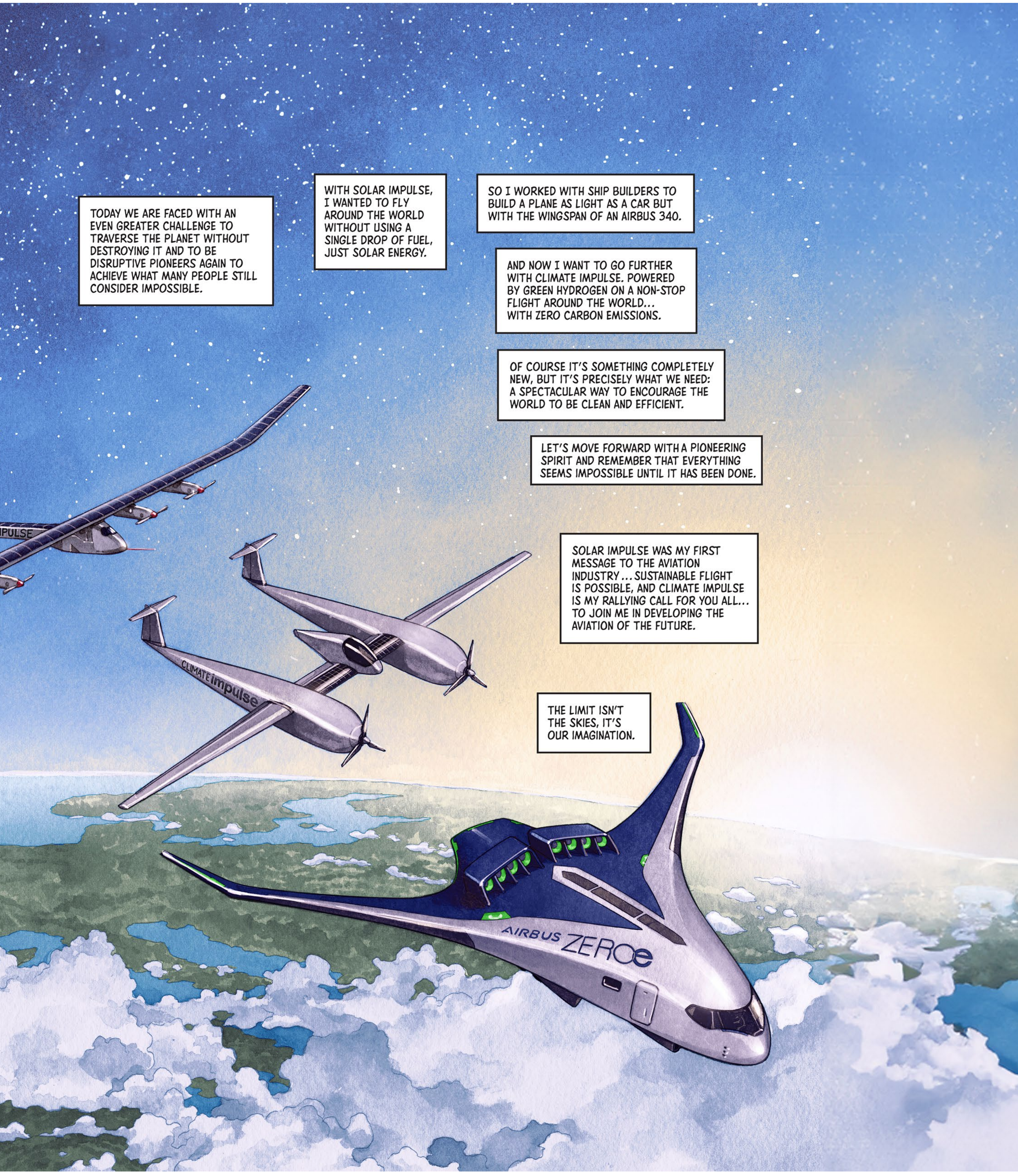
For further information linked to the environmental performance of the aviation sector and more extensive information on Stakeholder Actions, we invite you to visit the EASA website (www.easa.europa.eu/eaer). This contains the previous European Aviation Environmental Reports, and the latest updated news and information. Questions associated with this report should be sent to EASA (eaer@easa.europa.eu).

[1] Stefan Bickert (BMVI); Jean-Francois Brouckaert, Sebastien Dubois (CAJU); Iris Dupont de Dinechin, Nora Susbielle, Olivier Meynot (DGAC France); Roland Faludi, Dimitar Nikov, Laura Lonza (DG CLIMA); Panagiota Dilara, Marco Paviotti (DG ENV); Jana Rejtharova (DG JRC); Andrei Mungiu, Thomas Rousing-Schmidt, Cecile Gajate, Lendina Smaja, Alexis Chausteur, Frederik Rasmussen (DG MOVE), Michail Kyriakopoulos (DG RTD); Steve Arrowsmith, Ivan de Lepinay, Andreas Busa, Joonas Laukia, Mara Dame, Santiago Haya Leiva, Achilleas Achilleos, Anatolij Oniscenko, Bastian Rauch, Daniel Brousse-Rivas, Emanuela Innocente, Guillaume Aigoin, Guillaume Malaval, Illimar Bilas, John Franklin, Lisa Ernle, Victoria Esteban, Jozef De Moor, Julia Egerer, Ken Engelstad, Mario Mitschke, Martin Schaefer, Martina Di Palma, Vera Tavares, Werner Hoermann, Wim Eeckhout, Thomas Bock (EASA); Beatrice Adolehoume, Mark Rodmell (ECAC); Ian Marnane, Suzanne Dael, Tommaso Selleri (EEA); Frederic Riehl, Stefano Mancini, Claire Leleu, David Brain, Gerard Boydell, Robin Deransy, Laurent Box, Laurent Cavadini, Marylin Bastin, Nicolas De Brabanter, Pascal Hop, Rachel Burbidge (EUROCONTROL); Alice Suri, Urs Ziegler (FOCA); Joe Sultana (SES PRB); Ralph Schwarzendahl (SESAR DM) and Olivia Nunez, Stella Saldana (SESAR JU).

The Steering Group gratefully acknowledges once again the support of the Advisory Group[2], whose representatives provided valuable input and comments on the report. Some of the latest information on actions being undertaken by the aviation sector are provided within the 'Stakeholder Action' boxes. The collaboration with this diverse set of organisations ensures that the report provides a balanced perspective and conveys what the sector is doing to turn sustainability goals into action.

2 Alexandre de Joybert (ACI Europe); Donal Handley (AerCap); Kevin Goddard, Olivier Husse (Airbus); Artur Sousa (ANAC); Sergi Alegre Calero (ARC); Belarmino Paradela (ASD); Reynir Sigurdsson, Tanel Rautits (BOREALIS); Johnny Pring (CANSO Europe); Jan Fuglestvedt (CICERO); Alice Liberman, Laura Le Bihan (Dassault); Ulrike Burkhardt, Marc Gelhausen (DLR); Alberto Anglade (ENAC); Delphine Grandsart (EPF); Dave Tompkins (European Express Association); Laurent Donceel (A4E); Irene Boyer-Souchet (Air France); Antoine Toulemont (ERA); Alice Suri (FOCA); Marina Garcia Aedo (IAG); Lisanne van Wijngaarden (KLM); Adrienn Keszei, Sara Sandor (Wizz Air); Jayant Mukhopadhaya (ICCT); Tim Johnson (AEF); Gilles Dufrasne (Carbon Market Watch); John Stewart (HACAN); Jo Dardenne (T&E); Maryna Hritsyshyna (Ineratec); Dario Formenti, Norbert Schmitz (ISCC); David Lee, Bethan Owen (MMU); Patrizia Reisinger (Neste); Carlos Diazg (Repsol); Jen Houghton (Rolls-Royce); Blanca de Ulibarri (RSB); Giovanni Zucchetta (Ryanair); Eugene Kors, Valerie Guenon (SAFRAN); Inmaculada Gómez Jiménez, Raúl Martín Fontana (SENASA); Tom Berg (SkyNRG); Ivan Iatsenko (Ukraine DfT) and Matteo Prussi (University of Torino).


FOREWORD – THE PIONEERING SPIRIT
BETWEEN 1903 AND 1973, AVIATION WAS THE SYMBOL OF THE TECHNOLOGICAL REVOLUTION, GOING FROM THE WOODEN AEROPLANE OF THE WRIGHT BROTHERS TO THE CONCORDE.
BUT DURING THE LAST 50 YEARS, WE HAVE SEEN MORE OPTIMISATION OF PAST DESIGNS THAN REAL DISRUPTION.
Dr. Bertrand Piccard - Initiator, Chairman and Pilot of Solar Impulse and Climate Impulse
This Foreword has been developed by Bertrand Piccard in cooperation with Rewriting Earth, who are a global collaboration of storytellers communicating on the environment.


TODAY WE ARE FACED WITH AN EVEN GREATER CHALLENGE TO TRAVERSE THE PLANET WITHOUT DESTROYING IT AND TO BE DISRUPTIVE PIONEERS AGAIN TO ACHIEVE WHAT MANY PEOPLE STILL CONSIDER IMPOSSIBLE.
WITH SOLAR IMPULSE, I WANTED TO FLY AROUND THE WORLD WITHOUT USING A SINGLE DROP OF FUEL, JUST SOLAR ENERGY.
SO I WORKED WITH SHIP BUILDERS TO BUILD A PLANE AS LIGHT AS A CAR BUT WITH THE WINGSPAN OF AN AIRBUS 340.
AND NOW I WANT TO GO FURTHER WITH CLIMATE IMPULSE. POWERED BY GREEN HYDROGEN ON A NON-STOP FLIGHT AROUND THE WORLD... WITH ZERO CARBON EMISSIONS.
OF COURSE IT'S SOMETHING COMPLETELY NEW, BUT IT'S PRECISELY WHAT WE NEED: A SPECTACULAR WAY TO ENCOURAGE THE WORLD TO BE CLEAN AND EFFICIENT.
LET'S MOVE FORWARD WITH A PIONEERING SPIRIT AND REMEMBER THAT EVERYTHING SEEMS IMPOSSIBLE UNTIL IT HAS BEEN DONE.
SOLAR IMPULSE WAS MY FIRST MESSAGE TO THE AVIATION INDUSTRY... SUSTAINABLE FLIGHT IS POSSIBLE, AND CLIMATE IMPULSE IS MY RALLYING CALL FOR YOU ALL... TO JOIN ME IN DEVELOPING THE AVIATION OF THE FUTURE.
THE LIMIT ISN'T THE SKIES, IT'S OUR IMAGINATION.
CLIMATE impulse
AIRBUS ZEROe

EXECUTIVE SUMMARY

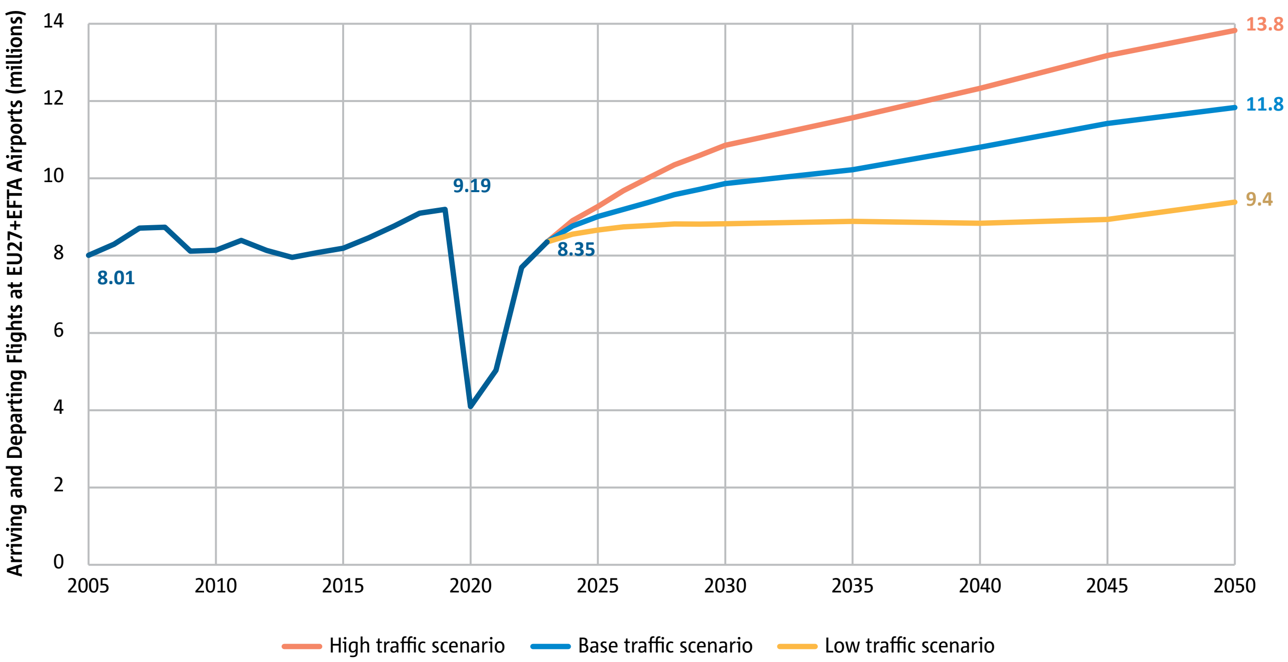
As expected, this decade is proving to be decisive in dealing with climate change. 2023 and 2024 have seen temperature records broken around the world and subsequent climate change trends that are transforming the planet, with Europe warming faster than any other continent [1].

Along with all other economic sectors, aviation finds itself at a crossroads in its decarbonisation transition, with increasing pressure to deliver against agreed environmental goals and challenges due to supply chain issues delaying fleet renewal as well as the premium price of Sustainable Aviation Fuel and limited production capacity. While aviation is strategically important for Europe and provides significant benefits through connectivity, employment and the wider economy, there is a greater scrutiny of its negative effects (noise, air quality and climate change) on the health and quality of life for European citizens and a desire for intensified action [2, 3, 4, 5, 6, 7].

These challenges have been acknowledged within Europe and the last few years have seen significant developments under the European Green Deal. The focus must now be on turning sustainability goals into action in order to manage an orderly transition to cleaner aviation while maintaining a high uniform level of safety and connectivity. This 4th European Aviation Environmental Report provides an overview of current progress and the way forward.

EAER DASHBOARD

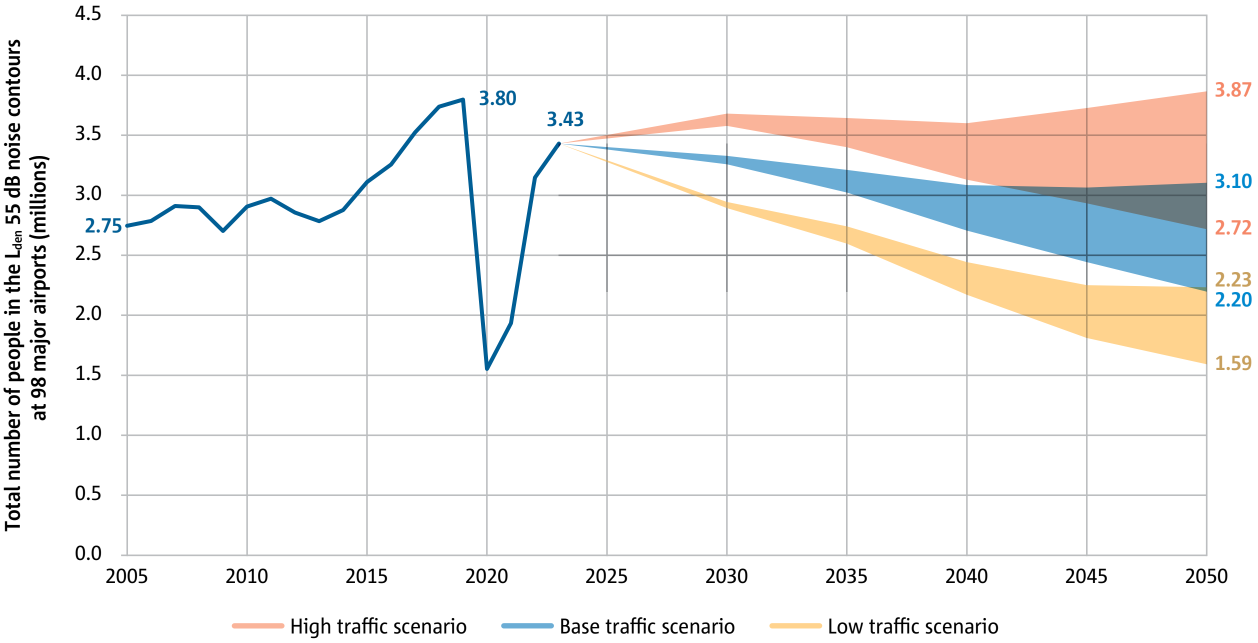
TRAFFIC



Indicator	Units	2005	2019	2023	2030[3]
Number of flights[4]	million	8.01	9.19	8.35	9.9
Passenger kilometres[5]	billion	777	1 459	1 375	1 683
Number of city pairs served most weeks by scheduled flight		5 368	7 991	7 695	N/A

3 Base traffic scenario
4 All departures and arrivals in EU27+EFTA.
5 All departures from EU27+EFTA.

NOISE



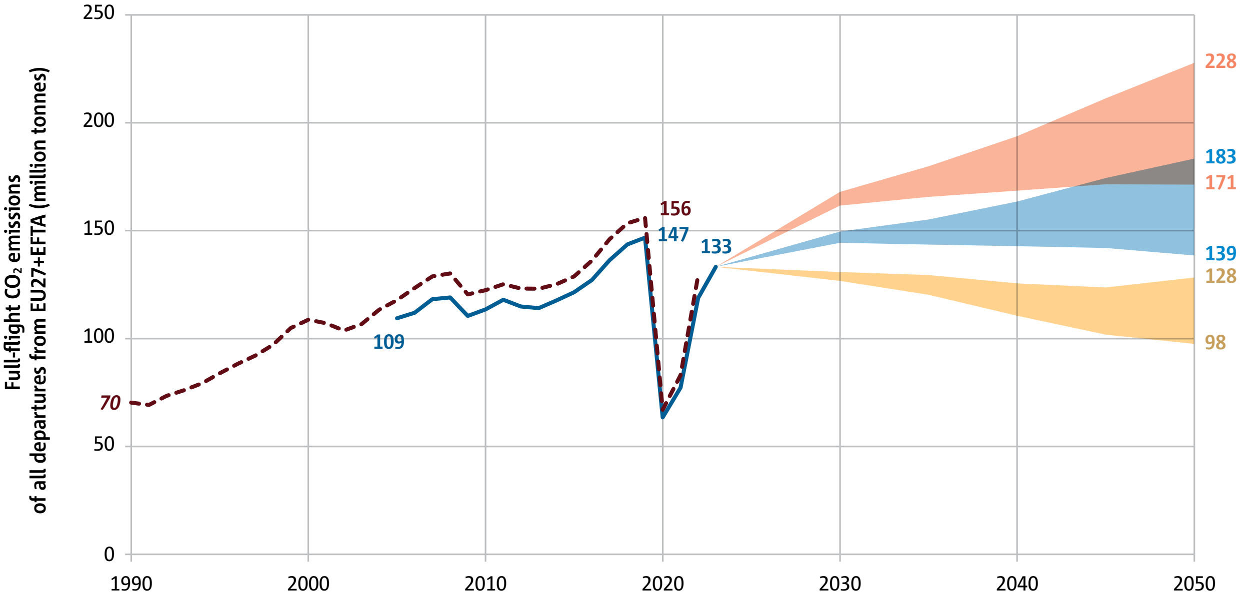
Assumptions:
- Airport infrastructure is unchanged (no new runway)
- Population density around airports is unchanged after 2020
- Local landing and take-off noise abatement procedures are not considered

For each traffic scenario, the upper bound of the range reflects the fleet renewal scenario with frozen technology; the lower bound reflects the scenario with aircraft/engine technology improvements (see Appendix C for detailed assumptions).

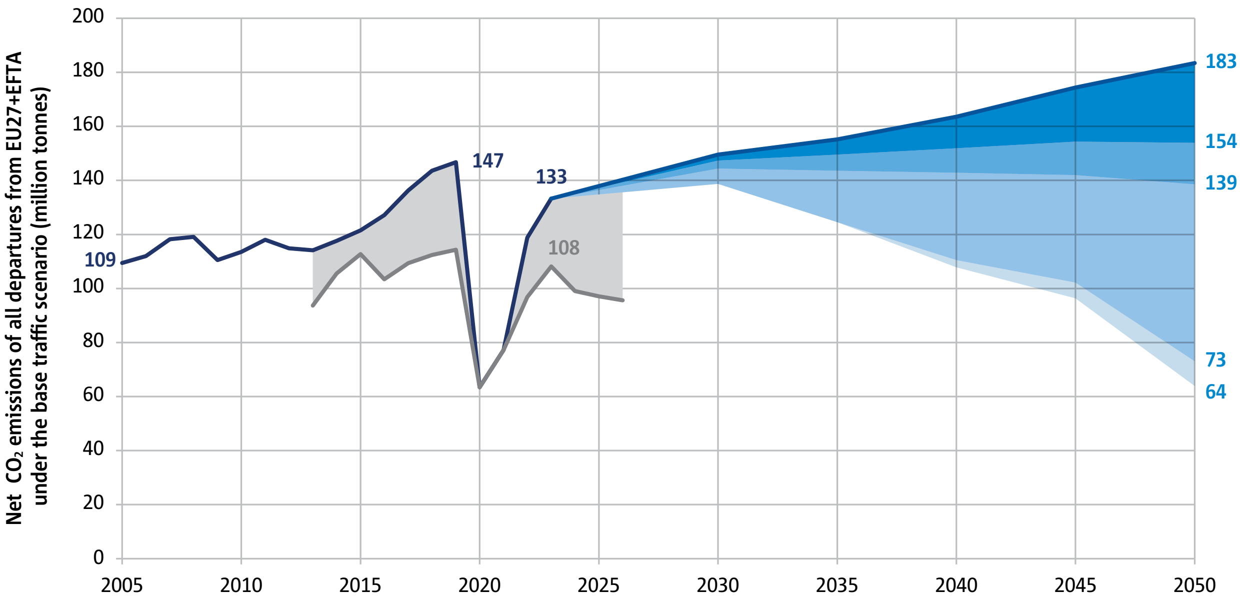
Indicator	Units	2005	2019	2023	2030[6]
Number of people inside L_{den} 55 dB airport noise contours[7]	million	2.75	3.80	3.43	3.26
Average noise energy per operation[8]	10^9 Joules	0.76	0.68	0.63	0.55

6 Base traffic scenario with aircraft/engine technology improvements.
7 All departures and arrivals at 98 major European airports.
8 All departures and arrivals in EU27+EFTA.

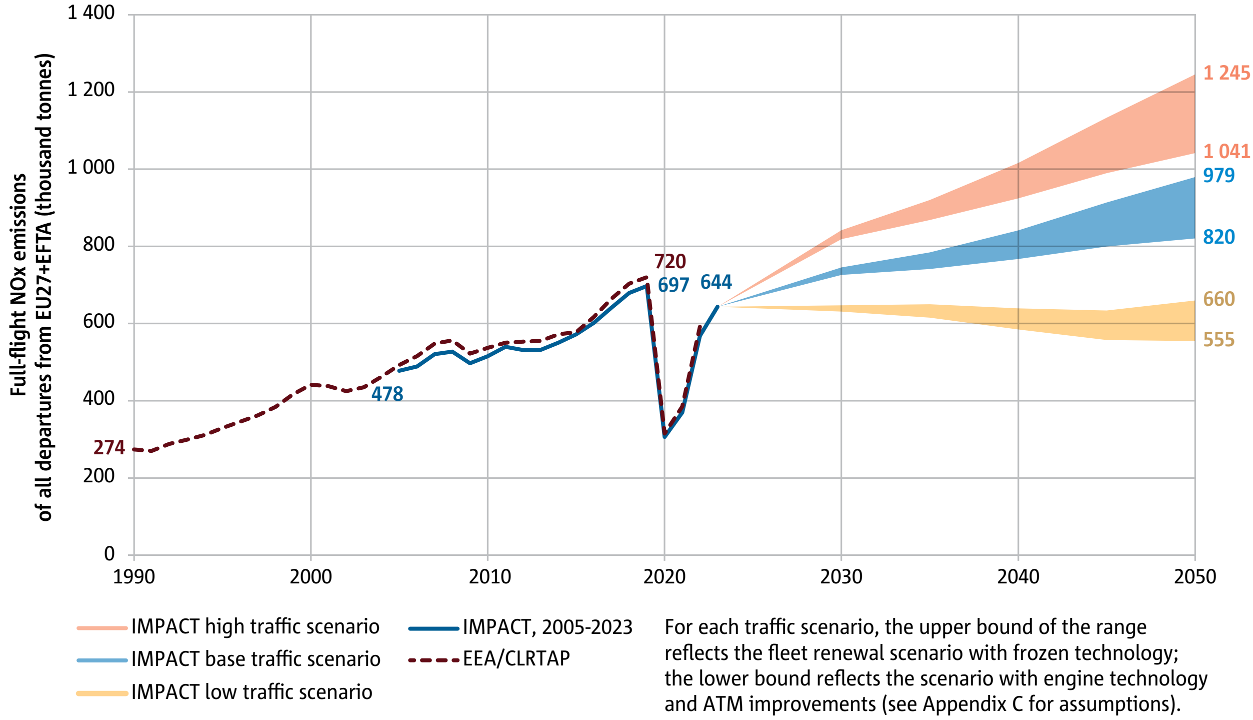
EMISSIONS



For each traffic scenario, the upper bound of the range reflects the fleet renewal scenario with frozen technology; the lower bound reflects the scenario with aircraft/engine technology and ATM improvements (see Appendix C for detailed assumptions).



The blue wedges include the effect of in-sector measures under the base traffic forecast: CO_2 emissions reductions from conventional aircraft technology and ATM-Operations, as well as CO_2eq reductions from SAF (in line with ReFuelEU Aviation supply mandate and minimum emissions reduction thresholds) and electric/hydrogen propulsion. The grey wedge shows the effect of market-based measures: EU ETS (2013-2026), CH ETS (2020-2026) and ICAO CORSIA (2021-2026). See Appendix C for detailed assumptions.



Indicator[9]	Units	2005	2019	2023	2030
Full-flight CO_2 emissions[10]	million tonnes	109	147	133	144
Full-flight 'net' CO_2 emissions[11]	million tonnes	109	114	108	139
Full flight NO_X emissions[10]	thousand tonnes	478	697	644	726
Average fuel consumption[10]	litres fuel per 100 passenger kilometre	4.8	3.5	3.3	2.9

9 All departures from EU27+EFTA
10 2030 value is for the base traffic scenario with technology and operational improvements.
11 2030 value is for the base traffic scenario with technology and operational improvements and sustainable aviation fuels. 2019 and 2023 values include emissions reductions from market-based measures.

KEY MESSAGES

Overview of Aviation Sector

- The number of flights arriving at and departing from EU27+EFTA airports reached 8.35 million in 2023, which is still 10% below the pre-COVID 2019 level.
- Low-cost operators have recovered faster from the COVID crisis than mainline operators.
- Since February 2022, flight operations have been affected by the war in Ukraine and the subsequent airspace and operator restrictions. From October 2023, some re-routings have also been caused by the conflict in the Middle East.
- The average number of passengers (135) and distance (1 730 km) per flight continues to grow, as does the average fleet age (11.8 years).
- Future traffic growth was revised downwards compared to previous outlook, with 9.4, 11.8 and 13.8 million flights now foreseen in 2050 under the low, base and high traffic scenario respectively.
- At 98 major European airports during 2023, 3.4 million people were exposed to L_{den} 55 dB aircraft noise levels and 1.6 million people were exposed to more than 50 daily aircraft noise events above 70 dB.
- While the total European airport noise exposure is still slightly below 2019 levels, there are different trends at the individual airport level with an increase in noise exposure at about one third of these major airports between 2019 and 2023.
- Single-aisle jets generated 71% of the total landing and take-off noise energy in EU27+EFTA during 2023.
- Fleet renewal could lead to a reduction in total noise exposure at European airports as measured by the L_{den} and L_{night} indicators over the next twenty years. However, the evolution of these indicators may differ significantly between airports.
- In 2023, flights departing from EU27+EFTA airports emitted 133 million tonnes CO_2, which is 10% less than in 2019. Single and twin-aisle jets accounted for 77% of these flights and 96% of the CO_2 emissions. 6% of the flights were long-haul (>4 000 km) and accounted for 46% of the CO_2.
- The average mass of CO_2 emitted per passenger kilometre further reduced to 83 grams in 2023, equivalent to 3.3 litres of fuel per 100 passenger kilometres.
- Market-based measures should help stabilise European aviation's net CO_2 emissions in the short term.
- Meeting the ReFuelEU Aviation supply mandate for sustainable aviation fuels could cut the net CO_2 emissions by at least 65 million tonnes (47%) in 2050.
- NO_X emissions have grown faster than CO_2 emissions since 2005 and are expected to continue to do so without further improvement in engine technology.
- In 2021, the sector accounted for 10% of the population exposed to transport noise above L_{den} 45 dB in EU27+EFTA.
- In 2022, flights departing from EU27+EFTA represented 12% of total transport greenhouse gas (GHG) emissions and 4% of total GHG emissions in EU27+EFTA.

Aviation Environmental Impacts

- Latest IPCC, WMO and Copernicus Climate Change Service all highlight widespread, rapid and record-breaking changes in the climate and extreme weather events, with Europe warming twice as fast as the global average making it the fastest warming continent in the world.
- The overall climate impact from aviation is a combination of both its CO_2 and non-CO_2 emissions (e.g. NO_X, PM, SO_X, water vapour and subsequent formation of contrail-cirrus clouds).

- The estimated Effective Radiative Forcing (ERF) from historic non-CO_2 emissions between 1940 and 2018 accounted for more than half of the aviation net warming effect, but the level of uncertainty from the non-CO_2 effects is 8 times higher than that of CO_2.

- Further research on the climate impact of non-CO_2 emissions from aviation, especially on induced changes in cloudiness and methodologies to estimate aircraft GHG inventories, is required to reduce uncertainties and support robust decision-making.

- Emissions with a short-term climate impact (e.g. NO_X) can be expressed as equivalent to emissions with long-term climate impacts (e.g. CO_2) in order to assess trade-offs of mitigation measures, but this is influenced by the metric and time horizon used.

- A non-CO_2 MRV framework began on 1 January 2025 aiming at monitoring, reporting and verifying the non-CO_2 emissions produced by aircraft operators. This framework is designed to provide valuable data for scientific research that will enhance our understanding of non-CO_2 effects and help address aviation climate impacts more effectively.

- A European Parliament pilot project was launched in 2024 to explore the feasibility of optimizing fuel composition in order to reduce the environmental and climate impacts from non-CO_2 emissions without negatively impacting safety (e.g. lower aromatics, sulphur).

- The Aviation Non-CO_2 Expert Network (ANCEN) has been established to facilitate coordination across stakeholders and to provide objective and credible technical support that can inform discussions on potential measures to reduce the climate impact from non-CO_2 emissions.

- Aviation adaptation and resilience to climate change will be critical to address projected future trends in hazardous weather events (e.g. severe convective storms and clear air turbulence) and changes to climatic and environmental conditions (e.g. sea level rise, changes to prevailing surface winds, upper atmosphere turbulence).

- Aircraft engine emissions (mainly NO_X and particulate matter) impact air quality around airports. Exposure to NO_2 and ultrafine particles levels from aviation could be significant in residential areas in the vicinity of airports.

- The Environmental Noise Directive 2022 data estimates 649 000 people experience high levels of annoyance due to aircraft noise, while 127 000 suffer from significant sleep disturbances.

- The REACH[12] Regulation restrictions on Substances of Very High Concern (e.g. chromium trioxide, PFAS) are impacting the aviation sector due to the absence of immediate alternatives.

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.

- The average margin to the latest noise standard of new regional, single-aisle and twin-aisle jet deliveries is levelling off, and the rate of deliveries is still recovering from the COVID crisis.

- 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.

- All new aircraft joining the European fleet since 2020 have engines that meet the latest CAEP/8 NO_X standard, thereby suggesting a need to review this standard during the CAEP/14 work programme (2025-2028).

12 Registration, Evaluation, Authorisation and restriction of CHemicals (REACH)

- Environmental technology standards will be important in influencing new aircraft and 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.
- Discussions have been initiated within ICAO CAEP to review the noise limits for light propeller-driven aircraft and helicopters, which have been unchanged since 1999 and 2002 respectively.
- 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.

Air Traffic Management and Operations

- 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 recognized 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 (2030-2034).
- 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 most emissions originate from the 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.

- A 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.

Airports

- During 2023, EASA took over the management and hosting of the Aircraft Noise and Performance (ANP) legacy data, approved prior to EASA's legal mandate under the 'Balanced Approach' Noise Regulation, in order to establish a single source of ANP data within Europe.

- An assessment of the Environmental Noise Directive implementation in 2023 concluded that the Commission should assess possible improvements, including noise reduction targets at the EU level as per the Zero Pollution Action Plan.

- This same assessment noted that Member States needed to accelerate compliance efforts and ensure that mitigation measures are in line with the Balanced Approach.

- There is growing pressure to address environmental impacts at the 'airport system' level or else face more stringent operational restrictions.

- Revisions to the EU Ambient Air Quality Directives agreed in 2024 included development of air quality action plans where limits are exceeded, enhanced monitoring of compliance, greater transparency for citizens as well as penalties and compensation for infringements.

- In 2022, the 1st Zero Pollution Action Plan Monitoring Assessment concluded that the 2030 noise target is unlikely to be met, while good progress had been made on air pollution targets.

- 51% of operations in Europe were made by aircraft compliant with the latest Chapter 14 noise standard in 2023.

- 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 Sustainable Aviation Fuel (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.

- 118 airports in Europe have announced a net zero CO_2 emissions target by 2030 or earlier, of which 16 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.[13]

Sustainable Aviation Fuels

- The ReFuelEU Aviation Regulation has set a minimum supply mandate for Sustainable Aviation Fuels (SAF) in Europe, starting with 2% in 2025 and increasing to 70% in 2050.
- A sub-mandate for synthetic e-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).
- In 2023, the ICAO CAAF/3 conference agreed 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 labeled as meeting 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.

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 was 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.

[13] Scope 1: direct airport emissions. Scope 2: indirect emissions under airport control from consumption of purchased electricity, heat or steam. Scope 3: emissions by others operating at the airport such as aircraft, surface access, staff travel.

- 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, 129 out of 193 ICAO States have volunteered to participate in the CORSIA offsetting scheme.
- Offsetting under the CORSIA scheme is expected to start for the year 2024 based on data to be reported in 2025. A total of 19 Mt 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 on fuel for intra-EU passenger flights.

International Cooperation

- Global environmental challenges require global cooperation to achieve agreed future goals.
- International Cooperation is a key element to reach the global aspirational goal for international aviation of net-zero carbon 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, European 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.

RECOMMENDATIONS

EASA
European Union Aviation Safety Agency

European Environment Agency

PROGRESS ON EAER 2022 RECOMMENDATIONS

The following highlights key areas of progress on the previous Recommendations from EASA and EEA since the European Aviation Environmental Report (EAER) 2022 was published:

- Establishment of collective aspirational goals at ICAO level:
    - ◊ Net zero carbon emissions from international aviation by 2050.
    - ◊ Reduction in CO_2 emissions from international aviation by 5% in 2030 with the increased production of Sustainable Aviation Fuel and other clean energy initiatives.

- Adoption of ReFuelEU Aviation Regulation with a long-term Sustainable Aviation Fuel (SAF) supply mandate increasing to 70% in 2050 and the creation of a Flight Emissions Label.
- Establishment of supporting measures to deliver ReFuelEU Aviation mandate (e.g. Renewable and Low-Carbon Fuels alliance, EU Clearing House, Taxonomy, Green Deal Industrial Plan).
- Initiation of European Fuel Standard project to consider optimization of fuel composition to mitigate non-CO_2 emissions.

- Completion of an assessment on new dual ICAO aircraft noise and CO_2 standards that are technically feasible, economically reasonable and environmentally beneficial to inform a decision in 2025.
- Development of environmental requirements to support the design and operational integration of new markets into the aviation sector (e.g. drones, urban air mobility, supersonic transport) at EU and ICAO level.

- Launch of significant research initiatives to increase knowledge and insight on how to address the overall climate change effect from aviation emissions (CO_2 and non-CO_2).

- Adoption of modest Single European Sky reforms and update to European Air Traffic Management Master Plan with a target of 9.3% reduction in CO_2 emissions per flight by 2050 compared to 2023.
- Increase from 90 to 118 European airports that have a net zero CO_2 emissions target by 2030.

- Revision of EU Emissions Trading System to include a gradual phase-out of free allowances to airlines, a reduction to the aviation emissions cap from 2024 onwards, establishment of a non-CO_2 MRV framework and a price-bridging mechanism of 20 million ETS allowances to support SAF uptake.
- Amendment of EU Taxonomy System to define aviation products and services that are considered environmentally sustainable.

- European entities (e.g. States, Institutions and Stakeholders) committed more than €20M to support civil aviation environmental protection initiatives across Africa, Asia, Latin America and the Caribbean.
- Coordination between EAER and the European Common Section of the ECAC State Action Plan processes to harmonise information at an EU and ICAO level.
- Creation of European Networks to facilitate coordination across stakeholder groups on the impacts of climate change on the aviation sector, sharing of climate adaptation best practices and technical support on measures to reduce the climate impact from aviation non-CO_2 emissions.

EAER 2025 RECOMMENDATIONS

This section identifies further recommendations from EASA and EEA building on the information and analysis within EAER 2025. They aim to improve the level of environmental protection in the area of civil aviation, without compromising safety, and assist the European Union in ensuring that the aviation sector contributes to the objectives of the European Green Deal[14] through effective collaboration, commitment and verification.

1. Ensure effective oversight and progress towards policy objectives

- Continue to enhance the EAER such that it delivers a comprehensive monitoring system on the environmental performance of the European aviation sector and allows prioritising actions[15] and use of resources to achieve agreed objectives.
    - ◊ Provision of aviation sector data and analysis to demonstrate the effectiveness of European Green Deal policies.
    - ◊ Supply information for robust decision-making and harmonise reporting at the European and ICAO level.
    - ◊ Closer cooperation between European organisations (e.g. EU, EUROCONTROL, ECAC), and their Member States, is critical in achieving this objective.
- Respond to concerns of European citizens by promoting accurate, transparent and effective communication[16] on the environmental performance of aviation.

2. Technology standards to incentivise innovation

- Agree on ambitious CO_2 and noise standards for new aircraft types at CAEP/13 in 2025 in order to influence future designs and contribute to achieving agreed sustainability goals (e.g. EU Climate Law and Zero Pollution Action Plan; ICAO goal of net zero carbon emissions by 2050).
- Review the current NO_X emissions standard for aircraft engines, and enhance non-volatile Particulate Matter emissions measurement procedures, during the CAEP/14 work programme (2025-2028).
- Update the current ICAO independent experts 10-year medium (2027) and 20-year long-term (2037) technology goals so they remain relevant and fit for purpose.
- Enhance the understanding of aircraft engine emissions characteristics, including during the certification process, so as to improve the modelling accuracy of non-CO_2 emissions in cruise.
- Ensure technological, industrial and certification readiness of new concept aircraft and engines to meet the planned in-service schedule and use of 100% SAF.

3. Step-up efforts to implement Single European Sky sustainability objectives

- Build on the recent Single European Sky (SES2+) reform to modernise Air Traffic Management (ATM) and to incentivise environmental performance.
- Accelerate development of new SESAR solutions, and their deployment, with environmental benefits (e.g. 'Common Project 1' ATM functionalities and Master Plan Strategic Deployment Objectives).
- Drive forward improvements in ATM infrastructure and aircraft operations through closer cooperation, and the development of suitable key performance indicators to achieve better climate and environmental performance in the European aviation network.

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14 The European Green Deal encompasses in particular the European Climate Law, the Sustainable and Smart Mobility Strategy and the Zero Pollution Action Plan.

15 In 2023, single-aisle jets generated 71% of the total landing and take-off noise energy at all EU27+EFTA airports. Single and twin-aisle jets accounted for 77% of flights departing from EU27+EFTA airports and 96% of CO_2 emissions, while 6% of the flights were long-haul (>4 000 km) accounting for 46% of CO_2. In 2050, the aviation sector in the EU27+EFTA should reduce its CO_2 emissions from departing flights by at least 65% through in-sector measures (technology, operations, fuels). This would leave almost 60 million tonnes of CO_2 that would need to be addressed through out-of-sector measures (e.g. market-based measures).

16 e.g. EAER, Certified aircraft-engine environmental data, SES Performance Scheme KPIs, Flight Emissions Label, annual ReFuelEU SAF Reports, ETS / CORSIA emissions data, Zero Pollution Monitoring Reports.

4. Implement effective airport action plans

- Foster onsite production of renewable energy at airports, with the support of the Connecting Europe Facility, to electrify ground operations and mitigate noise, air quality and climate impacts.
- In line with ReFuelEU Aviation, take all necessary measures to facilitate the access to and uptake of SAF through infrastructure investment, cooperation with supply chain stakeholders, financial incentives and supportive policy / governance frameworks.
- Consider improvements to the 'Balanced Approach' Noise Regulation for managing noise impacts around airports that facilitate consistent implementation by Member States, accelerated compliance and ensures operational restrictions are used only after consideration of all other elements.

5. Scale up Sustainable Aviation Fuels to achieve emission reduction targets

- Reduce the price gap between SAF and fossil-based fuels by building on the Green Deal Industrial Plan, the allocated ETS allowances and ReFuelEU Aviation supporting measures to deliver the supply mandate.
- Promote SAF with the greatest emissions reductions to maximise their contribution to the European Green Deal as well as the ICAO LTAG and CAAF/3 objectives.
- Explore the potential of accounting mechanisms for SAF to facilitate the traceability and claiming of SAF benefits, while preserving the environmental integrity of decarbonisation schemes.
- Progress towards alignment of SAF sustainability certification across regulatory compliance regimes.
- Identify how aviation fuel composition, both fossil and SAF fractions, can be optimised to mitigate overall climate and air quality impacts (e.g. fuel standards).

6. Market-based incentives to promote innovation in sustainability

- Incentivise sustainable finance within the sector, including via the implementation of the EU Taxonomy System for aviation activities.
- Support the 2025 CORSIA Periodic Review to ensure the effectiveness of the scheme in contributing to the sustainable development of the global aviation sector and encourage participation of ICAO States during the voluntary Phase 1 period (2024-2026).
- Progress proposed revisions to the Energy Taxation Directive to encourage the use of low or zero carbon energy sources.
- Ensure the quality and credibility of voluntary and compliance-based carbon credits, including carbon removals, used to offset or reduce emissions within the aviation sector.

7. Facilitate research and implementation of solutions

- Increase research resources and coordination at the EU (e.g. Horizon Europe, EU Innovation Fund) and National level on strategic priorities across all areas (technology, operations, fuels) to meet the 2030 climate target and ensure the aviation sector is on the right path for the 2040 target.
- Bring greater cohesion to the research on the climate effect of aviation non-CO_2 emissions. This would aim to advance scientific understanding and to develop robust decision-making capabilities that take into account uncertainties as part of a risk-based assessment to ensure mitigation measures lead to an overall reduction in climate impact (CO_2 and non-CO_2).
- As Europe's climate is warming twice as fast as the global average, place a greater priority on ensuring the aviation sector's resilience and preparedness for these future changes.

8. Global cooperation to address global challenges

- Step up green diplomacy and technical collaboration with Partner States to address global aviation sustainability challenges.
- Facilitate the transition to sustainable economic models, including through the realisation of viable SAF businesses.
- Maximise the use of international cooperation resources through the effective coordination of European actions with Partner States.

INTRODUCTION

Welcome to the 4th European Aviation Environmental Report (EAER)!

The main aim of this report is to provide an objective, clear and accurate source of information on the past and forecasted environmental performance of the aviation sector at the European level. This reference document is published every 3 years to inform strategic discussions and support the prioritisation of future work and resources to drive forward the issue of sustainability and coordinate a comprehensive approach across different initiatives.

There has been a loss of trust that the sector is addressing these issues and telling the truth [8, 9], and this needs to be regained. Honest, transparent and effective communication is critical to addressing these challenges, as is attracting the next generation of skilled personnel and reigniting aviation's pioneering and innovative spirit to secure a sustainable aviation future and a license to continue to operate in a carbon constrained world. Europe is positioning itself to make the most of this new green economy and this latest EAER provides an overview of this transition.

What is the **enviromental performance** of the European aviation sector?

How might the sector's performance evolve in the **future**?

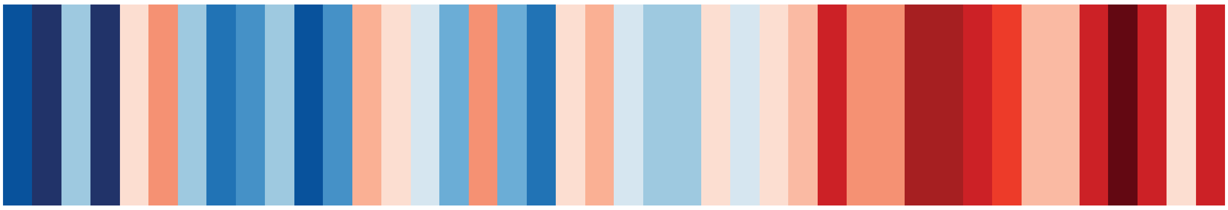
What **measures** are reducing climate change, noise and air quality impacts?

How can the sector further **improve** its level of environmental protection?

Aviation Warming Stripes

The aviation warming stripes on the pages that separate the Chapters in this report were developed in collaboration with the University of Oxford, Manchester Metropolitan University, and the NERC National Centre for Earth Observation.

Based on a recent study that quantified aviation's contribution to global warming [10], the below aviation 'warming stripes' have been developed with the aim of communicating a complex message in a visually simple and memorable way that people can relate to. Warming stripes typically communicate on the impact of global warming in terms of changes in average surface temperature over time at the global or national level [11]. In comparison, the colours of the aviation warming stripes below represent the modelled % contribution of aviation emissions to overall global warming (temp. increase against a pre-industrial baseline) for a given year between 1980 (1.9% on left) and 2021 (3.7% on right). Note that there remain uncertainties with regard to the climate effects of aviation non-CO_2 emissions (see Chapter 2 on Environmental Impacts).



European policy on noise and air quality

In 2021, the European Union (EU) adopted the Zero Pollution Action Plan [12] that set out a vision to reduce air, water and soil pollution to levels no longer considered harmful to health and natural ecosystems by 2050. Key intermediate 2030 targets, compared to 2017 levels, have also been identified to: (1) reduce pollution at source, including the reduction of the share of people chronically disturbed by transport noise by 30% and (2) improve air quality to reduce the number of premature deaths caused by air pollution by 55%. Subsequent Zero Pollution Monitoring Assessments have been published in 2022 and 2025 [13] to monitor progress towards these targets.

The Environmental Noise Directive [14] and the Balanced Approach Regulation [15] are the EU legislation under which environmental noise is monitored, communicated to the public and actions subsequently taken by Member States to reduce noise exposure in cities and near major transport infrastructure. EU air pollution legislation is implemented through air quality standards that were updated in 2024 [16, 17] and source-based mitigation controls (e.g. engine emissions and fuel quality standards). Binding national limits for emissions of the most important pollutants have also been established in the EU, but not all aviation activities are included [18].

European policy on climate change

In 2019, the European Commission presented the European Green Deal [19], which aims at improving the well-being of people and making Europe climate-neutral by 2050. The 2021 European Climate Law [20] incorporated this goal into legislation, such that EU institutions and Member States are bound to take the necessary measures at EU and national level to meet the target, taking into account the importance of promoting fairness and solidarity among Member States.

The 2021 Climate Law includes:

- a legal objective for the Union to reach climate neutrality by 2050; and
- an ambitious 2030 climate target of at least 55% reduction of net emissions of greenhouse gases as compared to 1990.

In 2024, the European Commission presented its assessment for a 2040 climate target and recommended reducing the EU's net greenhouse gas emissions by 90% by 2040 relative to 1990 [21] in order to:

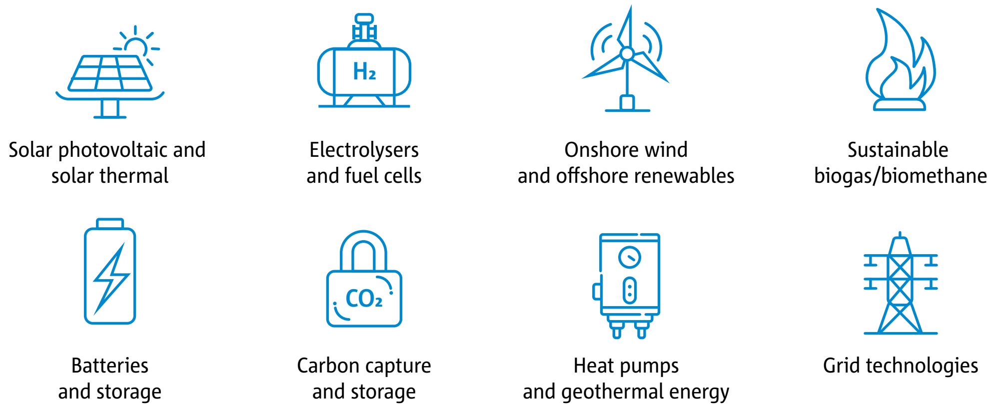
- put Europe on course towards climate neutrality by 2050, thereby building a healthier and safer future;
- ensure predictability for citizens, businesses and investors, by making sure that resources invested now and in the upcoming decades are compatible with the EU's pathway to climate neutrality, thereby avoiding wasted investments in the fossil fuel economy;
- boost the competitiveness of Europe's businesses, create stable and future-proof jobs, and enable the EU to lead in developing the clean technology markets of the future; and
- make Europe more resilient and strengthen its strategic autonomy.

The European Green Deal includes a goal to reduce emissions from the transport sector by 90% in 2050 compared to 1990 levels. Specific objectives on mobility and transport were subsequently presented in 2020 within the Sustainable and Smart Mobility Strategy [22] together with an Action Plan of 82 initiatives. This strategy laid the foundation for how a smart, competitive, safe, accessible and affordable EU transport system can achieve its green and digital transformation and become more resilient to future crises. All transport modes need to become more sustainable, with concrete milestones to keep the green transition on track.

In 2021, the 'Fit for 55' legislative proposals [23] were published setting out the ways in which the Commission will reach its updated 2030 target in real terms. It covers a wide range of policy areas, some of which effected the aviation industry (revision of the EU Emission Trading System Directive concerning aviation, ReFuelEU Aviation Initiative, revision to the Renewable Energy Directive and revision to the Energy Taxation Directive). Final agreements in these policy areas were adopted in 2023, apart from the revision to the Energy Taxation Directive, and are summarized in the relevant Chapters of this report.

In February 2024, the European Parliament and the Council reached a political agreement on the Net-Zero Industry Act [24]. This initiative from the Green Deal Industrial Plan aims to scale up the manufacturing of technologies in the EU that support the clean energy transition by simplifying the regulatory framework and increasing the competitiveness of European industry. The aim is that the Union's overall strategic net-zero technologies manufacturing capacity is about 40% of annual deployment needs by 2030. The Act addresses key strategic technologies that will make a significant contribution to decarbonisation, including Sustainable Aviation Fuels. A report on the future of European competitiveness [25], published in September 2024, has estimated that the investment needs to decarbonize the aviation sector lies in the region of €61 billion a year from 2031 to 2050.

Key Decarbonisation Technologies



ICAO State Action Plans on CO_2 Emissions Reductions

ICAO encourages all States to submit a voluntary State Action Plan (SAP) for CO_2 emissions reduction from international aviation every 3 years, in order that ICAO can continue to compile the quantified information in relation to achieving the agreed global aspirational goals [26]. For the SAP due in 2024, it was agreed that input for the European Civil Aviation Conference (ECAC) / European Union (EU) SAP Common Section be developed in cooperation with the EASA European Aviation and Environment Report (EAER) process. This has facilitated an efficient cooperation of European States and organisations and helped to promote a consistent message at both European and ICAO level.

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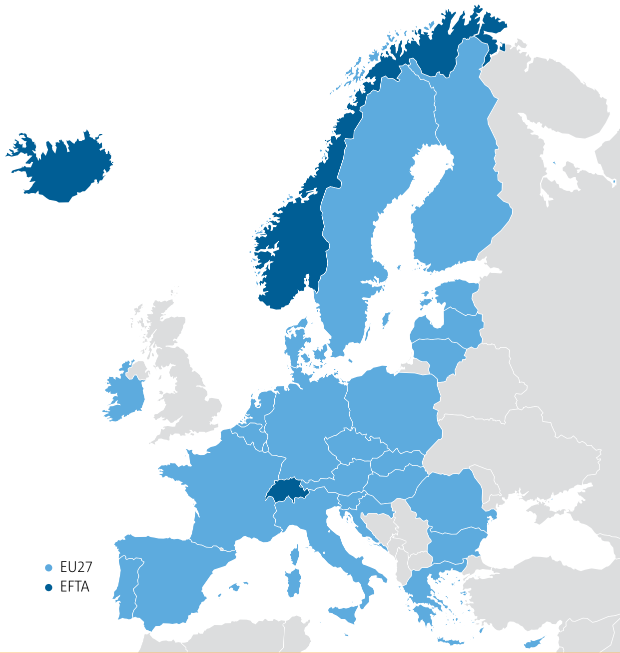
OVERVIEW OF AVIATION SECTOR

- The number of flights arriving at and departing from EU27+EFTA airports reached 8.35 million in 2023, which is still 10% below the pre-COVID 2019 level.
- Low-cost operators have recovered faster from the COVID crisis than mainline operators.
- Since February 2022, flight operations have been affected by the war in Ukraine and the subsequent airspace and operator restrictions. From October 2023, some re-routings have also been caused by the conflict in the Middle East.
- The average number of passengers (135) and distance (1 730 km) per flight continues to grow, as does the average fleet age (11.8 years).
- Future traffic growth was revised downwards compared to previous outlook, with 9.4, 11.8 and 13.8 million flights now foreseen in 2050 under the low, base and high traffic scenario respectively.
- At 98 major European airports during 2023, 3.4 million people were exposed to L_{den} 55 dB aircraft noise levels and 1.6 million people were exposed to more than 50 daily aircraft noise events above 70 dB.
- While the total European airport noise exposure is still slightly below 2019 levels, there are different trends at the individual airport level with an increase in noise exposure at about one third of these major airports between 2019 and 2023.
- Single-aisle jets generated 71% of the total landing and take-off noise energy in EU27+EFTA during 2023.
- Fleet renewal could lead to a reduction in total noise exposure at European airports as measured by the L_{den} and L_{night} indicators over the next twenty years. However, the evolution of these indicators may differ significantly between airports.
- In 2023, flights departing from EU27+EFTA airports emitted 133 million tonnes CO_2, which is 10% less than in 2019. Single and twin-aisle jets accounted for 77% of these flights and 96% of the CO_2 emissions. 6% of the flights were long-haul (>4 000 km) and accounted for 46% of the CO_2.
- The average mass of CO_2 emitted per passenger kilometre further reduced to 83 grams in 2023, equivalent to 3.3 litres of fuel per 100 passenger kilometres.
- Market-based measures should help stabilise European aviation's net CO_2 emissions in the short term.
- Meeting the ReFuelEU Aviation supply mandate for sustainable aviation fuels could cut the net CO_2 emissions by at least 65 million tonnes (47%) in 2050.
- NO_X emissions have grown faster than CO_2 emissions since 2005 and are expected to continue to do so without further improvement in engine technology.
- In 2021, the sector accounted for 10% of the population exposed to transport noise above L_{den} 45 dB in EU27+EFTA.
- In 2022, flights departing from EU27+EFTA represented 12% of total transport greenhouse gas (GHG) emissions and 4% of total GHG emissions in EU27+EFTA.

Analysis scope and assumptions

Historical air traffic data in this section comes from Eurostat and EUROCONTROL. The coverage is all flights from or to airports in the European Union (EU27)[1] and European Free Trade Association (EFTA). The forecast of European flights comes from the EUROCONTROL Aviation Long-term Outlook 2050. For more details on models, analysis methods, forecasts, supporting data sources and assumptions used in this section, please refer to Appendix C.



1.1 AIR TRAFFIC

Flights recovered to 91% of pre-COVID levels in 2023

Traffic recovery after the COVID outbreak has followed the trend forecasted in the previous report, namely a rebound in 2022 followed by a more moderate increase to reach 8.35 million flights at EU27+EFTA airports in 2023 (Figure 1.1), which is still 9% below the 2019 level. While low-cost and mainline carriers had an identical share of total flights in 2019 (one third each), the low-cost market post-COVID recovery was faster and had the largest share in 2023.

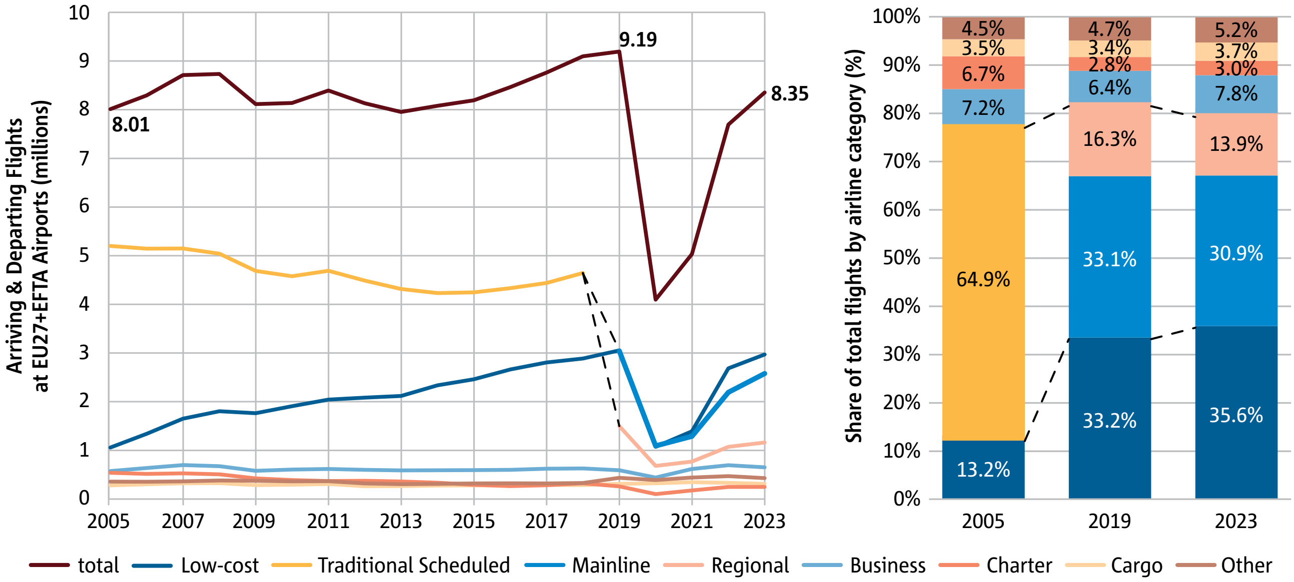
The number of passengers recovered faster from COVID than flights, with 774 million passengers flying from EU27+EFTA airports in 2023, which is just 4% below the 2019 level. This is in part due to the high average passenger load factor of 84.5%, which exceeded the previous 2019 record of 83.4%. The average distance per flight also reached a peak in 2023 (1 730 km), such that total passenger-kilometres were close to their pre-COVID level during that year.

After a peak in 2021, the number of cargo flights was back to pre-COVID levels in 2023, although the total tonnes of cargo transported was 5% lower than in 2019. In 2023, business jet operations exceeded the 2019 level by 10% after almost reaching their 2007 record of 700 000 annual flights during 2022. Several bankruptcies and the shift to low-cost airlines or high-speed rail on certain city pairs has driven the reduction in number of flights by regional airlines between 2019 and 2023.

While the COVID outbreak had the greatest impact on aviation over the period 2020-2023, the Russian invasion of Ukraine in February 2022 and the subsequent airspace closures and operator restrictions have also affected air traffic, with neighbouring airspace absorbing more traffic and diverted flights overloading the busy South-East axis. In addition, the EU sanctions have hindered the recovery of traffic between Europe and Asia. Since October 2023, the conflict in the Middle East has also had an impact on air traffic flows, especially overflights, and there has been a significant increase in military operations within European airspace.

[1] The geographical scope is constant through the entire time period covered in this Chapter. Consequently, the data does not include UK for those years preceding Brexit.

Figure 1.1 Low-cost recovered faster from COVID than mainline carriers



Note: From 2019 onwards the 'traditional scheduled' carrier category has been split into two categories, 'mainline' and 'regional'. See Appendix C for more information about market segments.

Updated 2050 traffic outlook foresees slower growth

As in previous reports, the traffic forecast out to 2050 includes three scenarios on how European aviation may develop in the future (Figure 1.2). These scenarios take economic growth, price of travel (including conventional and sustainable aviation fuel prices), sustainability goals and regulation into account, as well as airport capacity, high-speed rail and the arrival of new aircraft, fuel and propulsion. More details are provided in Appendix C. In the most-likely 'base' scenario the traffic at EU27+EFTA airports is expected to return to its 2019 level of 9.2 million flights in 2026, and then grow to 9.9 million flights in 2030 and 11.8 million flights in 2050, representing an average annual growth of 1.1% between 2025 and 2050. Over the same period and under the 'base' scenario, passenger-kilometres are expected to grow slightly faster at an average 1.3% per annum as the average aircraft size and flight distance both continue to increase. Under the 'high' scenario, flights and passenger-kilometres are assumed to grow by 1.6% and 1.8% per annum respectively between 2025 and 2050, while the 'low' scenario foresees almost no growth out to 2045. These growth rates are slightly lower than those in the previous traffic outlook. This is mostly driven by higher fuel price predictions and a revision of the maximum flight capacity at airports.

The number of very short-haul flights (less than 500 km) decreased steeply between 2005 and 2013 and then stabilised until 2019, while the number of flights in other haul categories increased (Figure 1.3). Very short-haul flights still represented 25% of all flights in 2023 but their post COVID recovery has been slower than other categories. Competition with high-speed rail is strongest for the short-haul category, with rail emerging as a favoured option in the context of growing environmental awareness and changing consumer preferences.

Figure 1.2 Annual flights could exceed 10 million shortly after 2030

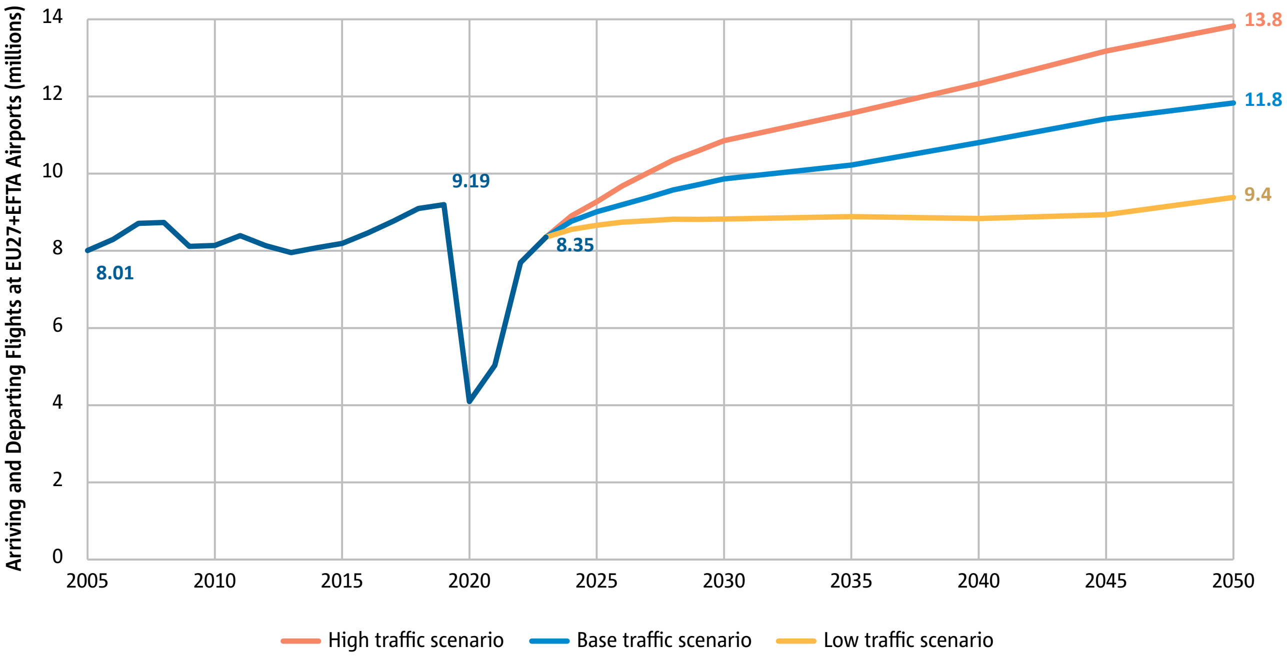
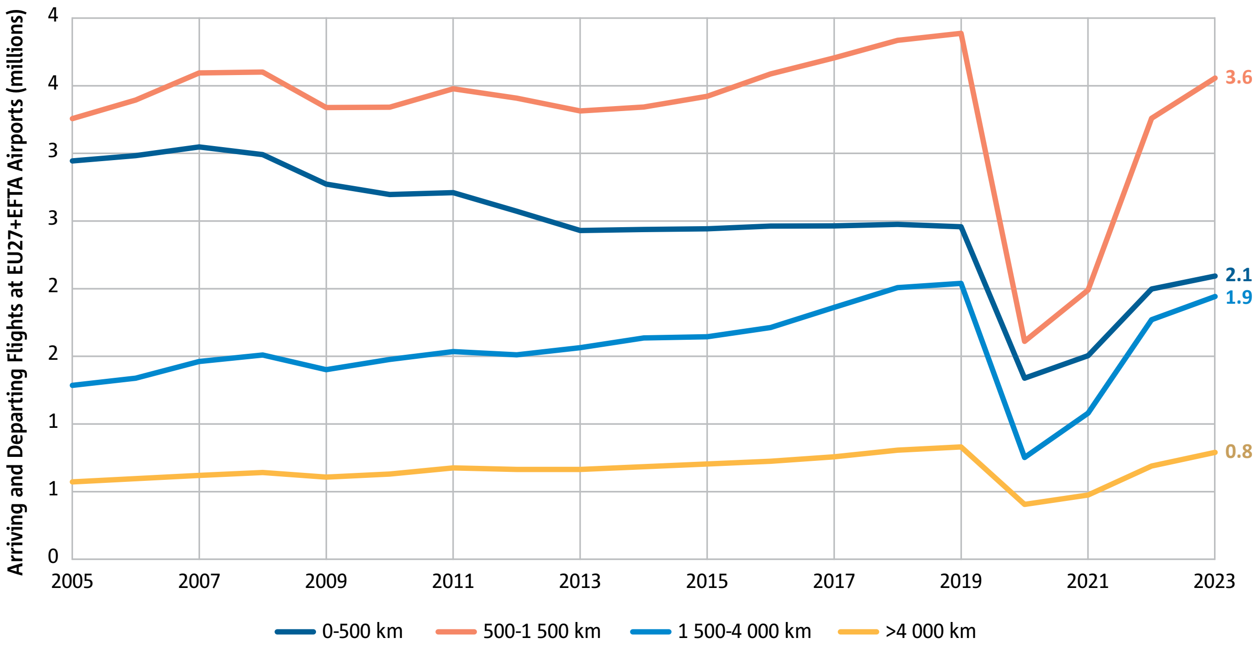
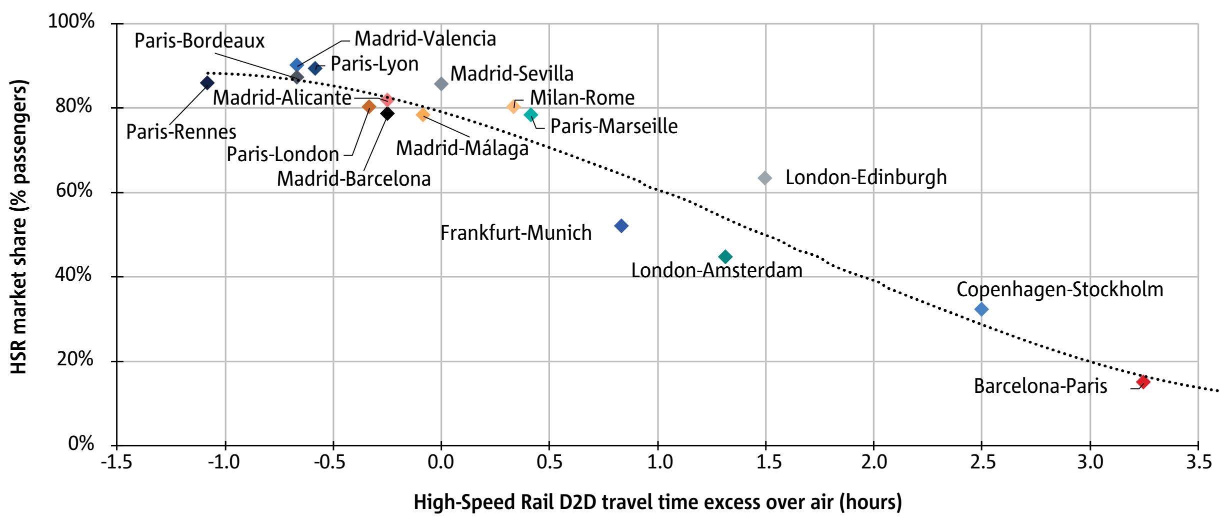


Figure 1.3 Very short-haul flights show the slowest recovery after COVID crisis



High-speed rail and air traffic

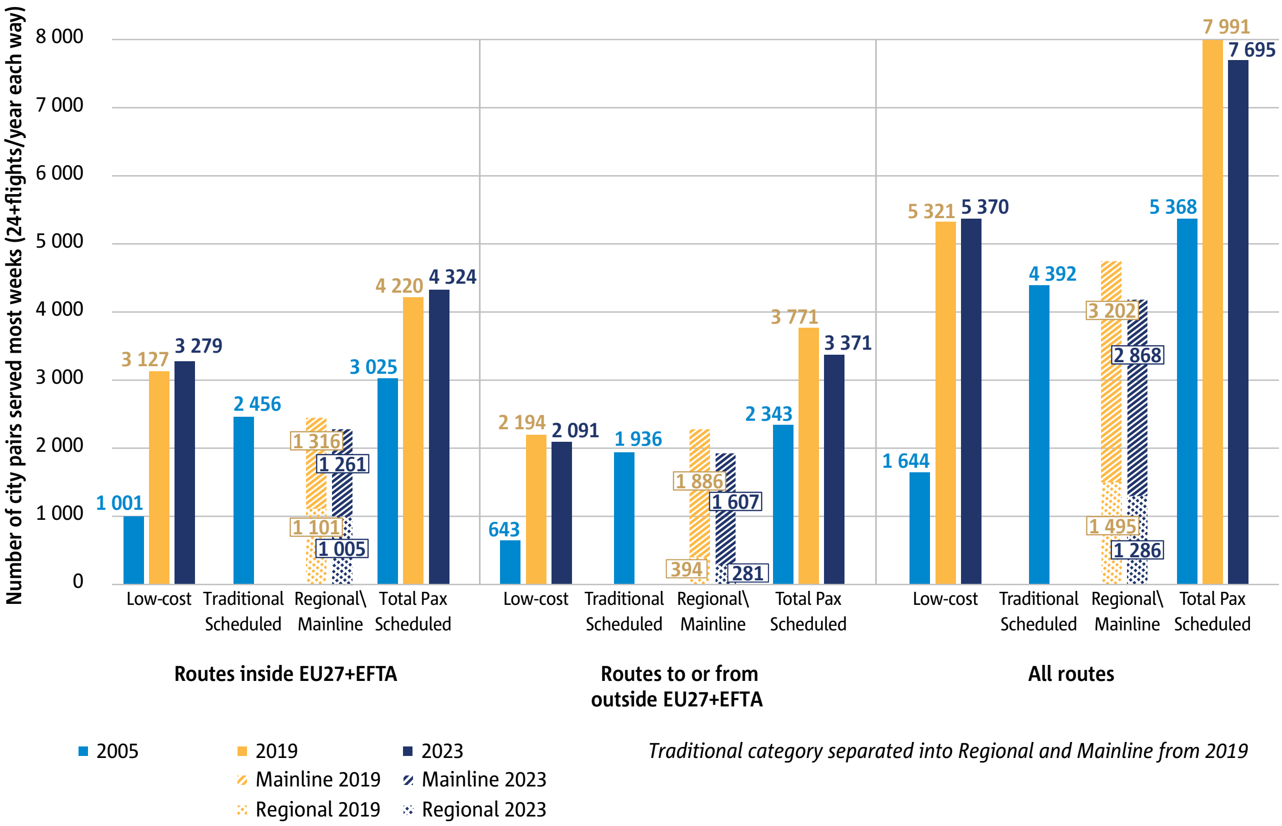
High-speed rail (HSR) often offers a competitive alternative to air travel on shorter routes, providing similar or even superior door-to-door (D2D) time efficiency. This capability has led to a shift in passenger preference from planes to trains on routes where HSR has been implemented. A 2024 study [10] shows that the market share of HSR on a given route is highly correlated to the D2D travel time reduction it offers compared to air travel. Even when travelling by train takes longer than by air, train can still take a significant share of passengers due to other factors such as price, frequency, punctuality, and comfort.



The study also highlights that improving the attractiveness of train, via faster connections or reduced fares, can lead to induced demand (i.e. increase the total number of passengers on a route) which may partly limit the environmental benefits of the modal shift. For example, the completion of the Madrid-Barcelona HSR link saw a 28% increase in the number of people travelling between these two cities.

A multimodal approach that better integrates HSR with air travel can reduce the need for short-haul flights while maintaining high levels of connectivity and convenience for passengers. This could be achieved by improving the connectivity between the HSR network and hub airports (new infrastructure) and fostering partnerships between air and train operators to facilitate tickets purchase, baggage handling and management of delays.

Figure 1.4 **Extra-European connectivity recovering slower than intra-European after COVID**



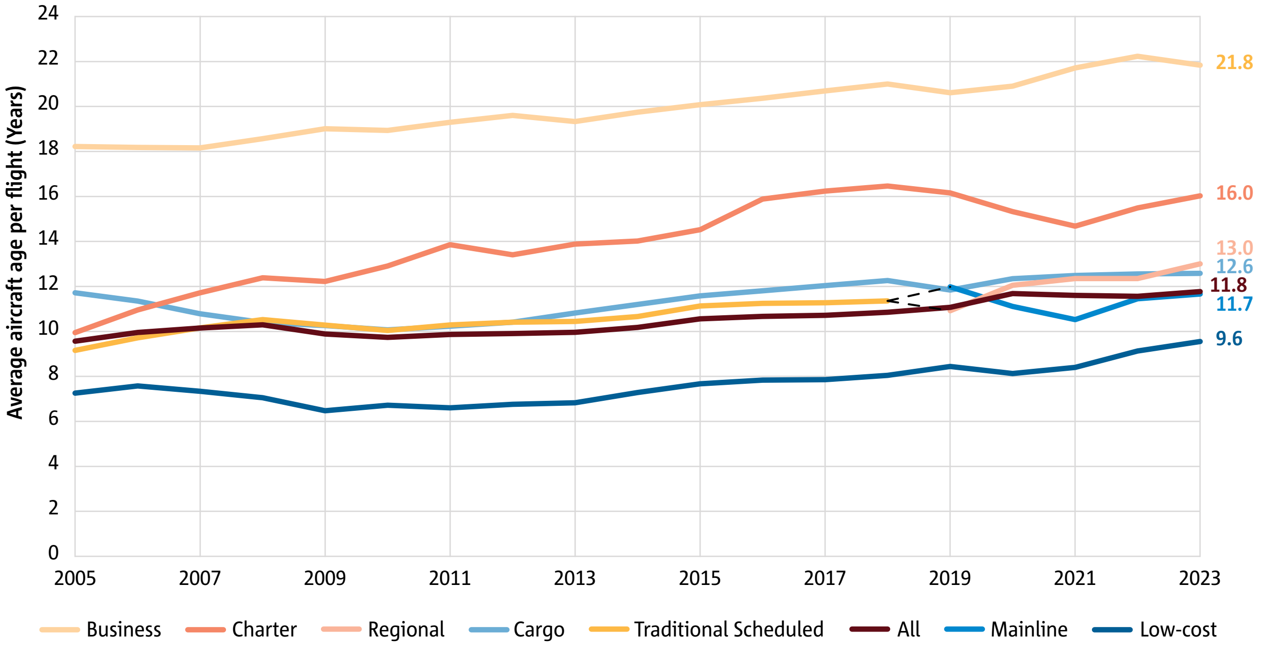
Connectivity is almost back to pre-COVID level

As in previous reports, aviation connectivity is measured using the number of city pairs with more than 24 direct flights per year each way (Figure 1.4). Total connectivity in 2023 was just 4% below 2019 levels at about 7 700 city pairs. Intra-European connectivity has already exceeded its 2019 level mostly thanks to low-cost operators, but this does not compensate for the lower extra-European connectivity which still falls short of its 2019 level for all operator categories. Low-cost operators continue to offer more direct connections than mainline operators both inside and outside Europe.

European fleet keeps on slowly aging

The majority of aircraft which were parked during the COVID crisis have returned into service, leading to a rapid increase in average aircraft age for mainline, low-cost and charter carriers between 2021 and 2023 (Figure 1.5). Overall, the average age of the European fleet continues to increase and reached 11.8 years in 2023 compared to 11.6 years in 2021. The two notable exceptions are business jet aircraft which average age has stabilised around 12.5 years, and cargo aircraft which went down below 22 years again in 2023. The high average age of cargo aircraft is mainly driven by their low daily utilisation leading to longer amortisation periods for those aircraft, and the absence of purpose-built short-haul freighters leading to the use of converted single-aisle passenger aircraft for this market segment. The average retirement age of aircraft registered in Europe went down from 27.7 to 24.5 years between 2012 and 2022.

Figure 1.5 Fleet continues to age slowly for most carrier categories



Night traffic at airports recovered faster than total traffic

The night traffic at airports is driven by the economic models of the passenger and freighter markets, as well as the need for connectivity to other parts of the world. The proportion of flights that take-off or land during the nighttime period (23:00 to 07:00) at EU27+EFTA airports has increased since 2019 to reach about 5.5% of total traffic in 2023, even though the absolute number of night flights was still lower than in 2019 (Figure 1.6a). This indicates that night traffic has recovered faster than total traffic after the COVID crisis. In 2023, the top 10 busiest airports during the nighttime period represented 27% of all night movements, which is similar to the share of the top 10 busiest airports during the daytime period (25%).

The hourly distribution of the total 2023 traffic (Figure 1.6b) confirms that the number of arrival flights towards the beginning of the night period (22:00 to midnight) far exceeds departures, while departures exceed arrivals towards the end (06:00 to 08:00).

All passenger-related indicators are for commercial flight departures only (other indicators include arrivals). Passenger kilometres are based on the shortest (great circle) distance between origin and destination. Cargo is for both all-cargo and passenger aircraft.

Figure 1.6(a) **The number of night flights is still below 2019 level but their share of total flights is higher**

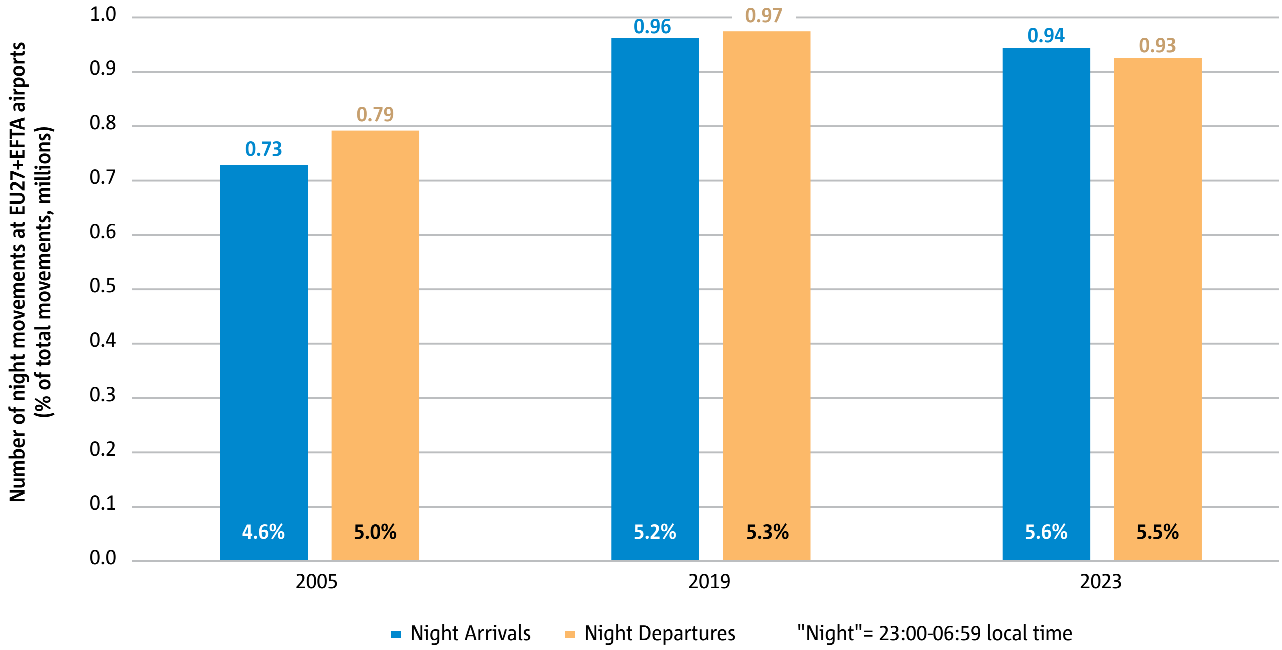


Figure 1.6(b) **Airport traffic peaks just before and after the night period**

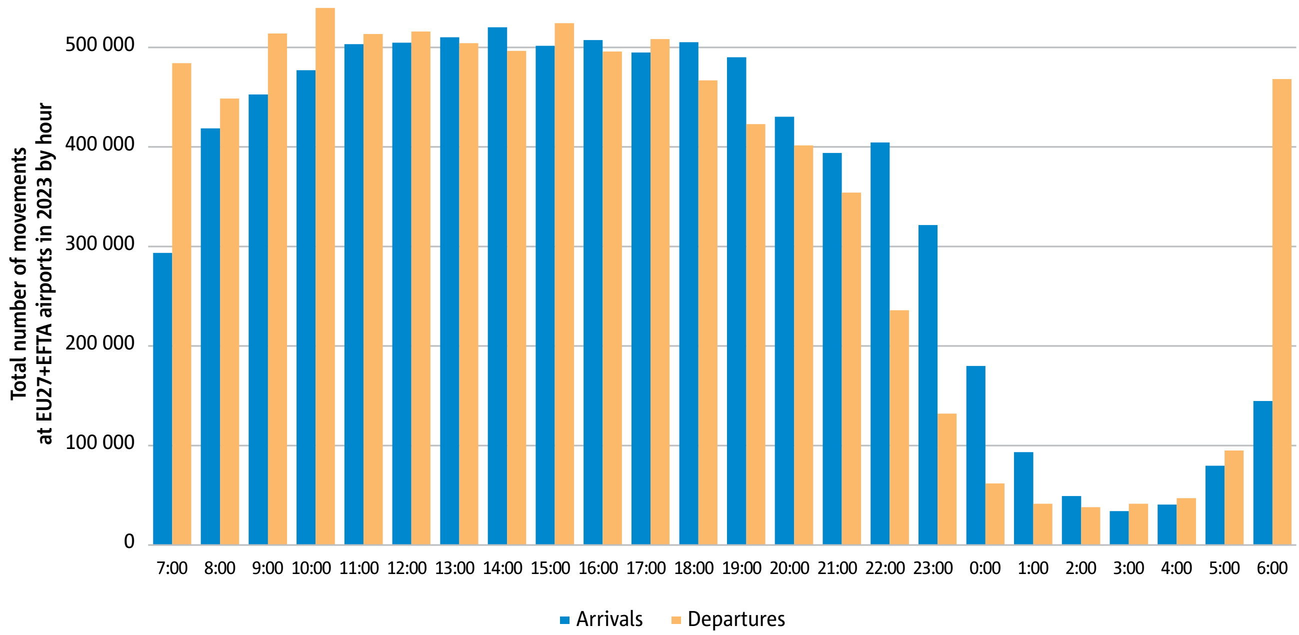
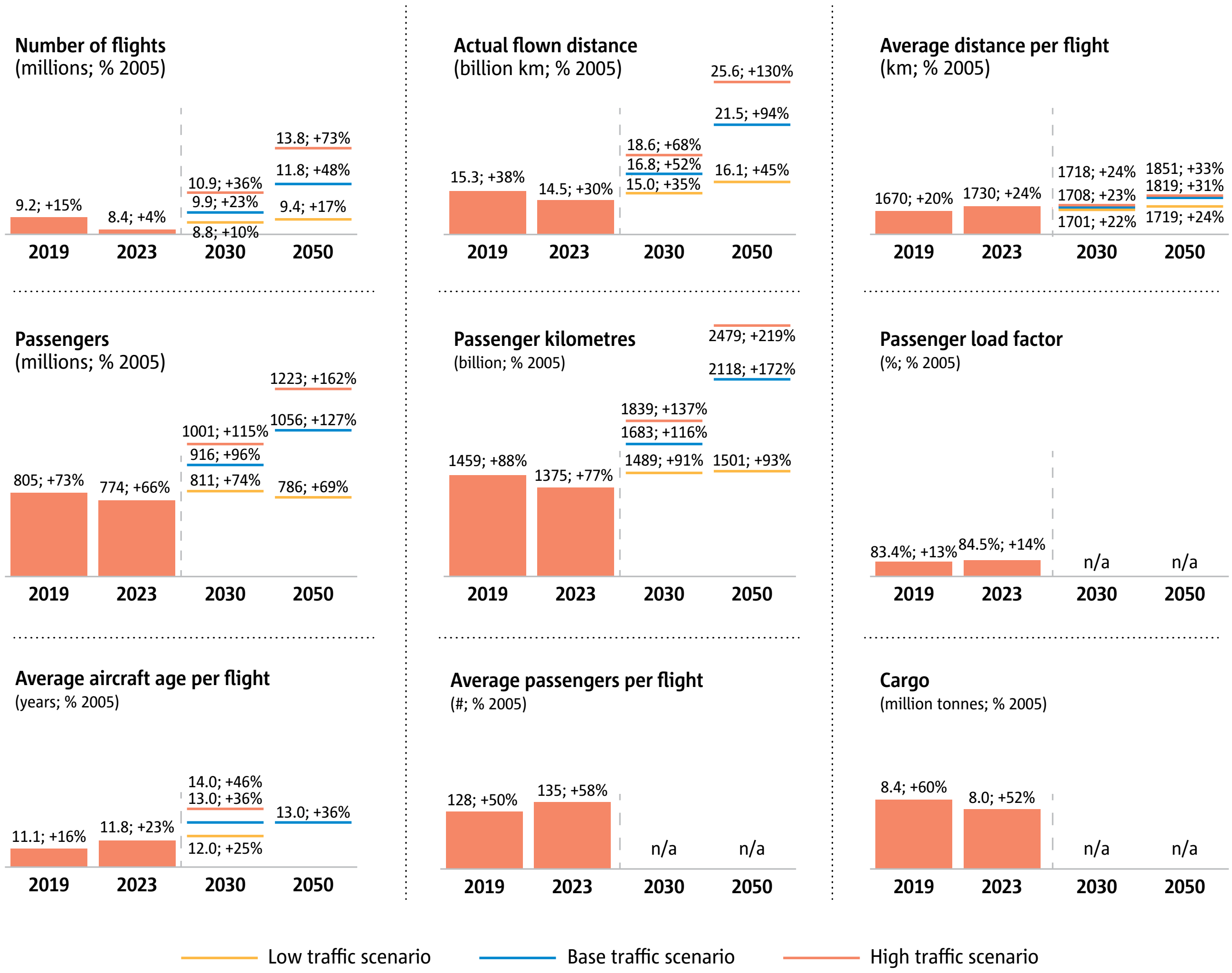


Figure 1.7 Summary of air traffic indicators (% change to 2005)



Note: *All passenger-related indicators are for commercial flight departures only (other indicators include arrivals). Passenger kilometres are based on the shortest (great circle) distance between origin and destination. Cargo is for both all-cargo and passenger aircraft.*

1.2 NOISE

Total airport noise exposure is still below pre-COVID level but local situations may differ

Following the trend in traffic, the total noise exposure at 98 major EU27+EFTA airports, as measured by the L_{den} and L_{night} indicators,[2] was still below but close to pre-COVID levels in 2023. The total population inside the L_{den} 55 dB and L_{night} 50 dB airport noise contours were 10% and 4% lower than in 2019 respectively (Figures 1.8 and 1.9). These thresholds of 55 and 50 dB were chosen based on the reporting thresholds specified in the Environmental Noise Directive (2002/49/EC). However, the World Health Organization (WHO) has identified that negative health effects start to occur at noise levels below these thresholds [6], suggesting that the above exposure estimates could underestimate the actual number of people at risk of health impacts due to aircraft noise exposure. See Chapter 2 on Environmental Impacts for further information on the impacts of noise based on the data reported under the Environmental Noise Directive.

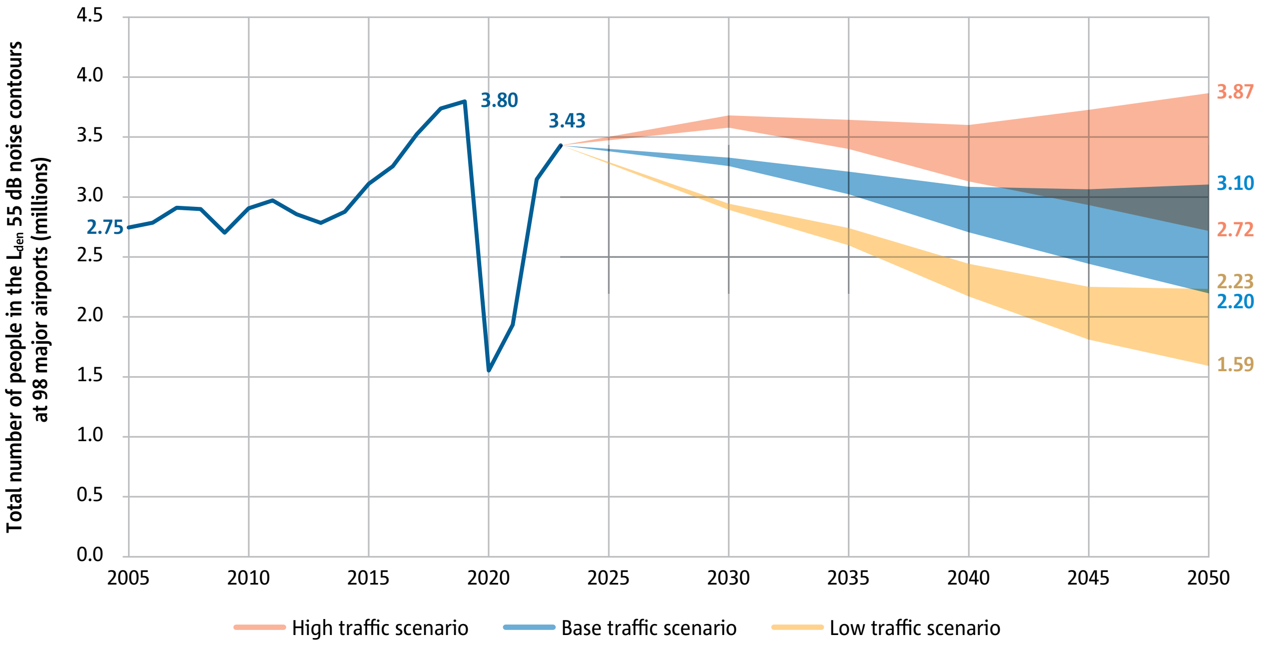
The census database used to assess population inside noise contours has been improved compared to the previous report (see Appendix C for more details on data sources), leading to an overall increase in all population-based indicators. However, the trend of the indicators over time is similar with that shown in the previous report.

Under the three traffic scenarios, fleet renewal with the latest generation of quieter aircraft is still expected to stabilise or even reduce average noise exposure until 2040 in terms of the L_{den} and L_{night} indicators. This is primarily due to the renewal of the single-aisle and twin-aisle jets in the fleet which account for the bulk of landing and take-off noise energy (respectively 71% and 21% in 2023, see Figure 1.13). However, noise impacts may increase again in the longer term if manufacturers do not develop new quieter aircraft that can offset the effect of traffic growth.

The total indicators hide the diversity of trends between the 98 major EU27+EFTA airports included in the assessment. Between 2019 and 2023, the area of the L_{den} 55 dB and L_{den} 50 dB contours has actually increased at 32 and 43 of those airports respectively. The top 10 airports in terms of L_{den} 55 dB population exposure still accounted for half of the total population exposure across all 98 airports during 2023.

[2] L_{den} is the sound pressure level averaged over the year for the day, evening and nighttime periods, with a +5 dB penalty for the evening and +10 dB for the night. L_{night} is the sound pressure level averaged over the year for the nighttime period only.

Figure 1.8 **Total L_{den} 55 dB population around major airports may stay below pre-COVID level**



Assumptions:
- Airport infrastructure is unchanged (no new runway)
- Population density around airports is unchanged after 2020
- Local landing and take-off noise abatement procedures are not considered

For each traffic scenario, the upper bound of the range reflects the fleet renewal scenario with frozen technology; the lower bound reflects the scenario with aircraft/engine technology improvements (see Appendix C for detailed assumptions).

How many airports are covered by the Environmental Noise Directive?

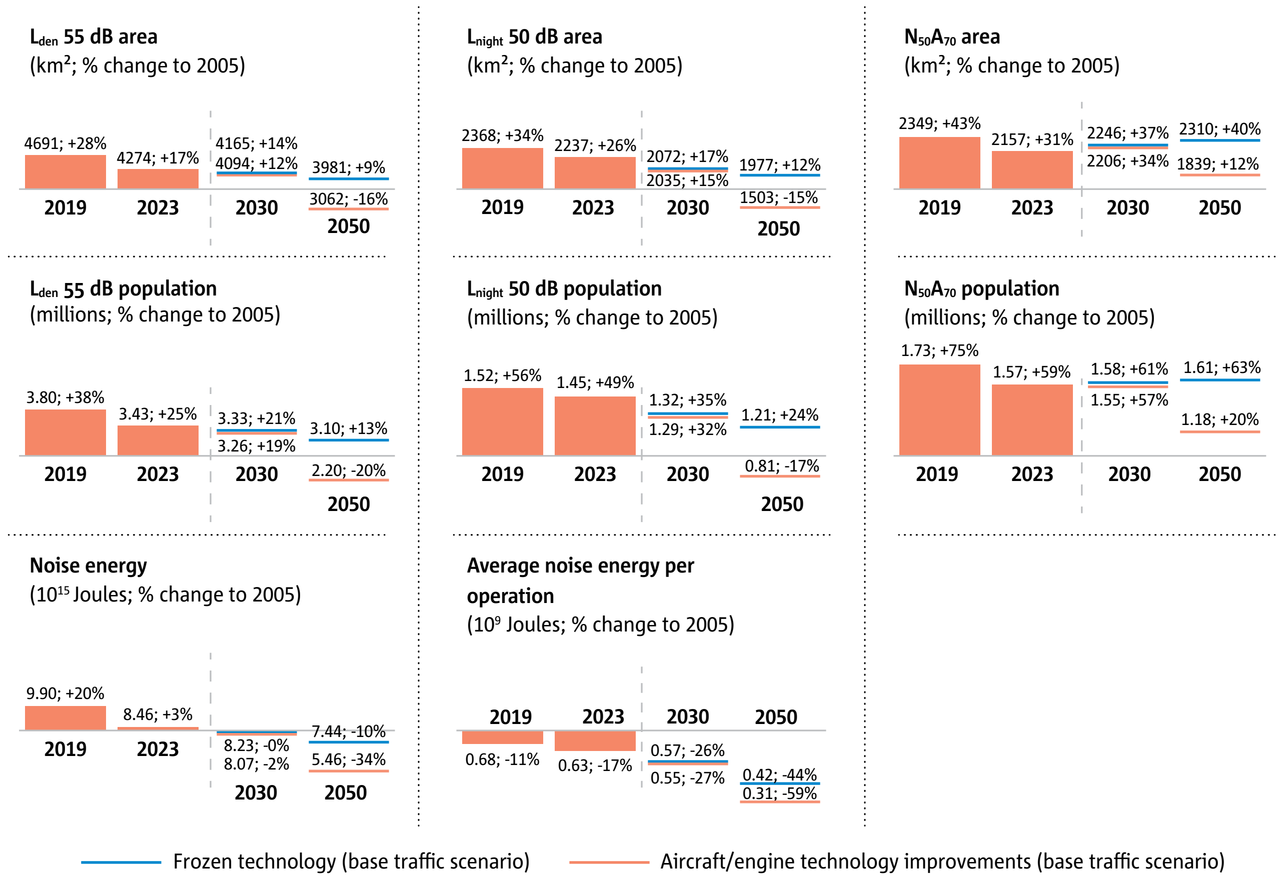
70 airports had more than 50 000 movements (departures and arrivals) during 2023 in the EU27+EFTA region. This is still below the 2018 peak (77 airports) but the number is expected to increase further and could reach 85 by 2050 under the base traffic forecast. All airports with more than 50 000 annual movements are included in the EAER assessment, as well as additional airports below the movement threshold in order to obtain a more comprehensive overview of aircraft noise within Europe (see Appendix C for the list of 98 airports).

The $N_{50}A_{70}$ population indicator[3] continues to show the largest increase compared to 2005 (Figure 1.9). In 2023, 1.6 million people were exposed to more than 50 aircraft noise events above 70 dB per day at the 98 major airports, which is 59% more than in 2005. While under the base traffic forecast the total L_{den} 55 dB and L_{night} 50 dB area and population could reduce below their 2005 level by 2050, the total $N_{50}A_{70}$ ones may remain above.

In 2023, using the dose-response curves developed by the World Health Organization Europe [6] and the population exposed to L_{den} above 45 dB and L_{night} above 40 dB, the number of people highly annoyed by aircraft noise was estimated to be 4.0 million, and the number of people suffering from aircraft-induced high sleep disturbance was estimated to be 1.8 million. This is 7% and 5% less than in 2019 respectively.

[3] This is the number of people exposed to more than 50 aircraft noise events exceeding 70 dB every day.

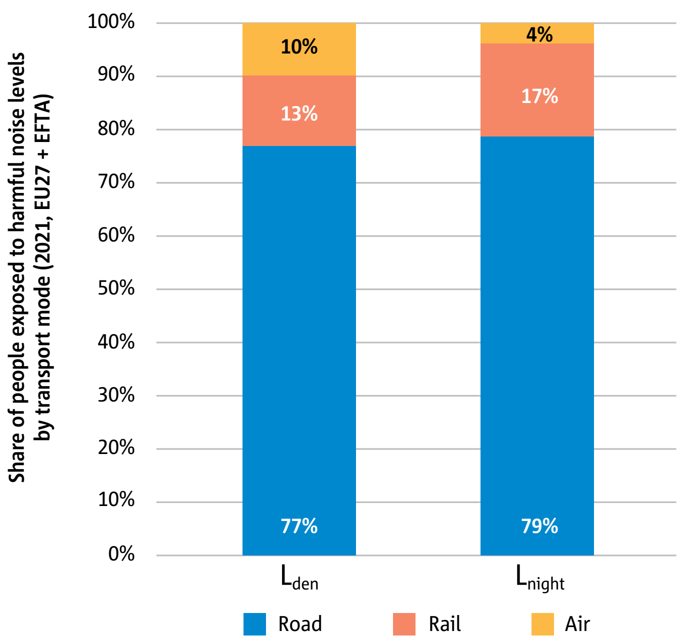
Figure 1.9 Summary of noise indicators (% change to 2005)



Note: *2030 and 2050 values are for the base traffic scenario. Blue and orange lines represent the range of aircraft/engine technology improvements. L_{den}, L_{night} and $N_{50}A_{70}$ indicators are for the 98 major European airports; noise energy is for all EU27+EFTA airports. An operation is either a departure or an arrival. Population concentration around airports is assumed constant after 2020.*

Aviation noise in context

Based on data reported by Member States every five years under the Environmental Noise Directive 2002/49/EC, it is estimated that in 2021 aviation represented around 11% of people who are highly annoyed by noise, based on exposure exceeding the WHO guideline values [11]. In terms of the number of people exposed above safe (WHO) guideline values, aviation represented about 10% of the EU27+EFTA population exposed to L_{den} levels above 45 dB and 4% of the population exposed to L_{night} levels above 40 dB in 2021. While this is a smaller share than road and railway, aircraft noise is generally perceived as more annoying than road or railway noise and health effects exist at noise levels around 10 dB lower than other sources [6].



1.3 EMISSIONS

Solutions exist to curb CO_2 emissions, but NO_X remains a challenge

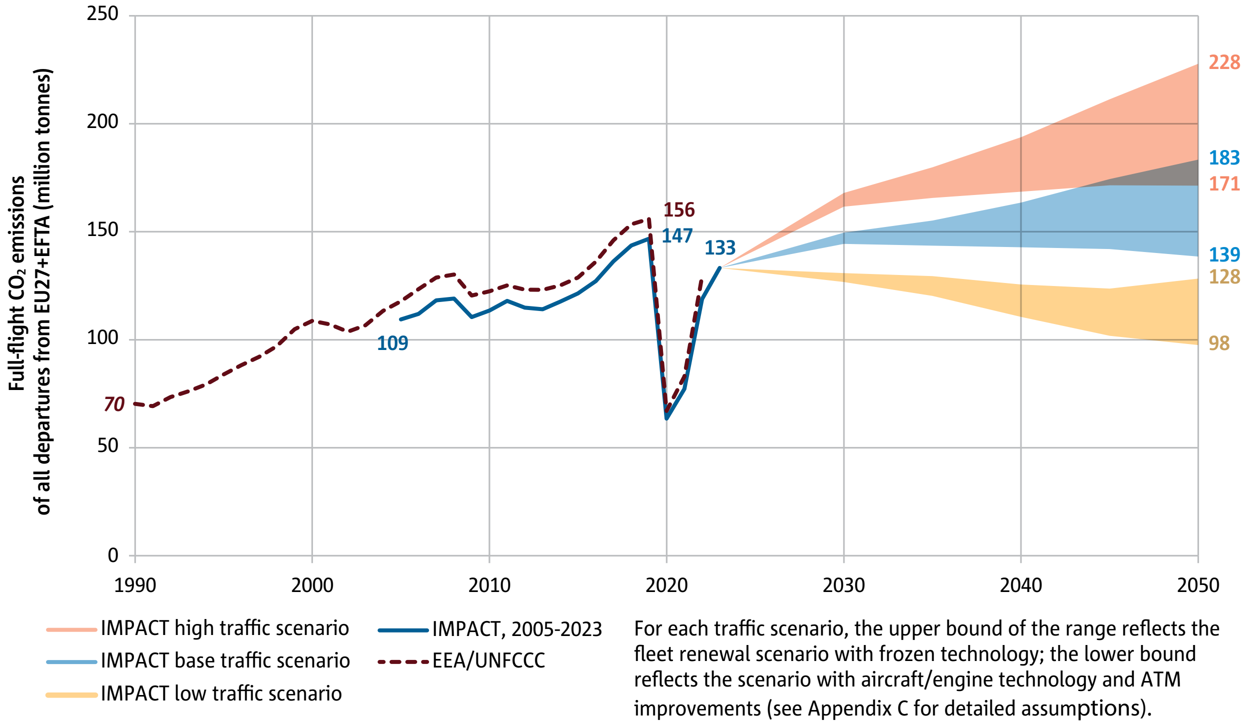
The full-flight carbon dioxide (CO_2) emissions of all flights departing from EU27+EFTA airports have followed a similar pattern to noise and were estimated to be 133 million tonnes in 2023, which is 10% below the 2019 peak (Figure 1.10a). Mainline and low-cost operators accounted for 52% and 28% of CO_2 emissions respectively in 2023 (Figure 1.11). Single-aisle and twin-aisle jets emitted 96% of total CO_2 emissions (almost equally split between the two categories), while long-distance flights (above 4 000 km) represented 46% (Figure 1.13). Flights with a destination outside EU27-EFTA accounted for 61% of CO_2 emissions (Figure 1.14).

In the short term, market-based measures are expected to stabilise European aviation's net (i.e. lifecycle) CO_2 emissions, while sustainable aviation fuels still show the greatest potential for reduction in the 2050 timeframe (Figure 1.10b). During 2023 the EU Emissions Trading System (ETS) achieved net CO_2 reductions of about 25 million tonnes (Mt) through the purchase of allowances by operators. In combination, the EU ETS, the CH ETS and the ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) could yield an average 39 Mt net CO_2 reduction per year over the period 2024-2026 (see Market Based Measures chapter for details).

Meeting the ReFuelEU Aviation [4] supply mandate for Sustainable Aviation Fuels (SAF) would cut net CO_2 emissions by at least 65 Mt (47%) in 2050 under the base traffic scenario. This is lower than the estimated 60.8% emissions reduction in the European Commission Impact Assessment for ReFuelEU Aviation due to more conservative assumptions [12]. The emission reductions in Figure 1.10b are based on the final ReFuelEU Aviation minimum level of SAF supply and emissions reductions in line with the mandate and sustainability criteria (see Appendix C for more details on the SAF scenario). Under ReFuelEU Aviation, EASA will collect data from aircraft operators and aviation fuel suppliers on SAF, including their sustainability characteristics. The actual reported values of SAF uptake and the CO_2eq emissions reductions for each SAF category will be used to inform the net CO_2 estimates in future versions of this report.

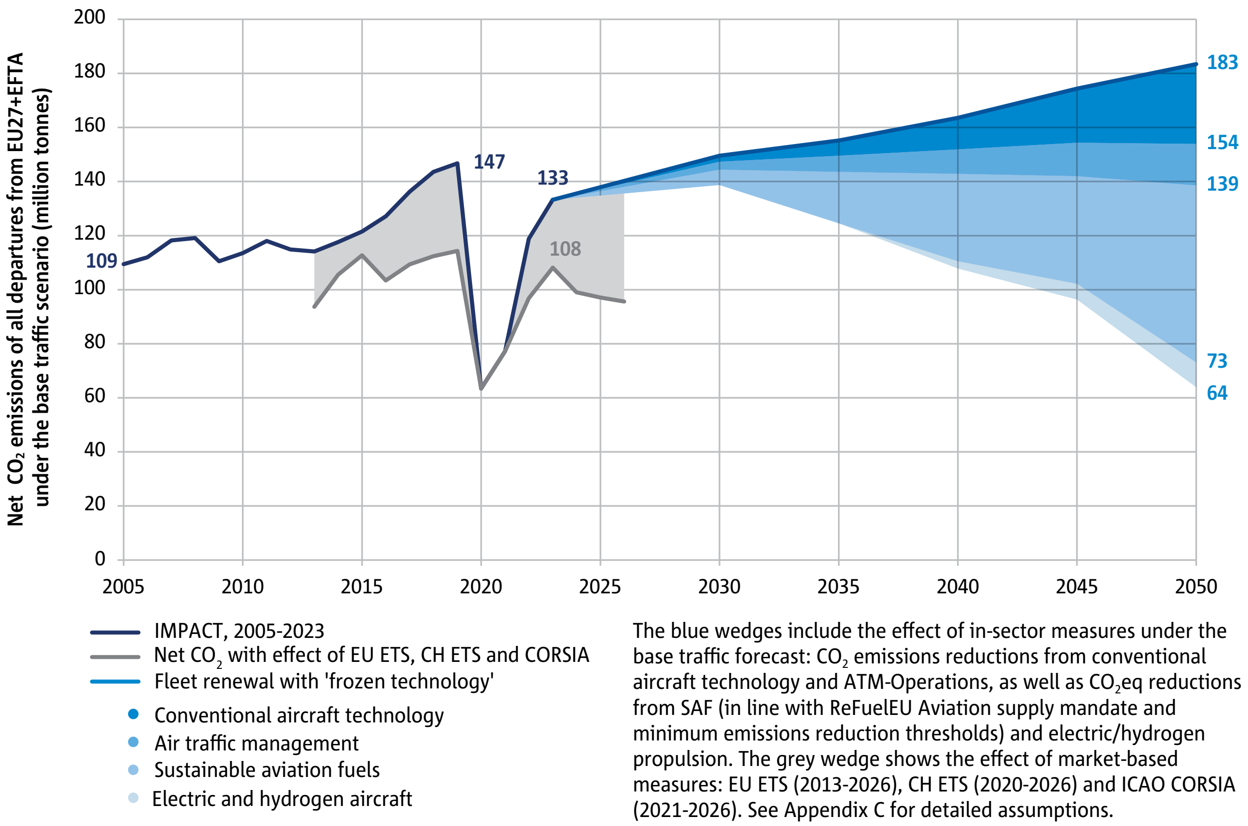
Electric and hydrogen aircraft were assumed to deliver an additional 5% net CO_2 reduction by 2050 and may have a larger emission reduction potential beyond this date.

Figure 1.10(a) **Aircraft technology and ATM improvements could prevent further growth in European aviation's CO_2 emissions over the next decades**



For each traffic scenario, the upper bound of the range reflects the fleet renewal scenario with frozen technology; the lower bound reflects the scenario with aircraft/engine technology and ATM improvements (see Appendix C for detailed assumptions).

Figure 1.10(b) **Meeting the SAF supply mandate would cut net CO_2 emissions by at least 47% in 2050**

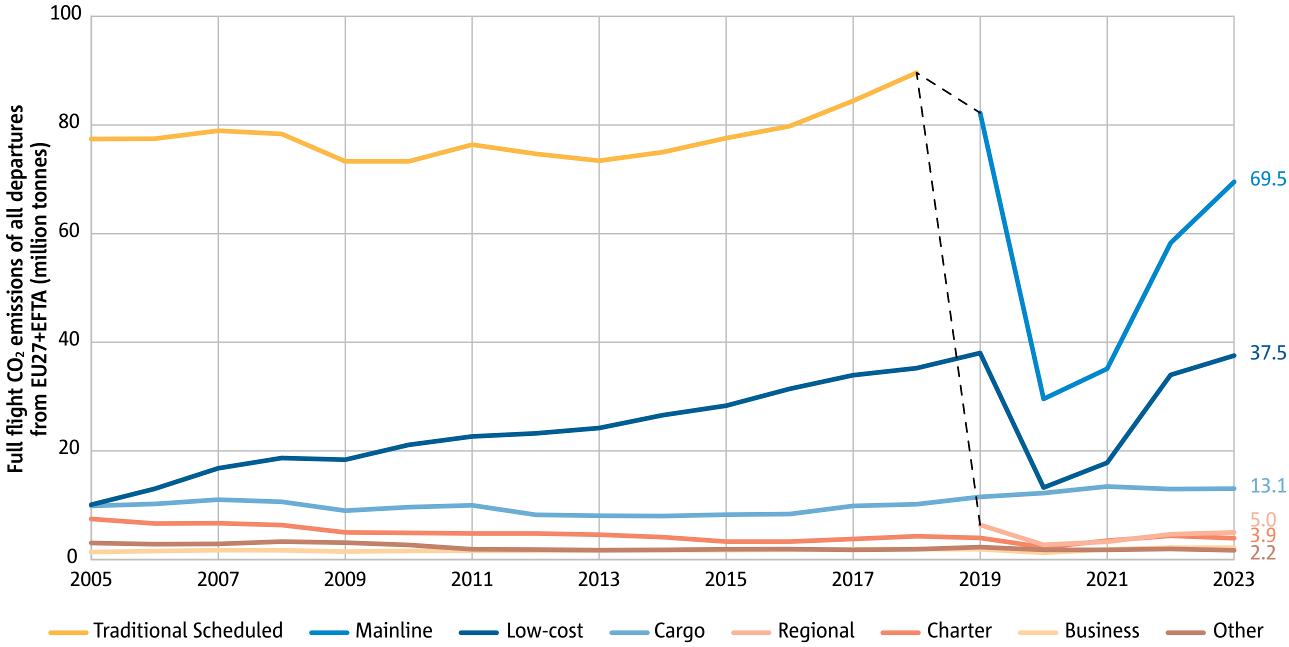


The blue wedges include the effect of in-sector measures under the base traffic forecast: CO_2 emissions reductions from conventional aircraft technology and ATM-Operations, as well as CO_2eq reductions from SAF (in line with ReFuelEU Aviation supply mandate and minimum emissions reduction thresholds) and electric/hydrogen propulsion. The grey wedge shows the effect of market-based measures: EU ETS (2013-2026), CH ETS (2020-2026) and ICAO CORSIA (2021-2026). See Appendix C for detailed assumptions.

ICAO Long Term Global Aspirational Goal

The 41st ICAO Assembly in October 2022 adopted a global Long-Term Aspirational Goal (LTAG) for international aviation of net-zero carbon emissions by 2050 in support of the Paris Agreement's temperature goal [13]. The LTAG does not attribute specific obligations or commitments in the form of emissions reduction goals to individual States. Instead, it recognizes that each State's special circumstances and respective capabilities will inform the ability of each State to contribute to the LTAG within its own national timeframe. Each State will contribute to achieving the goal in a socially, economically and environmentally sustainable manner and in accordance with its national circumstances, and ICAO will regularly monitor progress on the implementation of all elements of the basket of measures towards the achievement of the LTAG [14].

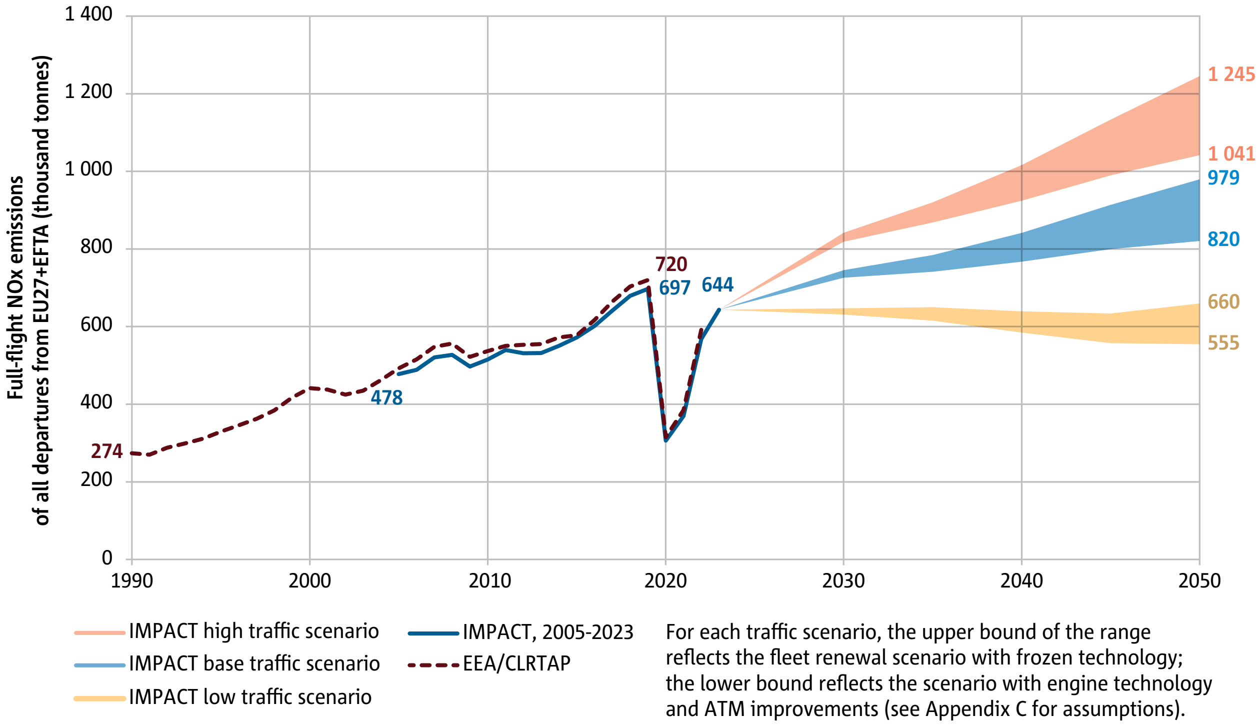
Figure 1.11 Mainline and low-cost operators account for 80% of total CO_2 emissions



Compared to the previous report, a slightly more conservative future engine technology scenario was used to predict emissions of nitrogen oxides (NO_X) out to 2050. The updated emissions trends chart (Figure 1.12) confirms that mitigating the growth in NO_X emissions over the next decades remains a challenge. The same conclusion applies to a lesser extent to volatile particulate matter (PM) emissions (Figure 1.15). Emissions of carbon monoxide (CO), unburnt hydrocarbons (HC) and non-volatile PM are expected to stabilise or even reduce by 2050 through the effect of fleet renewal and ATM improvements.

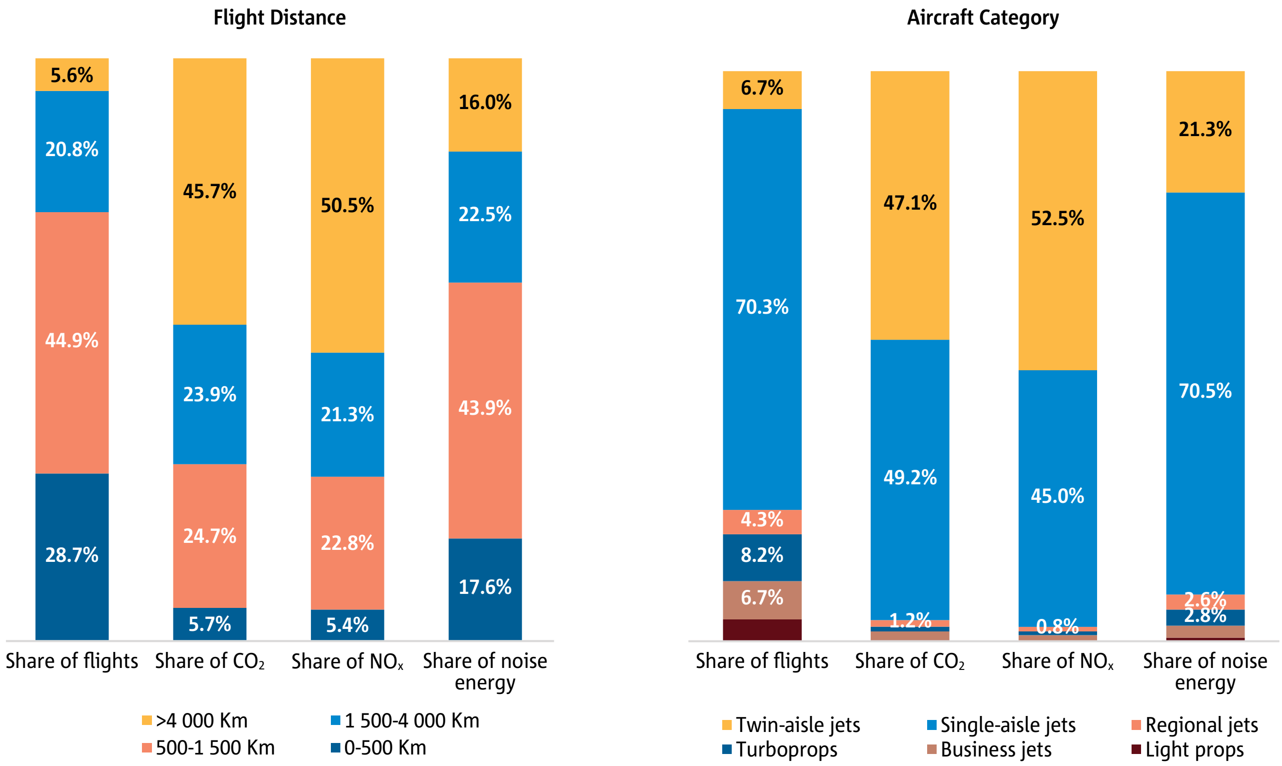
See Chapter 2 on Environmental Impacts for further information on the impacts of air pollutants, including ultrafine particles from aircraft, which is an emerging pollutant of concern that will be monitored under the revised EU Ambient Air Quality Directive.

Figure 1.12 NO_X emissions may continue to grow with traffic



For each traffic scenario, the upper bound of the range reflects the fleet renewal scenario with frozen technology; the lower bound reflects the scenario with engine technology and ATM improvements (see Appendix C for assumptions).

Figure 1.13 Single-aisle and twin-aisle jets generated over 90% of noise and emissions in 2023



European aviation emissions in context

In 2022, flights departing from EU27+EFTA represented 12% of total transport greenhouse gas (GHG) emissions and 4% of total GHG emissions in EU27+EFTA. Aviation GHG emissions of 2022 have already almost reached the pre COVID pandemic levels and increased by 84% compared to 1990. Overall, aviation was the third largest source of GHG emissions in the transport sector after road and waterborne transport [7]. This increase is mostly due to traffic growth outpacing energy efficiency improvements and reductions of emissions from other sectors [8].

NO_X emissions from aviation have more than doubled since 1990 in EU27+EFTA, reaching a share of 14% in overall NO_X transport emissions of EU27+EFTA in 2022, which is similar to the pre-COVID share and represents an increase of 11% compared to 1990. This increase is mostly due to the growth in air traffic not being offset by the incremental improvements in engine technology to mitigate NO_X emissions, which is more technically complex compared to other modes of transport. In 2022, aviation was responsible for 4% of all $PM_{2.5}$ emissions from transport in EU27+EFTA, with absolute emissions increasing by 35% since 1990. Similar to NO_X emissions, the overall share of $PM_{2.5}$ is essentially back to pre-COVID levels. Black carbon, sulphur oxides and ammonia are among the other pollutants for which emissions from aviation have also increased since 1990 [9].

Despite the ongoing decarbonisation efforts, and the development of low carbon emissions aircraft (e.g. electric or hydrogen), air pollution from the sector will remain a challenge in the future.

Figure 1.14 **Extra-EU27+EFTA flights represented 23% of departures and 61% of CO_2 emissions in 2023**

Flight Emissions Label

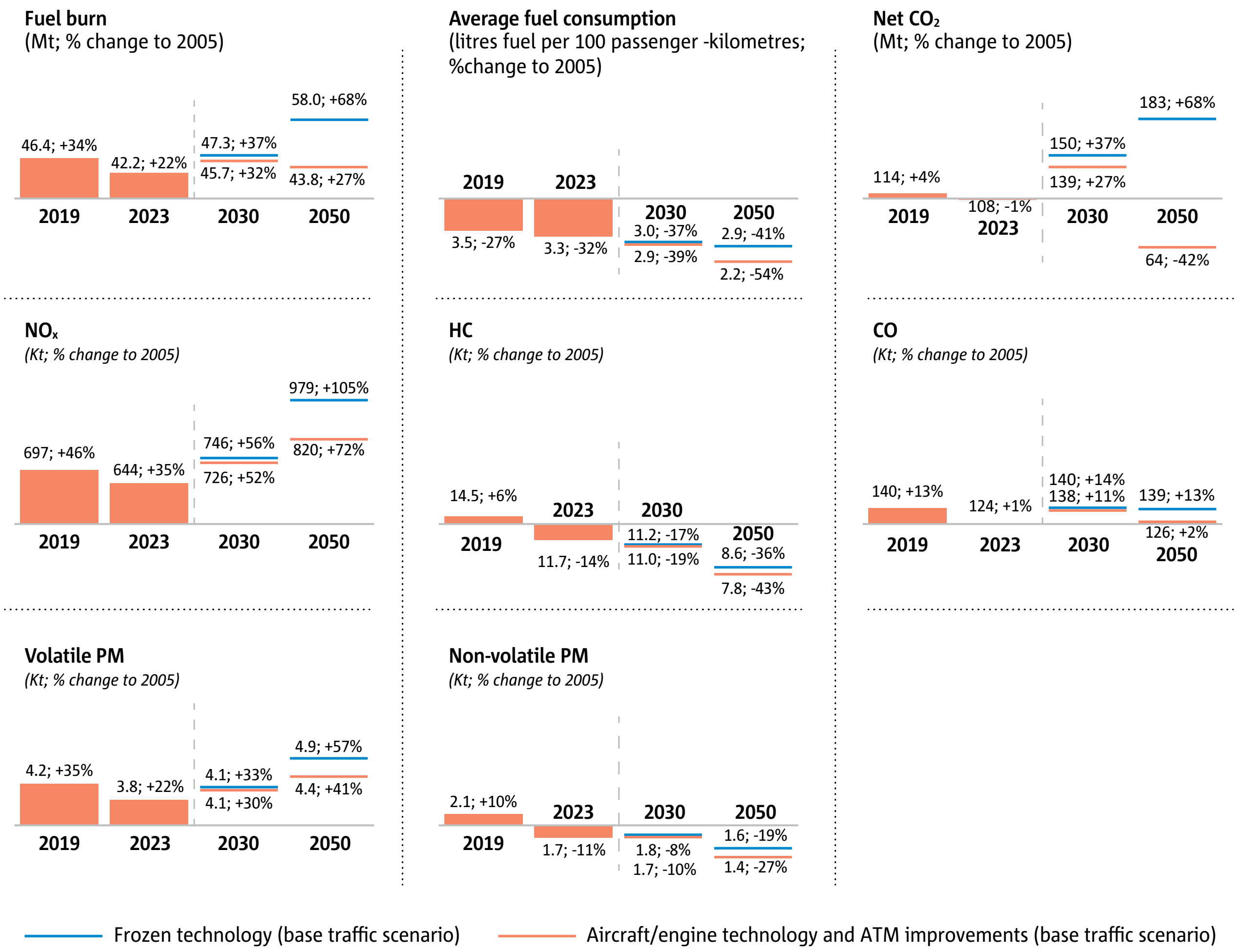
Passengers need to be able to trust the information from aircraft operators regarding the environmental performance of their flights to make informed choices when comparing different options. The current lack of a common methodology, criteria and indicators with adequately reported, certified and monitored results does not facilitate this. As such, in order for consumers to be able to make an informed choice, more robust, reliable, independent and harmonised information is needed on the environmental impact of flights.

Pursuant to Article 14(11) of the ReFuelEU Aviation Regulation [4], the European Commission prepared an Implementing Act to be adopted by the end of 2024 setting out a standardised and science-based methodology to be applied for the estimation of flight emissions. The rules and conditions laid down in the proposal will incentivise competition between aircraft operators to reduce their emissions by improving the legal certainty of their environmental claims in relation to aviation fuels they purchase and use in their flights.

Airlines who volunteer to participate in the Flight Emissions Label will have to report operational data to EASA who will estimate emissions of future flights. In return airlines will receive an approved label based on two metrics (kgCO_2eq per passenger and kgCO_2eq per passenger-kilometre). EASA is also tasked with setting up a website to provide passengers with detailed information on the flight emissions label, such as the methodology, assumptions and emissions estimations.

In April 2024, the European Commission and the EU Consumer Protection Cooperation Network initiated an investigation against 20 airlines with respect to potentially misleading green claims [1]. This followed a similar finding in a Dutch court that environmental claims made by an airline were misleading and were in breach of consumer protection laws [2]. These types of claims are not confined to the aviation sector, and the European Commission is proposing a new Directive on Green Claims to increase confidence in the environmental information provided by companies on their product and services [3]. This type of policy measure to increase transparency recorded the highest levels of public support in a recent survey [5].

Figure 1.15 Summary of full-flight emission indicators (% change to 2005)



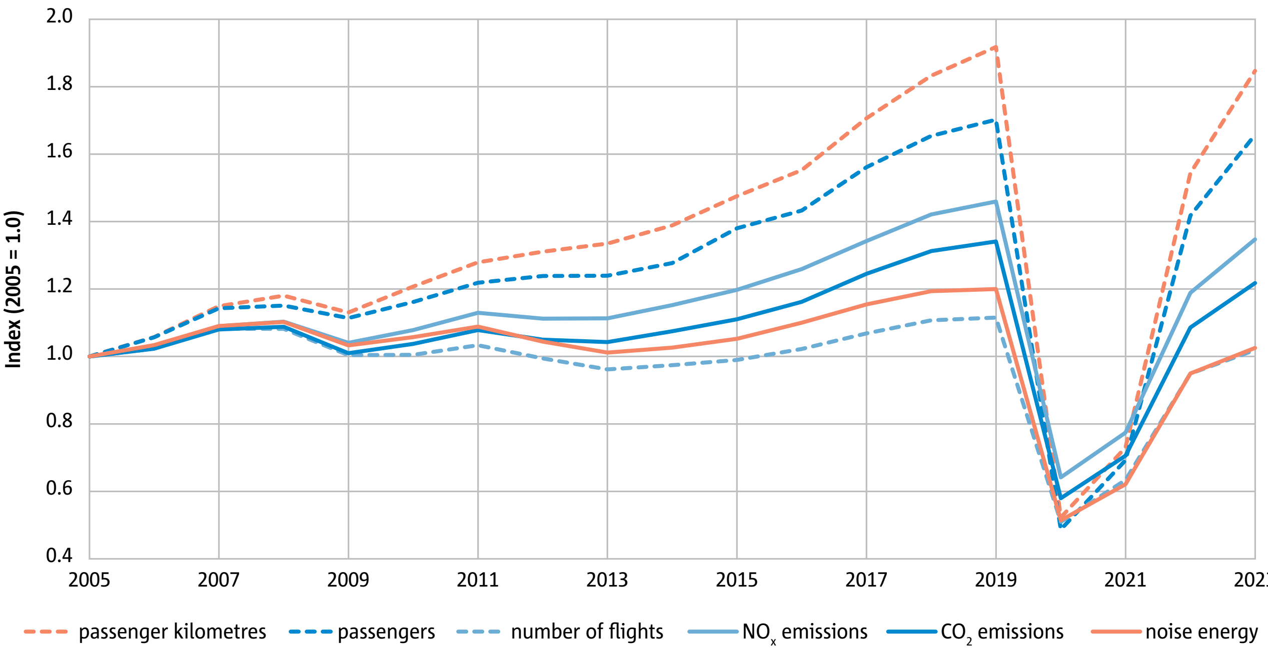
Note: *2030 and 2050 values are for the base traffic scenario. Blue and orange lines represent the range of aircraft/engine technology and ATM improvements. The net CO_2 indicator includes emission reductions from the EU ETS up to 2023, sustainable aviation fuels (SAF) and electric/hydrogen propulsion out to 2050. No assumptions on potential improvements to HC, CO and PM have been made out to 2050 from technology and SAF.*

Average fuel consumption is for commercial passenger aircraft only and does not take into account belly freight. Kilometres used in this indicator represent the shortest (or great circle) distance between origin and destination, while fuel consumption is based on the actual flown distance (i.e. this indicator includes the effect of ATM horizontal inefficiency).

1.4 ENVIRONMENTAL EFFICIENCY

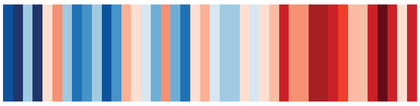
After the COVID pandemic, noise and emissions of European aviation have resumed their growth, although at a slower rate than passenger kilometres (Figure 1.16). The average grams CO_2 per passenger kilometre (gCO_2/pkm) was 83 in 2023, against 89 in 2019, equivalent to an average 2.1% per annum fuel efficiency improvement since 2005. It could continue decreasing down to 56 gCO2/pkm (or 2.2 litres fuel per 100 passenger kilometres) in 2050 under the considered fuel efficiency improvement scenario for future aircraft deliveries and ATM improvements scenario. NO_X emissions have grown faster than CO_2 since 2009 and are expected to continue to do so without further improvement in engine technology.

Figure 1.16 **CO_2 emissions continue to grow faster than noise energy, but slower than NO_X**



2

AVIATION ENVIRONMENTAL IMPACTS



- Latest IPCC, WMO and Copernicus Climate Change Service all highlight widespread, rapid and record-breaking changes in the climate and extreme weather events, with Europe warming twice as fast as the global average making it the fastest warming continent in the world.
- In 2022, all departing flights accounted for 4% of EU27+EFTA total greenhouse gas (GHG) emissions.
- The overall climate impact from aviation is a combination of both its CO_2 and non-CO_2 emissions (e.g. NO_X, PM, SO_X, water vapour and subsequent formation of contrail-cirrus clouds).
- The estimated Effective Radiative Forcing (ERF) from historic non-CO_2 emissions between 1940 and 2018 accounted for more than half of the aviation net warming effect, but the level of uncertainty from the non-CO_2 effects is 8 times higher than that of CO_2.
- Further research on the climate impact of non-CO_2 emissions from aviation, especially on induced changes in cloudiness and methodologies to estimate aircraft GHG inventories, is required to reduce uncertainties and support robust decision-making.
- Emissions with a short-term climate impact (e.g. NO_X) can be expressed as equivalent to emissions with long-term climate impacts (e.g. CO_2) in order to assess trade-offs of mitigation measures, but this is influenced by the metric and time horizon used.
- A non-CO_2 MRV framework began on 1 January 2025 aiming at monitoring, reporting and verifying the non-CO_2 emissions produced by aircraft operators. This framework is designed to provide valuable data for scientific research that will enhance our understanding of non-CO_2 effects and help address aviation climate impacts more effectively.
- A European Parliament pilot project was launched in 2024 to explore the feasibility of optimizing fuel composition in order to reduce the environmental and climate impacts from non-CO_2 emissions without negatively impacting safety (e.g. lower aromatics, sulphur).
- The Aviation Non-CO_2 Expert Network (ANCEN) has been established to facilitate coordination across stakeholders and to provide objective and credible technical support that can inform discussions on potential measures to reduce the climate impact from non-CO_2 emissions.
- Aviation adaptation and resilience to climate change will be critical to address projected future trends in hazardous weather events (e.g. severe convective storms and clear air turbulence) and changes to climatic and environmental conditions (e.g. sea level rise, changes to prevailing surface winds, upper atmosphere turbulence).
- Aircraft engine emissions (mainly NO_X and particulate matter) impact air quality around airports. Exposure to NO_2 and ultrafine particles levels from aviation could be significant in residential areas in the vicinity of airports.
- The Environmental Noise Directive 2022 data estimates 649 000 people experience high levels of annoyance due to aircraft noise, while 127 000 suffer from significant sleep disturbances.
- The REACH[1] Regulation restrictions on Substances of Very High Concern (e.g. chromium trioxide, PFAS) are impacting the aviation sector due to the absence of immediate alternatives.

[1] Registration, Evaluation, Authorisation and restriction of CHemicals (REACH)

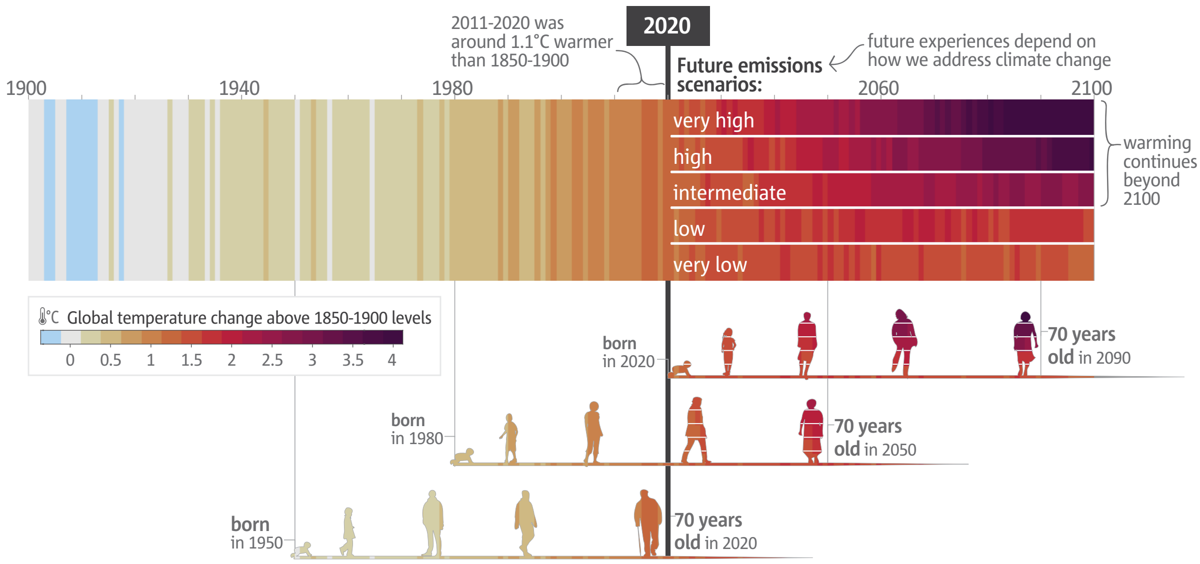
2.1 CLIMATE CHANGE

The United Nations Intergovernmental Panel on Climate Change (IPCC) is responsible for providing policymakers with regular scientific assessments. In 2023 the IPCC published the Synthesis Report which integrates the findings from Working Group reports and the Special Reports during the 6th Assessment cycle [1]. It concluded that human activities, principally through emissions of greenhouse gases (GHG), have unequivocally caused global warming, with global surface temperature reaching 1.1°C above a baseline 1850-1900 level in 2011-2020. Global GHG emissions have continued to increase, with unequal historical and ongoing contributions arising from unsustainable energy use, land use and land-use change, lifestyles and patterns of consumption and production.

The impact of a rapid-warming climate can already be noted across the globe, with widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere exacerbating weather and climate extremes. The extent to which current and future generations will experience a hotter and different world depends on choices made now and in the near term (Figure 2.1).

In 2023, the WMO State of the Global Climate Report [3] and the European State of the Climate Report [4] both

Figure 2.1 Future warming scenarios depend on choices made now and in the near term[2] [2]



[2] Observed (1900–2020) and projected (2021–2100) changes in global surface temperature (relative to 1850-1900), which are linked to changes in climate conditions and impacts, illustrate how the climate has already changed and will change along the lifespan of three representative generations (born in 1950, 1980 and 2020). Future projections (2021–2100) of changes in global surface temperature are shown for very low (SSP1-1.9), low (SSP1-2.6), intermediate (SSP2-4.5), high (SSP3-7.0) and very high (SSP5-8.5) GHG emissions scenarios. Changes in annual global surface temperatures are presented as 'climate stripes', with future projections showing the human-caused long-term trends and continuing modulation by natural variability (represented here using observed levels of past natural variability). Colours on the generational icons correspond to the global surface temperature stripes for each year, with segments on future icons differentiating possible future experiences.

highlighted that records were once again broken for greenhouse gas levels, surface temperatures, ocean heat and acidification, sea level rise, Antarctic Sea ice cover loss and glacier retreat. A recent acceleration in the increase of atmospheric CO_2 concentrations was also reported resulting in the highest ever level in the last 800 000 years of 427 parts per million in 2024 [5]. Extreme weather events under climate change, such as heatwaves, floods, droughts, wildfires, and rapidly intensifying tropical cyclones have impacted millions of lives and inflicted billions of euros in economic losses [6]. 2023 was confirmed as the warmest year on record with the global average near-surface temperature at 1.45°C above the pre-industrial baseline, culminating in the warmest ten-year period on record (Figures 2.2 and 2.3).

Figure 2.2 Ranking of annual average sea surface temperature in 2023 [4]

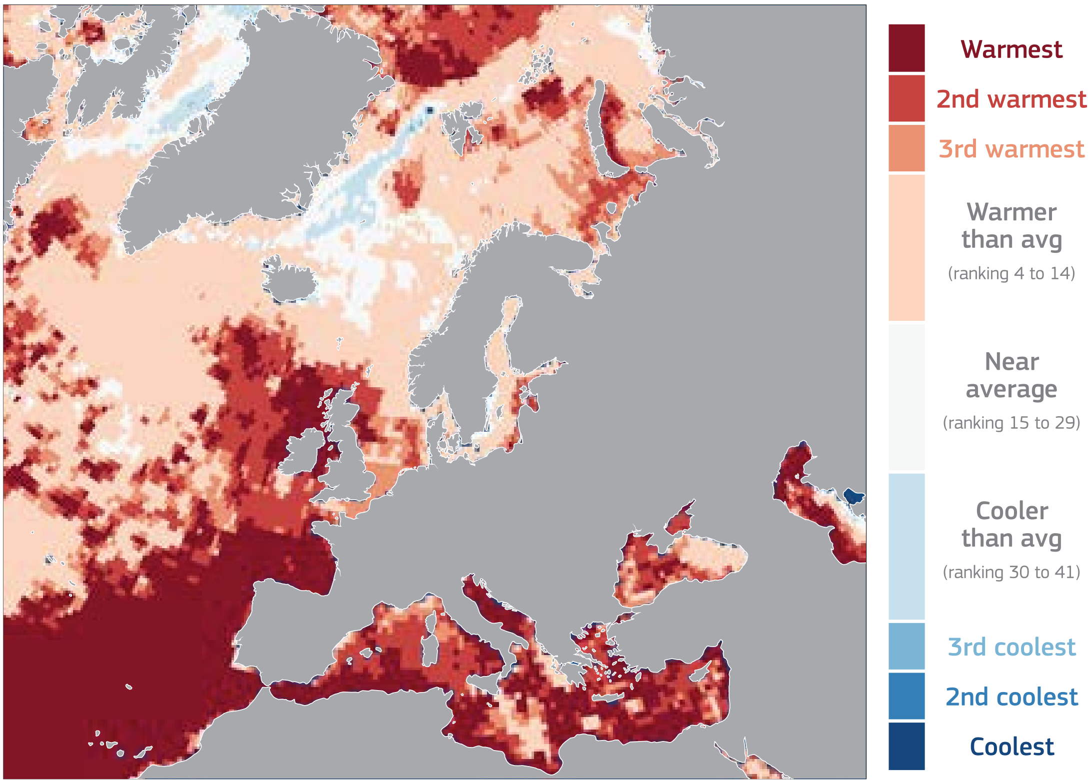
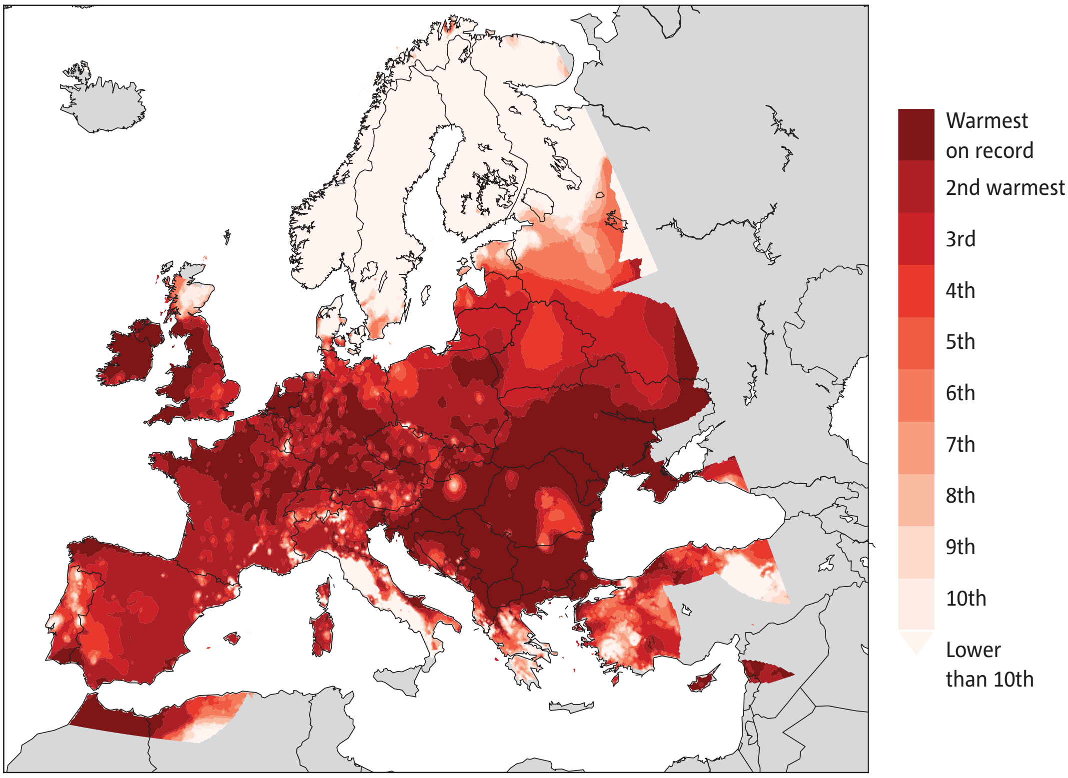


Figure 2.3 Ranking of annual average surface air temperature in 2023 [4]

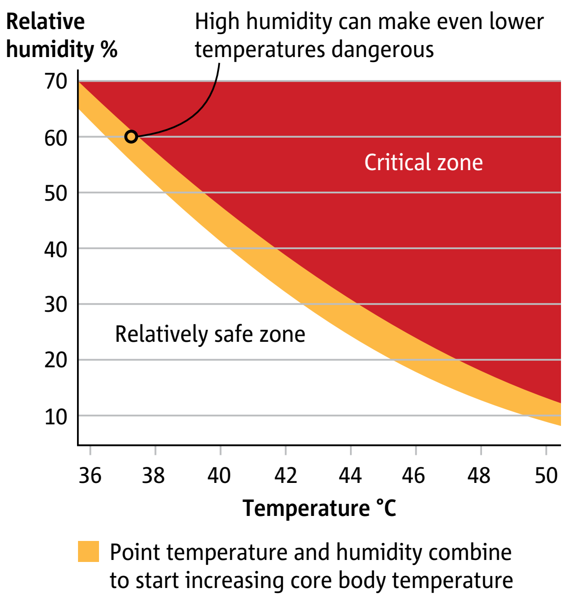


How hot is too hot for the human body? [7]

The IPCC states that climate change adversely affects both physical health and mental health.

Our body's ability to cool down through sweat that evaporates into the air is impeded by humidity, as such the critical zone where core body temperature starts to rise rapidly is defined by both temperature and humidity.

Once a core body temperature of 41-42 degrees centigrade is reached, this can lead to heat stroke and significant medical problems if not treated appropriately.



Aviation CO_2 emissions

Aviation accounted for approximately 2.5% of global CO_2 emissions in 2023. Absolute emissions have been growing significantly with 47% of aviation CO_2 emissions between 1940 and 2019 having occurred since 2000 [8].

Aviation non-CO_2 emissions

The overall climate impact from aviation emissions is a combination of both its CO_2 and non-CO_2 emissions that include Nitrogen Oxides (NO_X), Particulate Matter (soot), Sulphur Oxides (SO_X) and water vapour as well as the subsequent effects from the formation of contrail-cirrus clouds and aerosol-cloud interactions.

Aviation emissions and their climate effects

In terms of departing flights from the EU27+EFTA, EEA/UNFCCC data on GHG emissions from aviation peaked at around 156 $MtCO_2e$ in 2019 (an increase of 122% compared to 1990) and represented 4% of total GHG emissions in 2022. This increase was mostly driven by international aviation, including between EU27+EFTA States, that in 2019 emitted 8.7 times more than domestic aviation.

The latest assessment on the climate impact from historic air traffic emissions between 1940 and 2018 [9] estimated that the Effective Radiative Forcing (ERF)[3] from non-CO_2 emissions accounted for more than half of the aviation net warming effect. However, it is also important to note that uncertainties associated with such estimates are up to 8 times larger than that from CO_2 and the overall confidence levels of the largest non-CO_2 effects are 'low' (Figure 2.4), and there are currently no best estimates for the ERF from aerosol-cloud interactions. This calls for a continuous research effort to increase the overall confidence of such calculations.

When considering the effect of mitigation measures on the climate impact of future aviation emissions, it is important to note that CO_2 represents a long-term (decades to millennia)[4] climate forcer and non-CO_2 emissions are short-term (weeks to decades) climate forcers. This effect can be seen in Figure 2.5 where an approximate 70% reduction in air traffic during 2020 due to the COVID pandemic led to a reduction in the annual ERF from non-CO_2 emissions while the ERF from CO_2 emissions remained fairly constant.

Air traffic-induced changes in cloudiness are considered to be potentially significant aviation climate forcing components but also the most uncertain. Changes in cloudiness are caused by the formation of contrails and their persistence in ice supersaturated air leading to the formation and persistence of contrail cirrus, and additionally to changes in the formation of natural clouds from aviation aerosols. The initially line-shaped contrails can be detected in satellite images and can transform within a few hours, if persistent, into contrail cirrus that may be indistinguishable from naturally formed cirrus clouds (Figure 2.6).

The properties and climate impact (cooling / warming) of contrail cirrus can vary widely depending on the time of day, ambient atmospheric conditions and on the aerosols emitted by the aircraft. Further research into the aspects of aviation induced changes in cloudiness will enhance understanding of aviation non-CO_2 effects. This includes:

1. The formation of contrail ice crystals on remaining soot particles and emitted volatile particulate matter, in the case of lean burn engines, and on oil droplets [13], chemi-ions and ambient aerosols mixed into the aircraft plume [14].

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3 Radiative Forcing (RF) is a term used to describe when the amount of energy that enters the Earth's atmosphere is different from the amount of energy that leaves it. Energy travels in the form of radiation: solar radiation entering the atmosphere from the sun, and infrared radiation exiting as heat. If more radiation is entering Earth than leaving, then the atmosphere will warm up thereby forcing changes in the Earth's climate. The metric Effective Radiative Forcing (ERF) was introduced in the IPCC Fifth Assessment Report in 2013 as a better predictor of the change in global mean surface temperature due to historic emissions by also accounting for rapid adjustments in the atmosphere (e.g. thermal structure, clouds, aerosols etc.).

4 At its simplest, carbon dioxide cycles between the atmosphere, oceans and land biosphere. Its removal from the atmosphere involves a range of processes with different time scales. About 50% of a CO_2 increase will be removed from the atmosphere within 30 years, and a further 30% will be removed within a few centuries. The remaining 20% may stay in the atmosphere for many thousands of years (IPCC 4th Assessment Report, 2007). This is further elaborated in the 5th and 6th assessment reports.

Figure 2.4 Latest best estimates for climate forcing terms of historic global aviation emissions from 1940 to 2018 [9]

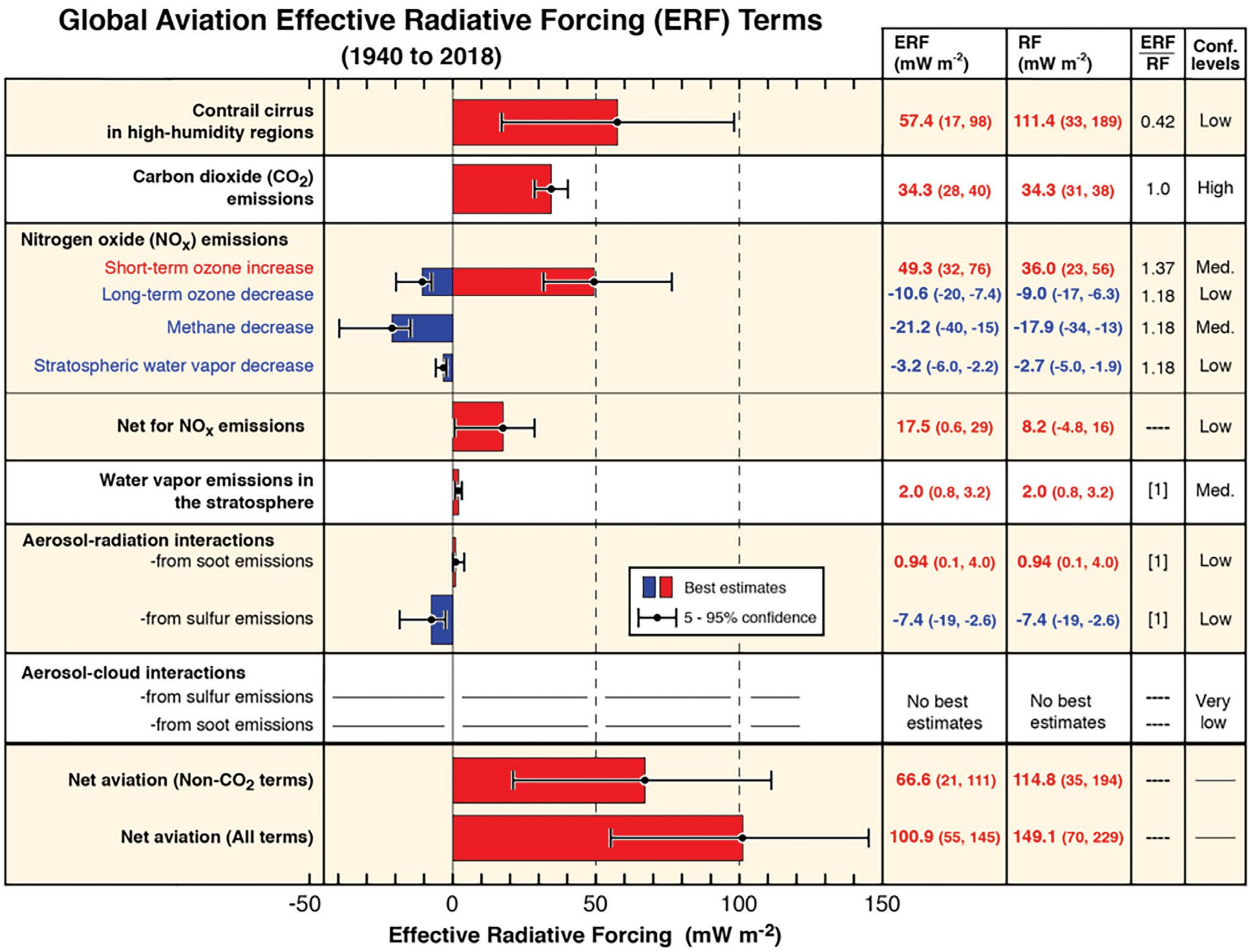
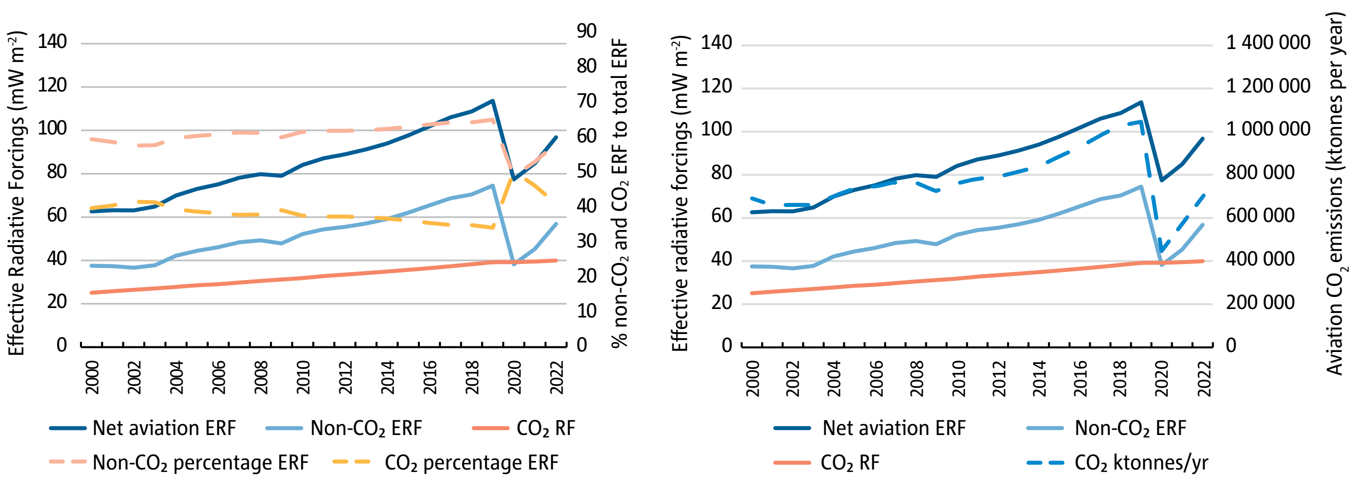


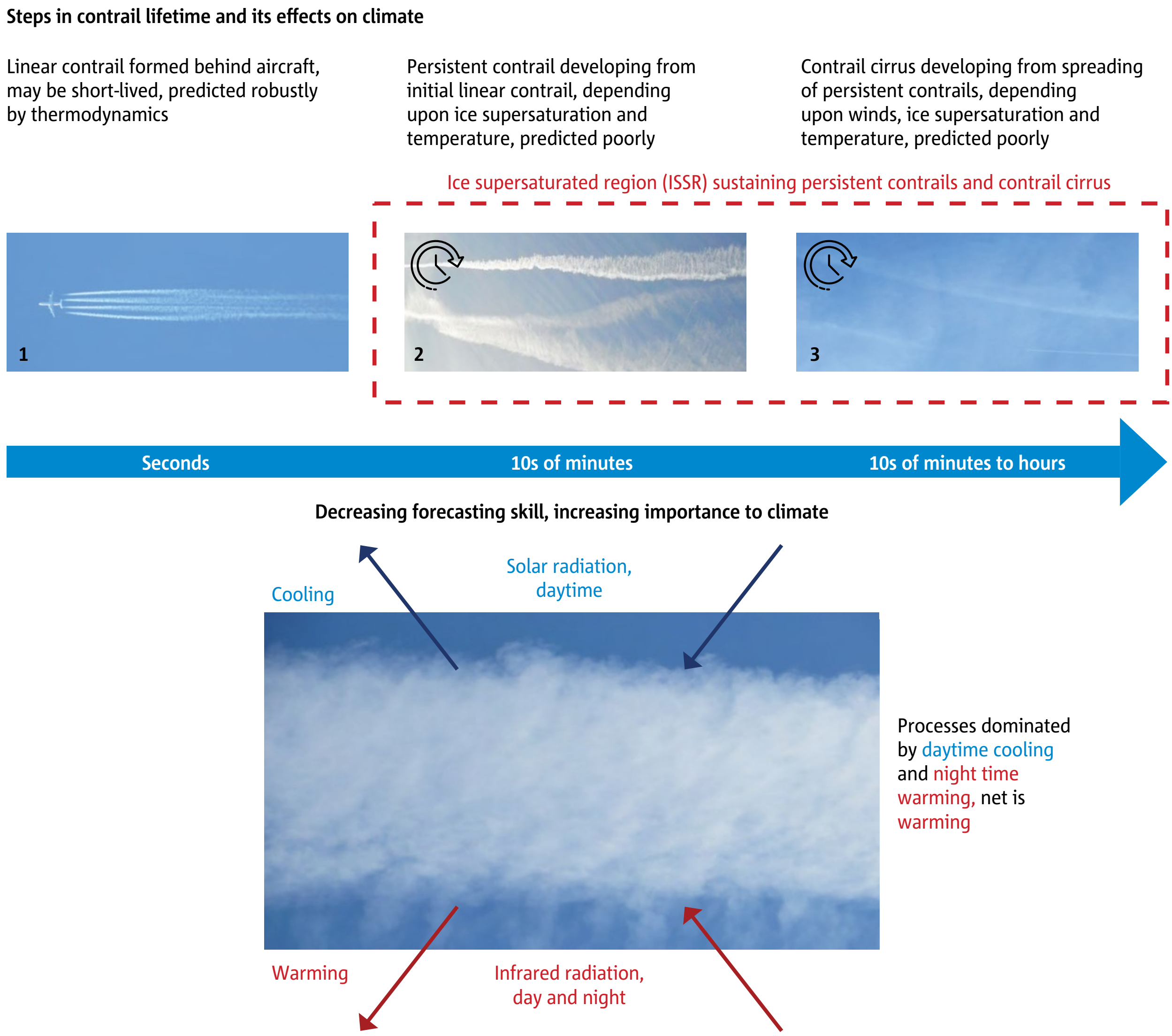
Figure 2.5 Effect on CO_2 and non-CO_2 Effective Radiative Forcing (ERF) during the COVID pandemic [extended analysis based on 9]



2. The formation of contrail cirrus may lead to reductions in natural cirrus cloudiness, although the size of this effect is even more uncertain than the contrail cirrus climate impact, with only one study suggesting this feedback may reduce the contrail cirrus climate impact by half [15].
3. Natural cloudiness changes when aircraft fly through clouds, due to contrail formation within clouds [16], is an effect that is currently not included in estimates of contrail climate impact.
4. The impact of aerosols emitted by air traffic on the formation of natural clouds is highly uncertain. Studies disagree on the magnitude of the impact of soot emissions on cirrus cloudiness, although most suggest a cooling to near zero net effect. In contrast, the cooling effect connected with changes in mid-tropospheric cloudiness caused by sulphur emissions is clear, but the magnitude is similarly uncertain [17].

Introducing new technology such as lean burn engines or alternative fuels, including hydrogen, could also lead to changes in aerosol emissions and as mentioned, to the chemistry of climate forcing compounds in general. With the potential emergence of future aircraft fuelled by liquid hydrogen from renewable energy, these aircraft could support zero CO_2 emissions flights but would still emit NO_X and water vapour, although technical solutions (e.g. fuel cells) are also looking to limit these emissions. Gaseous hydrogen emissions could also affect atmospheric chemistry by impacting the lifetime of other greenhouse gases, namely methane, ozone, and water vapour, with an overall climate warming effect [18]. As such, existing best practice methodologies to estimate aircraft GHG inventories may need to be reviewed and updated in order to remain fit for purpose [19].

Figure 2.6 Formation of contrails and timescales [10]



Mitigation measures to reduce the overall climate impact

In-sector mitigation measures from technology, operations and fuels, which are covered in other Chapters of this report, contribute to reductions in both CO_2 and non-CO_2 emissions and the achievement of both ICAO goals and general European climate targets as part of the path towards climate neutrality.

When assessing the future effect of mitigation measures on the climate impact of aviation emissions, the impact from non-CO_2 emissions could be expressed as CO_2 equivalent emissions in order to assess trade-offs. However, this equivalence is influenced by the inherent uncertainties in the ERF terms as well as the metric (e.g. ATR, GWP),[5] background atmospheric conditions and time horizon chosen. Cost-effective actions should continue to be considered in order to reduce the overall climate impact from all aviation emissions, taking into

5 The metric Average Temperature Response (ATR) include 'efficacy', which is particularly useful for accounting for the impact of contrails as it represents the change in global mean temperature per unit climate forcing exerted by the forcing agent, relative to the response generated by a standard CO_2 forcing starting from the same initial climate state. Global Warming Potential (GWP) is commonly used in international climate policy and agreements, including in the Paris Agreement, and can be adjusted with efficacy.

European body for jet fuel standards and safety certification

This European Parliament has requested a pilot project (2023-2027), implemented by DG MOVE and EASA, to explore the feasibility of optimising fuel composition in order to reduce the environmental and climate impacts from non-CO_2 emissions without negatively impacting safety (e.g. lower aromatics, sulphur). The project includes preparatory work to develop a fuel standard for kerosene whilst maximizing SAF benefits, as kerosene and SAF will be increasingly blended in the future. The project will also assess the potential establishment of an EU Aviation Fuels Standardisation Body.

account the remaining uncertainties in non-CO_2 effects as part of a risk-based assessment in order to ensure confidence in robust mitigation gains.

Past efforts to mitigate the climate impact from aviation have focused on CO_2 emissions to a large extent. However, there are existing measures to mitigate the impact of non-CO_2 emissions including aircraft engine emissions certification standards for NO_X and nvPM and the promotion of Sustainable Aviation Fuels (SAF). The large sensitivity of contrail formation and, consequently, the contrail climate impact of aerosol emissions [11] indicates that introducing cleaner fossil-based fuels and Sustainable Aviation Fuels (e.g. lower aromatics, sulphur), would be a promising mitigation method in the formation of persistent contrail-cirrus clouds. Nevertheless, the introduction of SAF alone may not balance the increase in contrail cirrus climate impact due to the current and forecasted increases in air traffic [12].

Additional mitigation measures are being explored within Europe and internationally. This includes efforts to promote cleaner fuels through fuel standards and to demonstrate the feasibility of incorporating contrail mitigation into the routine operations of the Single European Sky Network Manager and Air Navigation Service Providers. Research to enhance weather and contrail forecasting capabilities will be critical to assess where significant mitigation benefits can be achieved and the associated costs to avoid persistent contrail formation [20, 21, 22]. The updated EU Innovation Fund has supported mitigating these impacts since 2023.

Based on the 2023 revisions to the EU ETS Directive [23] and the 2040 climate target communication [24], the European Commission has also developed a Monitoring, Reporting, and Verification (MRV) framework in line with the precautionary principle to address the non-CO_2 aviation effects on climate change [25]. The revised EU ETS Directive requires aircraft operators to monitor and report once a year on the non-CO_2 aviation effects occurring from 1 January 2025. By the end of 2027, based on the results from the application of the MRV framework for non-CO_2 aviation effects, the Commission shall report and, where appropriate, act with a legislative proposal to mitigate non-CO_2 by expanding the scope of the EU ETS.

The MRV is applicable from 1 January 2025 and is based on the two guiding principles of:

1. Flexibility
    - Use of GWP metric with multiple time horizons (20, 50 and 100 years);
    - Simplified approach for small aeroplane operators with emissions below a threshold;
    - MRV IT tool provided by the Commission to automate processes and minimise administrative effort (operators also allowed to use their own alternative tools); and
    - Provision of default values, where needed to fill data gaps (e.g. engine identifier, fuel properties).
2. Precision – requires the ‘weather-dependent’ approach to be used as a default approach.

Research and Coordination Initiatives

This project is funded from the European Union's Horizon Europe Programme

In 2020, EASA published a report on the latest scientific understanding of the climate impact from aviation non-CO_2 emissions and associated policy measures [26]. Since then, there have been significant new research initiatives looking at how to mitigate the overall climate impact of aviation emissions (CO_2 and non-CO_2) within various EU programmes (e.g. Horizon Europe, Clean Aviation, SESAR) as well as national projects.

In order to bring greater cohesion to this research, the European Commission and EASA set-up the Aviation Non-CO_2 Experts Network (ANCEN) in 2024. The network, fully funded by Horizon Europe, serves as a forum to facilitate a coordinated approach among key European experts from various stakeholder groups, including policymakers, scientific/research community, industry and civil society. It aims to reach a common understanding on issues in order to provide objective, timely and credible technical advice to inform discussions across various areas (e.g. research, analysis, policy, technology, operations, fuels). While not a regulatory body, ANCEN seeks to support the development of capabilities (e.g. data, modelling) that can inform robust decision-making on the implementation of mitigation measures. Information on the terms of reference, membership, future work and an overview of ongoing non-CO_2 research initiatives in Europe can be found on the ANCEN website [27].

2.2 AVIATION ADAPTATION AND RESILIENCE TO CLIMATE CHANGE

Since the 1980s, Europe has been warming twice as fast as the global average, thereby becoming the fastest-warming continent on Earth [4]. As such, Regulation (EU) 2021/119, which is known as the 'European Climate Law' [28], requires Union institutions and Member States *'to ensure continuous progress in enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change'.*

Adapting to climate change is a priority for the EU, which has adopted a 'Strategy on Adaptation to Climate Change' in 2021 [29]. This strategy addresses the need to improve the existing knowledge and management of the uncertainties associated with climate change and foresees the development of adaptation policies in all sectors.

The 6th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) explains that climate change magnifies the impacts of severe weather and climate related events, such as storms and hurricanes, heatwaves, heavy precipitation, river flooding, storm surges, droughts, wildfire, sand and dust storms. Such severe events are becoming both more intense and/or more frequent and occurring in new regions or at new times of the year, thereby leading to significant operational disruptions for aviation with an associated safety and economic impact. The first European Climate Risk Assessment (EUCRA) published in 2024 [30] has highlighted that Europe's policies and adaptation actions are not keeping pace with the rapidly growing risks.

Research on climate change in the coming decades has predicted:

- a significant increase of hazardous levels of Clear Air Turbulence (CAT)[6] at typical cruise levels over Europe, North Atlantic, North America, North Pacific and Asia.
- an increase in frequency of severe thunderstorms (especially over southern Germany, Italy and southern France) with associated increasing risks for aircraft and ground equipment related to hail and lightning strikes.
- an increase of the duration and intensity of heatwaves in Europe, North America and Asia, decreasing aircraft take-off performance, potentially causing significant damage to ground infrastructure and equipment and health risks for passengers and personnel.

An overview of climate effects on commercial aviation safety/health, operations and infrastructure is provided in Figure 2.7. More detailed information on scientific works regarding these trends can be consulted in the annual report of the EASA Scientific Committee [31].

Given that the typical lifetime of aircraft and infrastructure equipment is several decades, costly or complex corrective measures to maintain an appropriate level of safety and service continuity may be incurred if the effects of climate change are not well anticipated (e.g. mandatory retrofit of airborne equipment, significant infrastructure modifications, operational restrictions).

As the European aviation network is heavily interconnected, disruption at one point can cascade across the network. In summer 2023, adverse weather delays were experienced in almost 1 in 4 days [32]. As such, risk assessments and the implementation of measures to enhance the resilience of all aspects of European commercial aviation should be a priority for action.

In response to these climate effects, EASA decided to add this topic to the strategic priorities of the European Plan for Aviation Safety [33], the regional aviation safety plan for Europe. In response to this decision, the EASA Scientific Committee has been reviewing the scientific publications on weather hazard trends caused by climate change, and which are a concern for commercial aviation. To date, this has covered trends regarding severe convective storms, clear air turbulence, airborne icing, dust storms and sandstorms, and surface temperatures. In addition, EASA

[6] A 'Hazard' designates a condition or an object with the potential to cause or contribute to an aircraft incident or accident (ICAO doc 9859, Safety Management Manual). CAT is turbulence occurring in cloudless regions. It is not detectable with a conventional radar, so that it typically occurs without warning.

Figure 2.7 Overview of key climate effects on commercial air transport

	Climate change effect	Impacts on commercial aviation
Temperature increase (heatwaves and permafrost thaw)	Europe continues to warm more quickly than the global average, with increases in mean and extreme temperatures. Increased frequency and intensity of heatwaves worldwide. Permafrost thawing in high mountains and the Arctic region (including Northern Scandinavia) may cause ground collapse and landslides.	Reduced safety margins for take-offs performed at high air surface temperature (due to reduced aircraft take-off performance). Reduced aircraft payload during hot days. Impact more significant for airports with shorter runways and/or located at higher altitude. Increased need for brakes' cooling system. Increased air conditioning needs within airport terminals. Heat and permafrost thaw damage to infrastructure (e.g. equipment, runways). Seasonal and geographical changes in tourism demand patterns.
Changes to rain and snow patterns	Projected decrease in mean precipitation in the South of Europe. More frequent extreme rainfall events in Europe. Less snow overall, but possibly more intense snowfall events.	Increased risk of runway excursion due to runway contamination. Closure of multiple airports leading to cancellations and possible massive diversions of flights, thereby increasing the risk of fuel emergency and/or loss of separation. Flooding of airports and access routes, with long lasting damage. Change in snow clearance needs.
Changes to storm patterns (convective storms and windstorms)	Increase in storms with extreme wind speeds in North and Central Europe. Increased frequency of the strongest Medicanes. Increased frequency of severe convective storms. Increased frequency of hail with large hailstones and of lightning strikes.	Increased risk of damage to the aircraft or its engines, which would require an emergency landing. Risk of loss of control in flight. Ground equipment temporarily inoperative causing capacity reduction or loss of flight crew / air traffic controllers situational awareness. Damage to landing guidance systems (e.g. instrument landing system, visual approach slope indicator Closure of multiple airports leading to cancellations and possible massive diversions of flights, thereby increasing the risk of fuel emergency and/or loss of separation. Damage to airport terminals.
Changes to wind and turbulence patterns	Change in jet stream strength, position and curvature. More frequent severe clear-air turbulence over the Northern Hemisphere. Changes in prevailing wind direction (surface winds and high-altitude winds).	Clear air turbulence: Increased risk of serious injuries to unfastened passengers and flight attendants, and increased risk of a temporary loss of control. Increased risk of abnormal runway contact or runway excursion caused by unfavourable surface wind direction (tailwind or crosswind). Crosswind changes affecting capacity. High-altitude winds: Variability in trans-Atlantic times and routes.
More frequent and persistent droughts, changing exposure to dust and sand and wildfires	Droughts in Southern and Central Europe, thereby changing ground conditions. Increased wildfires in Southern Europe. Expansion of fire-prone areas and longer fire seasons in most European regions. More frequent and intense dust / sandstorms from Sahara and 'global dust belt'. Increasing dust concentration levels in the atmosphere.	Increased risk of engine failure in flight and/or electronic equipment failure due to sand or dust. Damage to windshield and other external parts of the aircraft. Ground equipment temporarily inoperative causing capacity reduction or loss of flight crew / air traffic controllers situational awareness. Damage to landing guidance systems (e.g. instrument landing system, visual approach slope indicator system). Damage to airport infrastructure such as runways and taxiways. Delays, rerouting and cancellations due to wildfire and smoke risks. Fire damage to infrastructure.
Sea level rise	Uncertainty over storm surges. Increased probability of coastal flooding. Accelerated erosion of coastlines.	Ground equipment temporarily inoperative causing capacity reduction or loss of flight crew / air traffic controllers situational awareness. Damage to landing guidance systems (e.g. instrument landing system, visual approach slope indicator system). Permanent or temporary loss of airport capacity, infrastructure and access. Delays and flight cancellations.

has launched the European Network on Impact of Climate Change on Aviation (EN-ICCA) to assess weather hazard trends, their effect on aviation safety and effectiveness of mitigation measures [34].

This work is performed in coordination with the ACI EUROPE and EUROCONTROL European Aviation Climate Change Adaptation Working Group (EACCA-WG), which provides aviation stakeholders with guidance, peer support and good practices on adapting to the impacts of climate change in both summer and winter [35, 36, 37]. Further efforts in this area are also being undertaken in cooperation with ICAO [38, 39] and WMO [40].

There are essentially two types of strategies, which have already been implemented by some organisations, to address the increasing impact of severe weather events caused by climate change:

1. **Avoid or reduce exposure** to the hazardous or disruptive effects of severe weather events through improved forecasting that allows aviation stakeholders to take measures to protect the aircraft, ground equipment and infrastructure. For example,

    - enhancing capabilities of airborne weather radar, and training flight crews to use it;
    - using advanced clear-air-turbulence (CAT) forecasts, combined with real-time observation data from multiple aircraft, to produce reliable and accurate CAT maps;
    - uplinking satellite weather observation data to the cockpit throughout the flight to provide for better weather situational awareness; and
    - positioning meteorologists at airports to enhance knowledge of local weather conditions and produce forecasts tailored for the airport operator and airport users.

2. **Increase the capability to withstand the effects** of these severe weather events by adapting the design of assets (aircraft, ground safety equipment and infrastructure) and the way they are operated so that continuous safe operation can be ensured. For example,

    - Enhancing take-off performance of new aircraft designs so they are less sensitive to high surface air temperatures;
    - Ensuring the runway pavement is capable of withstanding high temperatures; and
    - Increasing the capacity of the water drainage system of the airport.

2.3 AIR QUALITY

Air pollution is one of Europe's largest environmental risks, with impacts on health and wellbeing as well as premature death mostly related to cardiovascular and respiratory diseases and lung cancer. There is also increasing evidence of additional impacts such as mental health and diabetes. The EU Ambient Air Quality Directives [41, 42] contain regulatory limits for various pollutants, including amongst others, particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), ozone (O_3), heavy metals and sulphur dioxide (SO_2). By the end of 2024, a revised EU Ambient Air Quality Directive is due to be adopted and will set 2030 EU air quality standards aligned more closely with the 2021 World Health Organization recommendations in order to mitigate air quality impacts on health [43, 44].

Estimates show that in 2022, 96% of the EU's urban population was exposed to concentrations of fine Particulate Matter ($PM_{2.5}$) above the WHO guideline level for mean annual concentration of $5 \mu g/m^3$. Moving close to the WHO guideline values would significantly reduce the current number of estimated premature deaths in the EU attributable to $PM_{2.5}$ (253 000), NO_2 (52 000) and O_3 (22 000) during 2021 [45, 46, 47]. National Air Pollution Control Programmes set out how Member States intend to achieve emission reduction commitments [48].

Aviation's Contribution to Air Pollution

While a main source of air pollution in the vicinity of airports originates from aircraft operations, air quality is also impacted by ground support equipment, surface access road transport and airport on-site energy generation.

Aircraft engines produce similar emissions to other sources of fossil fuel combustion with the most significant from an air quality perspective being nitrogen oxides (NO_X),[7] particulate matter, volatile organic compounds (VOCs), sulphur dioxide (SO_2) and carbon monoxide (CO). Studies also reported that aircraft emissions can contribute to elevated ozone (O_3) levels [49].

Furthermore, aircraft engines emit ultrafine particles (UFP) under a wide range of operating modes, which is a subset of particulate matter smaller than 100 nanometres in size ($PM_{0.1}$). Studies show health impacts on respiratory and cardiovascular systems, as well as long-term effects on premature deaths, from exposure to UFP that can enter the bloodstream and act as carriers of toxic substances [43, 50, 51].

New engine technology developments, such as lean burn combustors, are mitigating particulate matter emissions at source. The development of cleaner fuels (lower volatile organic compounds and sulphur content) through hydrotreatment of fossil fuels and use of sustainable aviation fuels can also reduce particulate matter emissions and thereby reduce air quality impacts [52]. However, aviation's contribution to air pollution will continue to remain a challenge in the future (see Sector Overview chapter).

Impacts on Local Air Quality

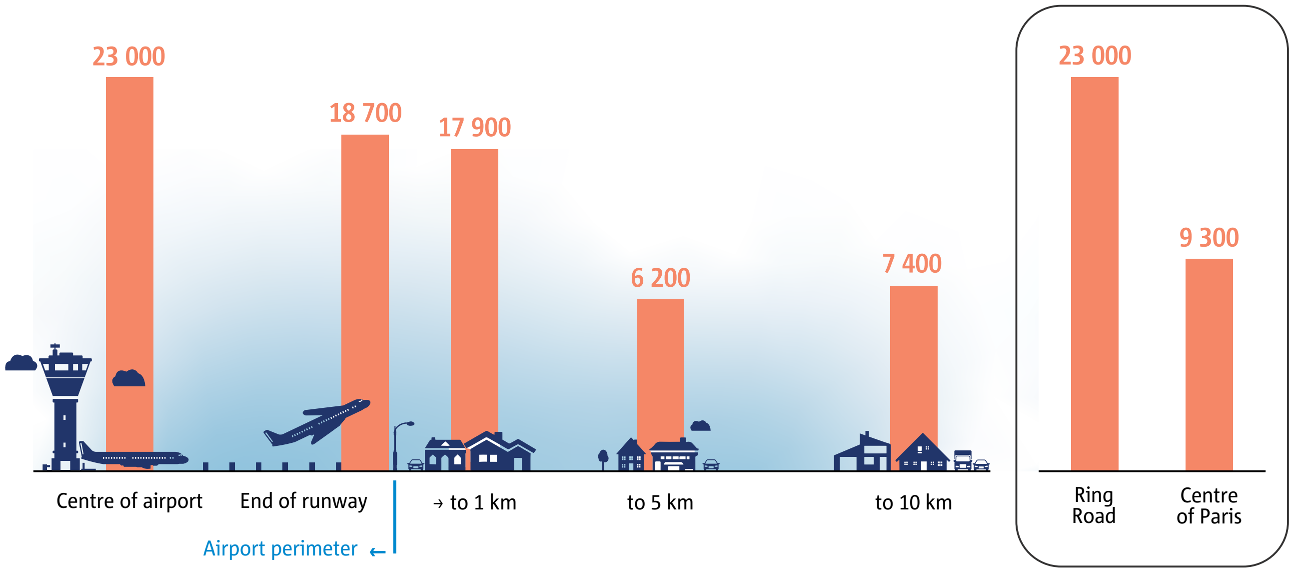
Currently applicable EU Ambient Air Quality Directives do not require mandatory air quality measurements near airports, as air quality must be measured where the levels of pollutants are representative of the general population's exposure, normally in nearby residential areas.

A recent study [53] modelled the atmospheric concentrations of air pollutants in 2018 for six cities in Europe with large airports (Paris Charles de Gaulle, Amsterdam Schiphol, Frankfurt am Main, Munich, Brussels Zaventem and London Heathrow). The results from the simulations showed that the contribution from aviation on the average annual concentrations in the respective city centres was 2.5% for NO_2, 1.8% for SO_2, 0.5% for PM_{10} and 0.3% for $PM_{2.5}$, whereas the average contribution at the airport location was 38% for NO_2, 45% for SO_2, 6.0% for PM_{10} and 4.5% for $PM_{2.5}$.

Exposure to high NO_2 from aviation could be significant in residential areas around airports. While the NO_2 contribution from aircraft at one airport location was 55%,

[7] Nitrogen Oxides (NO_X) are a combination of Nitric Oxide (NO) and Nitrogen Dioxide (NO_2).

Figure 2.8 **Average concentration of UFP at and in the area around Paris Charles de Gaulle airport between September and December 2022 (number of UFP/cm³) [60].**



which represented a concentration of 17µg/m³ against a WHO guideline value for mean annual concentration of 10 µg/m³, the relative contribution of aircraft declines as a function of distance from the airport with a reduction rate of 63% for every 2.8 km separation from the airport. The declining trend as function of distance is also a result of a larger contributions from other sources in the city of (e.g., road transport and residential combustion) thereby reducing the relative contribution from aviation.

Following a request for information to the European Environment Information and Observation Network (Eionet), several studies were received from EU Member States measuring air quality around the airports of Vienna, Brussels, Copenhagen, Paris-Charles de Gaulle, Nantes, Bordeaux, Lille and Helsinki [54, 55, 56, 57, 58, 59]. All studies included UFP as a focus of concern around airport and some covered legislated pollutants (NO_2 and PM_{10}).

For UFP, high Particle Number Concentration (PNC) can be considered above 10 000 particles/cm³ (24-hour mean) or 20 000 particles/cm³ (1-hour). High PNC in air were registered under conditions of unfavorable atmospheric dispersion with direct inflow from the airport in most cases. A correlation between the UFP concentration in the surrounding area of the airport and the number of flight movement was also seen. This relationship was not so clear for nitrogen oxides and particulate matter as contributions from other sources such as road traffic could also be significant. These studies also noted the reduction in UFP concentration with increasing distance from the airport. Figure 2.8 illustrates these changes in relation to distance from Paris Charles de Gaulle airport [60], where airport activities are estimated to be the main source of UFP within a distance of 5 km from the airport.

There are some constraints, however, when comparing UFP studies which often use different methodologies, particle size ranges and monitoring time periods. Air quality levels are also highly influenced by meteorology and sampling points must be located downwind of the airport to properly monitor their impact on air quality levels in the surrounding areas.

While there are no guideline levels set for UFP by WHO, they have provided good practices for the management of UFP [43]. Furthermore, the revision of the Ambient Air Quality Directive [61] considers airports as possible air quality hotspots, defined as locations within a zone in which the population is likely to be directly or indirectly exposed for a period which is significant in relation to the averaging period of the air quality standard. Airports are also identified as one of the locations where UFP should be measured to ensure that adequate information is available.

2.4 NOISE

Exposure to aircraft noise impacts the health and wellbeing of millions of people in Europe, with those living in residential communities in the vicinity of airports particularly affected.

New insights into the health effects of aircraft noise exposure

Since the publication of the World Health Organisation (WHO) Europe noise guidelines in 2018 covering all transport modes [62], a substantial amount of research has been undertaken regarding the health impacts of exposure to aircraft noise, reinforcing earlier findings and uncovering new associations.

Aircraft noise exposure remains directly linked to higher levels of annoyance and sleep disturbances. Recent studies have also identified that these direct aviation noise impacts contribute, along with other related factors, to a broader range of health impacts, such as cardiovascular health (e.g. worsening blood vessels and heart functions), metabolic issues (e.g. obesity, diabetes), mental health (e.g. depression), and cognitive function, particularly in children (e.g. reading and language skills [63-83].

Airport Noise Monitoring in Europe

As part of the Environmental Noise Directive (END) [84], Member States are required to produce strategic noise maps for major airports handling more than 50 000 movements a year, as well as major and non-major airports within urban areas of more than 100 000 inhabitants, that can then be used as a basis for noise action plans. The END assessment thresholds[8] focus on areas that are exposed to noise levels equal or higher than L_{den} 55 decibels (dB) and L_{night} 50 dB. However, it is important to note that negative health impacts start below the END thresholds, and that WHO Europe recommends noise levels of L_{den} 45 dB and L_{night} 40 dB for air traffic noise [62].

According to data submitted under the 2022 round of END noise mapping, it is estimated that 2.4 million people are exposed to aircraft noise levels above L_{den} 55 dB, while 0.7 million are affected by noise levels above L_{night} 50 dB. If we consider the lower WHO Europe thresholds, then these numbers are estimated to increase to 14.9 million and 5.3 million, respectively (Figure 2.9). Note that the 2022 strategic noise maps reflect the situation of the preceding year, during which the effects of COVID on passenger transport were still significant.

[8] L_{den} is the sound pressure level averaged over the year for the day, evening and night time periods, with a +5 dB penalty for the evening and +10 dB for the night. L_{night} is the sound pressure level averaged over the year for the night time period only.

Based on the END 2022 data at 50 airports in EU27+EFTA, it is estimated that 649 000 people experience high levels of annoyance due to long-term exposure to aircraft noise, while approximately 127 000 individuals suffer from significant sleep disturbances [85]. WHO Europe thresholds would increase these figures to around 2.3 million and 680 000, respectively. Other health impacts from noise, where aircraft noise could be a contributory factor, were estimated to include 500 cases of cardiovascular diseases, 200 cases of type 2 diabetes, and 600 premature deaths. Furthermore, more than 7 900 schoolchildren may experience reading impairments as a result of aircraft noise in their schools (Figure 2.10). Overall, the burden of disease attributable to aircraft noise was estimated to be around 19 000 disability-adjusted life years (DALYs).[9]

Figure 2.9 Population exposure to aircraft noise based on END and WHO noise thresholds at 50 airports in the EU plus Iceland, Norway and Switzerland [85]

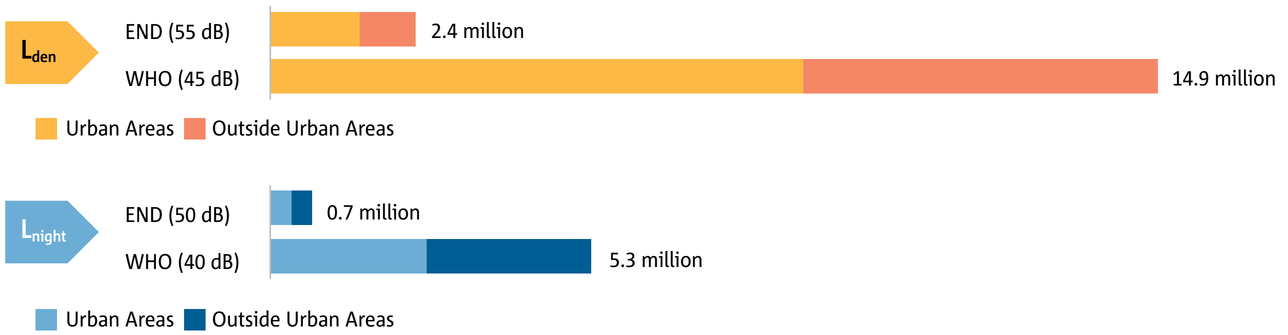
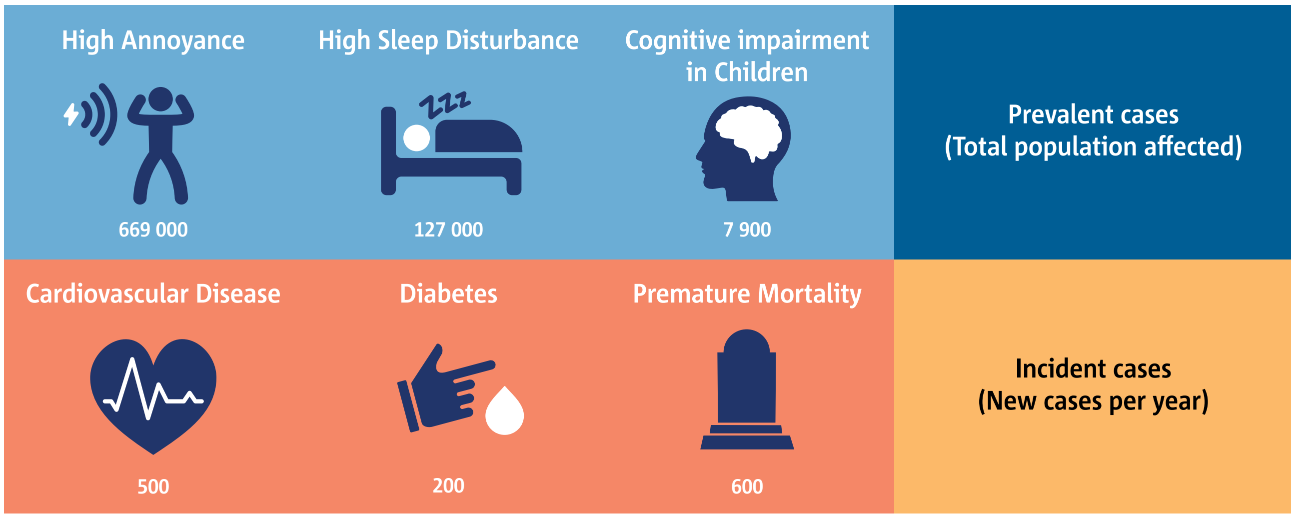


Figure 2.10 Estimated number of people suffering from various health outcomes due to long-term exposure to aircraft noise in the EU plus Iceland, Norway and Switzerland



[9] Disability-adjusted life years (DALY) is defined as the sum of years of life lost due to death and years of life lost due to health restrictions.

2.5 ADDITIONAL ENVIRONMENTAL PRESSURES

REACH

The primary objective of the REACH (Registration, Evaluation, Authorisation, and Restriction of Chemicals) Regulation (EC) No 1907/2006 is to protect human health and the environment by ensuring greater safety in the production and use of chemical substances [86, 87].

Risk management of chemical Substances of Very High Concern (SVHC), such as carcinogens, mutagens and toxic for reproduction chemicals, is done through an authorisation process [88] of three phases: (1) identification of SVHC; (2) recommendation for inclusion in the Authorisation List and (3) application for authorisation by industry. The European Chemicals Agency (ECHA), Member States, the European Commission and third parties are involved at various stages during the process. SVHCs that are included in the 'Authorisation List' (Annex XIV) can only be used after the 'sunset date' if authorised by the Commission. One previous example where an authorisation was granted to the aviation industry, due to the absence of alternative chemicals that were fit for this purpose, was in the use of chromium trioxide such as surface treatment to prevent corrosion [89].

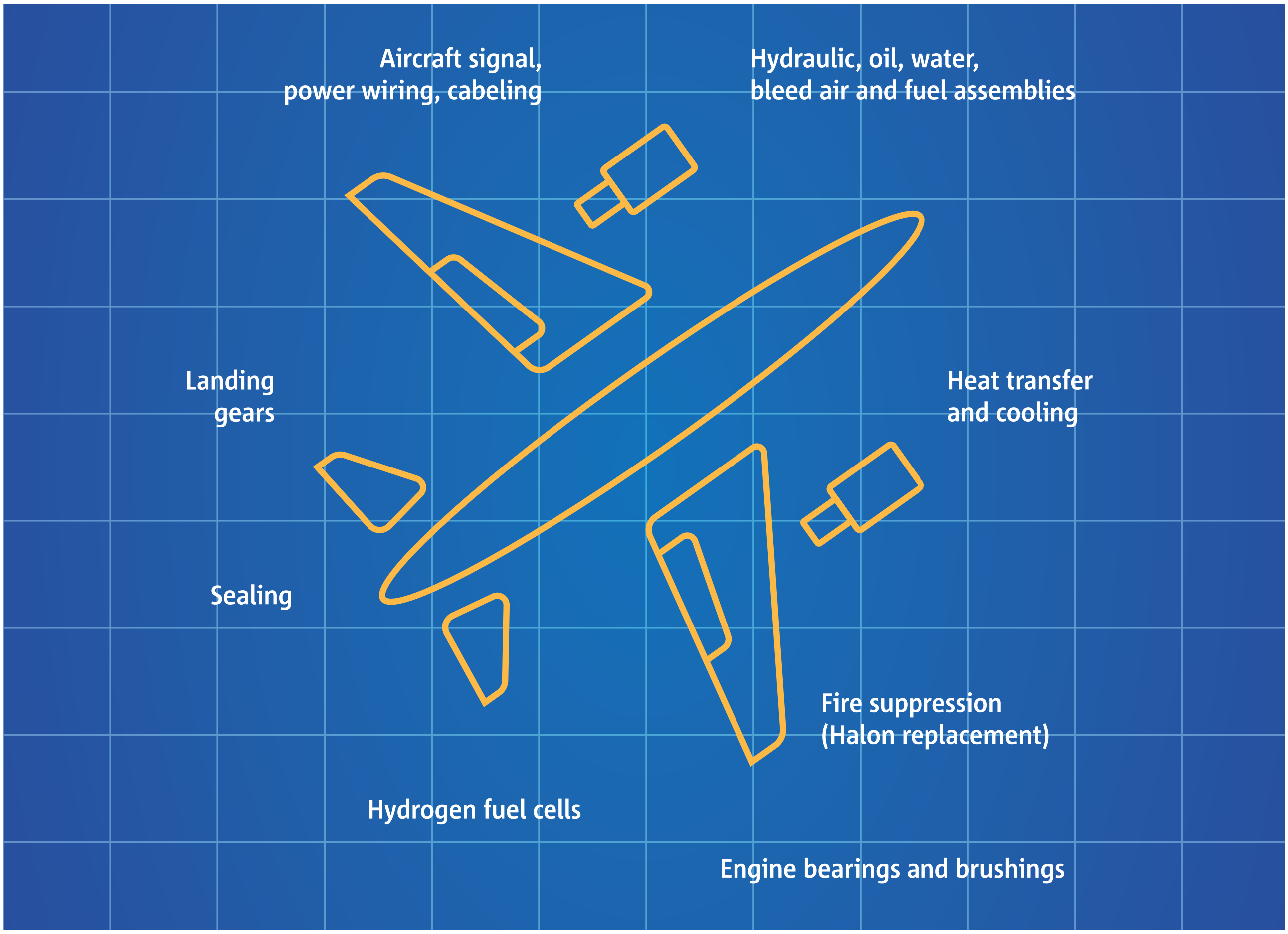
Restriction is used as a regulatory risk management tool when a Member State, or ECHA, at the request of the European Commission, are concerned that a certain substance (or a group of) poses an unacceptable risk to human health or the environment. Restrictions can result in limiting or banning the manufacture, placing it on the market or use of a substance. It can also set out specific conditions such as technical measures, emissions or exposure limits, labelling requirements, etc.

Another example of a restricted substance that has impacted the aviation sector is related to PFAS (per- and polyfluoroalkyl substances), which are synthetic chemicals that resist grease, oil, water, and heat [90]. Due to these properties, they are found in thousands of consumer products from raincoats to frying pans and are also used to meet safety requirements in modern aircraft (Figure 2.11) and at airports as fire-fighting foams. A study for the European Commission and the European Chemicals Agency found that up to 20 000 tonnes of PFAS containing fire-fighting foams are placed on the general market annually, with an estimated 9% destined for use at airports [91]. The scale of soil and groundwater contamination around airports due to use of PFAS has not yet been quantified [92] and further assessment is required to identify the scale of PFAS contamination across Europe.

PFAS have been identified as highly problematic chemicals for a number of reasons, including the fact that they remain in the environment for a long time, can contaminate soil and groundwater and are toxic to humans [93, 94]. To mitigate the risks of PFAS, five EU Member States submitted a restriction proposal to ECHA in 2023 to limit the use of this group of substances. The ECHA scientific committees are currently evaluating the proposal and will issue their opinion to the European Commission in due time. The impact on aviation will depend on how the restriction will ultimately be implemented by the European Commission.

REACH poses several challenges to the aviation industry due to its complex supply chain, low volume of chemicals, long design and production timelines and complex products, the highly regulated certification processes to ensure safety and aircraft operational longevity. EASA and ECHA have established a partnership to ensure aviation safety while implementing the REACH regulation and provide guidance on the key aspects of the authorisation process in the context of the aviation industry [95].

Figure 2.11 **Non-exhaustive illustration of safety-relevant use of PFAS in aircraft manufacturing**



Microplastic Emissions from Aircraft Tyres

The risks posed by microplastics and the micropollutants they release into the environment are only beginning to be understood, and there is increasing pressure to prevent microplastics entering the environment with a UN international convention on plastic pollution due to be agreed by the end of 2024 [96, 97]. The Zero Pollution Monitoring and Outlook Assessment 2024 [98] estimates that tyre wear is responsible for around one third of microplastic emissions in the environment. The contribution from aircraft tyres is likely to be much smaller overall than that from road transport, with one study estimating that aircraft tyres generate the equivalent of 2% of microplastic emissions from road tyres in the Netherlands [99]. However, the contribution may be relatively higher closer to the source, i.e. in the areas around airports.

3

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.
- The average margin to the latest noise standard of new regional, single-aisle and twin-aisle jet deliveries is levelling off, and the rate of deliveries is still recovering from the COVID crisis.
- 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.
- All new aircraft joining the European fleet since 2020 have engines that meet the latest CAEP/8 NO_X standard, thereby suggesting a need to review this standard during the CAEP/14 work programme (2025-2028).
- Environmental technology standards will be important in influencing new aircraft and 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.
- Discussions have been initiated within ICAO CAEP to review the noise limits for light propeller-driven aircraft and helicopters, which have been unchanged since 1999 and 2002 respectively.
- 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).

3.1 AIRCRAFT ENVIRONMENTAL STANDARDS

3.1.1 Aircraft Noise

The aircraft types in Table 3.1 are certified against noise standards that are referred to as Chapters 3, 4 and 14,[1] which became applicable from 1977, 2006 and 2018, respectively. The International Civil Aviation Organisation (ICAO) is currently reviewing the noise limits for these aircraft categories with the aim to create a new chapter that would become applicable in the next five years.

The ICAO also sets noise standards for light propeller-driven aircraft (Chapter 10) and helicopters (Chapters 8 and 11), whose noise limits were last updated in 1999 and 2002 respectively. Discussions have been initiated within the ICAO Committee on Aviation Environmental Protection (CAEP) noise technical working group to consider an update of these standards.

Figure 3.1 illustrates the differences on an operational basis between the successive noise certification standards for each aircraft category in Table 3.1. The circles represent the landing and take-off 80 dB noise footprint area for virtual aircraft that would just meet the limits of the Annex 16 Volume I Chapters and for an aircraft that represents the current state-of-the-art in its category.

Historic developments in certified aircraft noise levels are illustrated in Figure 3.2. The figure represents the cumulative margin[2] to the Chapter 3 limits for the heaviest weight variants and maximum thrust rating of aircraft types certified since 1990 [5]. The new data since the last report (e.g. Falcon 6X, Gulfstream GVIII-2, ATR 42/72 modified engine, A321 XLR) highlights the continued marginal improvements in noise levels since the 2010s. Jet aircraft continue to show cumulative margins of 8 to 15 EPNdB compared to the Chapter 14 limit. Margins for turboprops are lower, illustrating the slower development of noise reduction technology in this category. Overall, Figure 3.2 confirms that technology is available across all categories to support an increase in noise stringency in the short term.

In 2019, an Independent Experts Panel established by the ICAO CAEP agreed on medium-term (2027) and long-term (2037) noise goals for leading edge technology [6]. These goals were set for each aircraft category (except turboprops) and are also represented in Figure 3.2. As the medium-term goal of 2027 approaches, there is an opportunity to review whether this has been met and to update the goals with later target years for them to remain relevant.

1 These are chapters of ICAO Annex 16 Volume I, which contain international aircraft noise standards.
2 'Cumulative margin' is the sum of the individual margins (difference between certified noise level and noise limit) at each of the three Chapter 3 noise measurement points, expressed in Effective Perceived Noise deciBels (EPNdB).

Table 3.1 Aircraft categories covered by Chapters 3, 4 and 14

Aircraft Category	Definition	Examples of aircraft types
Twin-aisle jets (TA)	Large jet-powered aircraft for medium and long-range operations.	Airbus A330, A340, A350, A380; Boeing 747, 767, 777, 787
Single-aisle jets (SA)	Jet-powered aircraft intended for short to medium-range operations	Airbus A319, A320, A321; Boeing 737-700, 737-800, 737-900, 737MAX
Regional jets (RJ)	Jet-powered aircraft intended for short-range operations	Airbus A220; MHI CRJ Series; Embraer EMB145, ERJ-170, ERJ-190
Turboprops (TP)	Turboprop-powered aircraft (does not include small general aviation aircraft)	ATR 42, 72; DHC Dash 8
Business jets (BJ)	Small jet-powered aircraft with a seating capacity of 19 or less.	Beech 400A; Cessna 525, 650, 750; Dassault Falcon 2000, 7X; Gulfstream G450, G550

Figure 3.1 Single landing and take-off 80 dB noise contour areas for aircraft that just meet the noise limits of the Annex 16 Volume I Chapters plus a state-of-the-art in-production aircraft

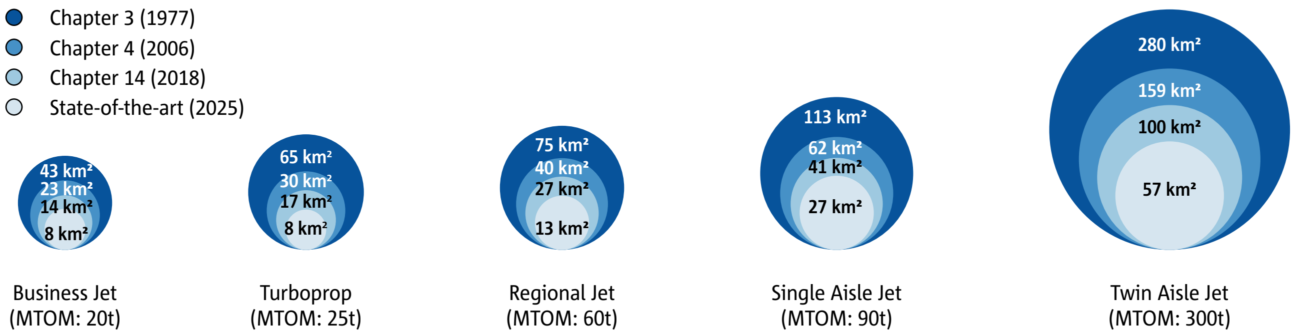
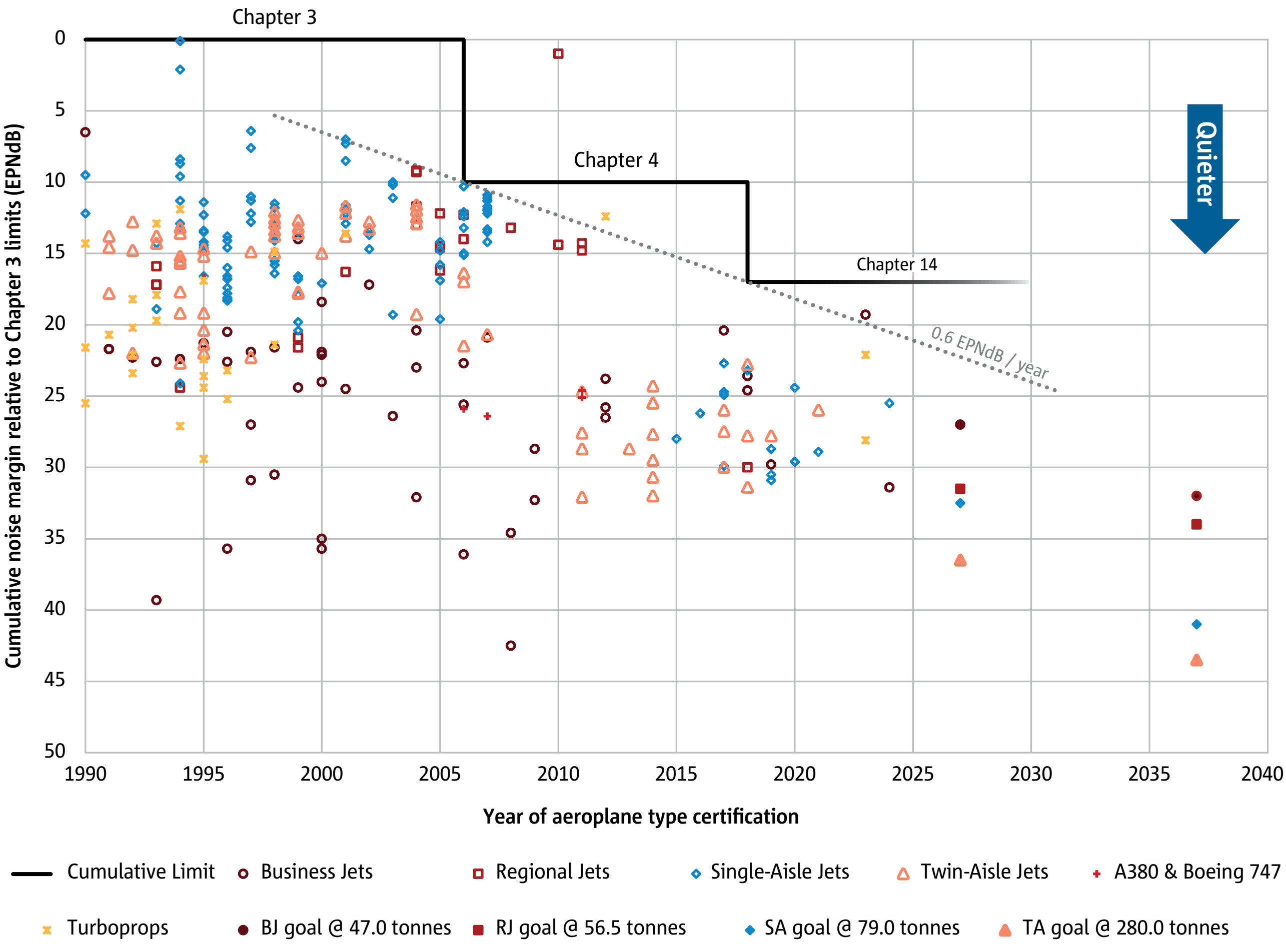


Figure 3.2 Evolution in certified aircraft noise levels over time

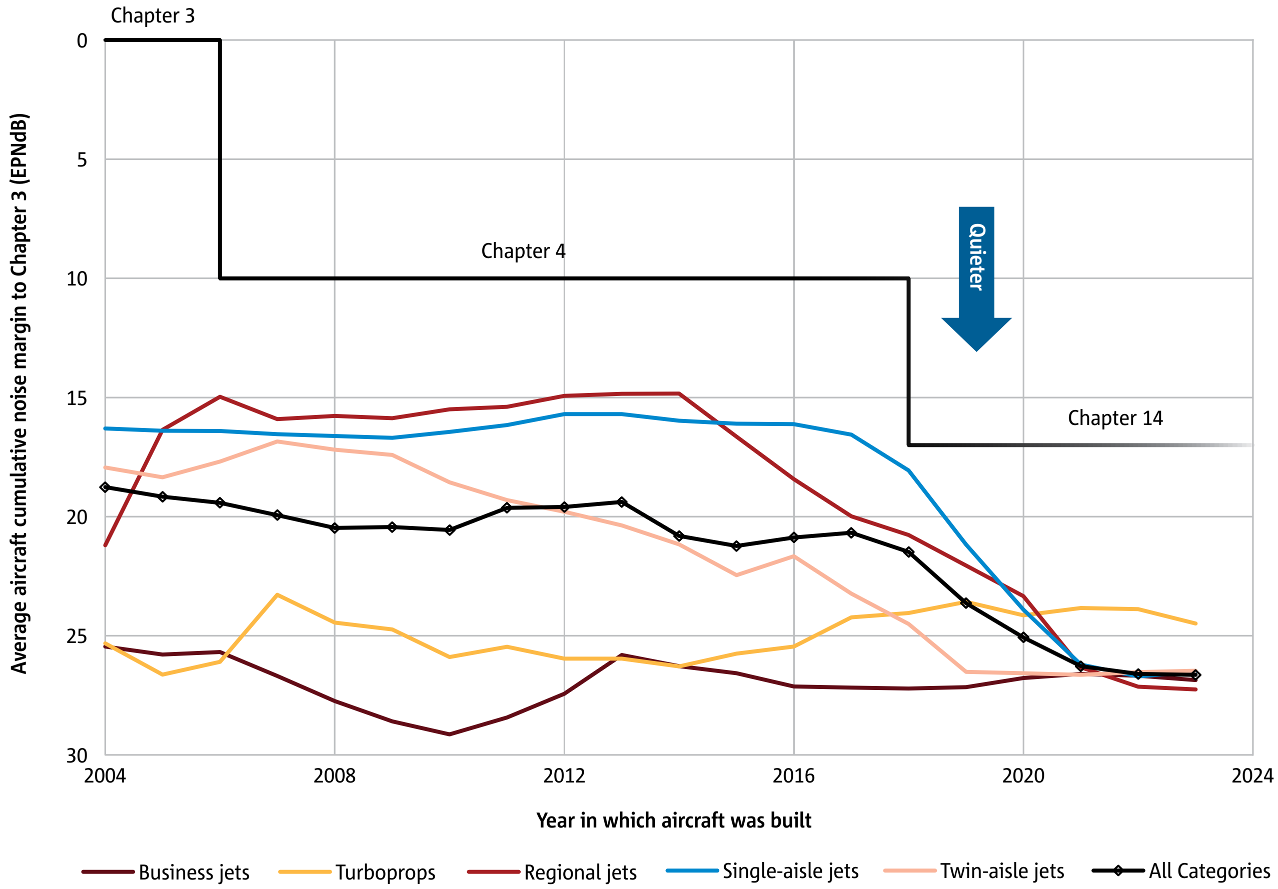


Noise performance of new aircraft deliveries

While Figure 3.2 contains certified noise levels of specific aircraft type designs, Figure 3.3 provides insight on the noise performance of the in-service European fleet registered in EU+EFTA at the start of 2024. The figure shows the trend over time of the average noise margin to the Chapter 3 limit for all aircraft built in a given year by aircraft category.

The average aircraft noise margins of regional, single-aisle and twin-aisle jets have flattened out over recent years. This suggests that new deliveries in these categories now consist entirely of aircraft types certified in the 2010s (e.g. Embraer ERJ E2, Airbus A320neo, A330neo, A350, Boeing 737Max, 787), which have a better noise performance than their predecessors. The average noise performance of the in-service fleet will continue to improve in the near to medium term as the older and noisier types still operating in Europe are gradually replaced. The rate of improvement will depend on the rate of new deliveries, which has been negatively affected by the COVID crisis and recent challenges in the supply chain to meet demand.

Figure 3.3 Average cumulative noise margin to Chapter 3 for in-service aircraft within the 2024 European fleet



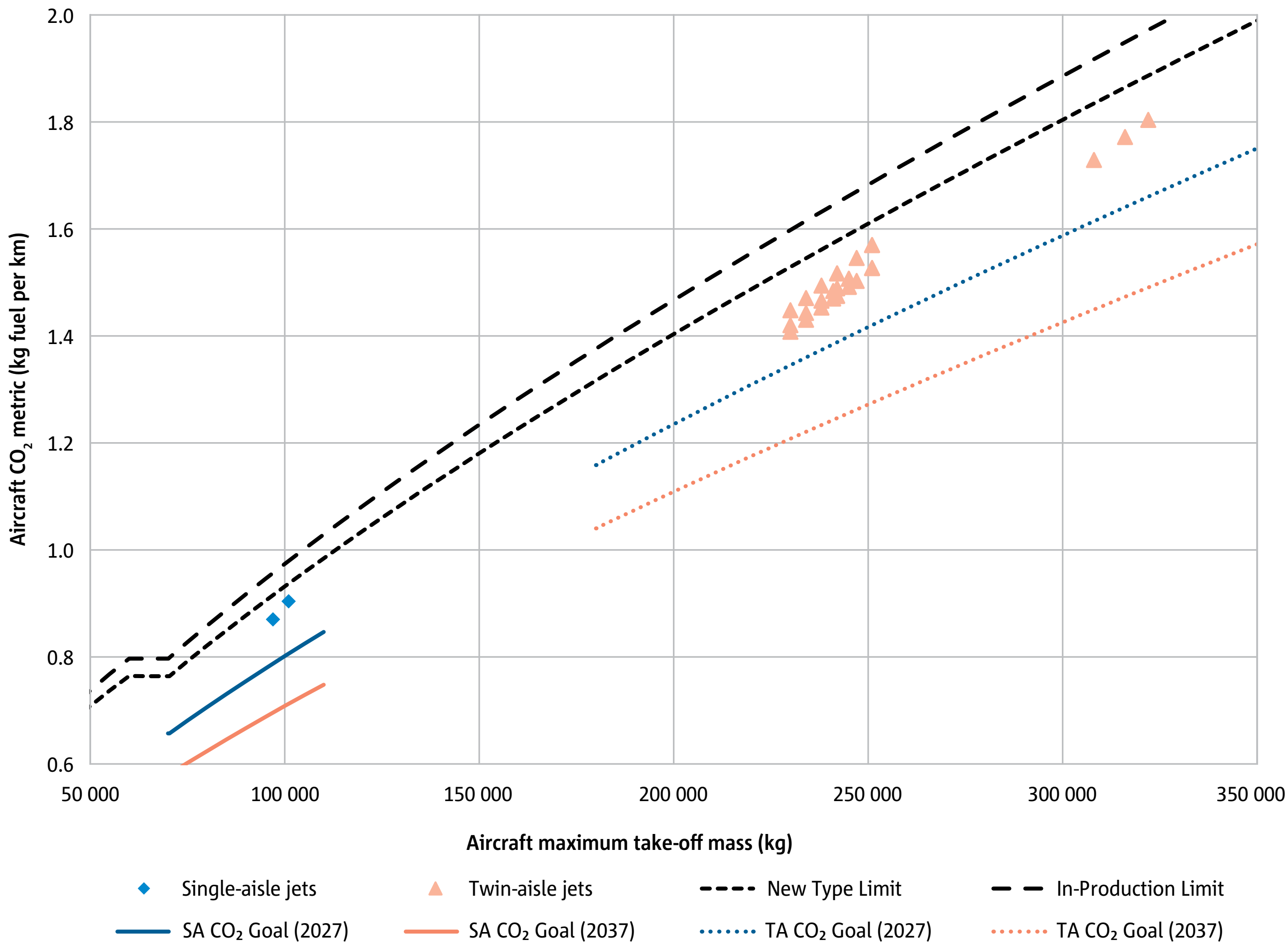
3.1.2 Aircraft CO_2 emissions

Since 1 January 2020, new aircraft types have to comply with a new type CO_2 standard,[3] 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 (Figure 3.4), and so the availability of certified CO_2 data remains limited [7]. 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. As per noise, 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.

3 ICAO Annex 16 Volume III 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.

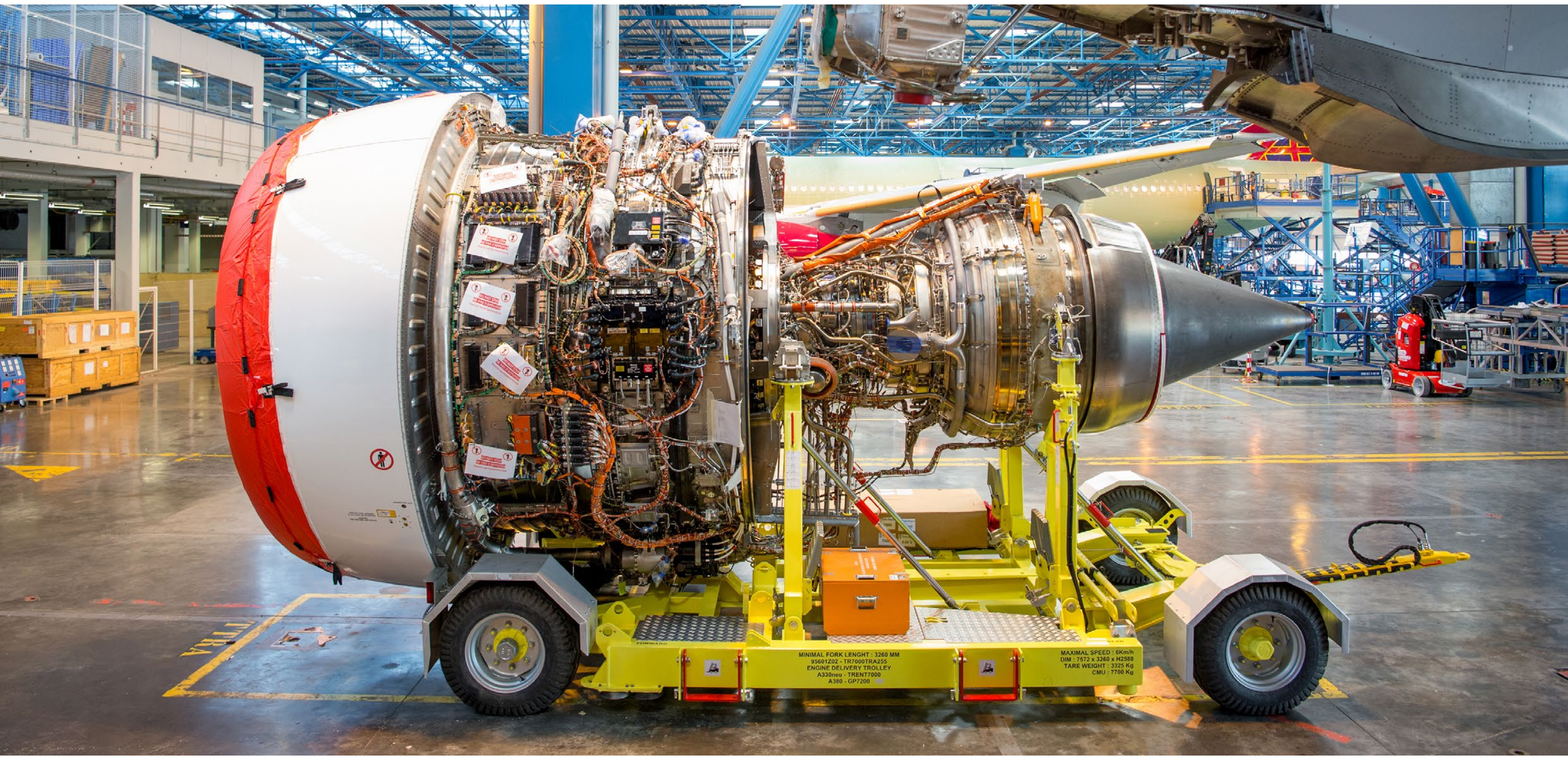
Figure 3.4 Certified aircraft CO_2 emissions performance



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 [8].



3.2 AIRCRAFT ENGINE ENVIRONMENTAL STANDARDS

The engine Oxides of Nitrogen (NO_X) and non-volatile Particulate Matter (nvPM) standards,[4] alongside the aircraft noise and CO_2 standards, define the design space for products to simultaneously address noise, air quality and climate change issues.

Figures 3.5, 3.7 and 3.8 highlight in red boxes the limited developments in certified aircraft engine types since the last report with the Trent 7000 performance improvement package and the new Pearl 700 and PW812 engines [9]. As per the aircraft level environmental standard, the ICAO Independent Experts Panel NO_X goals need to be updated for them to remain relevant and consideration should be given to the potential to set goals for nvPM emissions.

3.2.1 NO_X emissions

The NO_X standards[5] for aircraft engines have become more stringent between 1996 and 2014, and are typically referred to by the CAEP meeting in which they were agreed (CAEP/2, CAEP/4, CAEP/6 and CAEP/8).

NO_X performance of new aircraft engine deliveries

Figure 3.6 illustrates the trend over time of aircraft joining the European fleet and their performance against the various ICAO engine NO_X emissions standards. It highlights that all new aircraft engine deliveries were compliant with at least CAEP/6 by 1 January 2012, thereby meeting the CAEP/6 production cut-off date of 1 January 2013. In addition, all new aircraft engine deliveries have met the latest CAEP/8 NO_X standard from 1 January 2020 onwards, thereby suggesting a need to review this standard within the CAEP/14 work programme (2025-2028).

4 ICAO Annex 16 Volume II contains international aircraft engine emissions standards.

5 NO_X limits are defined as the mass (Dp) of NO_X emitted during the Landing and Take-Off (LTO) test cycle and divided by the thrust of the engine (Foo). The limit also depends on the overall pressure ratio of the engine.

Figure 3.5 Certified aircraft engine NO_X emissions performance

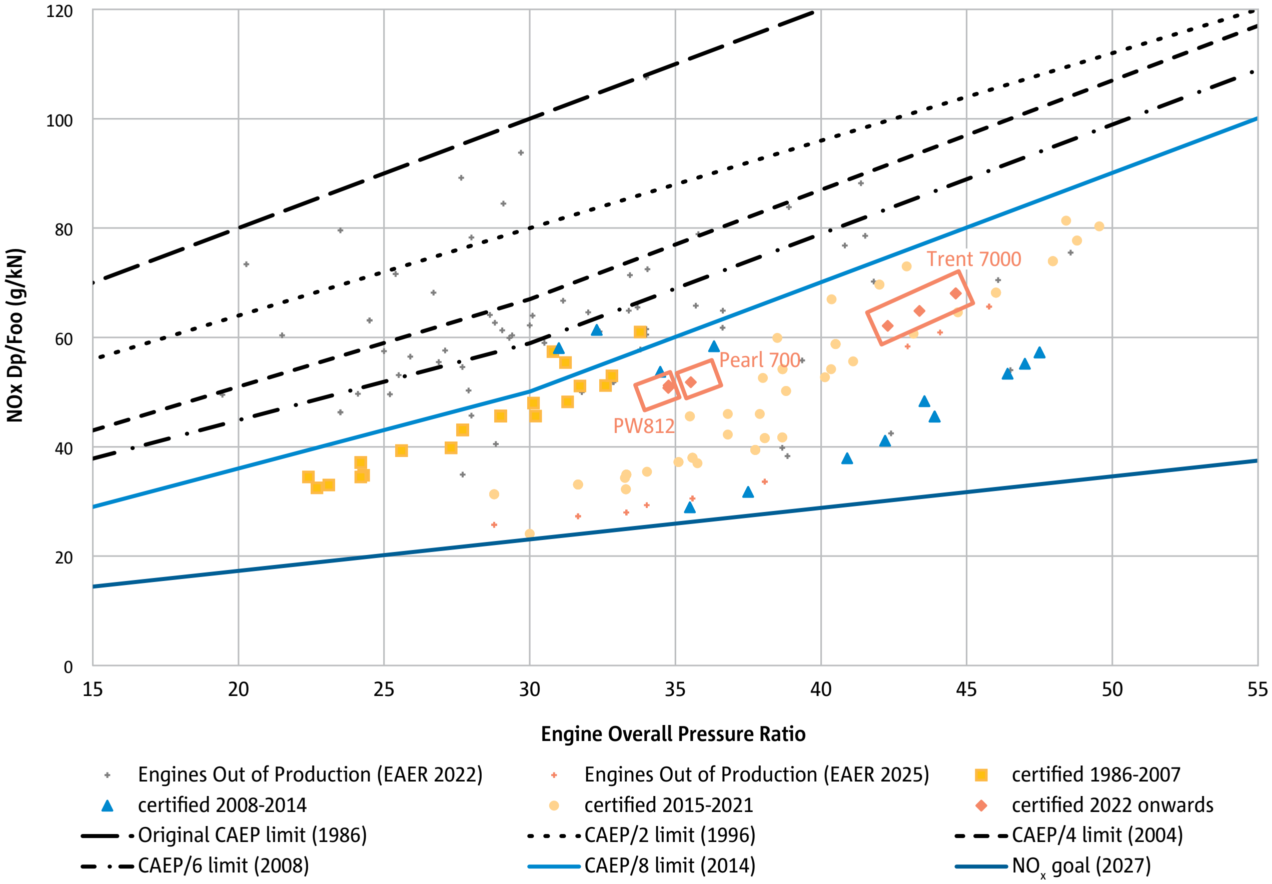
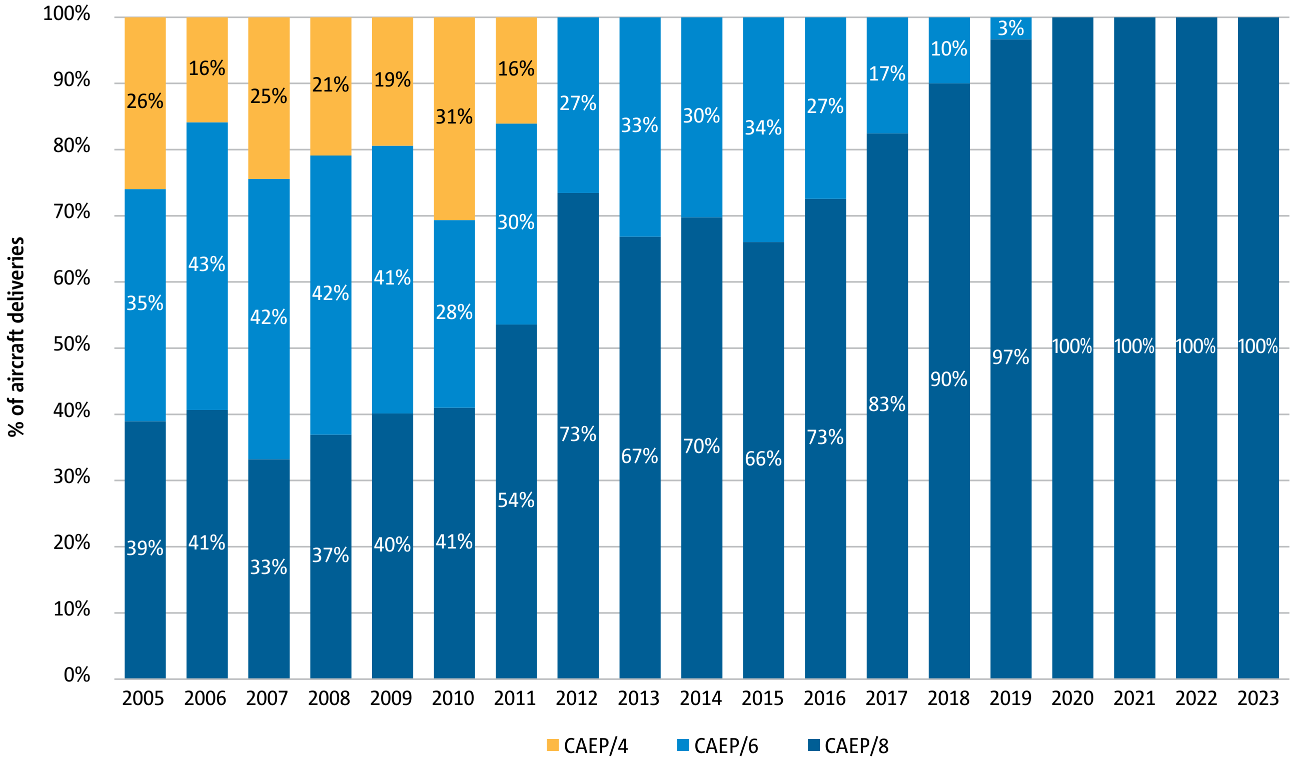


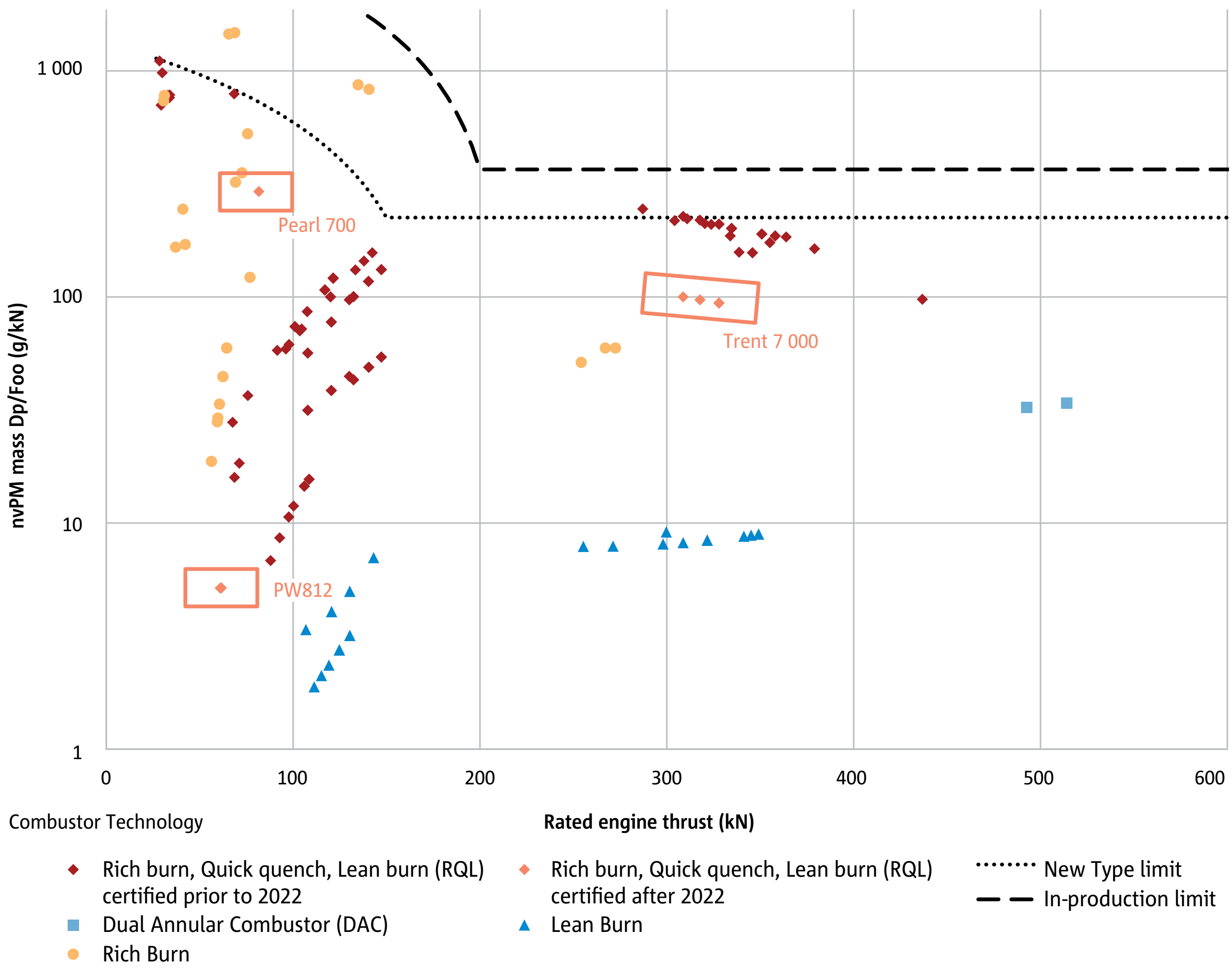
Figure 3.6 Share of delivered aircraft within the European fleet that meet CAEP NO_X standards



3.2.2 nvPM emissions

The latest certified aircraft engine nvPM mass and number emissions data is provided in Figures 3.7 and 3.8, and are grouped based on combustor technologies. The Y axis of those figures uses a logarithmic scale to differentiate between combustor types more easily.

Figure 3.7 Certified engine nvPM mass emissions performance

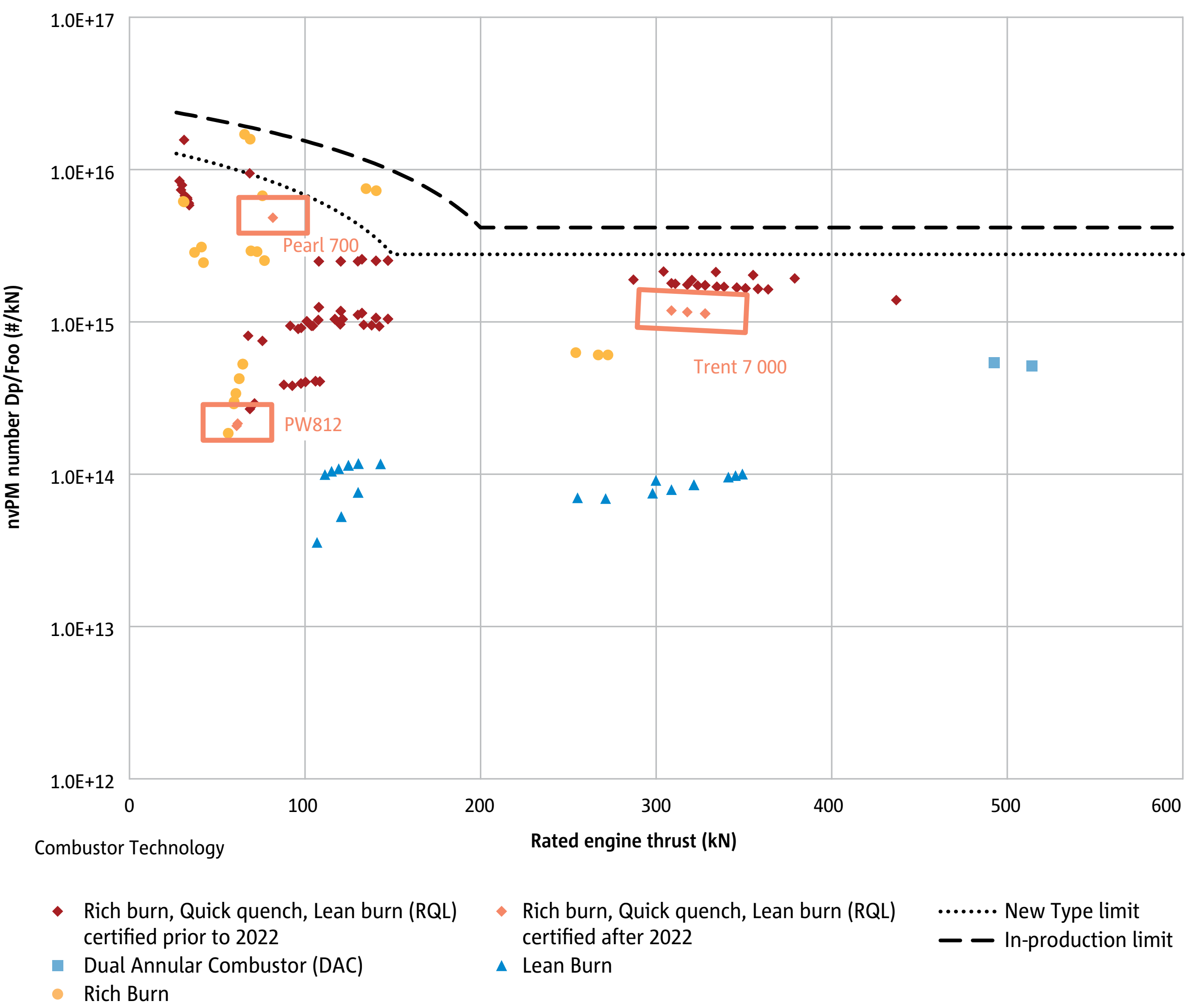


Modelling of non-CO_2 emissions in cruise

The CAEP/13 work programme (2022-2025) has evaluated the relationship between NO_X emissions measured in the reference Annex 16 Volume II certification Landing and Take-Off (LTO) cycle and NO_X emissions in cruise. A new cruise NO_X Metric System based on LTO data and Annex 16 Volume III fuel burn data is being considered with the aim of improving the modelling of cruise NO_X emissions for lean burn engines within the Boeing Fuel Flow Method (BFFM) and the assessment of the effect of non-CO_2 emissions on climate change [10].

In addition, a proposed 5[th] LTO reporting point for nvPM emissions at a cruise thrust setting (57.5% of maximum sea level static thrust) is proposed to be included in the ICAO Annex 16 Volume II certification requirements to enhance the understanding of engine nvPM emissions and improve cruise nvPM modelling, e.g. within the Mission Emissions Estimation Methodology (MEEM) [11].

Figure 3.8 Certified engine nvPM number emissions performance



3.3 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.

3.3.1 Electric propulsion

Since 2017, EASA has been conducting studies to support the development of noise standards for Unmanned Air Systems (UAS – otherwise known as Drones) and Vertical take-off and landing Capable Aircraft (VCA – otherwise known as Urban Air Mobility or Advanced Air Mobility vehicles) to ensure a uniform high level of environmental protection for EU citizens who have listed noise as the second main concern after safety in an EU-wide study [12]. These studies investigated how to obtain accurate and repeatable noise levels, characterized perceived annoyance (psychoacoustics), identified the best noise metric and derived dose-response relationships.

UAS belonging to the ‘open’ category of operations must already meet noise requirements covered by the ISO 3744 standard [13], while UAS of the ‘certified’ category undergo a typical certification program with EASA. Recognizing the need for noise standards in the intermediate ‘specific’ category, EASA published guidelines to measure the noise levels of UAS below 600 kg in October 2023 [14]. These guidelines contain procedures to measure noise in level-flight and hover conditions, and will assist national, regional, and municipal authorities in authorizing local UAS operations. UAS noise data collected according to these guidelines can be submitted to EASA (noise@easa.europa.eu) and will be published on the EASA Innovative Air Mobility Hub [15]. This product noise certification data will complement the U-Space operational concept to ensure a safe and sustainable integration of this emerging market within the aviation sector [16].

Regarding VCA, 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 [17], 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 [18], 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.

3.3.2 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.

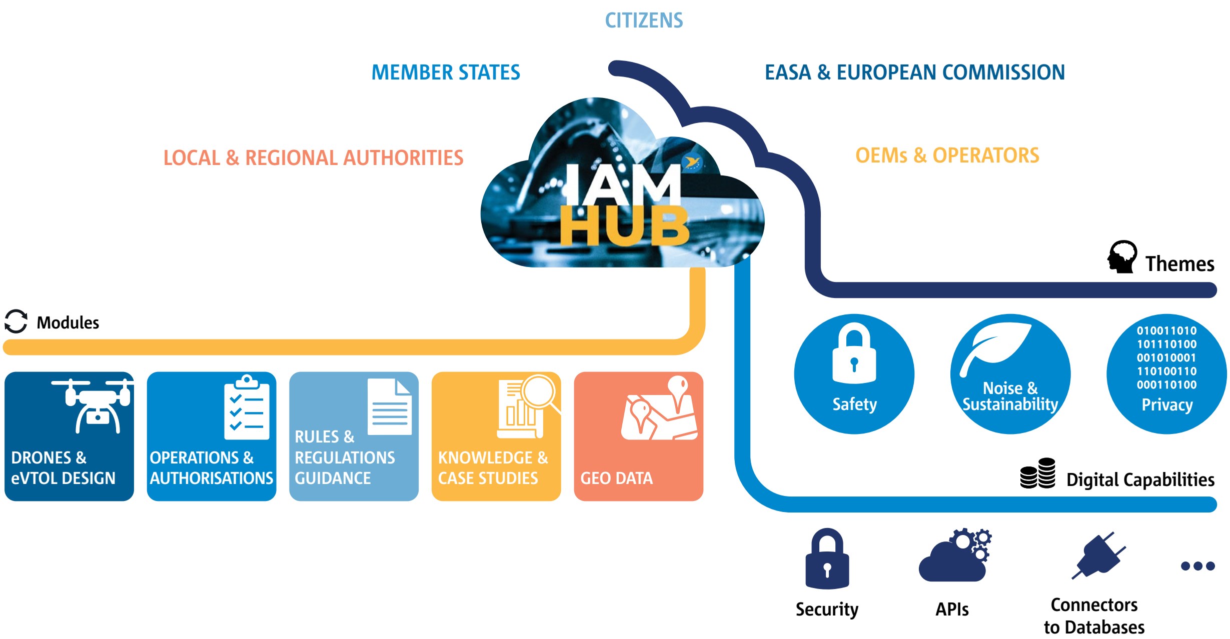
Pioneers in the field have advanced their flight test activity, with H2FLY conducting the world's first piloted flight of a liquid hydrogen powered electric aircraft in September 2023, using their HY4 demonstrator aircraft, operating from Maribor in Slovenia. Other notable flights include ZeroAvia's 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.

EASA Innovative Air Mobility Hub

The EASA Innovative Air Mobility (IAM) Hub [15, 20] 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 contains 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 [20].



3.3.3 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 [20]. 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 [21], 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 [22].

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 [23]. 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 [24]. 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 CONOPS is expected to be re-assessed once robust aircraft performance data becomes available.

The AZEA vision “Flying on Electricity and Hydrogen in Europe” published in June 2024 [25] 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 3.9 Air Transport Action Group (ATAG) indicative overview of where low- and zero-carbon energy could be deployed in commercial aviation alongside that of SAF [26]

	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

3.4 SUPERSONIC AIRCRAFT

Following the retirement of Concorde in 2003, several manufacturers have been looking into developing supersonic aircraft, 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 [27], and noise, specifically the impact of the sonic boom generated when flying at supersonic speed.

The existing Landing and Take-Off (LTO) noise certification standard for supersonic transport (SST) aircraft was adopted by ICAO in 1976. As part of the ongoing discussions in CAEP, it is anticipated that any future SST aircraft would have to comply with the same noise limits that are currently applicable to subsonic aircraft (ICAO Annex 16 Volume I, Chapter 14) in order to avoid undermining the benefits from reductions in aircraft noise over the last few decades. Updates to engine emissions standards for SST aircraft are also being assessed within CAEP, with an attachment to ICAO Annex 16 Volume II having been developed documenting the status of discussions on provisional requirements and potential regulatory levels of CO, HC and nvPM emissions, as a basis for on-going future work.

Building on initial concepts developed by EASA [28], a recommendation on a new SST LTO noise standard is due to be agreed at the CAEP/13 meeting in February 2025, alongside ‘green pages’ on SST engine emissions requirements.

In order to meet the Chapter 14 noise limits, manufacturers are looking to incorporate Variable Noise Reduction Systems (VNRS) into the design of SST aircraft. VNRS systems operate fully automatically without pilot interaction and can include various aspects including reductions in thrust, changes in the setting of the high-lift devices (e.g. flaps, slats) and changes in engine inlet or outlet diameter.

Flight test campaigns with the NASA X-59 aircraft are planned in the USA to investigate community responses to the sonic boom and support discussions on a noise standard for the cruise condition and potentially other flight phases [29]. The practical demonstration of publicly acceptable noise levels from “low boom” design SST aircraft is crucial for any consideration to allow flights at supersonic speed over land.

In Europe, various EU-funded research projects have provided support as part of these on-going discussions on appropriate environmental standards for the next generation of SST aircraft. These include RUMBLE, SENECA and MORE AND LESS [30, 31, 32].

3.5 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 [33]. 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.

3.6 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 [34]. Aviation specific research contributes primarily to the European Green Deal and the EU’s digital and competitiveness strategies across all three Horizon Europe pillars (Figure 3.10).

- **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 [35] that focuses on increasing the scientific knowledge of the hydrogen-air combustion of future hydrogen-fuelled aero-engines. Another example is BeCoM [36] 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 [37].

Figure 3.10 Horizon Europe programme structure

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 [38]. 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 was evaluated through a dedicated Technology Evaluator function with key assessment and reporting duties. The final assessment by the Technology Evaluator was performed in 2024 [39] and the results are summarised in Table 3.2.

Table 3.2 Final Clean Sky 2 Technology Evaluator Assessment Results

Mission Level Assessment

Concept Model	Assessment	CO_2 [6]	NO_x [6]	Noise[7]
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 TP 70)	1st	-20% to -34%	-56% to -67%	-20% to -68%
	2nd	-25% to -32.5%	-44% to -60%	+14% to -44%
Commuter[8] & 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%

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% (L_{den} [9])

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% Aircraft

6 CO_2 and NO_x values per passenger-kilometre.
7 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 3 dB reduction. 30% of noise reduction is equivalent to 5 dB reduction.
8 Only fossil fuel concepts, excluding the innovative E-Short Take-Off and Landing (STOL) hybrid-electric commuter concept.
9 Surface area Reduction of L_{den} contours for 60-65 dB (A) noise levels at the European airports considered.

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 [40]. 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 3.3 [41].

Table 3.3 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) [10]	Net CO_2 Emissions reduction (i.e. including SAF effect) [11]	Current share of air transport system emissions
Regional Commercial Aircraft	> Hybrid-electric (SAF + Batteries) coupled with highly efficient aircraft configuration > Same with H2-electric power injection(-Fuel Cells electric generation)	~2035 Beyond 2035	-30% Up to -50%	-86% Up to -90%	~5%
Short-Medium Range Commercial Aircraft	Advanced ultra-efficient aircraft configuration and ultra-efficient gas turbine engines	~2035	-30%	-86%	~50%
Hydro-gen-Powered Commercial Aircraft	Full hydrogen-powered aircraft (H2 Fuel Cells or H2 combustion)	~2035	-100%	N/A	N/A

[10] Improvement targets are defined as CO_2 reduction compared to 2020 state-of-the-art aircraft available for order/delivery

[11] 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 3.11 **Initial projects launched in 2023 to deliver important technology bricks in all three areas**

Hybrid Electric
Combining Innovative Airframe, Novel Systems & HE power train

HE-ART
2 150-2 850 MW Multi Hybrid Electric propulsion system for regional AiRcrafT
ROLLS-ROYCE (*)

AMBER
~2MW Multi Power train InnovAtive for hyBrid-Electric Regional Application
GE AVIO (*)

TheMa4HERA
Thermal Management Solutions for Hybrid Electric Regional Aircraft
HONEYWELL (*)

HECATE
Electrical Distribution Solutions for Hybrid-Electric Regional Aircraft
COLLINS (*)

HERWINGT
Hybrid Electric Regional Wing Integration Novel Green Technologies
AIRBUS (*)

Ultra Efficient/ Short Medium Range
Combined power plant & Airframe efficiency

HEAVEN
Ultrafan - Hydrogen & hybrid gas turbine design
ROLLS-ROYCE (*)

SWITCH
Sustainable Water-Enhanced-Turbofan (WET) Comprising Hybrid-electics
MTU AERO ENGINES (*)

OFELIA
Open fan engine demonstrator
incl. gas turbine design hybridisation for Environmental Low impact of Aviation
SAFRAN (*)

UP Wing
Ultra Performance Wing
AIRBUS (*)

FASTER-H2
Fuselage, Rear Fuselage and Empennafe Technologies for H2 Integration
AIRBUS (*)

Hydrogen Powered Aircraft
Novel concepts with H_2 direct burn & fuel cell based propulsion

CAVENDISH
Hydrogen and dual fuel combustion technologies
ROLLS-ROYCE (*)

HYDEA
Hydrogen engine integration in flying platform
AVIO AERO (*)

NEWBORN
NExt generation high poWer fuel cells for airBORNe applications
HONEYWELL (*)

H2ELIOS
HydrogEn Lightweight & Innovative tank for zerO-emisSion aircraft
ACITURRI(*)

FLHYing Tank
Liquid hydrogen load bearing tank for commuter
PIPISTREL (*)

HyPoTraDe
Hydrogen Fuel Cell Elecric Power Train Demonstraion
PIPISTREL (*)

(*) Consortium Leader

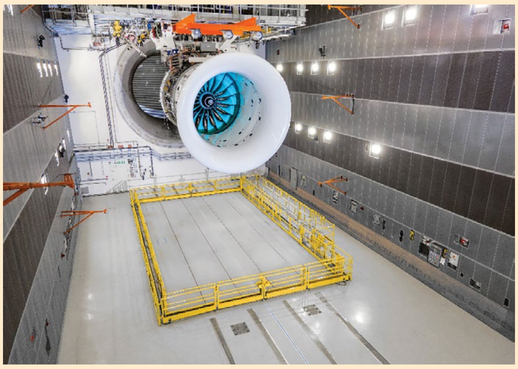
STAKEHOLDER ACTIONS

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.

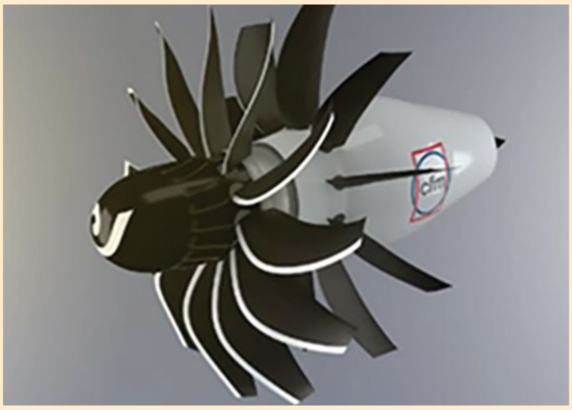


Hydrogen Fuel Cells

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 Auxiliary Power Unit (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.

4

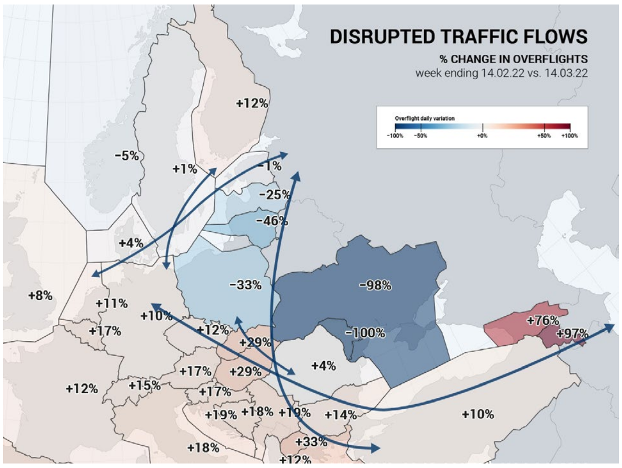
AIR TRAFFIC MANAGEMENT AND OPERATIONS

- 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 recognized 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 (2030-2034).
- 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 most emissions originate from the 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.
- A 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.

4.1 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 a 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[1] 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

[1] 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 [3]. 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.

in identifying universal solutions for monopolistic and state-owned 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 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.

4.2 SES ENVIRONMENTAL PERFORMANCE AND TARGETS

Overall context

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.

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

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 4.1). 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).

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)[2] and the shortest constrained trajectory (KES/SCR).[3] As with all other indicators, KEP and KES/SCR (Figure 4.2) 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 recognized that more suitable indicators are needed to give a clearer indication on the effectiveness of ANSP and Network Manager actions.

2 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.

3 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 4.1 KEA horizontal en-route flight inefficiency and targets for 2014 to 2029

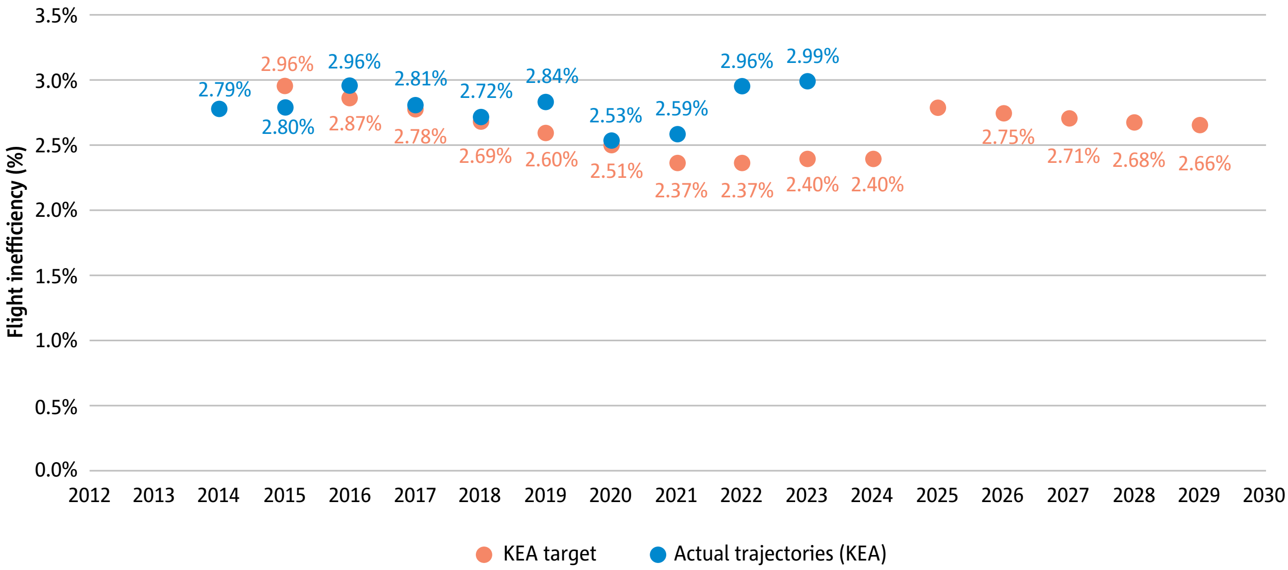
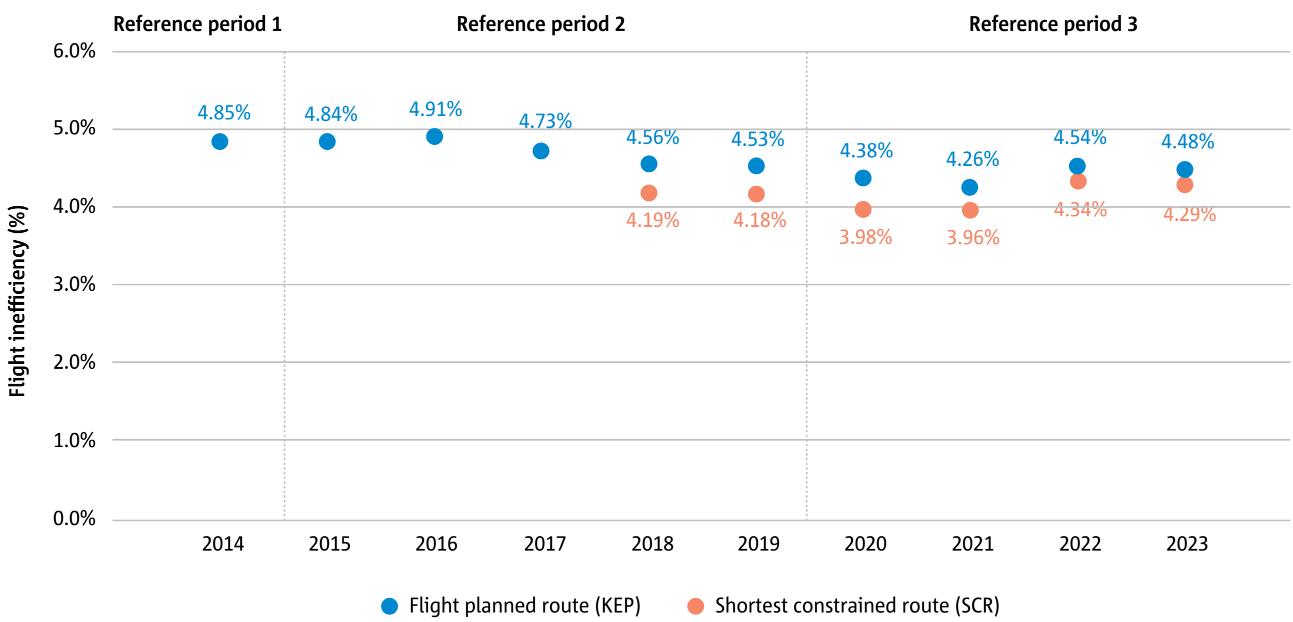


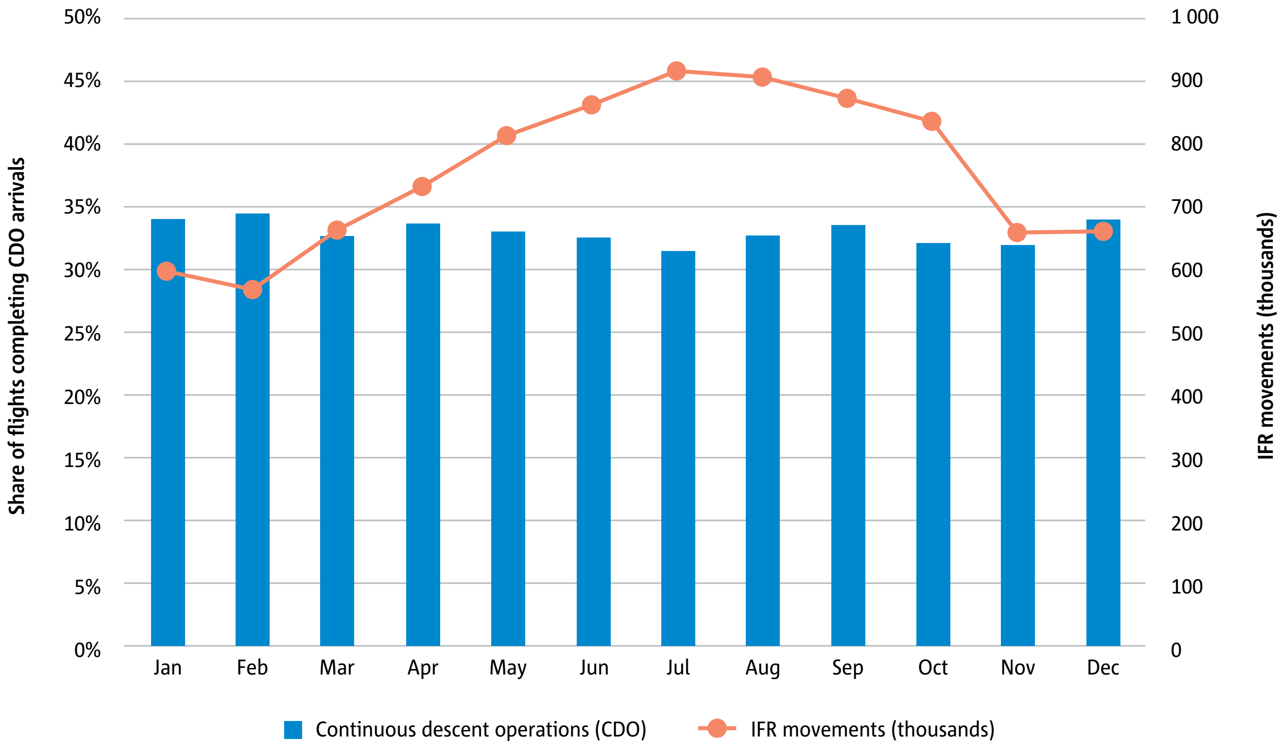
Figure 4.2 KEP horizontal en-route flight inefficiency and KES/SCR for 2014 to 2023



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 4.3) was fairly steady at around 30-35%, even during the summer period with a significantly higher number of flights. Air Traffic Controllers (ATCOs) will endeavor 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 4.3 illustrates that there is a limited capacity to accommodate CDOs.

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.

Figure 4.3 CDO vertical flight efficiency indicator for 2023



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. Recognizing 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 4.4) 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.

Significant variations exist between the top 40 busiest EU27+EFTA airports in terms of additional ASMA time (Figure 4.5).

Figure 4.4 Average additional ASMA and taxi-out times for the busiest EU27+EFTA 40 airports in terms of flight movements

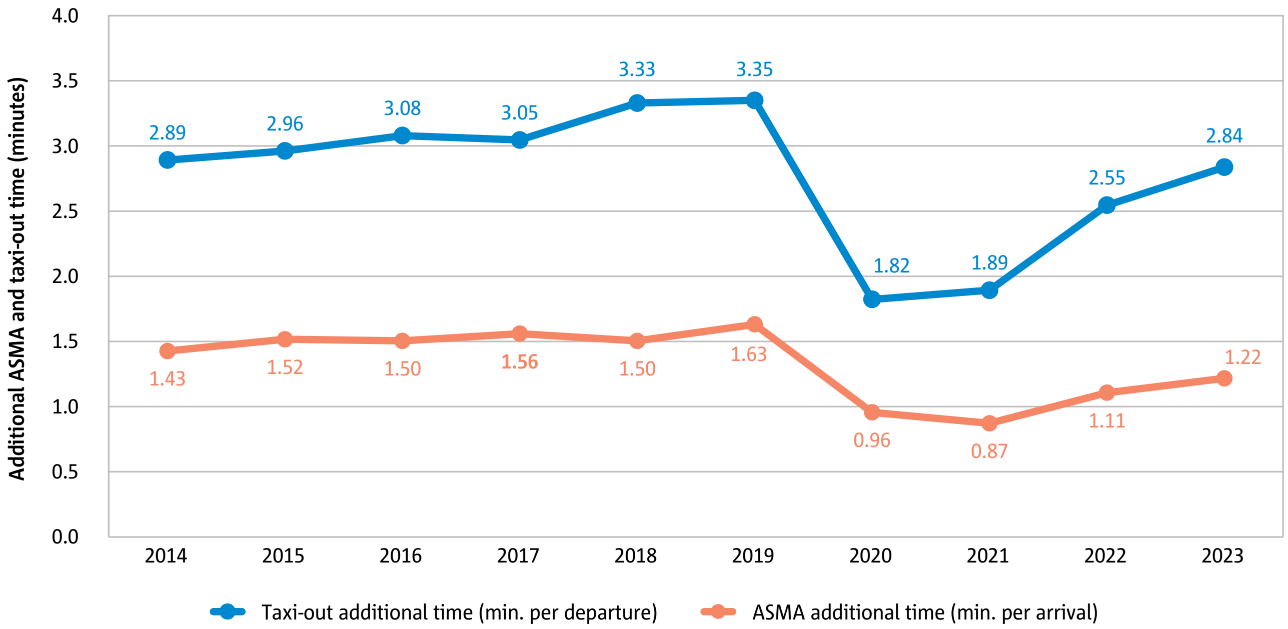
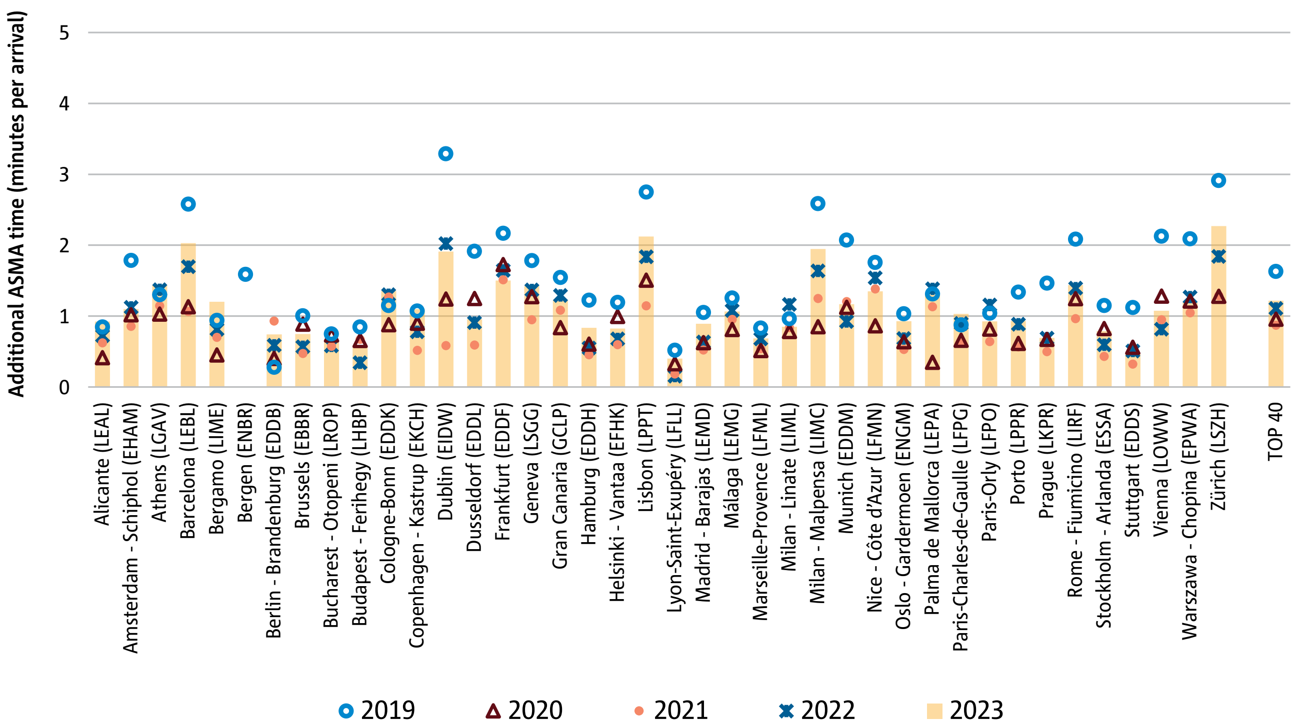


Figure 4.5 ATM related inefficiencies on the arrival flow (AMSA) at the 40 busiest EU27+EFTA airports (2019-2023)



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 should also 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 crisis due to insufficient Air Traffic Controllers (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.

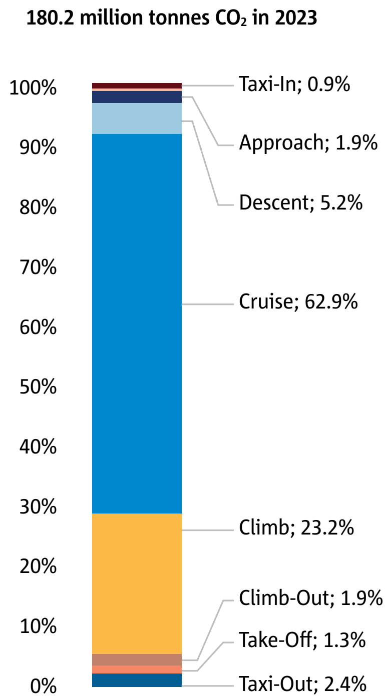
It is recognized that the SES performance scheme needs to be improved in terms of the ATM-related performance indicators for environment. KEA does not provide the needed granularity at national level to specifically assess the contribution of ATM to environmental efficiency. However, while this main 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.

4.3 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 4.6 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 4.6 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 4.7 highlights that 95% of NM departures fly less than 5 000 km and represent 55% of total fuel burn, meaning that just 5% of departures representing long-haul flights greater than 5 000 km burn 45% of total fuel.

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 FRA Alliance 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 below information illustrates the actual benefits of FRA achieved in 2018 and the estimated annual gains in 2026 with full FRA implementation.

Seamless Airspace

1.7M nmi to 4.7M nmi
237K min to 770K min

Cost Savings

Dependent on fuel price fluctuation

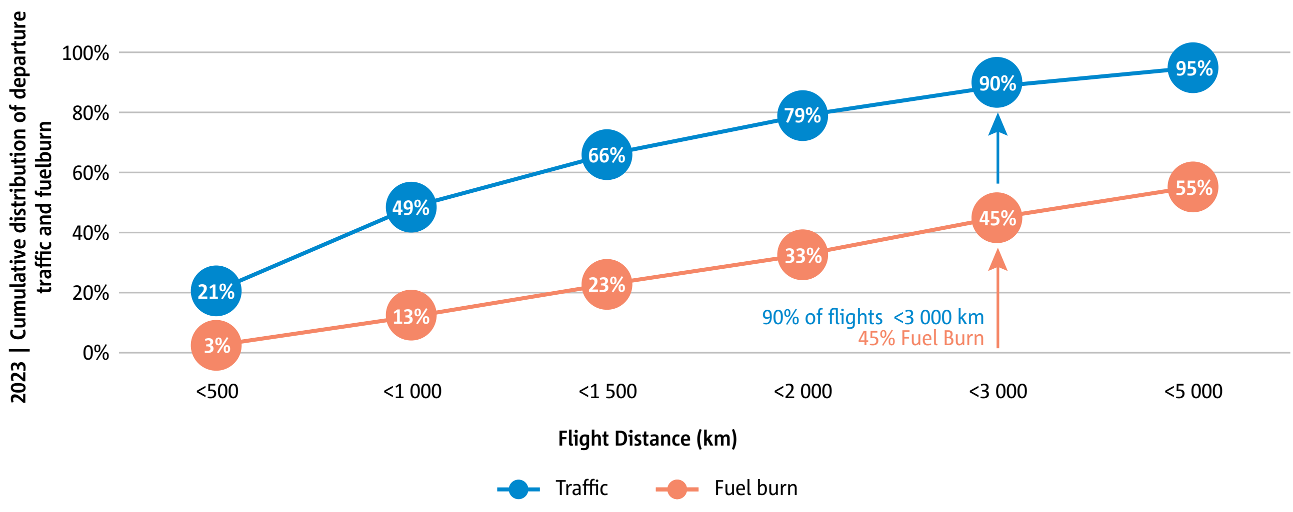
Reduced Fuel Burn

15kt to 30kt

Less Emissions

44kt to 94kt CO_2

Figure 4.7 Cumulative distribution of departure and fuel burn in 2023



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.

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

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.

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.

4.4 SESAR: TOWARDS THE DIGITAL EUROPEAN SKY

4.4.1 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 [5]. 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

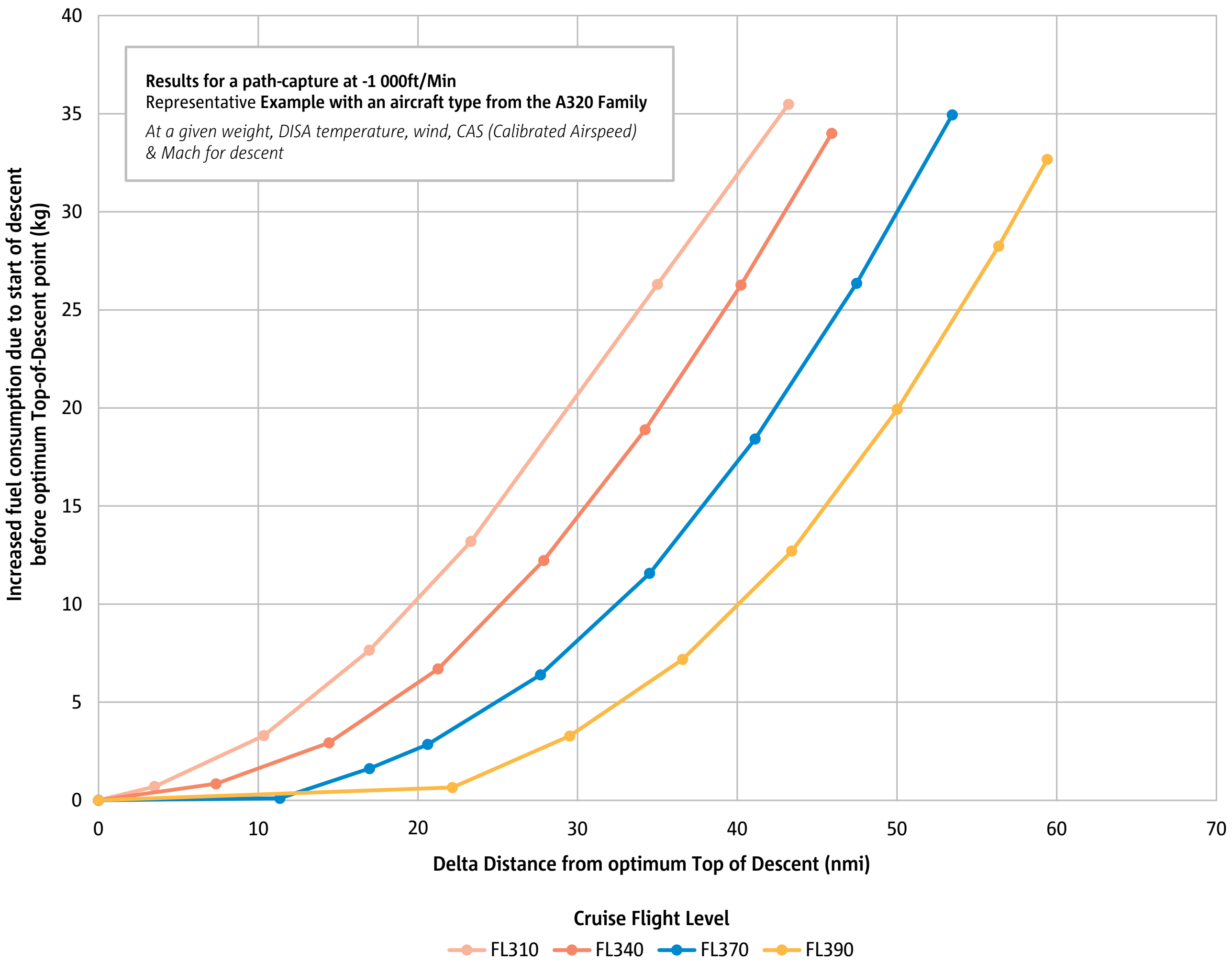
SESAR addresses the full scope of aviation's environmental impacts, from CO_2 and non-CO_2 emissions to noise and air quality at every phase of flight.

- **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% as showcased in the 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.[4] This leads to long thrust descent, which is inefficient even if it does not include intermediate level-offs (Figure 4.8). 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

Figure 4.8 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 50 nmi early, the additional fuel burn is 30 kg).



[4] SESAR Optimised Profile Descents Demonstration Report

dynamic deployment of RNP (Required Navigation Performance) route structures within the Terminal Maneuvering 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.

- **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 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.

4.4.2 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 4.9) 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.

Table 4.1 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 this table 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.

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 euro invested into CP1 deployment brought 1.5 euros in return during 2023 to the stakeholders in terms of monetizable benefits, as well as 0.6 kg of CO_2 savings (Table 4.2). Furthermore, the BCR and CO_2 savings are expected to increase overtime as CP1 AF are fully implemented (Table 4.3).

Figure 4.9 Overview of Common Projects 1 (CP1) ATM Functionalities

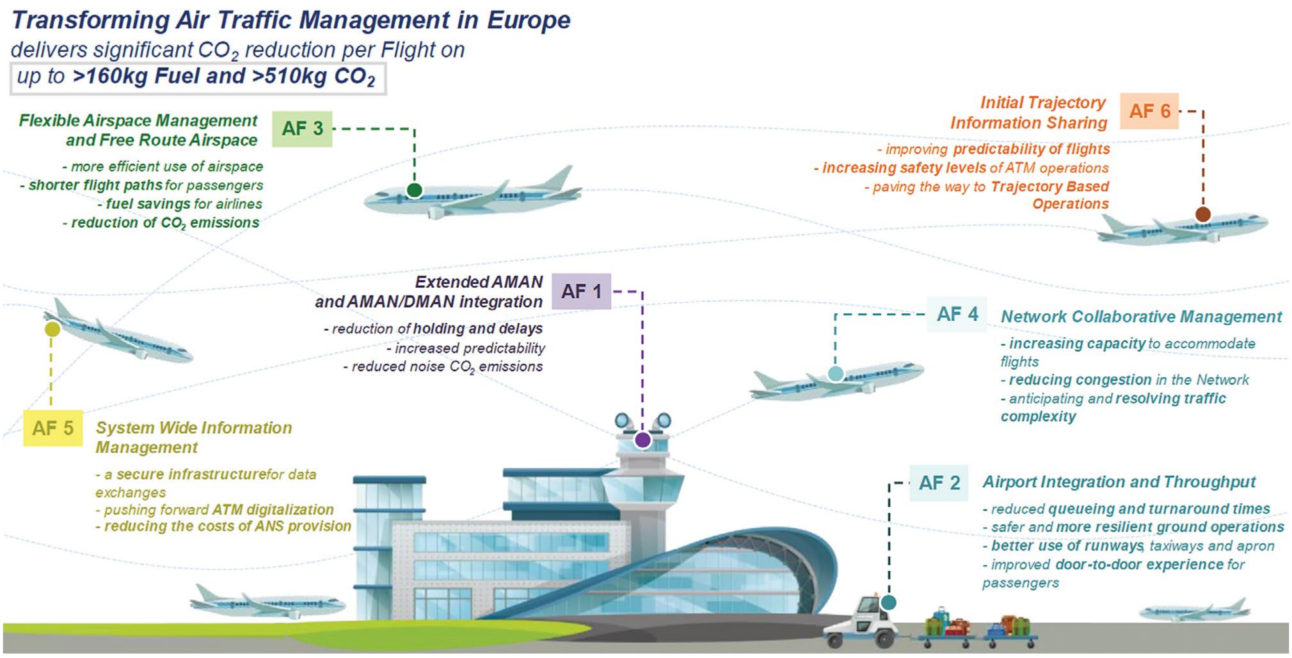


Table 4.1 CO_2 savings per Common Project 1 ATM Functionality

CP1 Functionality		Fuel saving per flight concerned	CO_2 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

Table 4.2 Benefit-Cost Ratio and CO_2 savings from CP1 AF implementation

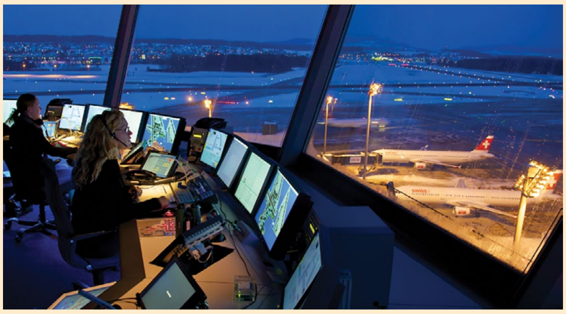
	Already achieved			
Metric	**2023**	**2030**	**2035**	**2040**
Best-cost ratio	**1.5**	3.8	5.9	8.0
CO_2	**0.6**	2.2	4.0	6.0

Table 4.3 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.

5

AIRPORTS

- During 2023, EASA took over the management and hosting of the Aircraft Noise and Performance (ANP) legacy data, approved prior to EASA's legal mandate under the 'Balanced Approach' Noise Regulation, in order to establish a single source of ANP data within Europe.
- An assessment of the Environmental Noise Directive implementation in 2023 concluded that the Commission should assess possible improvements, including noise reduction targets at the EU level as per the Zero Pollution Action Plan.
- This same assessment noted that Member States needed to accelerate compliance efforts and ensure that mitigation measures are in line with the Balanced Approach.
- There is growing pressure to address environmental impacts at the 'airport system' level or else face more stringent operational restrictions.
- Revisions to the EU Ambient Air Quality Directives agreed in 2024 included development of air quality action plans where limits are exceeded, enhanced monitoring of compliance, greater transparency for citizens as well as penalties and compensation for infringements.
- In 2022, the 1st Zero Pollution Action Plan Monitoring Assessment concluded that the 2030 noise target is unlikely to be met, while good progress had been made on air pollution targets.
- 51% of operations in Europe were made by aircraft compliant with the latest Chapter 14 noise standard in 2023.
- 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 Sustainable Aviation Fuel (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.
- 118 airports in Europe have announced a net zero CO_2 emissions target by 2030 or earlier, of which 16 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.[1]

[1] Scope 1: direct airport emissions. Scope 2: indirect emissions under airport control from consumption of purchased electricity, heat or steam. Scope 3: emissions by others operating at the airport such as aircraft, surface access, staff travel.

5.1 ENVIRONMENTAL PROTECTION REGULATORY FRAMEWORK

Noise

One of the main regulatory measures in Europe is the Environmental Noise Directive [1], which monitors and assesses the impact of aircraft noise on EU citizens living around major airports (>50 000 movements per year). This information is used to define a baseline, future objectives and a noise action plan in coordination with national and local initiatives.

The other key measure is the Noise Regulation [2] that implements the ICAO Balanced Approach [3] within European legislation, ideally through consultation and collaboration of stakeholders (e.g. airports, airlines, air navigation service providers, local authorities, local communities) in order to identify optimum solutions [4]. It establishes four main elements (Figure 5.1) for aircraft noise management that are critical to any airport noise action plan, and which can be adapted to the specific local circumstances and mitigation costs.

1. **Reduction of noise at source** through research programmes aiming at reducing aircraft noise through technology and design.
2. **Land-use planning and management policies** to avoid incompatible developments such as residential buildings in noise-sensitive areas.
3. **Noise abatement operational procedures** [5] to enable the reduction or redistribution of noise around the airport and make full use of modern aircraft and air navigation capabilities, while considering trade-offs with emissions.
4. **Aircraft operational restrictions** that limit access to or reduce the operational capacity of an airport, for instance noise quotas or flight restrictions. These are typically only implemented following due consideration of benefits that could be achieved form the other elements. Unlike aircraft compliant with Chapter 3 of ICAO Annex 16 Volume I, restrictions of Chapter 4 and 14 aircraft should be of a partial nature and not totally prohibiting access of these aircraft to the airport concerned.

Figure 5.1 Balanced Approach to aircraft noise management

EASA provides technical support in implementing the 'Balanced Approach' Noise Regulation through the verification and publication of aircraft noise and performance (ANP) data, which is used in models to compute airport noise contours (also called noise maps) and noise exposure of EU citizens living close to airports. During 2023, EASA also took over from EUROCONTROL the management and hosting of the ANP legacy data, which was approved prior to EASA's legal mandate in this area, in order to establish a single source of ANP data within Europe. In addition, the Agency gathers noise documentation of individual aircraft with a maximum take-off mass of 34 000 kg or more, or greater than 19 passenger seats, operating at European airports. The information is then made available to competent authorities, air navigation service providers and airports. As of 2024, the Agency has verified more than 15 ANP datasets and collected more than 15 500 aircraft noise documents from over 1 200 aircraft operators [6].

Assessment of Environmental Noise Directive implementation

The 3rd Implementation Report on the Environmental Noise Directive [7] was published by the European Commission in March 2023. Based on the main observations, the report contained the following conclusions, recommendations and next steps:

- Management of airport noise was confirmed as a priority action.
- The current regulatory framework is coherent (no overlaps or contradictions), but progress was hampered by the lack of a common noise policy objective.
- The noise target and commitments set out in the Zero Pollution Action Plan (ZPAP) [8] reinforced political momentum to accelerate and intensify policies and action to reduce noise.
- Optimal cooperation between national, regional, and local authorities is required, with local actors empowered and encouraged to replicate best practices.
- Civil society representatives should be encouraged to ensure noise action plans are implemented and deliver noise reduction improvements at local level.
- At the EU level, the Commission will, where needed, priortise action that includes:
  - ◊ Promote enhanced procedures to reduce noise from the landing and take-off of aircraft;
  - ◊ Introduce environmental charges to increase use of quiet aircraft when revising the Airport Charges Directive [9];
  - ◊ Support Member States with relevant tools and actions under the ZPAP;
  - ◊ Strengthen short-term actions on tackling noise at source; and
  - ◊ Assess possible improvements to the Directive, including noise reduction targets at the EU level as underlined in the ZPAP.
- At the national level, Member States need to accelerate compliance efforts and ensure airport noise abatement objectives and mitigation mesaures are in line with the Balanced Approach.

Implementation of the Noise Regulation Balanced Approach

Recent examples in the application of the Balanced Approach Regulation [10] suggest that clear guidance for Member States to implement the Balanced Approach effectively will help find comprehensive solutions to address aircraft noise impacts, while maintaining air connectivity and promoting consistency, transparency and inclusivity of all stakeholders.

Air Quality

The EU Ambient Air Quality Directives form the Regulatory Framework within Europe in this area. In October 2022, the European Commission introduced a proposal to revise the Directives, which drew on the lessons learnt from the evaluation of the current air quality legislation.

The revision strengthens provisions on monitoring, modelling and air quality plans to help local authorities achieve cleaner air, which includes improved monitoring at air quality hotspots that may include airports. Furthemore, it revises air quality standards to align them more closely with the World Health Organization recommendations, and foresees a regular review of the air quality standards in line with latest scientific evidence with a view to putting the EU on track to achieve zero pollution for air by 2050. Finally, it further improves the legal framework, providing more clarity on access to justice, damage redress, effective penalties, and better public information on air quality.

In February 2024, the European Parliament and Council of the EU reached a political agreement on the new Directive, which was adopted at the end of 2024 [11].

Zero Pollution Action Plan

The European Green Deal's Zero Pollution Action Plan (ZPAP) [8] was adopted in 2021 and aims to reduce air, water and soil pollution to levels no longer considered harmful to health and natural ecosystems by 2050. This was translated into the following 2030 targets with a 2005 baseline:

- reducing the share of people chronically disturbed by transport noise by 30%[2]; and
- improving air quality to reduce the number of premature deaths caused by air pollution by 55%.

The 1st Zero Pollution Monitoring Assessment was published in December 2022 [14]. The key messages / conclusions were:

- ZPAP noise target for 2030 is unlikely to be achieved unless additional measures are taken.
- Main obstacle to reaching this target is road traffic noise, while aircraft noise is forecast to decrease.
- Reducing the number of people chronically disturbed by transport noise requires action at all levels (EU, national, regional and local).
- Good progress has been made in reducing health impacts of air pollution. If the past trend continues, the EU is on track to meet the target of a 55% reduction.
- There has been a 45% fall in premature deaths since 2005, although aircraft NO_X and non-volatile PM emissions have increased.

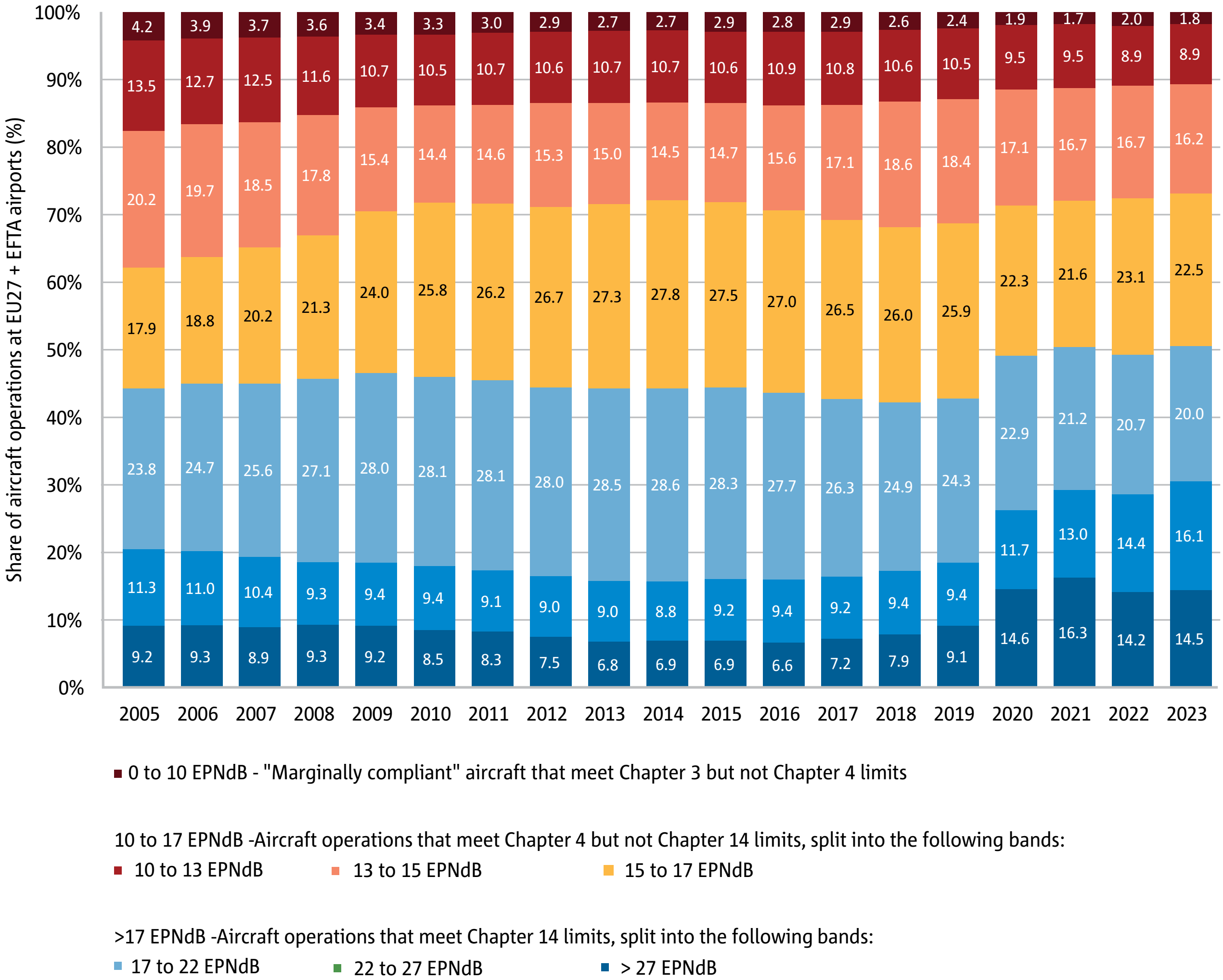
The 2nd Zero Pollution Monitoring Assessment is due to published in early 2025.

[2] This has been defined by EEA [12] as number of people 'highly annoyed' where high annoyance is based on the exposure-response functions outlined in the WHO environmental noise guidelines for the European Region [13] and reported data under the Environmental Noise Directive on the number of people exposed to annual average noise levels of 55 dB or higher during the day-evening-night period (Lden).

5.2 AIRCRAFT PERFORMANCE AT EUROPEAN AIRPORTS

The environmental performance of the aircraft operating within Europe has been improving over time as the latest technology penetrates the global fleet. Figure 5.2 illustrates the % share of EU27+EFTA operations by aircraft noise performance in terms of cumulative margin[3] to the oldest Chapter 3 limit. The trend following COVID has continued up to 2023 where only 1.8% of aircraft operations were marginally compliant Chapter 3, while 50.6% of aircraft operations complied with the most recent Chapter 14 limits. A similar trend has been observed in terms of aircraft NO_X emissions with 51.9% of operations having aircraft engines that comply with the most recent CAEP/8 limits.

Figure 5.2 Share of operations by cumulative margin to Chapter 3 limits at EU27+EFTA airports



[3] 'Cumulative margin' is the figure expressed in EPNdB obtained by adding the individual margins (i.e. the differences between the certificated noise level and the maximum permitted noise level) at each of the three reference noise measurement points in Chapter 3. See also Figure 3.2 in Technology and Design chapter.

5.3 AIRPORT MEASURES

5.3.1 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 [15] 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 (STARs) 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 [16], 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 [17]. 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)

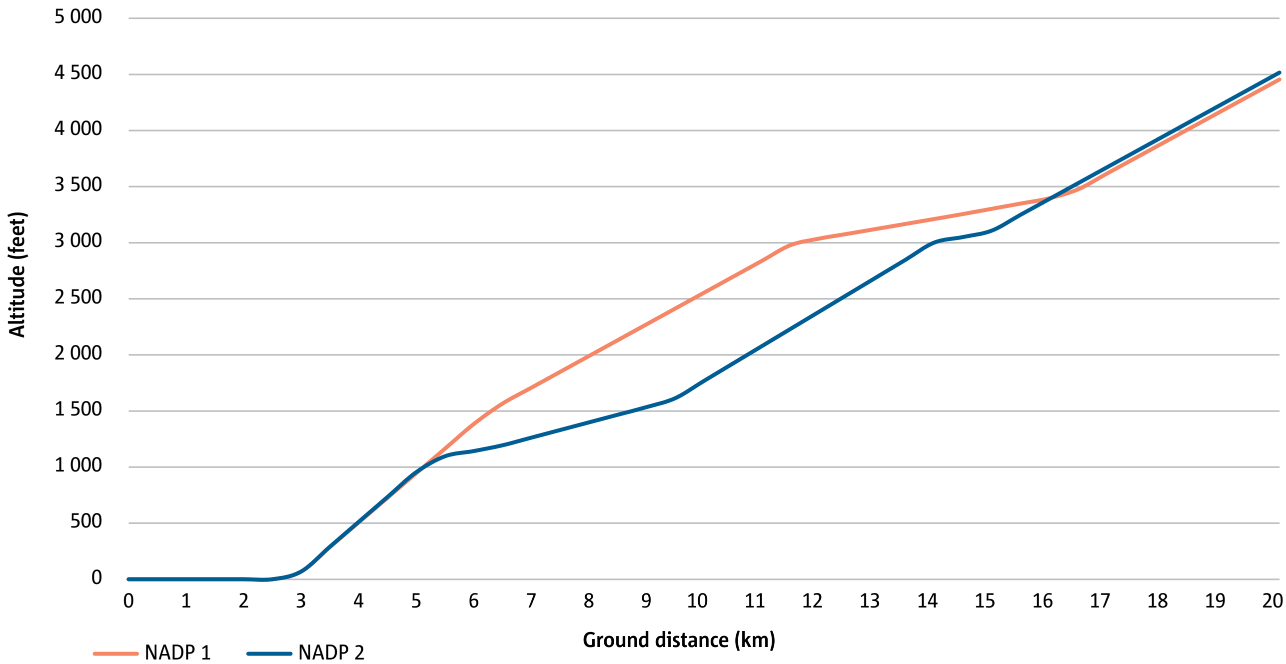
NADPs aim to reduce the noise impact of departing aircraft by selecting the appropriate moment to clean the aircraft (i.e. retract flaps), which has an impact on the flown vertical profile. NADP1 results in noise reductions close to the airport, while NADP2 reduces noise further away and has lower fuel consumption (Figure 5.3). 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.

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 solutionç 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 50 kg to 200 kg while only marginally increasing noise by 1 dB close to the airport.

Figure 5.3 Example of the difference between NADP 1 and 2 for a wide body aircraft with thrust reduction at 1 000ft.



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 [18]. The Concept of Operations (CONOPS) addresses the potential fuel burn reductions of several sustainable taxiing solutions, which could be up to 400 kg 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 temperatures 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.

5.3.2 Airport Infrastructure

Various EU research projects, including TULIPS [19], OLGA [20] and STARGATE [21], 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 (see Chapter 2). 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 [22].

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 [23]. This facility has provided such encouraging results that it has gradually expanded from 8.4 kW to 17.4 MW, 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 [24].

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 to support the large-scale introduction of zero-emission aircraft, which 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 [25]. 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 aircraft 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 [26]. 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 5.1). A detailed overview of these types of SAF incentive initiatives by European airports has been compiled by ACI EUROPE [27].

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 [28].

Table 5.1 Overview of airport initiatives to support the uptake of SAF

Supply Chain Investment
• Support airline on logistic issues 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.

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 [29], the Alternative Fuels Infrastructure Regulation [30] and their 'financial arm' in the form of the Connecting Europe Facility [31].

Trans-European Transport Network (TEN-T)
The revision of the TEN-T Guidelines [32] 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 [33, 34]. 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.

5.4 NET ZERO CO_2 EMISSIONS

The ACI EUROPE Sustainability Strategy was launched in 2019 [35], which included the Net Zero Resolution that has been updated in 2024 [36]. 303 European airports have since committed to net zero[4] carbon emissions from airport operations within their control by 2050 and provided a roadmap detailing how this will be achieved [37].

This net zero commitment covers Scope 1 direct airport emissions and Scope 2 indirect emissions (e.g. consumption of purchased electricity, heat or steam). 118 airports have announced a net zero target by 2030 or earlier, and 16 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 [38] and this was followed in 2023 with guidance on developing Net Zero carbon roadmaps [39].

[4] 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 5.4).

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).

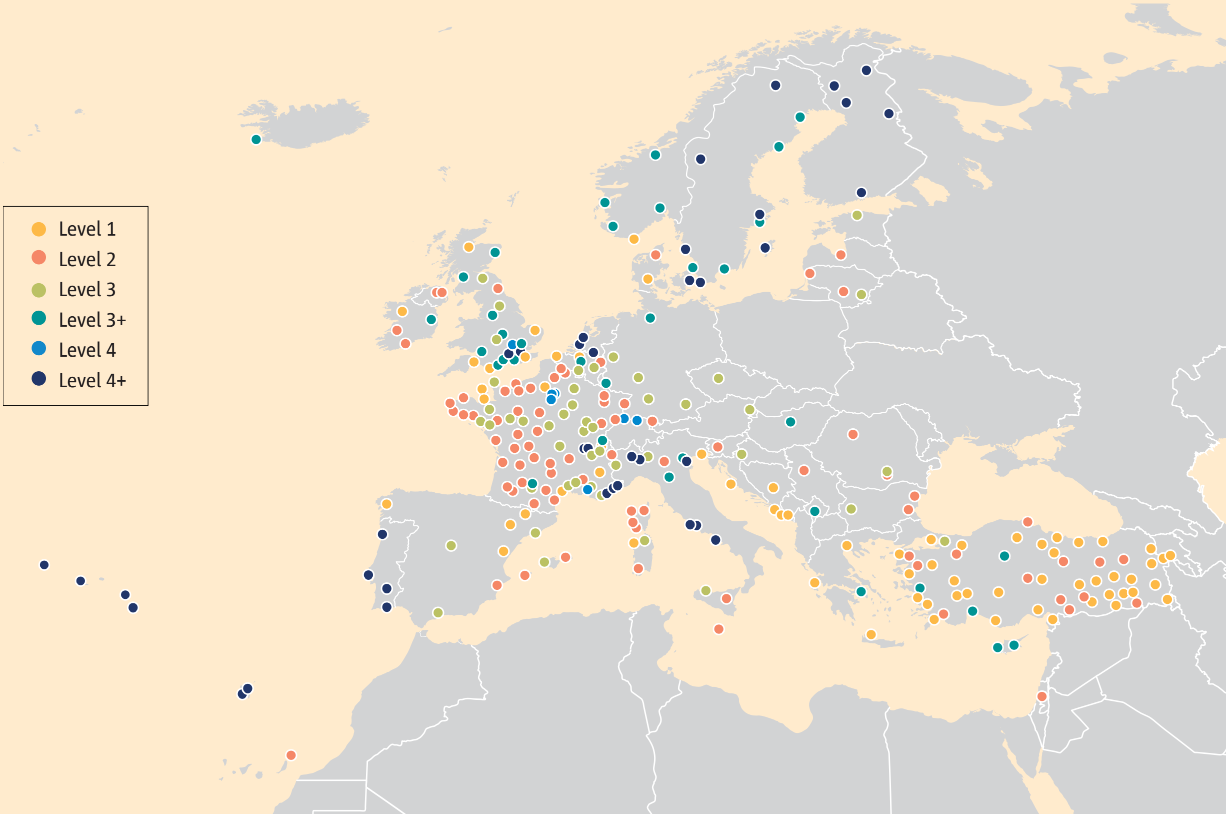
In 2020, Levels 4 (Transformation[5]) and 4+ (Transition[6]) have been added as interim steps towards the long-term goal of achieving net zero CO_2 emissions and to align it with the objectives of the Paris Agreement. Guidelines were also published to inform airports about offsetting options, requirements 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 [41] 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 [42], 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 milestones to gauge progress.

5 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.
6 All Levels 1 to 4 plus offsetting of the residual carbon emissions over which the airport has control.

Figure 5.4 European airports participating in the ACA programme



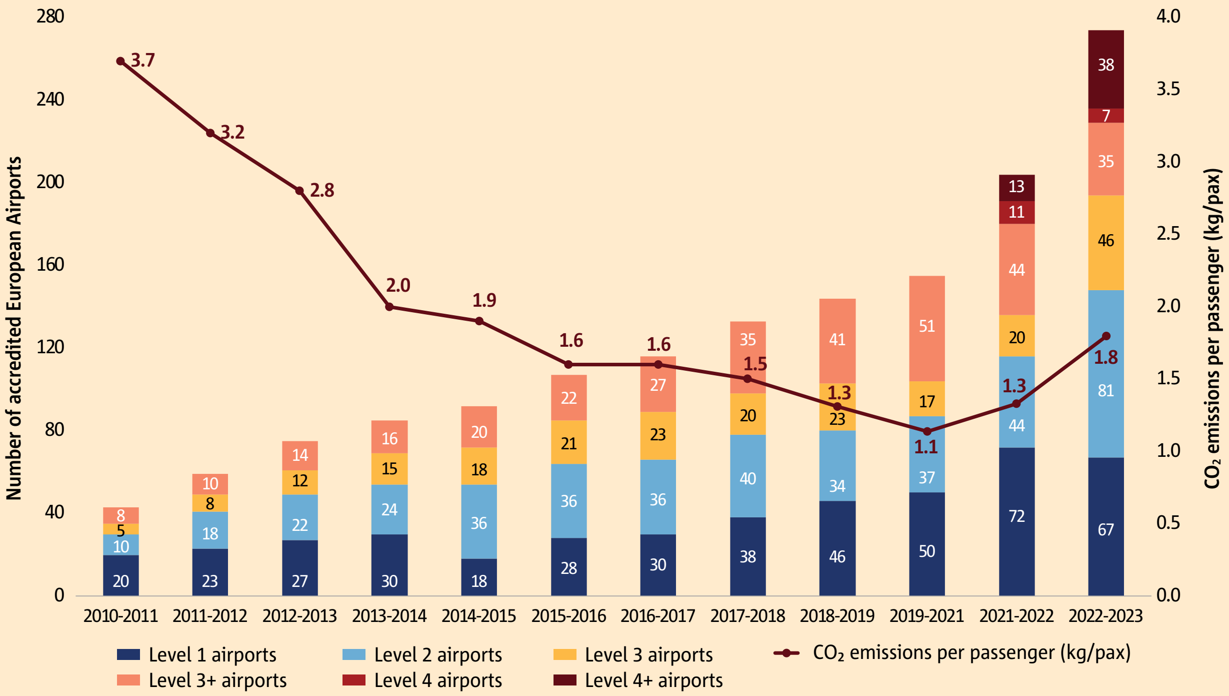
Ten airports were certified against Level 5 at launch, including 9 European airports (Amsterdam Schiphol, Eindhoven, Rotterdam-The Hague, Beja, Madeira, Ponta Delgada, Göteborg Landvetter, Malmö and Toulon-Hyères). Ivalo, Kittilä, Kuusamo and Rovaniemi airports were also subsequently accredited to Level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

The carbon emissions per passenger travelling through European airports at all levels of Airport Carbon Accreditation has increased to **1.8 kg CO_2/passenger** (Figure 5.5). A total reduction in Scope 1 and 2 emissions compared to a three year rolling average[7] of **452 893 tonnes of CO_2** for all accredited airports in Europe was also reported (Figure 5.6). This represents about 20% reduction compared to the three-year rolling average.

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.

7 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.

Figure 5.5 **Increasing number of accredited European airports as well as increasing CO_2 emissions per passenger since 2019-2021**



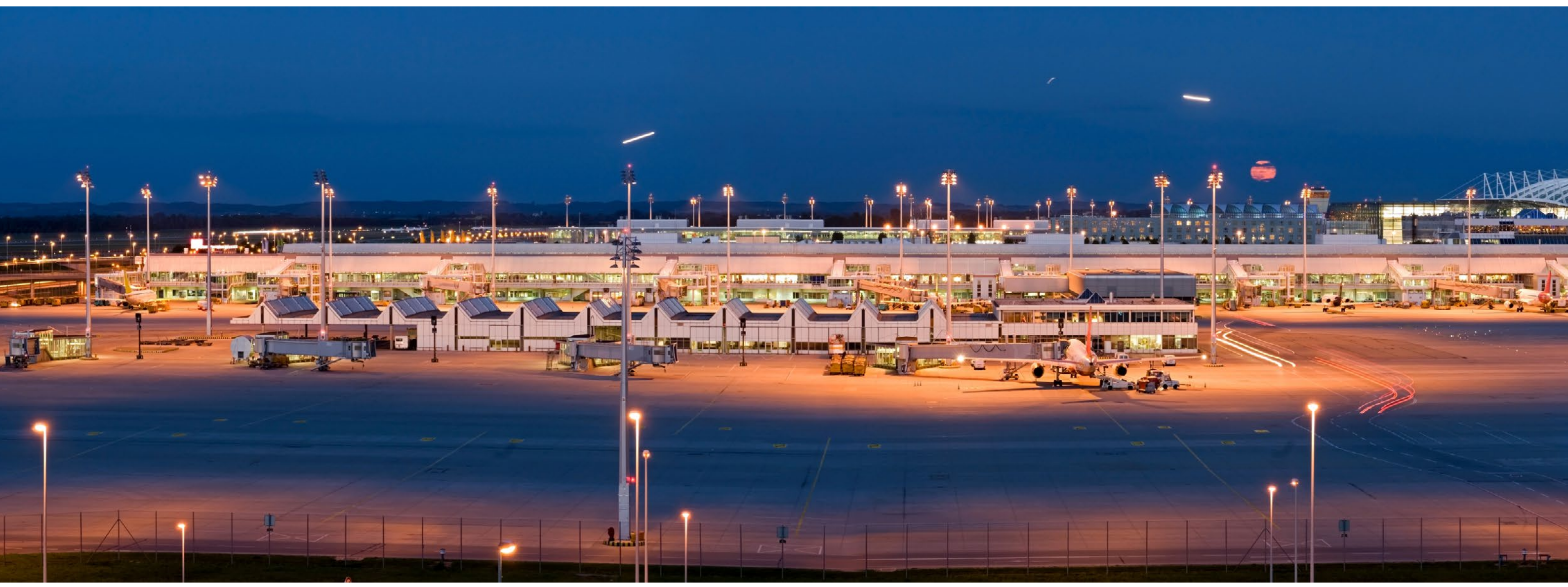
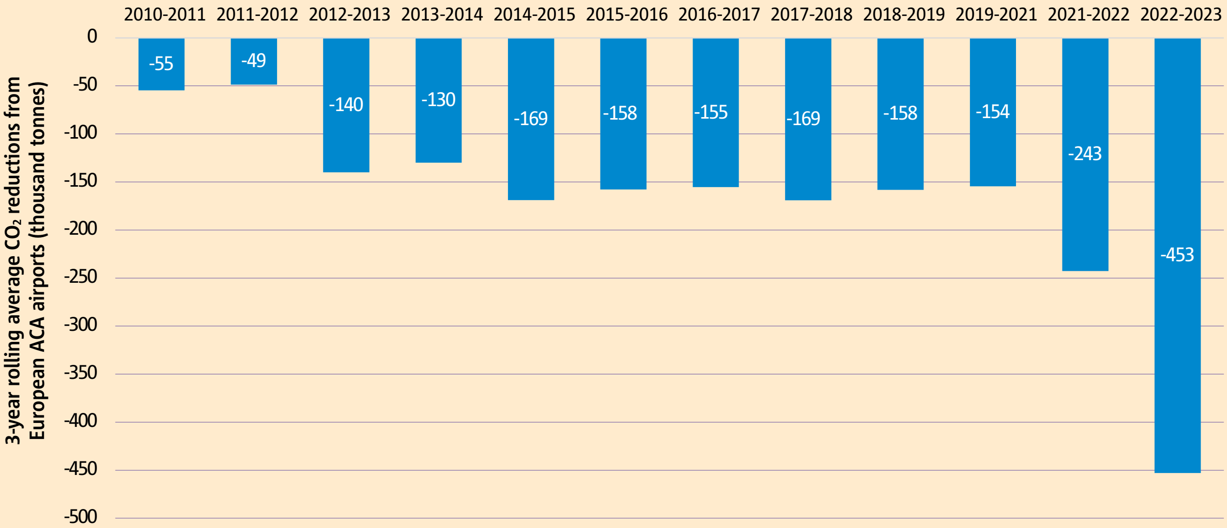


Figure 5.6 Scope 1 and 2 emissions reductions in airport CO_2 emission



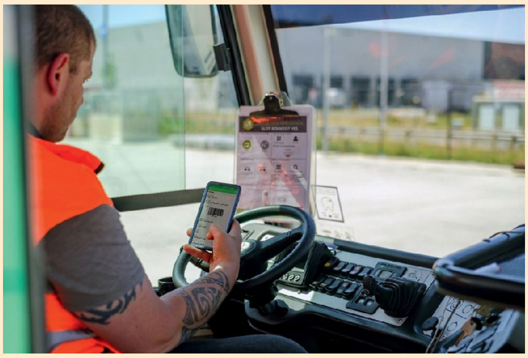
STAKEHOLDER ACTIONS

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 [43] 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.

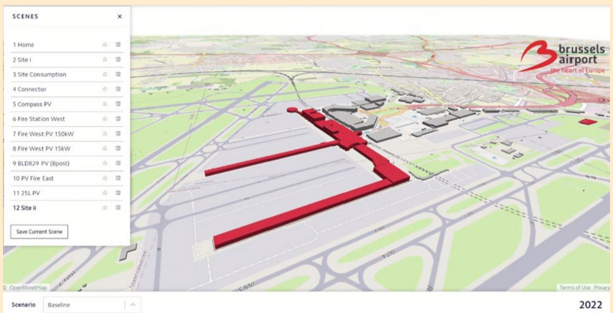


Airport Regions Council (ARC)

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' [44], 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 [45]. This tool uses Carbon Disclosure Project [46] 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 businesses [47].

6

SUSTAINABLE AVIATION FUELS

- The ReFuelEU Aviation Regulation has set a minimum supply mandate for Sustainable Aviation Fuels (SAF) in Europe, starting with 2% in 2025 and increasing to 70% in 2050.
- A sub-mandate for synthetic e-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).
- In 2023, the ICAO CAAF/3 conference agreed 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 labeled as meeting 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.

6.1 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 synthetic aviation 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 these mandates.

6.2 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 6.1). 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 6.1 ReFuelEU Aviation Regulation fuel categories

Type of ReFuelEU Aviation fuel	Definition in ReFuelEU	Price availability in 2023	Comments
Categories of sustainable aviation fuels (SAF) under ReFuelEU that are drop-in fuels manufactured for direct use by aircraft			
Synthetic aviation fuels	Art 3(12)	No	Renewable fuels of non-biological origin as defined in RED
Advanced aviation biofuels	Art 3(8)(a)	No	Biofuels produced from feedstock listed in Part A Annex IX of RED
Aviation biofuels	Art 3(8)(b)	Yes	Biofuels produced from feedstock listed in Part B Annex IX of RED
Other aviation biofuels	Art 3(8)(c)	No	Biofuels produced from feedstock not listed in Annex IX of RED[1]
Recycled carbon aviation fuels	Art 3(9)	No	Recycled carbon fuels as defined in RED
Categories of other renewable and low-carbon aviation fuels eligible under ReFuelEU			
Renewable hydrogen for aviation	Art 3(16)	No	Hydrogen for aviation that is renewable fuel of non-biological origin as defined in RED
Low-carbon hydrogen for aviation	Art 3(15)	No	Hydrogen for aviation that is produced from non-fossil non-renewable sources as defined in the Gas Directive
Synthetic low-carbon aviation fuels	Art 3(13)	No	Drop-in aviation fuel produced from non-fossil non-renewable sources as defined in the Gas Directive
Other relevant aviation fuels under ReFuelEU			
Conventional aviation fuel	Art 3(14)	Yes	Aviation fuels produced from fossil non-renewable sources of hydrocarbon fuels

1 ...and except for those produced from food and feed crops, intermediate crops, palm fatty acid distillate and palm and soy-derived materials, and soap stock and its derivatives.

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 a 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).

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).

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 fullfilling 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).

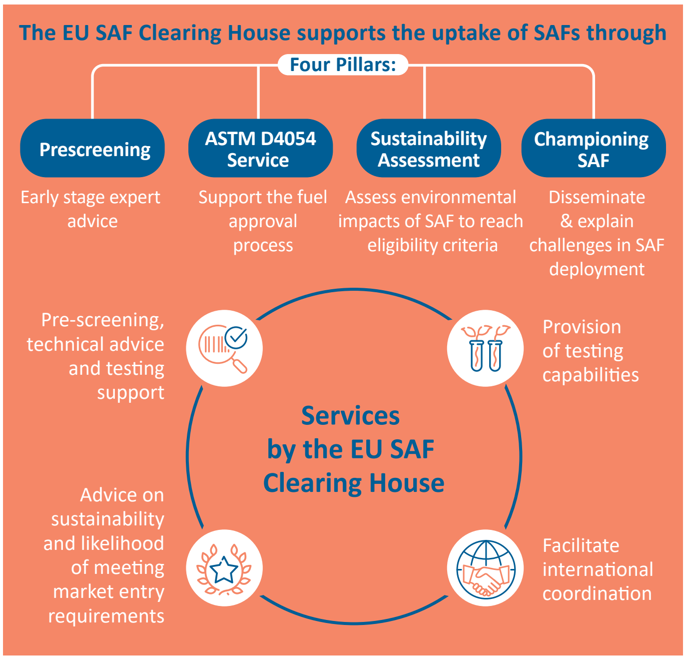
Table 6.2 Drop-in SAF qualified production pathways

Production pathway	Feedstocks[2]	Certification name	Maximum SAF share
Biomass Gasification + Fischer-Tropsch (Gas+FT)	Energy crops, lignocellulosic biomass, solid waste	FT-SPK[3]	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[4]	10%
Biomass Gasification + FT with Aromatics	Energy crops, lignocellulosic biomass, solid waste	FT-SPK/A[5]	50%
Alcohol to Jet (AtJ)	Sugar, starch crops, lignocellulosic biomass	ATJ-SPK	50%
Catalytic Hydrothermolysis Jet (CHJ)	Vegetable and animal fat	CHJ or CH-SK[6]	50%
HEFA from algae	Microalgae oils	HC-HEFA-SPK[7]	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%

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.



[2] The listed feedstocks are technologically feasible for the specific production pathway, but not necessarily applicable under certain regulations (e.g. ReFuelEU Aviation)
[3] FT-SPK: Fischer-Tropsch synthesised paraffinic kerosene.
[4] HFS-SIP: hydroprocessed fermented sugars to synthetic iso-paraffins.
[5] FT-SPK/A: Fischer-Tropsch synthesised paraffinic kerosene with Aromatics.
[6] CH-SK: catalytic hydrothermolysis synthesised kerosene.
[7] HC-HEFA-SPK: Synthesised paraffinic kerosene from hydrocarbon-hydroprocessed esters and fatty acids.

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

Approved SAF currently have associated maximum blending ratios (Table 6.2) 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.

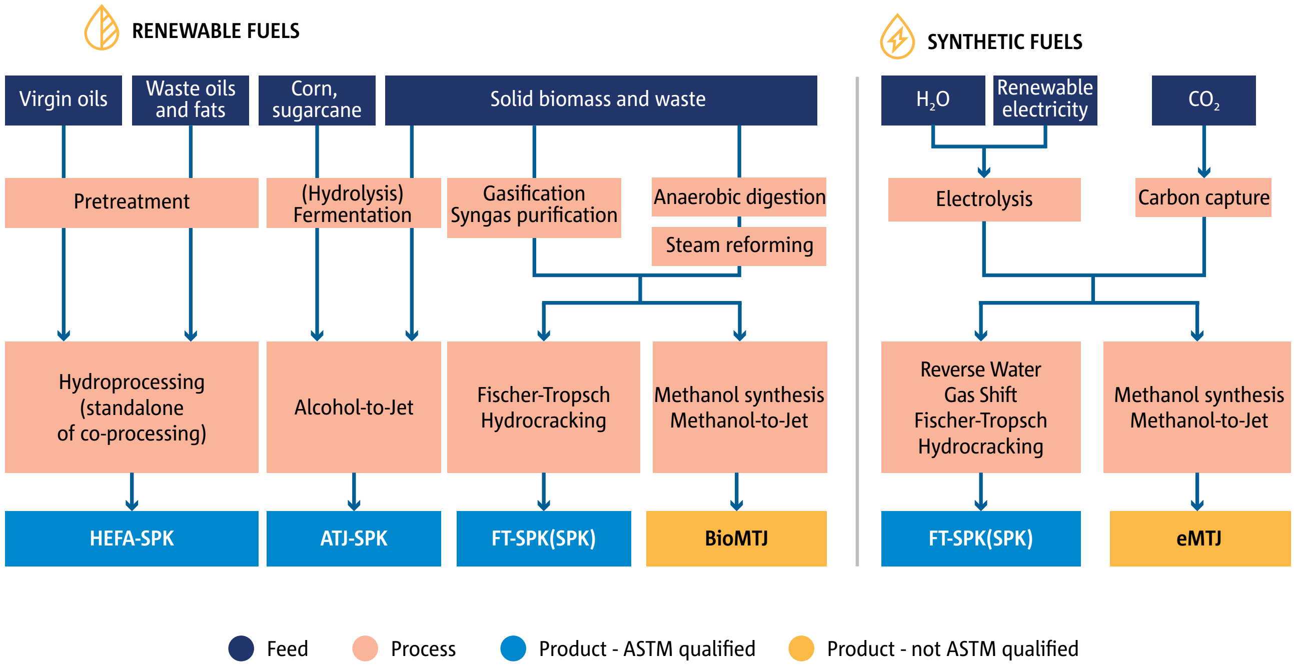
A collaborative effort across the aviation ecosystem aims to maximize global impact, with standardization and technical readiness currently in progress. Ongoing impact analysis focuses on fuel production, while further studies are necessary to address infrastructure challenges associated with 100% Non-Drop-In 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[8] 8-9), Alcohol 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.

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,

8 Technology Readiness Level

Figure 6.1 Main SAF production pathways with similar building blocks [8]



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 Sustainability Certification Schemes).

Alcohol 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.

6.3 HOW 'SUSTAINABLE' ARE SAF?

Sustainability criteria

Table 6.3 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].

GHG emissions reductions

The emissions reductions from drop-in SAF in a lifecycle assessment (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 those of fossil fuels. Many variables can influence the overall results of the LCA (Figure 6.2), but given historic concerns

Table 6.3 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, Human and labour rights, Land use rights and land use, Water use rights, Local and social development and Food security.

surrounding biofuel sustainability, it is encouraged to calculate actual life cycle emission values rather than applying a default value.

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 6.3 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.

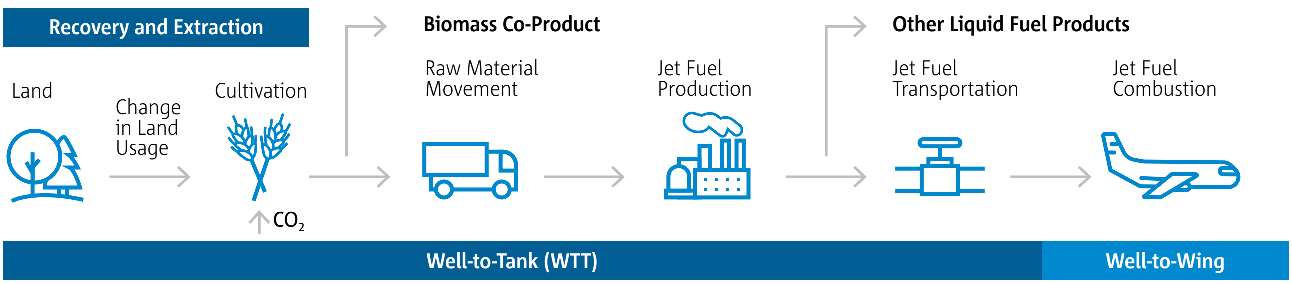
SAF and non-CO_2 emissions

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 (see Chapter 2 on Environmental Impacts).

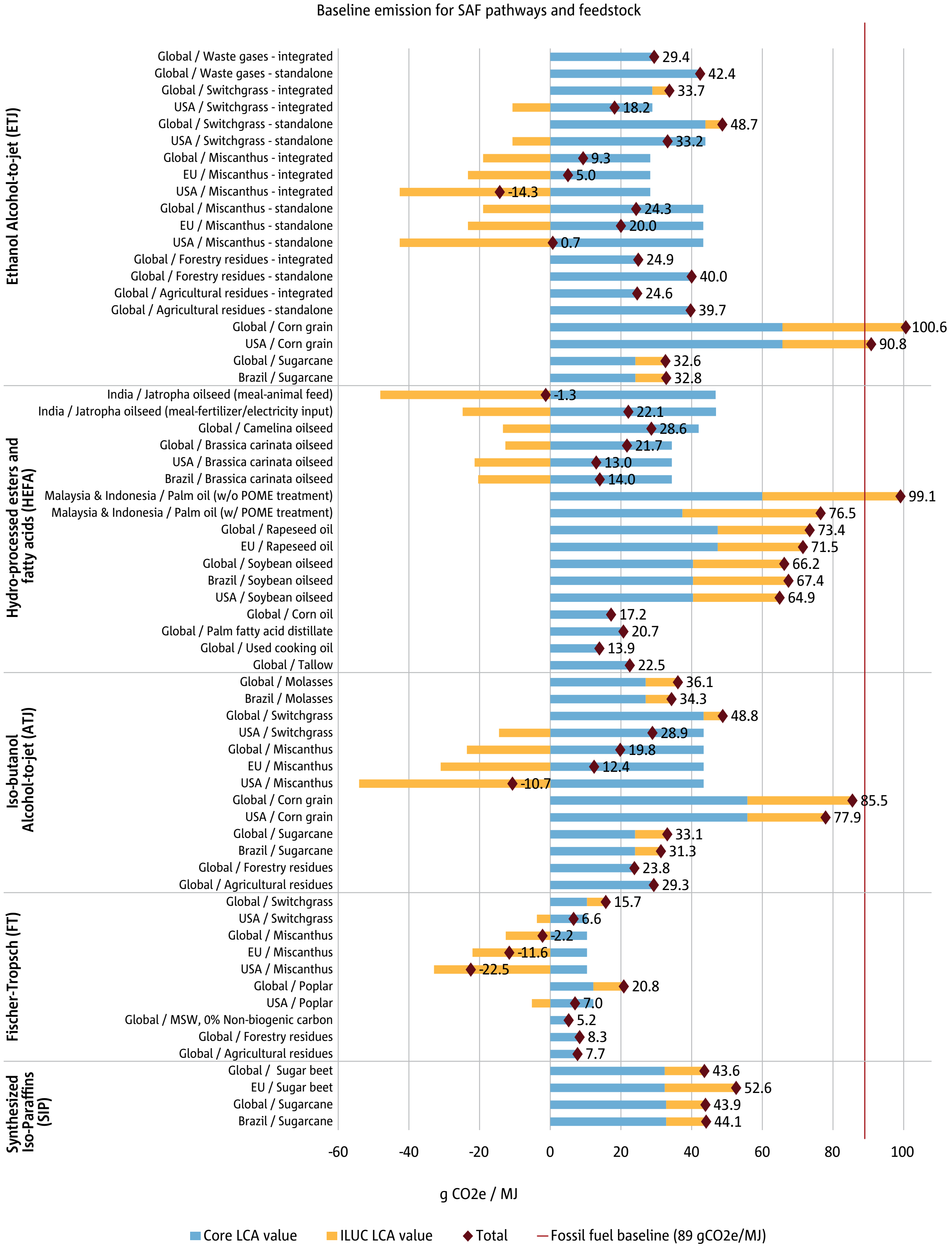
Research projects, such as AVIATOR and RAPTOR [14, 15] have shown that the use of certain types of SAF could have positive impacts on local air quality [16] due to lower levels of sulphur and aromatic content which contribute to volatile and non-volatile particulate matter (nvPM)

Figure 6.2 Components of typical well-to-wing LCA for biofuel-based jet fuel



9 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.

Figure 6.3 LCA emissions for CORSIA eligible SAF pathways and feedstock compared to CORSIA fossil fuel reference value (89 g CO_2e/MJ) [19][1]



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 lean-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].

Sustainability Certification Schemes – Combatting fraudulent practices

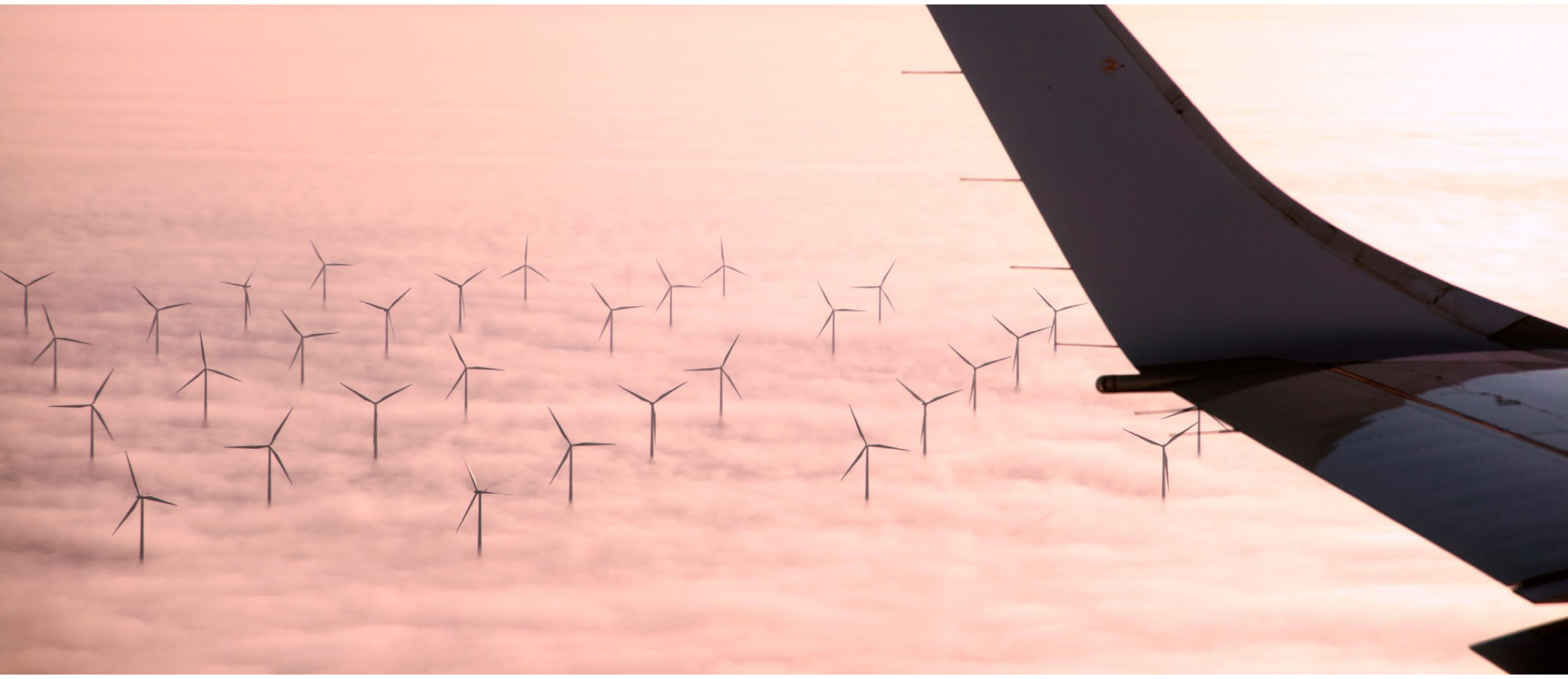
With so much emphasis being placed on SAF to help reduce aviation emissions, the 'S' in SAF needs to live up to its promise and ensure the effective delivery of emission reductions while avoiding unintended negative environmental and social impacts of its production, thus contributing to the credibility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

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.

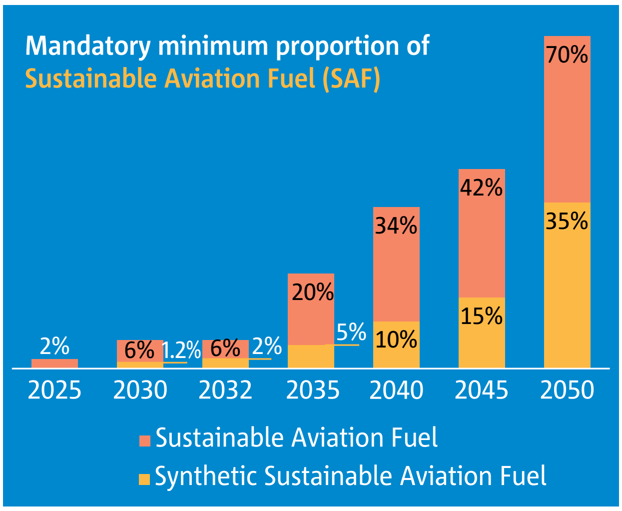
In response to these concerns, certification schemes have generally increased their efforts to enhance the credibility of the system, including unannounced integrity audits at randomly selected plants and economic operators. As a result, some sustainability certificates were withdrawn or temporarily 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].



6.4 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 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 aviation fuels to Union airports and this gradually increases to at least 70% by 2050. Synthetic aviation fuels are subject to a dedicated minimum share, 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 European Commission has published a report to 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).



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

- A zero emissions rating of SAF used under the **EU Emissions Trading System** (ETS);
- A maximum of 20 million ETS allowances (with an estimated value of €1.6 billion) allocated to aircraft operators between 2024 and 2030 for the uplifting of SAF to cover part of or all of the price difference with fossil kerosene, depending on the type of SAF and the uplift location;
- A favourable tax treatment of SAF under the proposed revision of the Energy Taxation Directive;
- A **Flight Emissions Label (FEL)** laying down harmonised 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;
- Financial support for research, innovation and deployment 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 the creation of an **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, as well as match-making emerging SAF projects with potential fuel off-takers, 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.

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.

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 Aviaton 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.

Non-EU policy action

This section contains an non-exhaustive overview of national policies outside the EU that promote the use of SAF.

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, thereby 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. Turkey 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].

Outside of Europe, the United States has introduced the 'SAF Grand Challenge' to produce at least 3 billion gallons (approx. 94 million tonnes) per year by 2030 [26]. This is being incentivized by tax credits for producers and a grant program to boost domestic SAF production. Both South Korea and Indonesia plan to have all departing international flights use a mix of 1% SAF from 2027, with Indonesia planning to ramp up this mandate from 2.5% in 2023 up to 50% in 2060 [27, 28]. Singapore aims at a 1% SAF target for all departing flights from 2026 that will increase to 3-5% by 2030, and which is supported by the introduction of a levy for the purchase of SAF [29]. The Japanese Ministry of Trade and Industry has set a 10% SAF blending target on domestic airlines fuel consumption by 2030 that includes support to develop new technologies to produce SAF [30].

6.5 SAF MARKET

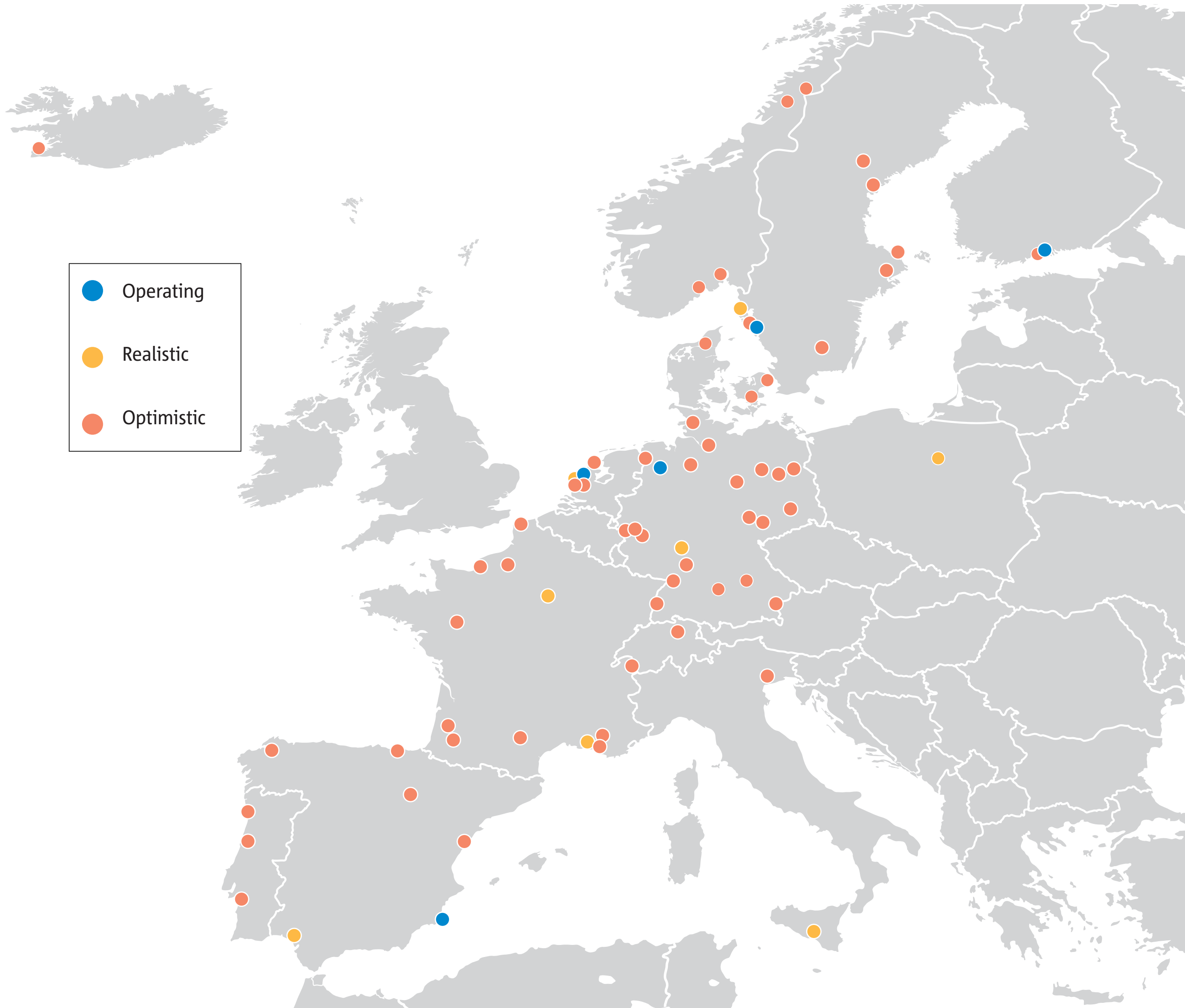
Global SAF production represented only 0.53% of jet fuel use in 2024, up from 0.2% in 2023 [31, 32, 33]. The EU SAF market, incentivized following the adoption of the ReFuelEU Aviation regulation and the revision of the EU ETS and the RED, is now in a transition phase. The regulation requires a significant 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 6.4), 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'**.

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 [34] estimates 3.8 Mt by 2030, including 0.3 Mt of PtL as well as some co-processing production, while the International Energy Agency (IEA) predicts roughly 3.8 Mt by 2038 [35]. 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.

Figure 6.4 Projected EU+EFTA SAF facilities in 2030 under the Optimistic scenario

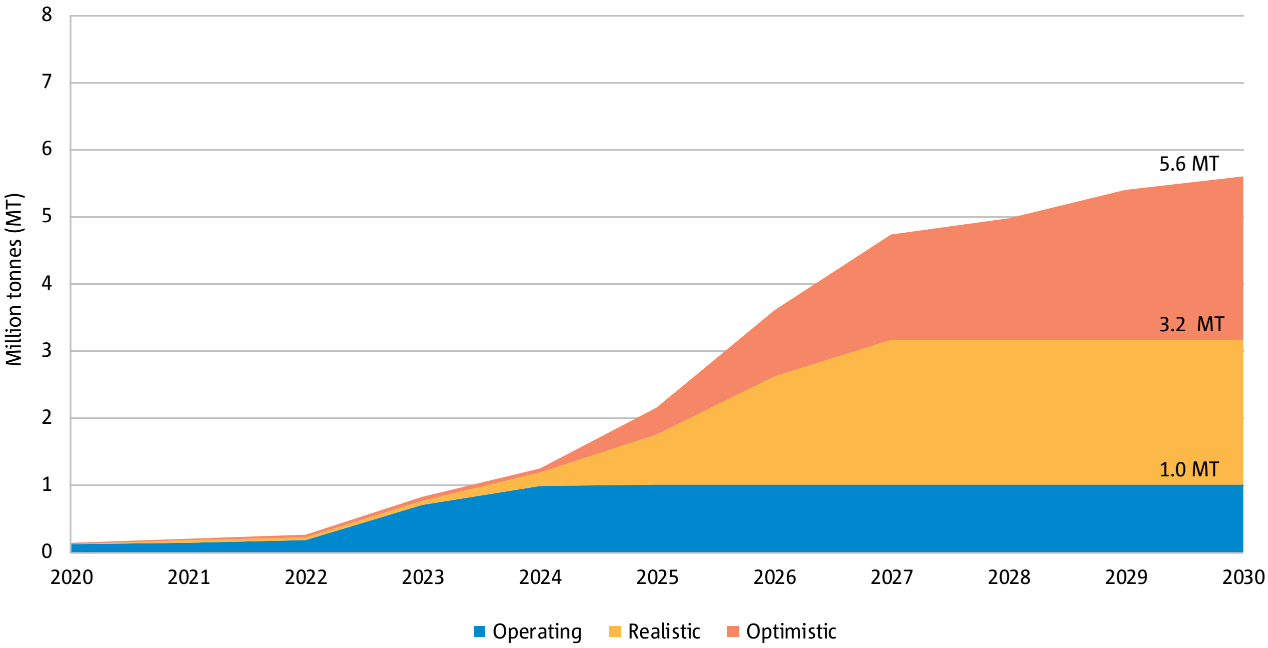


In addition to the operating and realistic scenarios, both the ReFuelEU Aviation Member State Network and the SkyNRG Market Outlook collected information to build up an **'optimistic scenario'**. This includes all projects in the pipeline to be in operation by 2030 and includes PtL projects, leading to a projected SAF capacity of 5.6 Mt and 5.5 Mt respectively.

Figure 6.5 illustrates all of the above scenarios out to 2030, including the capacity from co-production. While the realistic scenario (3.2 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.

Beyond 2030, projections of production capacity are more challenging and the potential SAF production will depend on the availability of feedstocks (eg. 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 [36]. Overall,

Figure 6.5 Projected EU+EFTA SAF capacity in 2030 by scenario



renewable energy passed 30% of the total global energy supply for the first time in 2023 [37]. 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 [36].

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[10] 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 [34].

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 [38].

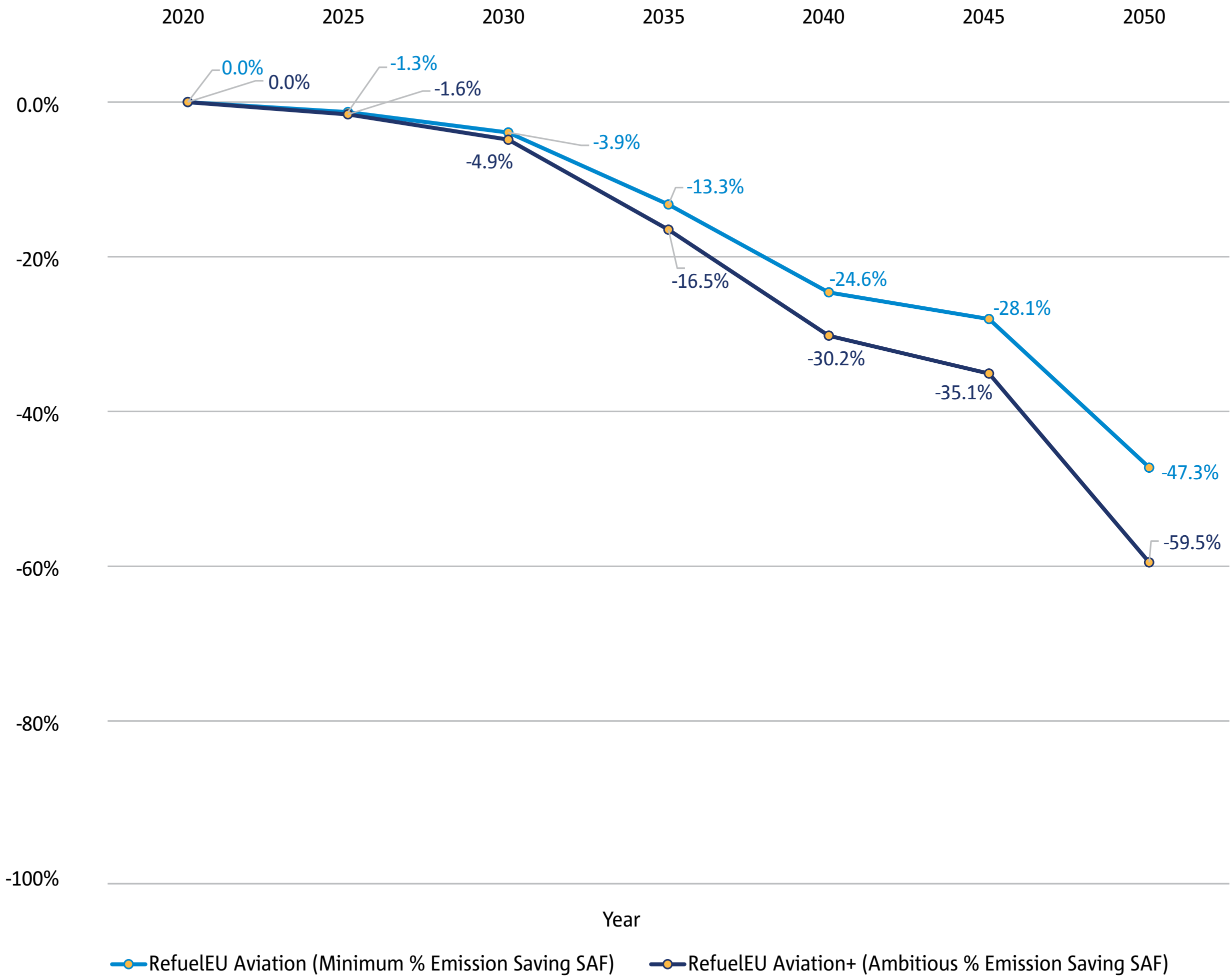
CO_2 emissions reductions

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 (Figure 6.6).

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.

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

Figure 6.6 % CO_2e emissions reductions from the uptake of SAF under ReFuelEU Aviation scenarios



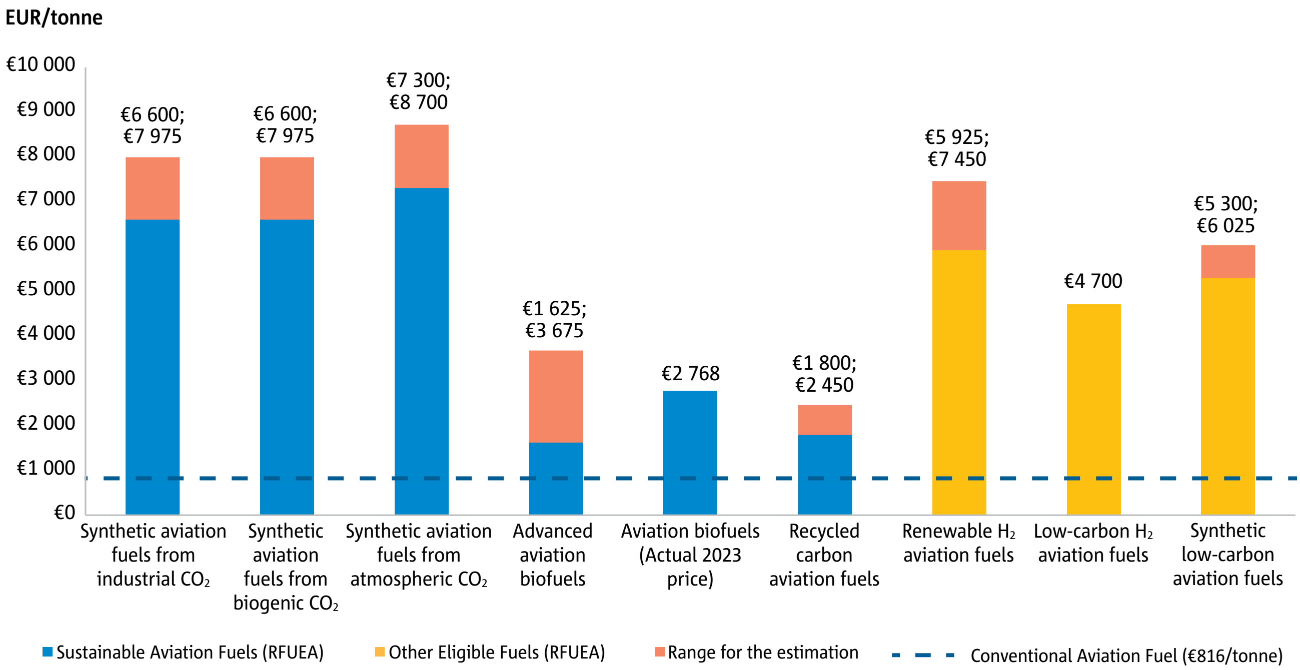
SAF Price

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%) [58]. 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 [39].[11, 12] 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 €1 600 per tonne for advanced aviation biofuels to €8 700 per tonne for PtL fuels. Figure 6.9 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 [40, 41].

Figure 6.7 Estimated prices and production costs in 2023 for ReFuelEU Aviation eligible fuels



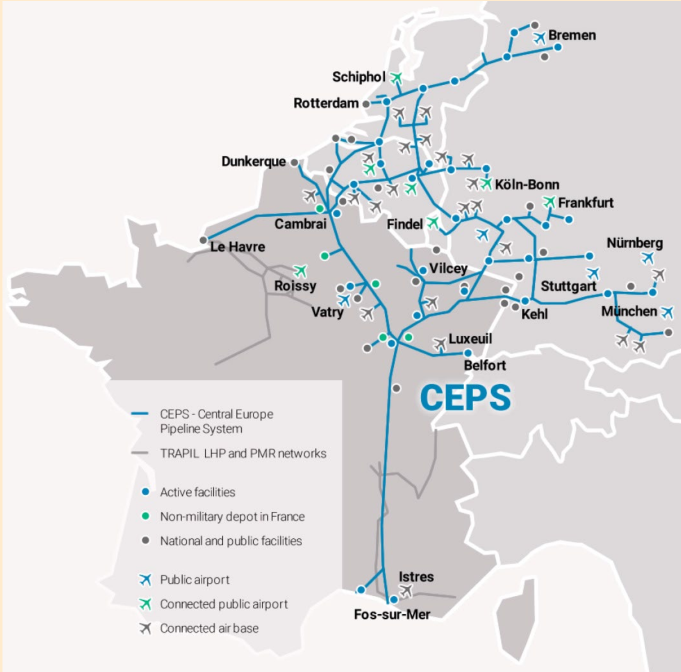
[11] Price Reporting Agencies (PRA) used as data source: S&P Global Commodity Insights (Platts), Argus Media and General Index

[12] With the density of kerosene of around 0.8 g/cm^3, 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) [42] 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 [61]. 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 an 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 [43]

A CORSIA certified batch of SAF was first supplied to a commercial airline in July 2022 when Neste delivered a batch of its Neste MY Sustainable Aviation Fuel™ to American Airlines at San Francisco International Airport.

This was part of a pilot project to certify SAF as a CORSIA eligible fuel that can be used by an airline to meet its emissions obligation under CORSIA. The Carbon Offsetting and Reduction Scheme for International Aviation ("CORSIA") is a carbon offset and reduction scheme to lower CO_2 emissions for international flights and curb the aviation impact on climate change.

First flight in history with 100% sustainable aviation fuel on a regional commercial aircraft [44]

Regional aircraft manufacturer ATR, Swedish airline Braathens Regional Airlines and Neste 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% sustainable aviation fuel

(SAF) certification process of ATR aircraft that started in September 2021. The test flight further supports aviation's decarbonisation targets and acceleration of SAF certification.

Bringing together airlines and corporates [45]

Project Runway is an iniative 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 allows 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 [46]

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 for a 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 [47]

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.

7

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 was 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, 129 out of 193 ICAO States have volunteered to participate in the CORSIA offsetting scheme.
- Offsetting under the CORSIA scheme is expected to start for the year 2024 based on data to be reported in 2025. A total of 19 Mt 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 on fuel 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.

7.1 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).[1] 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 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 (see Chapter 2 on Environmental Impacts)
- 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.

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

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.

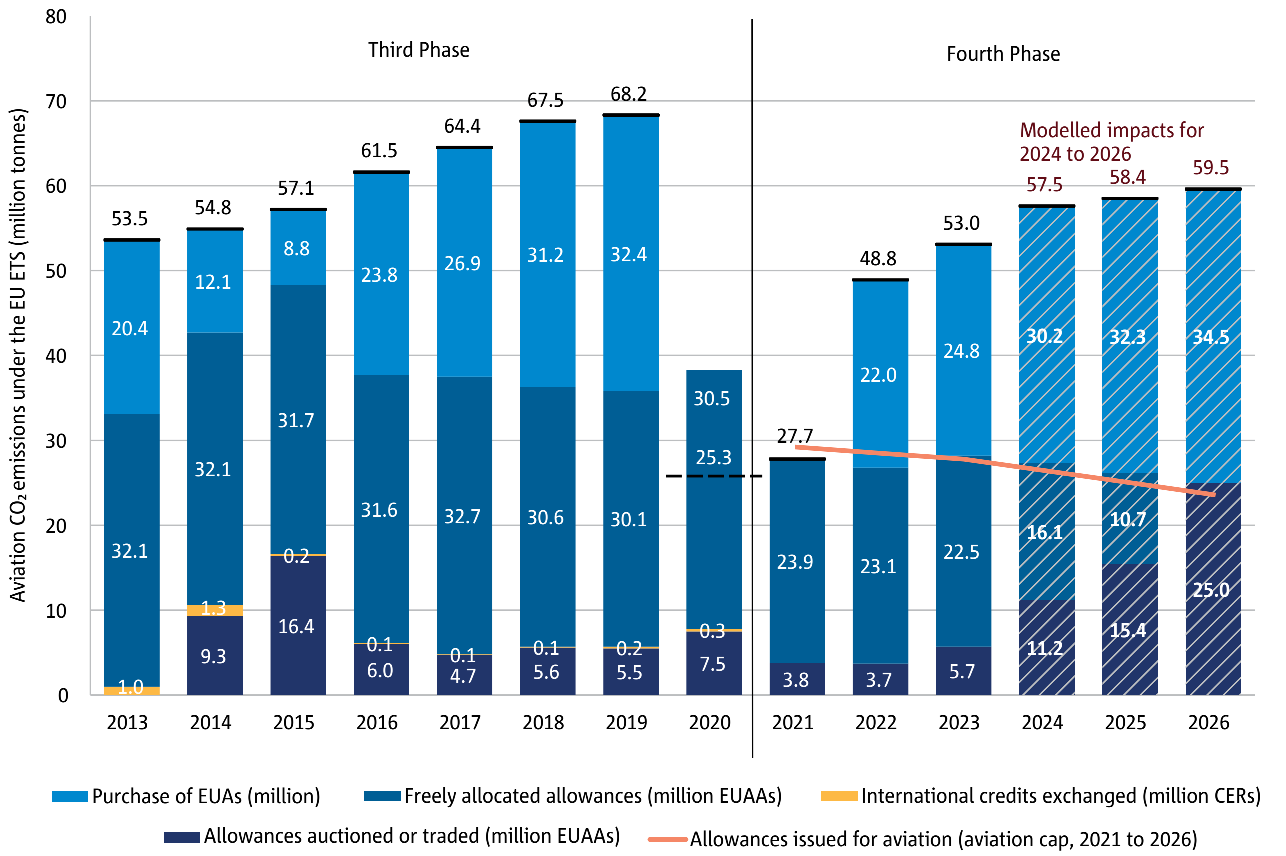
Historic and forecasted aviation emissions under EU ETS

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 7.1, 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 average 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 25.3 Mt in 2020 were below the freely allocated allowances for the first time (see Figure 7.1).

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 27.7 Mt, 48.8 Mt and 53.0 Mt respectively. The free allowances allocated to the aviation sector were 23.9 Mt in 2021, 23.1 Mt in 2022 and 22.5 Mt in 2023. Following the rebound of aviation sector's CO_2 emissions from the

Figure 7.1 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[2]



__Note:__ Data in Figure 7.1 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.

2 In addition, the Swiss (CH) 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.

COVID-19 pandemic, the sector became a net purchaser of EUAs again in 2022 (22.0 Mt) and in 2023 (24.8 Mt). 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 7.1, the modelled CO_2 emissions under the aviation ETS are expected to grow to 59.5 Mt 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 10.7 Mt in 2025 and then become zero from 2026 onwards. Purchase of EUAs is expected to grow from 30.2 Mt in 2024 to 34.5 Mt in 2026. Emissions benefits from the claiming of Sustainable Aviation Fuels (SAF) could grow from 0.5 Mt in 2024 to 1.7 Mt 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 9.8 Mt as a result of the carbon price incurred due to the EU ETS.[3]

As shown in Figure 7.2, 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 approximately 4-6% of airlines' total annual operating costs.[4]

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.

Figure 7.2 EU ETS Allowance Prices (2013-2024)

[3] Estimation from EASA AERO-MS model. See Appendix C for more details.
[4] Estimation from EASA AERO-MS model.

European Model for Impact Assessments of Market-based Measures

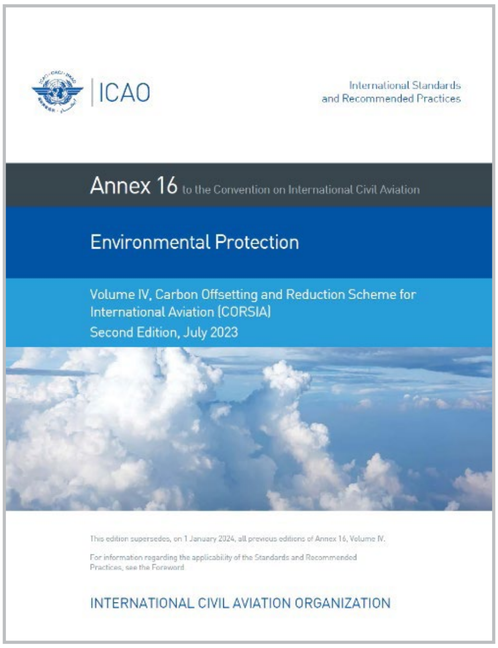
The EASA AERO Modelling System (AERO-MS) has been developed to assess the economic and environmental impacts of a wide range of policy options to reduce international and domestic aviation GHG emissions. These policies include taxes (e.g. fuel and ticket taxation), market-based measures (e.g. EU ETS, 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.

7.2 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 41st 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.[5] Implementation of CORSIA's monitoring, reporting and verification rules within the EU has been through the relevant ETS Regulations [5, 6, 7].

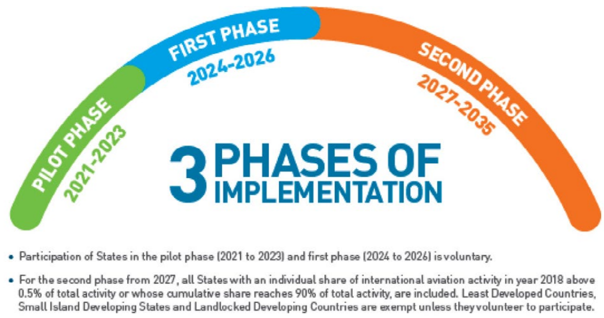
[5] As per the ETS Directive, EU ETS is being applied for flights within and between countries in the European Economic Area, as well as departing flights to Switzerland and to the United Kingdom.

CORSIA 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).

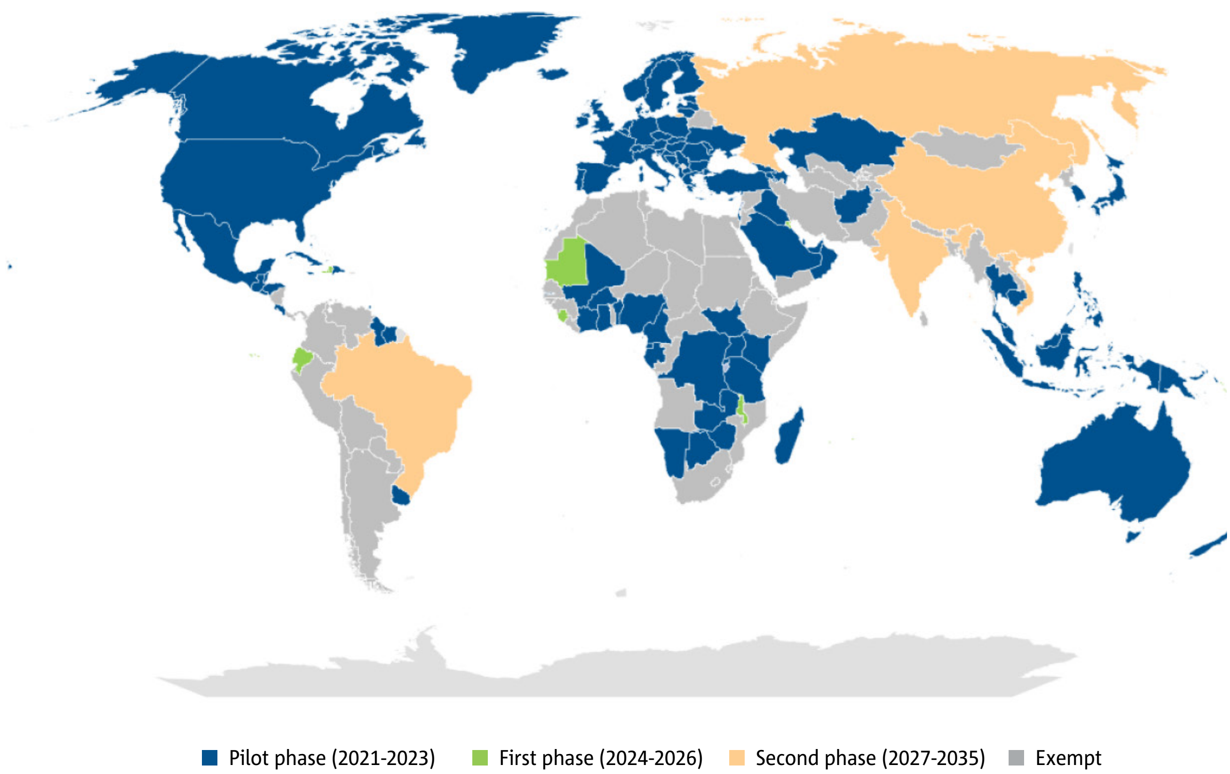
All aeroplane operators with international flights producing annual CO_2 emissions greater than 10 000 tonnes from aeroplanes with a maximum take-off mass greater than 5 700 kg, are required to monitor, verify and report their CO_2 emissions on an annual basis from 2019. The CO_2 emissions reported for 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 CO_2 emissions covered by CORSIA's offsetting requirements above these baseline levels.

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.



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

Figure 7.3 ICAO Member States participation in CORSIA offsetting in various phases



2019 levels by 2023, there has not been any offsetting requirements to airlines from CORSIA during its pilot phase. Figure 7.4 illustrates the reported CO_2 emissions from all international flights (blue bars) and a subset of these emissions (orange 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.

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 tonnes in 2024 to 7.3 tonnes in 2026[6] (Figure 7.5).

Figure 7.4 International aviation CO_2 emissions reported through the CORSIA Central Registry

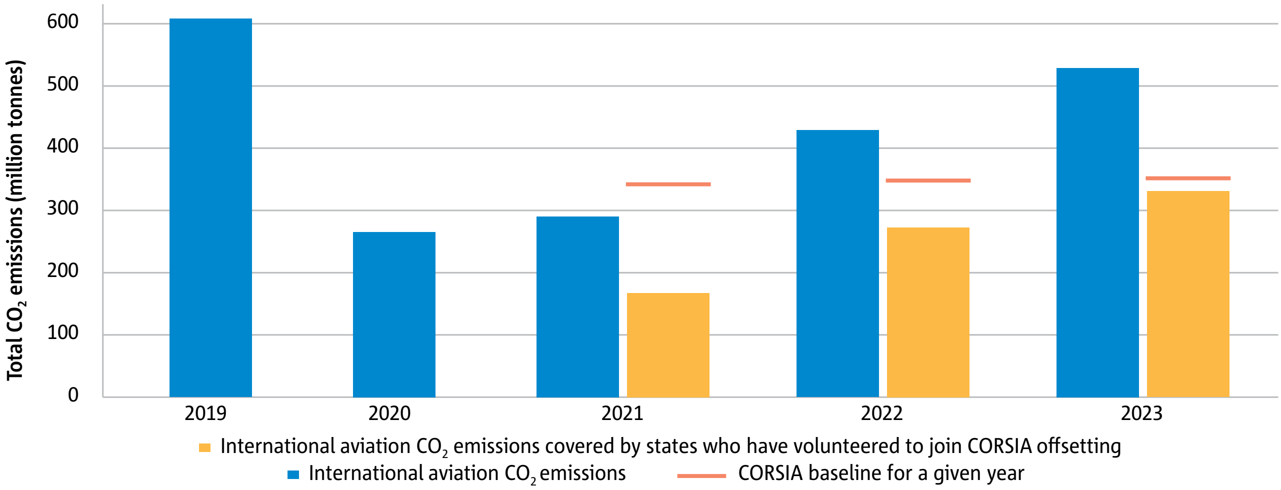
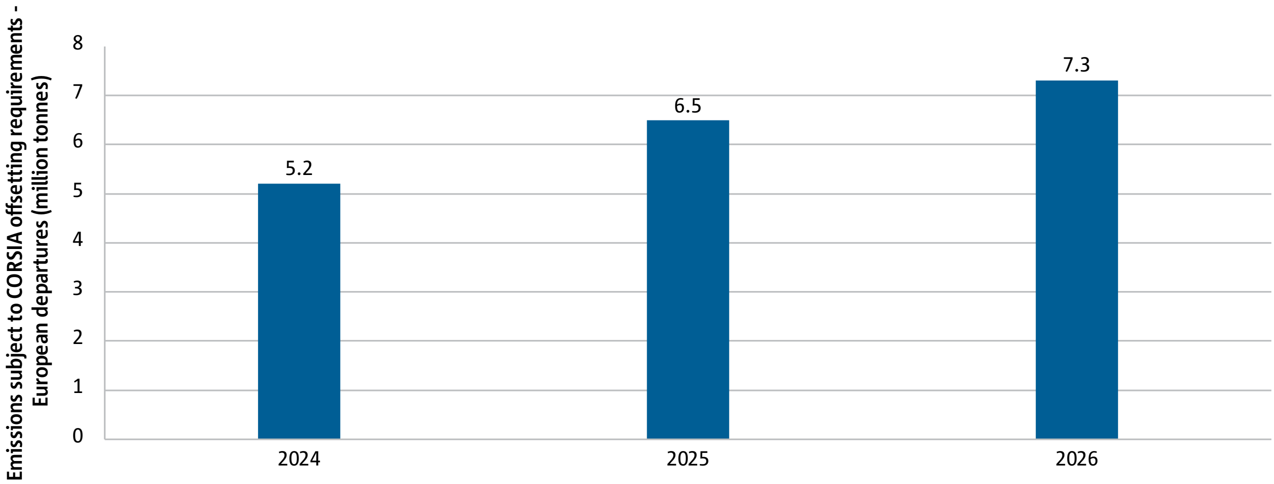


Figure 7.5 Estimated CORSIA offsetting requirements for departing flights from Europe during the First Phase (2024-2026)[7]



6 Estimation by EASA AERO-MS model.
7 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 Swiss (CH) ETS.

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

7.3 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 a 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 European 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 the "best-in-class" aircraft (see Table 7.1) is just one element in a wider set of TSC. 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 CAEP/10 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.

Table 7.1 "Best in class" aircraft, which is just one element of the Taxonomy Technical Screening Criteria

Emissions thresholds – % margins below CAEP/10 ICAO CO_2 Standard for new types

Aircraft MTOM	Until 2027	2028-2032	2032 -
5.7t – 60t	**11%**	Same as until 2027 + a/c certified to operate with 100% SAF	To be defined in a future review of the TSC
>60t – 150t	**2%**		
>150t	**1.5%**		

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.

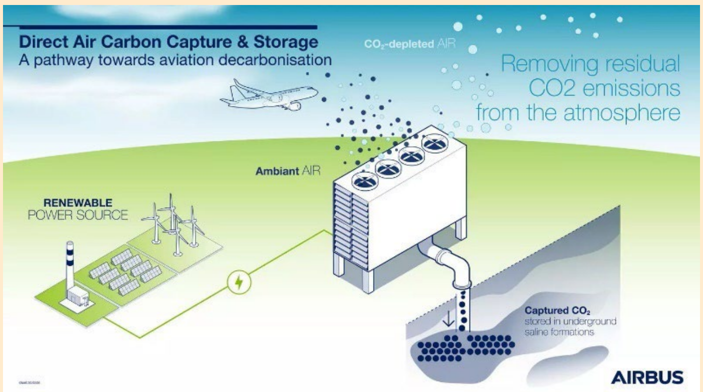
Voluntary Offsetting

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. additionality.[8] 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].

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.

8 “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]

8

INTERNATIONAL COOPERATION

- Global environmental challenges require global cooperation to achieve agreed future goals.
- International Cooperation is a key element to reach the global aspirational goal for international aviation of net-zero carbon 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, European 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.

This chapter reflects on the role of International Cooperation in supporting and increasing environmental protection commitments in the aviation sector worldwide. It also provides insights on International Cooperation initiatives by European entities (e.g. States, Institutions and Stakeholders) and the achievements from this cooperation with Partner States.

The information presented in this chapter has been provided by European focal points working on international cooperation projects as well as public sources on contributions to ICAO initiatives [1, 2]. This information, although not exhaustive, is representative of the European efforts to support an ambitious level of environmental protection and to foster a harmonised implementation of the relevant international environmental standards worldwide.

8.1 WHY INTERNATIONAL COOPERATION?

Europe has long been engaged in political dialogue worldwide, to collectively determine the ambitious objective of decarbonising aviation. It is committed to ICAO's "No Country left Behind" Initiative and contributes to its implementation.

The support includes the implementation of new standards and initiatives which require developing new technical capabilities and processes as well as addressing new areas of knowledge within a short timeframe to deploy across a number of organisations. This becomes more demanding when the initiatives require new sets of skills, addresses new areas of knowledge, or requires deployment across a number of organisations in a short timeframe. The deployment of rapidly evolving technologies and their enabling policies also necessitate feedback loops at all levels, thereby permitting the adjustment of the deployment of those policy frameworks to achieve the intended objectives. These factors are especially true for environmental protection initiatives in civil aviation.

International Cooperation initiatives facilitate engagement with Partner States in addressing those challenges by sharing knowledge and in-field experience of mutual benefit as well as the provision of resources. This collaborative effort is also a way to strengthen institutional ties and to enhance working relations with Partner States, thereby making it an additional key element in the basket of measures to achieve environmental goals such as net-zero CO_2 emissions by 2050 and to ensure that "No Country is Left Behind".

8.2 MAIN AREAS OF 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 European 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 [3]. The contribution of the European Commission to these programmes amounts to €56.5 million[1], 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

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

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.

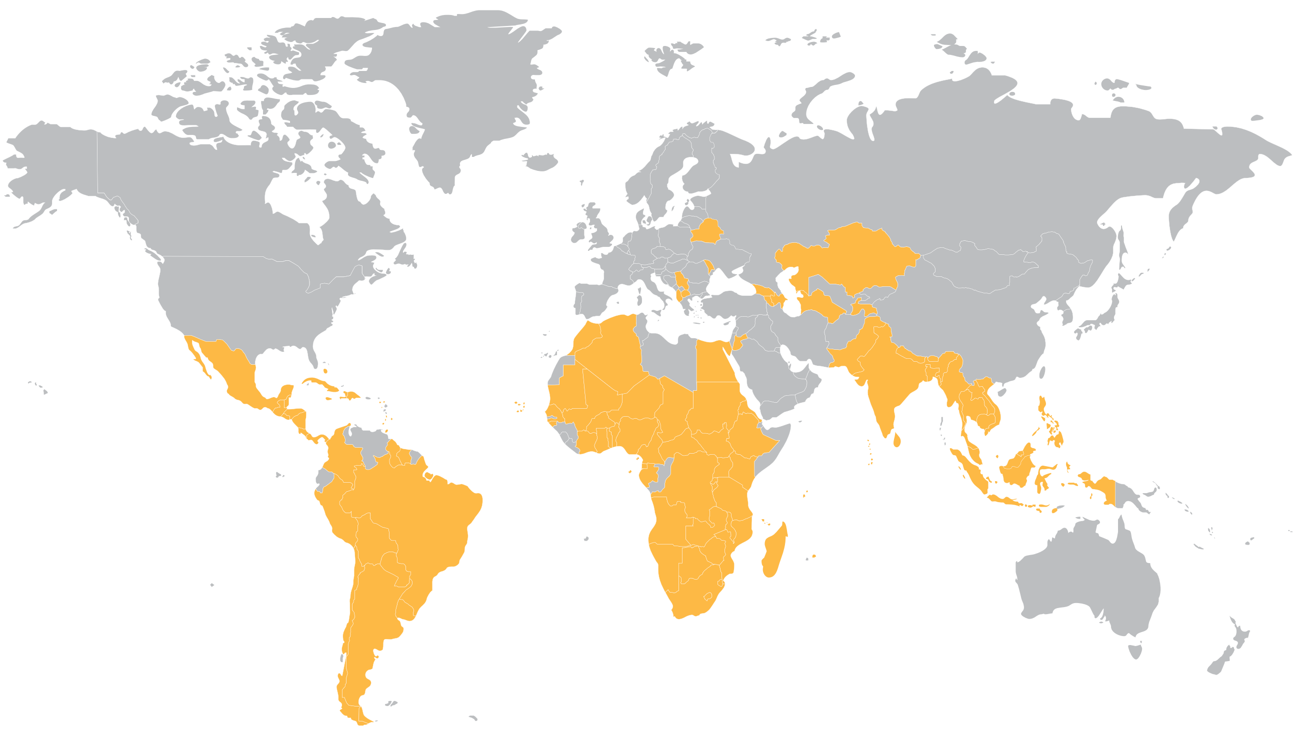
8.2.1 CORSIA Implementation

The initiatives of European 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 7 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.

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,

Figure 8.1 Partner States supported by European funded international cooperation initiatives on CORSIA.



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 TISI 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."

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.

8.2.2 State Action Plan for CO_2 Emissions Reduction

Another good example of the value of International Cooperation programmes is the support provided to develop a first or subsequent edition of a State Action Plan for CO_2 emissions reduction from International Aviation. The State Action Plan is a document developed by the State putting together all the reduction measures that the State and the aviation stakeholders in the country expect to implement in the years to come. The document is submitted to ICAO every three years, informing on the current emission baseline and the expected reductions and allowing ICAO to aggregate the information from all countries to build a global view. At State level, the compilation of the State Action Plan for CO_2 emissions reduction provides the opportunity to develop a collaborative, structured and data driven process between the State and the aviation stakeholders.

As of 2024, 148 States had submitted at least the 1st Edition of their State Action Plan for CO_2 emissions reduction to ICAO [4]. The information provided in the State Action Plans on a CO_2 emissions baseline, mitigating measures and estimated CO_2 reductions, was invaluable to inform the discussions on the Long-Term Aspiration Goal (LTAG) during the 41st ICAO General Assembly and will be a key input in monitoring the progress towards this goal over time.

During the period 2022-2024, European cooperation initiatives have supported or engaged with 22 States, resulting in 14 first editions and 4 updates of previous State Action Plans, all of which were submitted to ICAO in that timeframe.

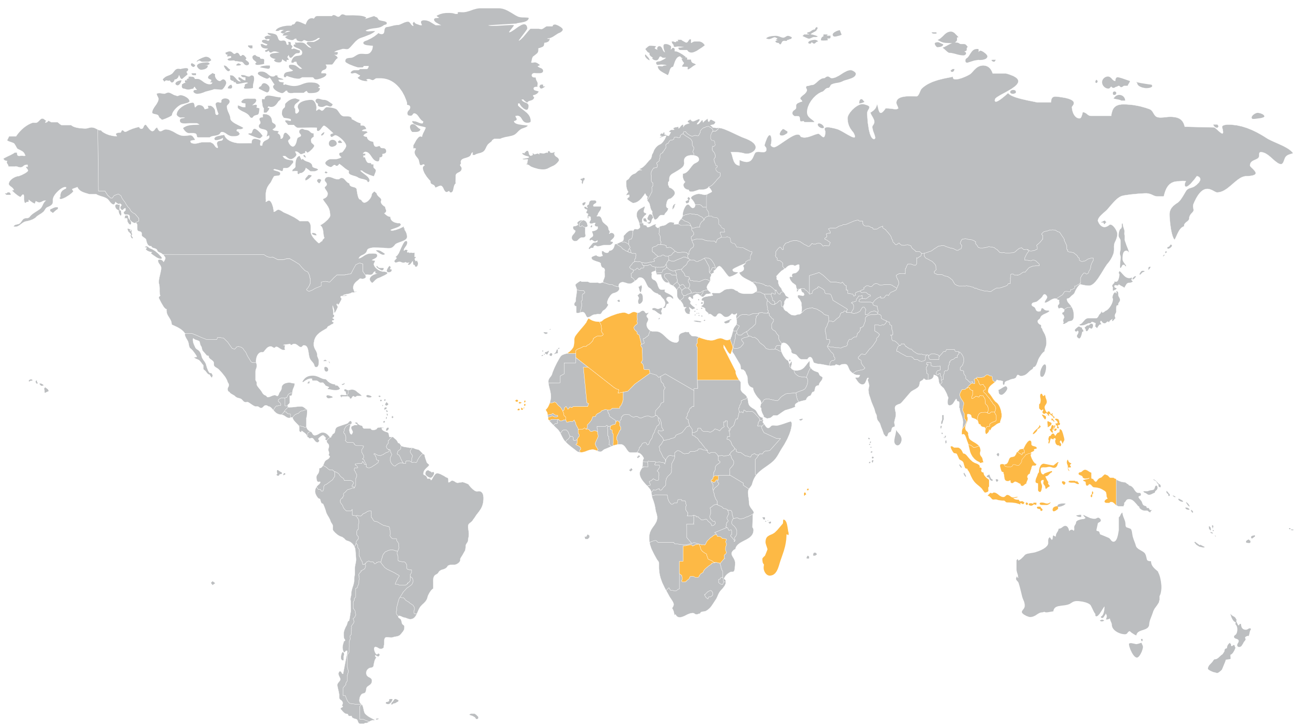
In the case of State Action Plans, most of the support has been delivered through EU funded projects either implemented by EASA or by ICAO. The approach taken to support the States has encompassed:

- Provision of training to State Authorities and to their aviation stakeholders on the use of ICAO statistical forms (M, A and C) and on the methods for calculating the baseline emissions;
- Facilitating technical discussions with aviation stakeholders on mitigating measures and the estimation of CO_2 emission reductions, as well as monitoring methodologies; and
- Assisting in the shaping of the final State Action Plan document, when needed.

The use of the ICAO Document 9988 [5] and other available material, has been essential in providing harmonised support as well as consistent tools and methods across all the Partner States.

While support has been primarily technical in nature, the most appreciated element has been facilitating the establishment of the State Action Plan as a collaborative and continuing process between the State Authorities and their aviation stakeholders.

Figure 8.2 Partner States supported in European funded international cooperation initiatives addressing State Action Plan for CO_2 emissions reduction.



Captain Md Jani Bin Md Dom
Deputy Chief Executive Officer, CAAM

"In order to identify inefficiencies in the aviation system and to propose solutions to reduce emissions, increase capacity and lower operational costs, it was essential to bring all our stakeholders together in several meetings. The way that the EU-SEA CCCA CORSIA Project advised us to address the State Action Plan provided particular added value and assisted Aviation Authorities in the ASEAN Member States to move forward together towards the common goal of reducing CO_2 emissions."

8.2.3 SAF Development

The development of Sustainable Aviation Fuels (SAF) 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 [6]. As part of this Framework, it was acknowledged that support to States and industry to develop and 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, European 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 have 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 [7, 8, 9, 10, 11, 12, 13]. Beyond Feasibility Studies, the technical cooperation initiatives from European 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.

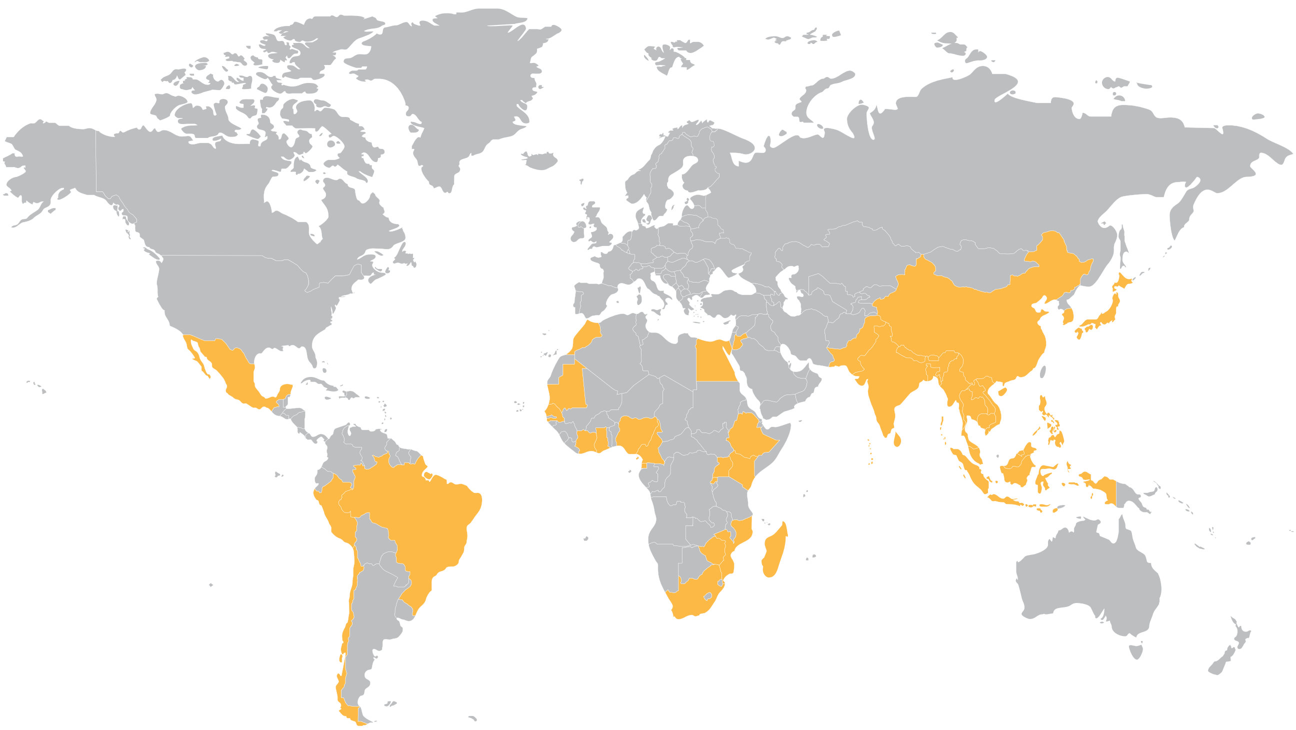
Similarly to the support provided on State Action Plans for CO_2 emissions, the most valuable contribution has been to facilitate a common understanding on SAF among the potential SAF actors in a State, and more crucially among different Governmental Departments (e.g. Ministries of Energy, Transport, 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, European 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 EASA, and aim to support States 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

Figure 8.3 Partner States in European funded international cooperation initiatives engaged in SAF development.



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 essential for aviation to become sustainable in short to long-term. SAF is also an opportunity for countries to develop their green economy and to gain greater independence in a strategic sector. However, the complexity of the product, the interdependencies with other economic sectors and the strategic decisions that are required to start producing SAF locally, demands a close coordination 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's ambition to be one of the first countries in Africa to produce SAF at a commercial scale. Under the National SAF Committee, Kenya ensures an orchestrated set of actions, establishes clear leadership and milestones, and provides a collaborative platform for all actors to achieve this ambitious but exciting endeavour."

8.2.4 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 within 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 [14]. 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).

Figure 8.4 South-East Asia Partner States where EMS has been facilitated

8.3 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, and 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 [15], 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.

8.4 AVIATION ENVIRONMENTAL PROJECT COORDINATION GROUP (AEPCG)

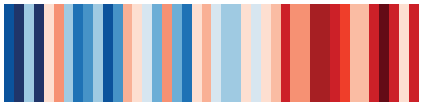
Mindful of the need to maximise the impact of the technical and financial resources made available to Partner States, the European Commission (EC) and the European Union Aviation Safety Agency (EASA) established the Aviation Environmental Projects Coordination Group (AEPCG) in 2020 as a forum to raise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

The AEPCG meets twice a year with an increasing number of participants[2] 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.

[2] 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.

APPENDIX A: LIST OF RESOURCES



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

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

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

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

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

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

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

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

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APPENDIX B: ACRONYMS AND UNITS

ANSP	Air Navigation Service Provider
ASK	Available Seat Kilometre
ATM	Air Traffic Management
CAEP	Committee on Aviation Environmental Protection
CEM	Collaborative Environmental Management
CO / CO_2	Carbon monoxide / Carbon dioxide
CO_2eq	Carbon Dioxide equivalent
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
dB	decibel
EASA	European Union Aviation Safety Agency
EC	European Commission
EEA	European Environment Agency
EFTA	European Free Trade Association
EPNdB	Effective Perceived Noise decibel
ETS	Emissions Trading System
EU	European Union
EU27	27 Member States of the European Union
ft	Feet
GHG	Greenhouse gas
GWP	Global Warming Potential
ICAO	International Civil Aviation Organization
IPCC	Intergovernmental Panel on Climate Change
kg	Kilogram
km	Kilometre
kN	Kilonewton
kt	kilotonnes
kW	kiloWatts
lbf	Pound (force)
L_{den} / L_{night}	Day-evening-night / Night-time sound pressure level
LTO	Landing and Take-Off
MJ	Megajoule
MRV	Monitoring, Reporting and Verification
Mt	Megatonne, million metric tonnes
MTOM	Maximum Take-Off Mass
MW	Megawatts
NM	Network Manager
nmi	nautical miles
NO_X	Nitrogen Oxides
NGO	Non-Governmental Organization
O_3	Ozone
pkm	Passenger Kilometre
PM	Particulate Matter (nvPM – non-volatile, vPM – volatile)
RED	Renewable Energy Directive
SES	Single European Sky
SESAR	Single European Sky ATM Research
SO_X	Sulphur Oxides
UAV	Unmanned Aerial Vehicle
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organization

APPENDIX C: DATA SOURCES, MODELS AND ASSUMPTIONS

This appendix provides an overview of the data sources, models and assumptions used to develop the information presented in Overview of Aviation Sector, Technology and Design, Airports and Market-Based Measures chapters. These modelling capabilities have been developed and used to support various European initiatives, as well as international policy assessments in ICAO.

SCOPE

The information in this report covers all flights from or to airports in the European Union (EU) and European Free Trade Association (EFTA). For consistency, regardless of the year, the EU here consists of the current 27 member States: Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden. EFTA members are Iceland, Liechtenstein, Norway and Switzerland. Airports in overseas territories are not included, except those in Azores, Canary, Madeira and Faroe Islands. Statistics for UK are therefore not included, also for the years preceding the Brexit.

DATA SOURCES

EUROCONTROL Flight Data

Historical 2005-2023 flight operations were extracted from the EUROCONTROL database of filed flight plans. This covers all instrument flight rules (IFR) flights in Europe. Flight data are enriched with and validated against, for example, radar updates, billing data from the Central Route Charges Office and an internal database of global aircraft. Each flight is categorised into one of the market segments: scheduled flights are divided into "low-cost" and "traditional scheduled" until 2018 and into "low-cost", "regional" and "mainline" from 2019 onwards[1]; "business aviation" captures flights by jets, turboprops and piston aircraft typically used for business aviation (mostly under 20 seats nominal size); "all-cargo" captures dedicated freighter flights; etc. These market segments are defined in terms of aircraft operator, aircraft type, ICAO flight type or callsign, as appropriate. The detailed definitions are available on the EUROCONTROL website.

Eurostat

European States collect statistics on air transport from their airports and airlines and provide these to Eurostat, which makes them public, although airline details are treated as confidential. Statistics on total activity (total passengers, total tonnes shipped, etc.) are as complete as possible. More detailed statistics, such as passengers and available seats for individual airport pairs, are focused on major flows. For example, we use these data to indicate trends in load factors, but we cannot calculate total available seat-kilometres solely from them. The estimates of total passenger kilometres flown in the Overview of Aviation Sector chapter are based on Eurostat directly, on analysis of other Eurostat flows and on data from the EUROCONTROL data warehouse. The great circle (i.e. shortest) distance between airport pairs is used when reporting passenger kilometres and calculating the average fuel consumption per passenger kilometre. The fuel consumption reported is however based on the actual distance flown. Consequently, the effect of ATM horizontal inefficiency is captured in the fuel efficiency indicator.

[1] The "regional" segment includes commercial flights by a list of regional aircraft types (19-120 seats); the "mainline" one includes other scheduled flights.

EUROCONTROL Aviation Long-term Outlook 2050

The EUROCONTROL Aviation Long-term Outlook 2050 published in December 2024 provided the flights and emissions forecast over the period 2030-2050 used in this report. It has three scenarios: the 'high' has strong economic growth with intense investment in technology to support sustainability, leading to relatively high growth in demand; the most-likely, 'base' scenario has moderate economic growth following current trends; the 'low' has slower economic growth and higher energy prices, leading to fewer flights and lower investment. As is usual for STATFOR forecasts, airports provided their future capacity plans, and the forecast traffic respects the capacity constraints implied by these plans, although the Outlook notes that increasingly the primary constraint is sustainability rather than capacity.

BADA

BADA (Base of Aircraft Data) is an Aircraft Performance Model developed and maintained by EUROCONTROL, in cooperation with aircraft manufacturers and operating airlines. BADA is based on a kinetic approach to aircraft performance modelling, which enables to accurately predict aircraft trajectories and the associated fuel consumption. BADA includes both model specifications which provide the theoretical fundamentals to calculate aircraft performance parameters, and the datasets containing aircraft-specific coefficients required to calculate their trajectories. The BADA 3 family is today's industry standard for aircraft performance modelling in the nominal part of the flight envelope and provides close to 100% coverage of operations in the European region. The latest BADA 4 family provides increased levels of precision in aircraft performance parameters over the nearly entire flight envelope and covers 73% of operations in the European region. This report uses BADA 4 (release 4.2), complemented by BADA 3 (release 3.16) for aircraft types not yet covered in BADA 4.

Aircraft Noise and Performance (ANP) Database

The Aircraft Noise and Performance (ANP) database is maintained by EASA and the US Department of Transportation. It provides the noise and performance characteristics for over 160 civil aircraft types, which are required to compute noise contours around civil airports using the calculation method described in Annex II of European Directive 2002/49/EC relating to assessment and management of environmental noise, ECAC Doc 29 and ICAO Doc 9911 guidance documents. ANP datasets are supplied by aircraft manufacturers for specific airframe-engine types, in accordance with specifications developed by the ICAO. EASA is responsible for collecting, verifying and publishing ANP data for aircraft which fall under the scope of Regulation (EU) 598/2014. This report uses the legacy ANP 2.3 version (which was previously hosted and maintained by EUROCONTROL and has been recently transferred to EASA), complemented by the ANP datasets verified and published by EASA before September 2024.

EASA Certification Noise Levels

EASA maintains a database of all aircraft noise certification levels which the Agency has approved. The database provides certified noise levels for over 35 000 aircraft variants, including jet, heavy and light propeller aircraft as well as helicopters. In this report, the certified noise levels are used to assess the Noise Energy Index, to attribute an ANP airframe-engine type to each aircraft type in the fleet using the ECAC Doc 29 4th Edition recommended substitution method, as well as to create the noise charts in the Technology and Design and Airport chapters.

ICAO Aircraft Engine Emissions Databank

The ICAO Aircraft Engine Emissions Databank (EEDB) hosted by EASA contains Landing and Take-Off (LTO) emissions data for NO_X, HC, CO, smoke number and non-volatile PM for over 450 jet engine types. The EEDB emission indices are used by the IMPACT model to compute NO_X, HC, CO and PM, and to create the NO_X charts in the Technology and Design chapter.

FOI Turboprop Emissions Database

The Swedish Defence Research Agency (FOI) hosts a database of NO_X, HC and CO emission indices for turboprop engine types. The data was supplied by the turboprop engine manufacturers, originally for the purposes of calculating emissions-related landing charges. It is used to complement the ICAO EEDB for the NO_X, HC and CO estimates in this report.

FOCA Piston Emissions Database

The Swiss Federal Office of Civil Aviation (FOCA) hosts a database of NO_X, HC, CO and aggregated non-volatile and volatile Particles Matters emission indices for piston engine types. The data was measured and calculated by the FOCA. It is used to complement the ICAO EEDB for the NO_X, HC, CO and Total Particles Matters estimates in this report.

CODA Taxi Times Database

EUROCONTROL's Central Office for Delay Analysis (CODA) collects flight-by-flight data from around 100 airlines including actual off-block and take-off times and delay causes. The post-ops data collection started in the early 2000's on a voluntary basis in return for performance and benchmarking reports, but increasingly the data collection is based on the mandatory data feed under the EU performance regulations IR2019/317, see also EUROCONTROL Specification for Operational ANS Performance Monitoring - Air Transport Operator Data Flow. CODA publishes aggregated performance statistics, such as on punctuality and all-causes delays from these data. The detailed actual taxi times from this source were used to assess taxi fuel burn and emissions.

Population Data

The JRC Global Human Settlement population spatial raster was used to estimate the number of people exposed to aircraft noise around airports. This dataset provides census data with a spatial resolution of 100 x 100 m and is multi-temporal, with a resolution of 5 years (1975 to 2030). For the past years (2005-2023), the population raster versions used were respectively 2005, 2010, 2015 and 2020. For all the future years and scenarios, the population distribution was then assumed to be unchanged over time by using the 2020 raster version.

MODELS AND METHODS

IMPACT

IMPACT is a web-based modelling platform developed and hosted by EUROCONTROL to assess the environmental impacts of aviation (noise and emissions). It allows to compute full-flight trajectories with associated fuel burn and CO_2 emissions thanks to an advanced aircraft performance-based trajectory model using a combination of ANP and BADA reference data. Other gaseous emissions such as NO_X, HC, CO and PM emissions are computed using the LTO emission indices from the ICAO EEDB, FOI Turboprop and FOCA Piston Emissions reference databases, combined with the Boeing Fuel Flow Method 2 (BFFM2). PM emission indices of jet engines are estimated using the First Order Approximation (FOA4) method,[2] which is detailed in the ICAO Airport Air Quality Manual (Doc 9889 2nd edition 2020). En-route non-volatile PM emissions[3] are calculated using the up-to-date implementation of the black carbon emissions methodology,[4] detailed by the nvPM Mission Emissions Estimation Methodology (MEEM).[5] The IMPACT calculation methods and reference

2 Due to the lack of smoke number data for turboprop engines, PM estimates currently exclude this category. As an indication, turboprop aircraft represented approximately 1% of the total fleet fuel burn in 2023.

3 Non-volatile particulate matter (nvPM) refers to particles measured at the engine exit and is the basis for the regulation of engine emissions certification as defined in ICAO Annex 16 Volume II, emitted particles that exist at a gas turbine engine exhaust nozzle plane, that do not volatilize when heated to a temperature of 350°C.

4 Stettler, Marc E. J.; Boies, Adam M.; Petzold, Andreas; R. H. Barrett, Steven (2016): Global Civil Aviation Black Carbon Emissions. ACS Publications. Collection. https://doi.org/10.1021/es401356v

5 Ahrens, Denise & Méry, Yoann & Guénard, Adrien & Miake-Lye, Richard. (2022). A New Approach to Estimate Particulate Matter Emissions From Ground Certification Data: The nvPM Mission Emissions Estimation Methodology (MEEM). 10.1115/GT2022-81277.

data to assess fuel burn and emissions may differ from those used by Member States to report their emissions to UNFCCC or CLRTAP, hence the delta in estimates between these data sources.

SysTem for AirPort noise Exposure Studies (STAPES)

STAPES is a multi-airport noise model jointly developed by the European Commission, EASA and EUROCONTROL. It consists of a software compliant with Annex II of Directive 2002/49/EC and the 4th Edition of the ECAC Doc 29 modelling methodology, combined with a database of over 100 airports with information on runway and route layout, as well as the distribution of aircraft movements over these runways and routes. The STAPES airport database also includes airport-specific aircraft vertical flight profiles and noise-power-distance (NPD) data, which reflect the average local atmospheric conditions at each airport in terms of temperature, pressure, wind speed and relative humidity.

Aircraft Assignment Tool (AAT)

AAT is a fleet and operations forecasting model jointly developed by the European Commission, EASA and EUROCONTROL. AAT converts a passenger and flight demand forecast into detailed operations by aircraft type and airport pair for a given future year and scenario, taking into account aircraft retirement and the introduction of new aircraft into the fleet. It is an integral part of the STATFOR long-term forecast methodology that was followed for the 2050 outlook. The forecast operations are processed through the IMPACT and STAPES models to assess the fuel burn, emissions and noise data for years 2030 to 2050 presented in the Overview of Aviation Sector chapter.

EASA AERO-MS

The AERO-MS is a tool developed specifically to support impact assessments for regulations to reduce greenhouse gas (GHG) emissions from aviation. The AERO-MS assesses the economic and environmental impacts of a wide range of policy options to reduce international and domestic aviation GHG emissions. Policy options that can be examined include the different taxation (including fuel and ticket taxation), emission trading schemes (such as the EU ETS) and offset schemes like CORSIA, the introduction of Sustainable Aviation Fuels (SAFs) and air traffic management (ATM) improvements. Such policy options, the model shows, can affect both the supply side and demand side of the air transport sector. The AERO-MS forecasts the impact on emission reductions of measures and policies but also the extent by which demand for air travel is reduced due to these higher prices. The AERO-MS has a global scope; the analysis is built on a Unified Database containing a detailed record of global aviation movements in the Base Year. As part of the latest AERO-MS update completed in 2024, the Base Year data in the AERO-MS relate to 2019. The Unified Database for 2019 records over 113 000 airport-pairs, covering a full network of all key airports, derived from the EUROCONTROL Database for European flights and Flightradar24 data for the rest of the world. Airline cost and fare data are based on relevant data from the International Air Transport Association (IATA) and the International Civil Aviation Organisation (ICAO). Aircraft type input data is based on the Cirium aircraft registration database and the ICAO aircraft engine emissions databank. For the specification of aircraft operational characteristics use is made of the EUROCONTROL BADA4 data.

ASSUMPTIONS

Fuel burn, emissions and noise assessment

For consistency with other international emission inventories, full-flight emissions presented in this report are for all flights departing from EU27 or EFTA, i.e. flights coming from outside EU27 or EFTA are not included. In contrast, noise indicators include all departures and all arrivals. Historical fuel burn and emission calculations are based on the actual flight plans from the EUROCONTROL Flight Data, including the actual flight distance and cruise altitude by airport pair. Default aircraft take-off weights from the ANP database (defined as a function of trip length) are used when assessing noise, fuel burn and emissions for this report; these may not always reflect the load factors and take-off weights observed in real operations. Future year fuel burn and emissions are based on actual flight distances and cruise altitudes by airport pair in 2023. Future taxi times are assumed to be identical to the 2023 taxi times; where non available, ICAO default taxi times are applied. Helicopter operations are excluded from the assessment.

The calculation of the L_{den}, L_{night} and $N_{50}A_{70}$ noise indicators was performed with the STAPES model over 98 major EU27+EFTA airports[6] (see below map) representing about 86% of the total landing and take-off noise energy emitted in the region during 2023.

The runway and route layouts of each airport were assumed to be constant over the full analysis period – i.e. only the fleet, the number and time of operations vary. The standard take-off and landing profiles in the ANP database were applied. For historical noise, the day/evening/night flight distribution was based on actual local departure and landing times assuming the Environmental Noise Directive default times for the three periods: day = 7:00 to 19:00, evening = 19:00 to 23:00, night = 23:00 to 7:00. For future years, the day/evening/night flight distribution at each airport was assumed to remain unchanged compared to 2023. For each year in the historic airport noise exposure reporting, the latest census year of the population spatial raster multitemporal dataset was used e.g., the 2005 dataset was used for years 2005 to 2009, the 2010 dataset was used for years 2010 to 2014, etc. Future airport noise exposure estimates were all based on the 2020 census dataset, i.e. the population density around airport was assumed to remain constant after 2020. The mapping of the fleet to the ANP aircraft follows the ECAC Doc 29 4th Edition recommended substitution method.

In addition to the noise contours at the 98 airports modelled in STAPES, the noise generated by aircraft take-offs and landings at all airports in the EU27 and EFTA area was estimated via the Noise Energy Index, by applying the following formula:

$$\textit{Noise Energy Index} = \sum_{\text{aircraft}} \left(N_{dep} 10^{\frac{LAT + FO}{20}} + N_{arr} 10^{\frac{APP - 9}{10}} \right)$$

where

N_{dep} and N_{arr} are the numbers of departures and arrivals by aircraft type weighted for aircraft substitution;

LAT, *FO* and *APP* are the certified noise levels in EPNdB at the three certification points (lateral, flyover, approach) for each aircraft type.[7]

Noise dose-response curves

To estimate the total population highly annoyed (HA) and highly sleep disturbed (HSD) by aircraft noise, the following dose-response regression curves recommended by WHO for the European region were used:

Share of population highly annoyed (%HA) =
$-50.9693 + 1.0168 * L_{den} + 0.0072 * L_{den}^2$

Share of population highly sleep disturbed (%HSD) =
$16.79 - 0.9293 * L_{night} + 0.0198 * L_{night}^2$

6 From 2021 onwards, the number of airports is 97 due to the closure of Berlin Tegel airport in 2020 and the reallocation of its traffic to Berlin Brandenburg airport.
7 For Chapter 6 and 10 aircraft (light propeller), the unique overflight or take-off level is used for the three values.

The total population at the 98 major airports in STAPES was assessed for L_{den} threshold values between 45 and 75 dB and for L_{night} values between 40 and 70 dB with one decibel increment, and then multiplied by the corresponding %HA and %HSD values. As the L_{den} and L_{night} values represent outdoor noise levels the annoyance and sleep disturbance estimates may not take into account the effect of local sound insulation campaigns for houses and buildings around airports.

Figure 1 Map of the 98 airports included in the EAER noise contour calculations

Future fleet technology scenarios

Future noise and emissions presented in the Overview of Aviation Sector chapter were assessed for different technology scenarios.

The most conservative 'frozen technology' scenario assumes that the technology of new aircraft deliveries between 2023 and 2050 remains as it was in 2023. Under this scenario, the 2023 in-service fleet is progressively replaced with aircraft available for purchase in 2023. This includes the A320neo, B737 MAX, Airbus A220 (or Bombardier CSeries), Embraer E-Jet E2, etc.

On top of the fleet renewal, technology improvements for fuel burn (CO_2), NO_X and noise are applied on a year-by-year basis to all new aircraft deliveries from 2023 onwards following an average technology scenario. This technology scenario was derived from analyses performed by a group of independent experts for the ICAO CAEP and is meant to represent the nominal noise and emission reductions that can be expected from conventional aircraft and engine technology by 2050.

For noise, the technology scenario used for this report assumes a reduction of 0.1 EPNdB per annum at each noise certification point for new aircraft deliveries. For fuel burn and CO_2, the technology scenario assumes a 1.16% reduction per annum for new aircraft deliveries. For NO_X, the scenario assumes a 50% achievement of the CAEP/7 NO_X Goals by 2036 and that improvements continue at the same rate after, i.e. that NO_X emissions of new aircraft deliveries reduce by 0.5% per annum until 2050. No technology improvement was applied when estimating future HC, CO and PM emissions.

The above technology scenarios represent improvements in conventional aircraft designs, i.e. they do not take into account potential future designs like supersonic aircraft, electric/hydrogen aircraft or UAVs. For the forecast of net CO_2 emissions, electric/hydrogen aircraft were assumed to enter the fleet in 2035 and bring an additional emissions reduction gradually ramping up to 5% in 2050.

Future ATM improvements

The European ATM Master Plan, managed by SESAR 3, 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 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.

Future SAF scenario

The sustainable aviation fuels (SAF) assumptions used in the base traffic scenario forecast of net CO_2 emissions (Figure 1.10b) are based on the ReFuelEU Aviation Regulation and the Renewable Energy Directive (RED) as adopted by the European Commission in October 2023. This assumes that SAF supply gradually increases to 20% of total fuel supply in 2035 and 70% in 2050. The lifecycle CO_2 emissions reductions, compared to fossil-based fuel, were assumed to be 65% and 70% for biofuels and RFNBOs respectively, which is in line with the minimum required reduction as defined in the RED sustainability criteria. These assumptions are different to those taken within the ReFuelEU Aviation Impact Assessment from 2021 and will be constantly reviewed in future EAERs, taking into account the annual reports published by EASA from 2025 under ReFuelEU Aviation on the evolving SAF market. It is also assumed that the use of SAF will not have any impact on NO_X emissions.

Future MBM scenario

The net CO_2 reductions generated by market-based measures (EU ETS and ICAO CORSIA) in the period 2024-2026 were estimated using the AERO-MS model that was upgraded in 2024. The scope and timeframe of the modelling in Figure 7.1 reflects the revised EU ETS

Directive, i.e., flights within and between countries in the European Economic Area, as well as departing flights to Switzerland and to the United Kingdom, are covered by EU ETS, while CORSIA is applied for flights to and from third countries. EU ETS has also been applied for flights between countries in the European Economic Area and the outermost regions, as well as between the outermost regions, unless they connect to the respective Member State's mainland. EU ETS also applies to flights from the outermost regions to Switzerland and the United Kingdom. Modelling also includes the gradual phase-out of the free ETS allocation to airlines as follows: 25% in 2024; 50% in 2025; and 100% from 2026, as well as applying an annual linear reduction factor of 4.3% to the EU Allowances issued for aviation from 2024 onwards.

Regarding the modelled impact of Swiss ETS, the Swiss ETS covers domestic flights in Switzerland and flights from Switzerland to the EEA or the UK. CO_2 emissions and allowances data of the Swiss ETS for the years 2020-2023 are taken from the website of the Swiss Federal Office for the Environment (FOEN). Modelled impacts of Swiss ETS are based on the proxy Mid Growth CAEP/13 scenario implemented in the AERO-MS. From 2024 onwards, flights from Switzerland to the outermost regions of the EU are no longer exempted from the Swiss ETS. The cap is reduced by 4.3% annually from 2024 onwards (linear reduction factor). Assumptions on free allocation for the period 2024-2026 are based on what is agreed for the EU ETS (i.e. 25% reduction in 2024; 50% reduction in 2025 and 100% reduction in 2026). It is also assumed that installations and aircraft operators in both the EEA and Switzerland can use both EUAs and CHUs to meet compliance obligations.

Estimated CORSIA offsetting requirements for departing flights from Europe in Figure 7.5 covers departing traffic for all airlines from EEA countries to third countries that participate in CORSIA offsetting, except for flights to Switzerland and the United Kingdom, which are covered by EU ETS. Assumption on States' participation to CORSIA offsetting in the CORSIA first phase is based on the list of CORSIA States for Chapter 3 State Pairs, published by ICAO,[8] and the assumption on States' participation in the second phase is based on maintaining the level of volunteering States in year 2025 plus the States that are required to join the second phase as per ICAO Assembly resolution A41-22.

8 CORSIA States for Chapter 3 State Pairs (icao.int)

www.easa.europa.eu/eaer

Postal address
Postfach 101253
50452 Cologne
Germany

Visiting address
Konrad-Adenauer-Ufer 3
50668 Cologne
Germany

Other contacts
Tel +49 221 89990-000
Fax +49 221 89990-000
Web www.easa.europa.eu