Annex 8
Air traffic management

A-S-I: improve (reduce emissions and noise through optimisation of operations)

Context: passenger and freight air transport

Time frame: short to medium

A8.1 Definition

Air traffic management (ATM) is the term normally used in the aviation sector to indicate all the systems that assist an aircraft and its crew during the different phases of the trip, including departure, the flight through the airspace and landing at the airport of destination. ATM is one of the many systems that enables air mobility (Steffen Liebig et al., 2021). It has specific tasks and responsibilities, mainly related to the infrastructure and its safe operation and it includes three main services: air traffic services (ATS), including air traffic control (ATC); air traffic flow management (ATFM); and airspace management (ASM). ATS assists aircraft in real time to ensure their safe travel by providing necessary information to the aircraft crew throughout the entire flight. This service is facilitated by ground-based air traffic controllers who follow the flights through specific sections of the airspace. To ensure efficient use of the airspace, ASM controls the allocation of airspace to different users (civil and military, although it should be noted that, in some EU countries, civil and military airspaces and ATM are segregated) and the way the airspace is structured. The air traffic flows are regulated by ATFM, which ensures that airspace and airport capacities are not exceeded to avoid congestion (SKYbrary, 2022; Wikipedia, 2022). The ATM is provided by air navigation service providers (ANSPs), which also provide other services such as meteorological, surveillance and communication services.

With the expected growth in urban air mobility the ATM system will need to integrate seamlessly with U-space, a set of new services relying on a high level of digitalisation and automation of functions and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones (SESAR Joint Undertaking, 2022a). This includes standard urban flights departing from airports.

A8.2 Context

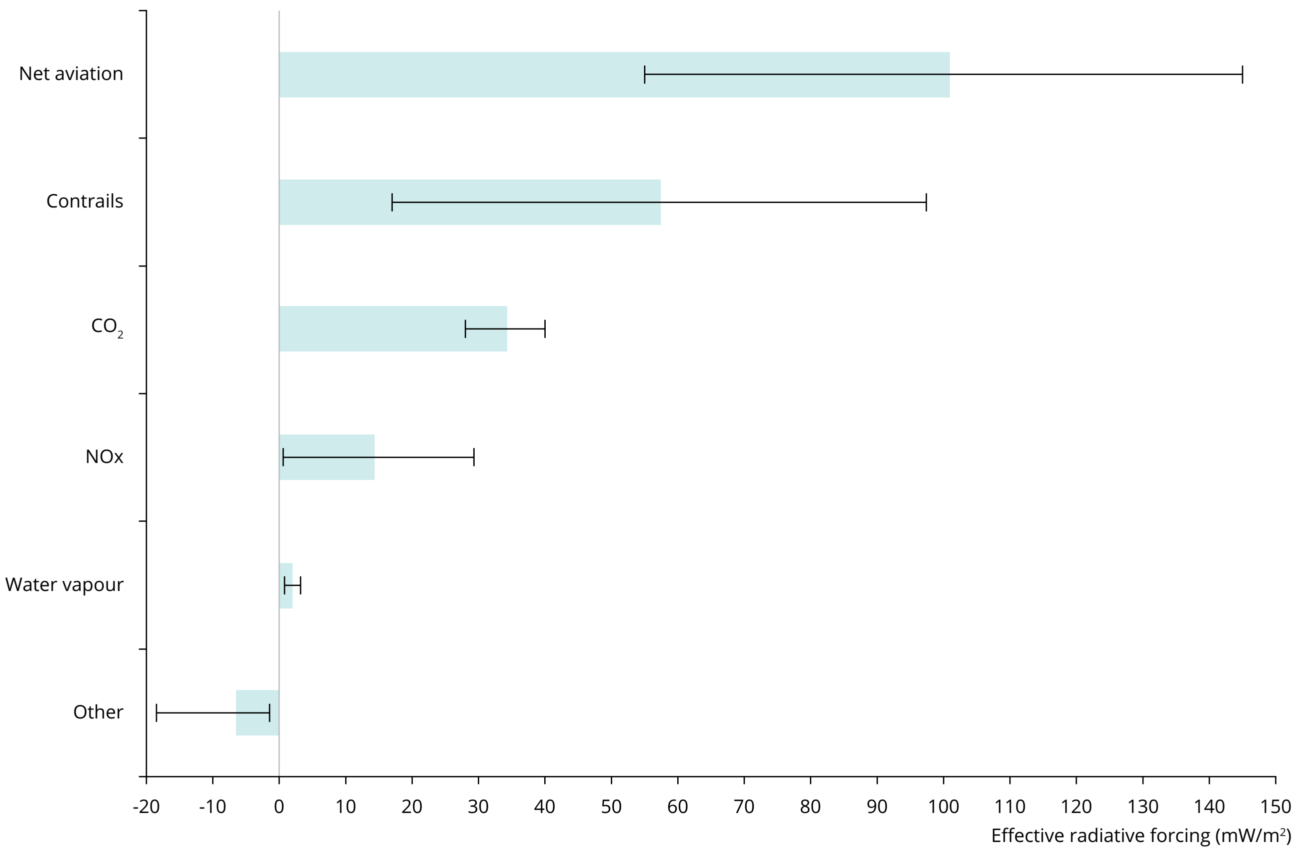
In 2019, aviation produced 3.6% of the total EU-27 and UK greenhouse gas (GHG) emissions and was responsible for 14.1% of the GHG emissions from transport (EASA et al., 2019; EEA, 2021a). The sector contributes to climate change in different ways, the most important being: (1) direct emissions of GHGs such as CO_2; (2) the formation of contrail cirrus clouds; and (3) emissions of nitrogen oxides (NOx), due to chemical reactions they induce in the atmosphere. Water vapour, soot particles and sulphur-containing aerosols can also have an effect. To estimate the impact of both CO_2- and non-CO_2-related phenomena on climate change, effective radiative forcing (ERF) is often used. This metric captures the influence that a factor (e.g. a compound released in the atmosphere) has in modifying the incoming and outgoing energy fluxes in the Earth-atmosphere system (IPCC, 2007). ERF is measured in W/m^2 and is positive when a substance has a warming effect on the Earth's atmosphere and negative when it has a cooling effect. For the aviation sector, it is estimated that CO_2 emissions contribute 34% of the total ERF while non-CO_2 effects are responsible of the remaining 66% (Lee, 2021; Brazzola et al., 2022). Among these, the most relevant mechanism is believed to be that induced by contrail generation.

Contrails are mostly formed from water vapour already present in the atmosphere, which can freeze, in specific conditions, when an aircraft flies through it. This phenomenon occurs when temperatures are sufficiently low and humidity sufficiently high and is triggered by the aeroplane emitting soot particles around which the vapour can solidify. The ice crystals formed can then expand into a contrail. Contrails can either quickly disappear or become a cirrus cloud, reflecting radiation and contributing in this way to global warming. It should be noted, however, that there is still considerable uncertainty on the overall impact of such phenomena, as demonstrated by the variation in the data reported in Figure A8.1. This is also due to their dependence on atmospheric conditions, which makes it much harder to predict. It should also be noted, however, that, while the impacts of CO_2 on climate change are well understood, the situation for non-CO_2 effects induced by contrail formation is more uncertain. It is still unclear what the overall long-term effect of implementing actions that will reduce non-CO_2 effects may be if this reduction is counteracted by an increase in CO_2 emissions (Lee et al., 2021).

NOx is the third largest contributor and accounts for approximately 20% of the total ERF from aviation. NOx has both a warming and a cooling effect on the climate, depending on the chemical compounds it reacts with. The overall net ERF is positive, though, meaning that it contributes to warming the atmosphere of the Earth.

As discussed in Chapter 2, the continuous increase in transport demand has significant environmental impacts, leading to a progressive increase in GHG and air pollutant emissions, often so large that they partially or totally counteract technological advancements. This is true also in the case of the aviation sector. Indeed, between 2005 and 2017, the number of passenger-km flown by commercial flights departing from within the EU-27 plus EFTA and the UK ([16]) increased by 60% (EASA et al., 2019) and the number of passenger-km is predicted to grow by 42% according to EASA et al. (2019), or by 44% by 2050 (Eurocontrol, 2022a). Despite a decrease in average fuel consumption (-24% between 2005 and 2017), CO_2 emissions have increased by 22%, as shown in Figure A8.2 (from 110 million tonnes in 2005 to approximately 134 million tonnes), and are forecast to grow by another 2-40% by 2040 in the base traffic scenario (EASA et al., 2019). Other estimates anticipate an increase of 67% by 2050 in a business-as-usual scenario, reaching approximately 315 million tonnes of CO_2 (NLR and SEO Amsterdam Economics, 2021).

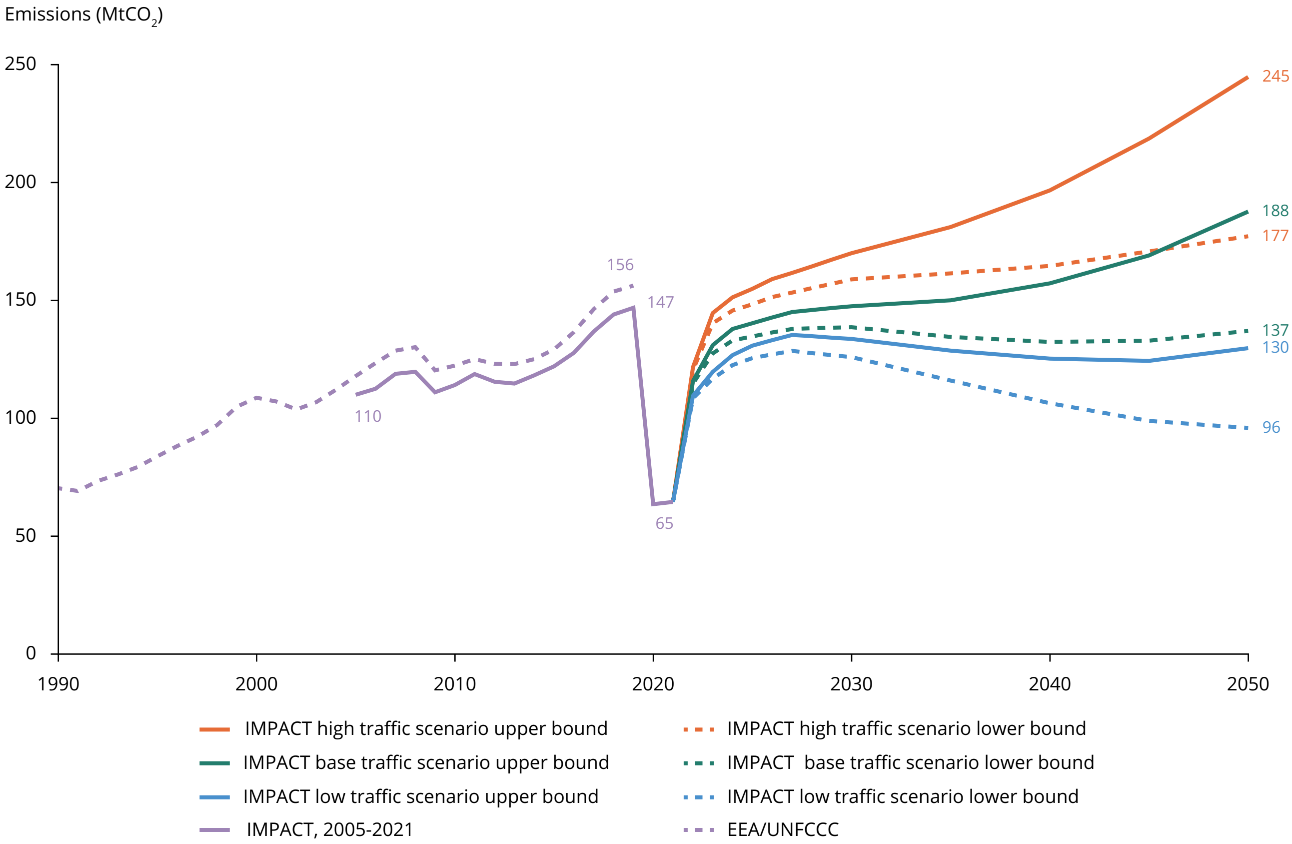
Figure A8.1 Global aviation effective radiative forcing



Source: EEA compilation based on Lee et al. (2021).

([16]) EU-27 plus EFTA comprises the 27 EU Member States plus Norway, Switzerland, Liechtenstein and Iceland.

Figure A8.2 Historical trend and long-term outlook for the CO_2 emissions from aviation in Europe

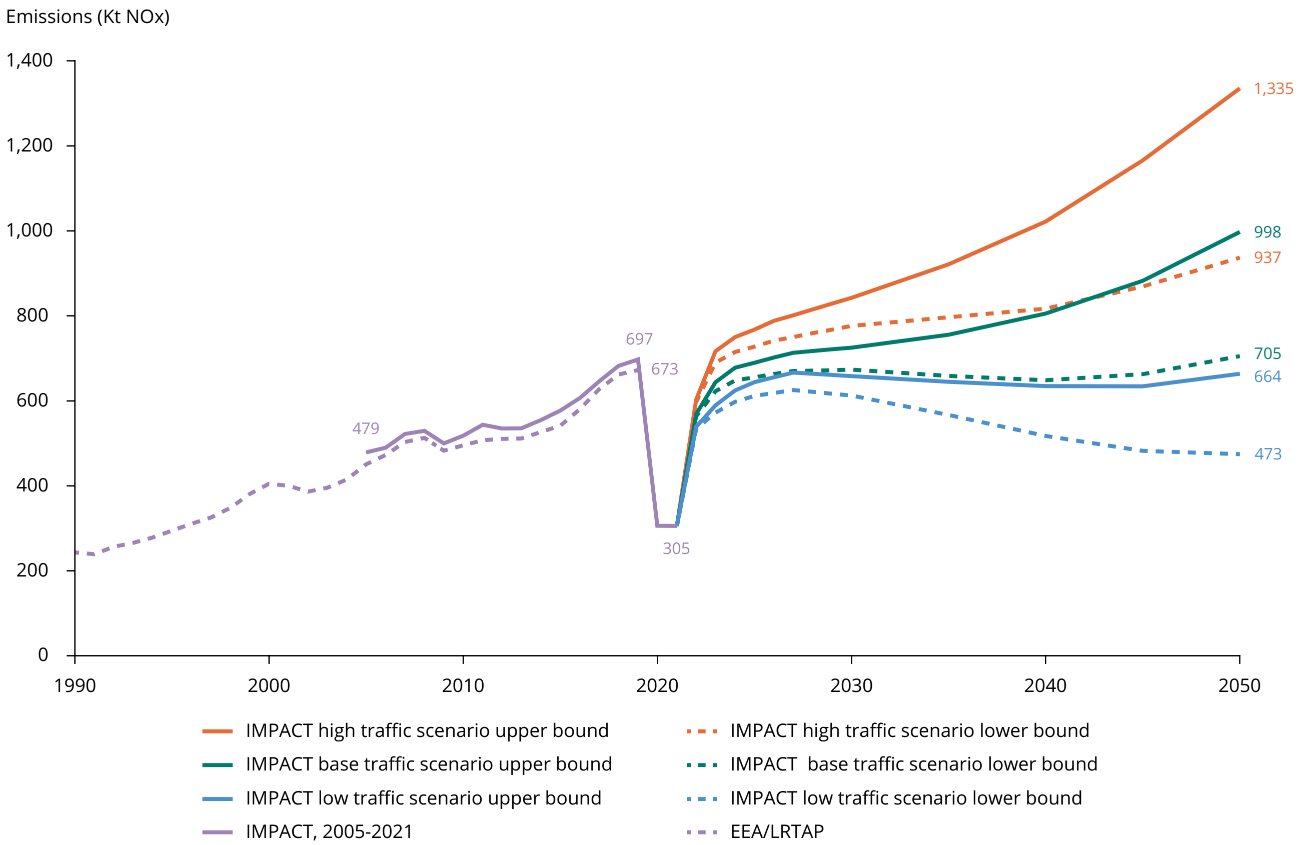


Source: EASA et al. (2022); estimates computed using the IMPACT model.

Similarly, NOx emissions are also predicted to grow by 2050. For the base traffic scenario the estimate growth by 2050 is projected to lie between 1.2% and 43%, as shown in Figure A8.3 (EASA et al., 2022). Other emissions, such as unburned hydrocarbons and carbon monoxide are more stable, and carbon monoxide emissions have even decreased (by 2% between 2005 and 2017) and are believed to have decreased even further. Particulate matter emissions are also believed to have risen (volatile particulate matter by 61%).

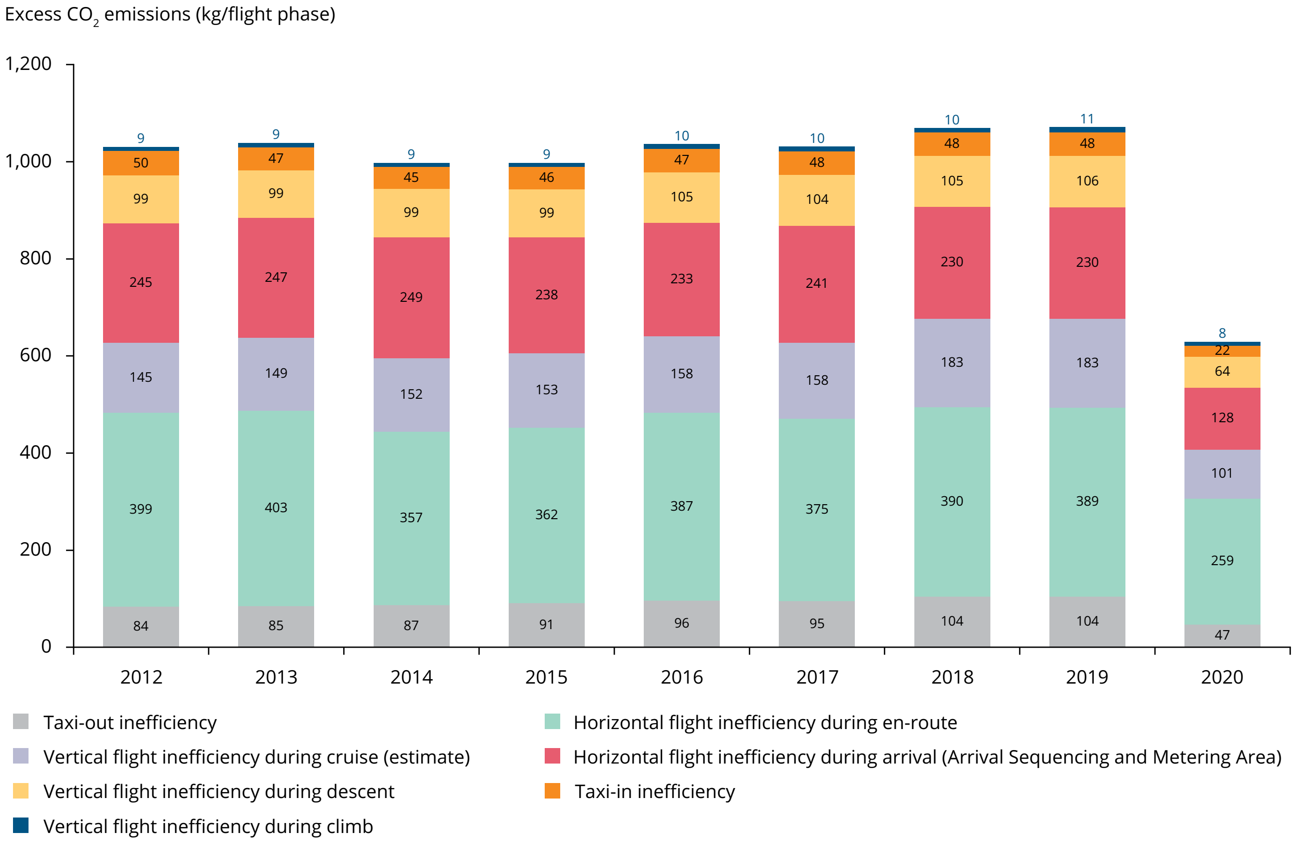
Emissions from aviation are highly correlated with the number of flight-km flown and, although the demand for flight-km is mainly dictated by the demand for air travel, inefficiencies in flight routes contribute to excess kilometres travelled and thus emissions. Today, the inefficiencies are captured through two key performance indicators (KPIs), measuring the difference between the shortest route between the origin and the destination and the last filed flight plan (also known as the KEP) or the actual trajectory flown (known as the KEA). The difference between these two KPIs is also called the horizontal flight efficiency. Non-optimal trajectories are not, however, the only source of inefficiency and, according to some authors, KEP and KEA indicators may not be an adequate measure of environmental performance, as, for example, the speed at which the trajectory is flown is not considered. In addition, horizontal flight efficiency does not account for the cruising altitude, which has a relevant impact on fuel consumption. It should also be mentioned that a high value for horizontal flight efficiency within a given airspace does not necessarily correspond to an optimal overall trajectory from origin to destination. Currently, values for these indicators are between 98% and 94% (Fricke, et al., 2021), and based on these alone there seems to be little room for improvement. Several authors argue (Edard, and Sitova, 2021; Fricke et al., 2021; Jarry, and Delahaye, 2021) that other indicators that also account for fuel efficiency should be adopted. For example, Eurocontrol network manager is developing a tool to assess fuel burn with a wheels-up/wheels-down approach (Eurocontrol, 2014). This could potentially help to better understand the environmental impact of flight trajectories and related choices. Aside from the in-route inefficiencies, they also occur around airports with non-optimal take-off and landing trajectories (which can be accounted for in the vertical flight efficiency (or VFE indicator), in which non-optimal arrival times cause unnecessary airborne holding and long taxi times at airports. The arrival sequencing and metering area (ASMA) time measures the additional taxi-out time and additional transit time within a radius of 40 nautical miles around an airport compared to the time during periods of low demand. Altogether these factors contribute to significant excess CO_2 emissions, shown in Figure A8.4, and to additional emissions of other pollutants (e.g. NOx).

Figure A8.3 Historical trend and long-term outlook for the NOx emissions from aviation in Europe (EU-27 plus EFTA and the UK)



Source: EASA et al. (2022).

Figure A8.4 Breakdown of gate-to-gate excess CO_2 emissions for an average flight in Europe

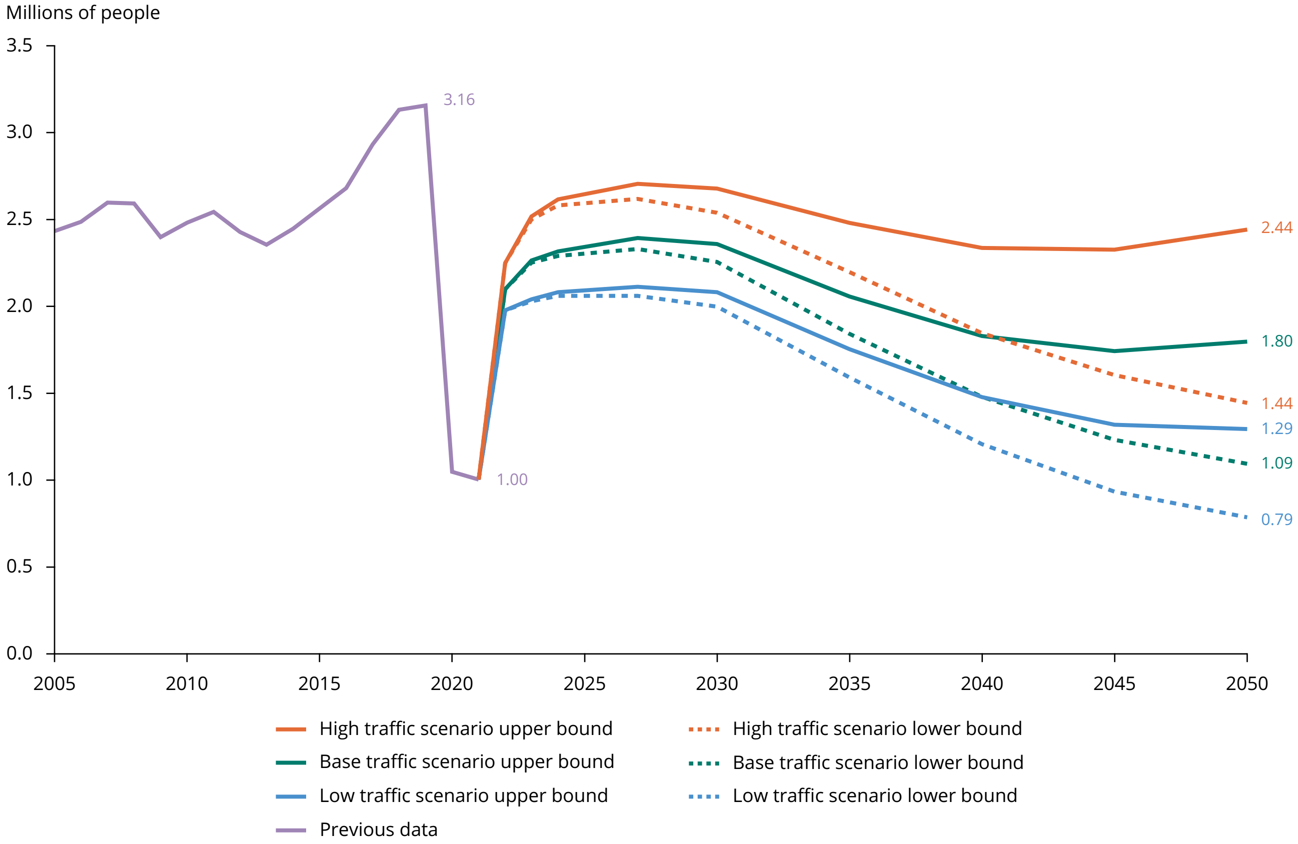


Source: EASA et al. (2022).

There are many reasons for the in-flight inefficiencies (Edard et al., 2021). First, since safety is a priority, traffic segregation is implemented, leading sometimes to longer routes. Second, aircraft are sometimes prohibited from using part of the airspace used for military purposes, etc., and need to circumvent some areas, increasing the length of their route. Sometimes airlines deliberately choose environmentally inefficient long routes to avoid delays or costs (e.g. high route charges). Lastly, weather can be another reason why the most efficient route cannot be followed. Climate change itself will have an impact on future weather patterns and will affect delays and flight efficiency (Eurocontrol, 2021a). The overall impacts will vary across Europe and, although delays due to major storms are expected to increase, the expected changes in high-altitude winds could lead to a reduction in fuel burn.

Aside from climate change impacts, aviation is also responsible for noise pollution. The noise impact of air traffic is mostly experienced around airports where the population is subjected to the noise of aircraft landing and taking off. It is estimated that in Europe in 2017, approximately 3 million people were subjected to day-evening-night average noise levels (L_{den}) equal to at least 55dB due to aircraft noise in urban areas and an additional 1 million people were affected in rural areas (EEA, 2020a). New landing and take-off procedures facilitated by ATC can reduce noise around airports (see case study 8.2). At variance with other impacts, the outlook for noise pollution is more favourable, as also shown in Figure A8.5. In the base load scenario the number of people living close to the 47 major EU airports and exposed to L_{den}≥55dB is projected to decrease by approximately 43% to 65% of the population by 2050 compared to 2019 (EASA et al., 2022).

Figure A8.5 Historical trend and long-term outlook for the number of people in the L_{den}≥55dB noise contours at 47 major European airports



Source: EASA et al. (2022).

To mitigate this increase in emissions and achieve the targets set out in the Fit for 55 package, improvements to ATM and aircraft operations are an important short- to mid-term step alongside other instruments such as demand management, sustainable fuels, improved aircraft technology and economic and policy measures. One of the main pillars for increasing the efficiency of ATM is the development of new digital solutions to optimise air traffic, both in-route and in airports. This resulted in the launch in 2004 of the Single European Sky initiative (SES) and the corresponding research projects (enabled by the SESAR Joint Undertaking, created in 2007). Initiatives include: (1) the integration of airport collaborative decision-making (A-CDM) systems to decrease ASMA time, (2) continuous climb and descent operations to optimise taking-off and landing trajectories and (3) the introduction of free route airspace allowing airlines to freely plan their route between origin and destination (see Sections A8.7-A8.9 for more information about these three initiatives).

A8.3 Time frame

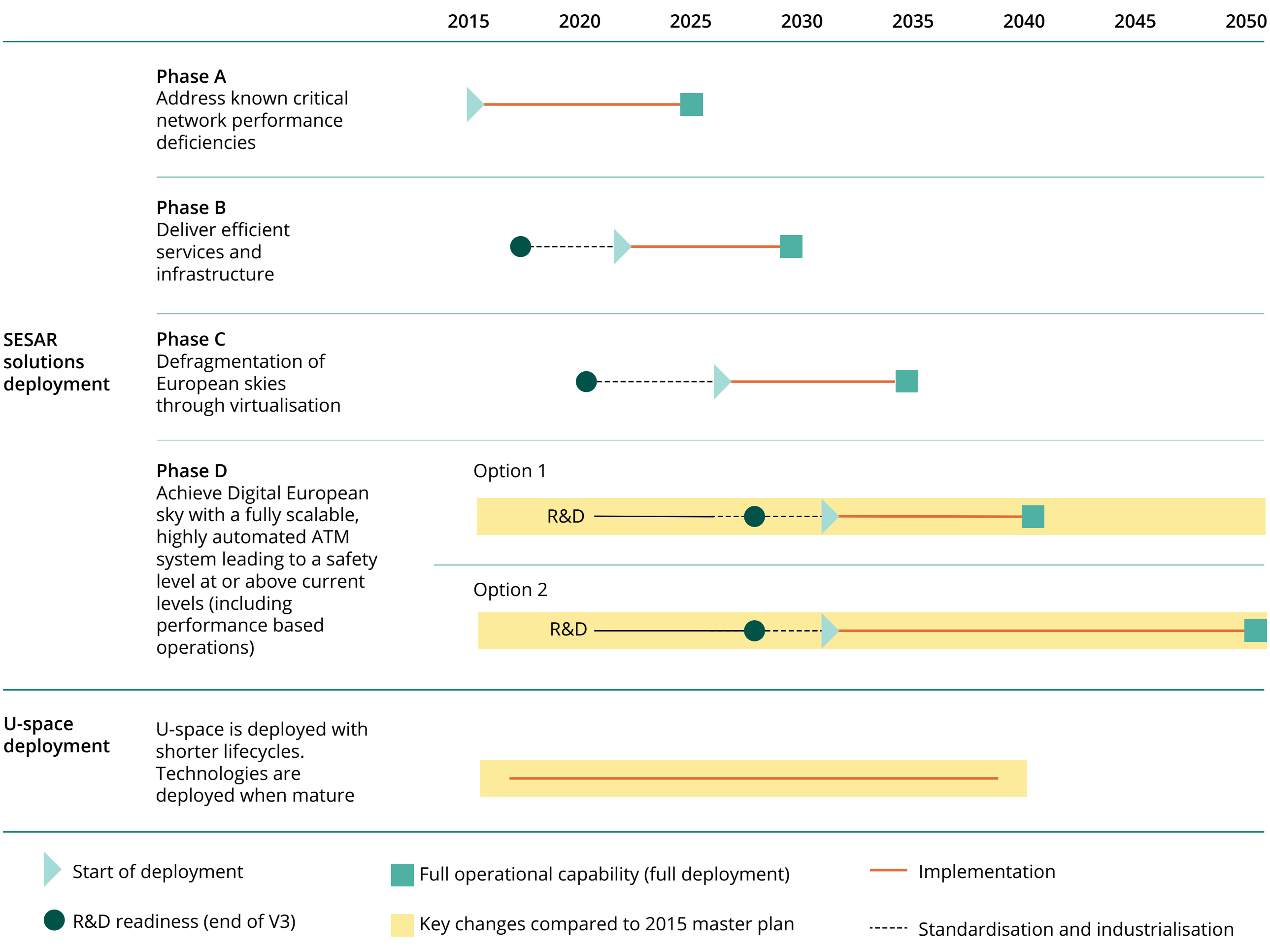
In 2004 the SES initiative was launched. The SES Framework (Regulation (EC) No 549/2004) laid down the framework for a single European sky. Initially, it was meant to provide solutions to excessive delays through a more integrated European ATM system, and the main goals were to defragment the European airspace and increase collaboration between the many ANSPs controlling it (Regulations (EC) No 550/2004, 551/2004 and 552/2004). For this to be possible, new technologies and a greater level of digitalisation were deemed necessary, and in 2007 the SESAR research programme was launched to coordinate EU research and development activities in ATM. In 2009, The SES II Regulation ((EC) No 1070/2009), amending the SES I Regulations, was approved. This set binding performance targets on safety, environment, capacity and cost-efficiency on the air traffic service providers. In addition, to improve the synchronisation of the deployment of the digital solutions developed under the SESAR framework, the SESAR Deployment Manager was created (SESAR Deployment Manager 2022). In 2013, the SES II+ proposal was made, which aims to increase competition between ANSPs and reinforce the role of the network manager in the hope of accelerating the rate of digitalisation in ATM.

The SESAR solutions are defined in the European ATM masterplan, in which the roadmap for implementation is set out until 2050 (Figure A8.6). The ambition is to reduce additional gate-to-gate flight time and CO_2 emissions by 3.2% and 2.3%, respectively, by 2035 (EASA et al., 2022).

A detailed catalogue of digital SESAR solutions can be found in SESAR Joint Undertaking (2021) (see also case studies 8.1-8.3). Despite the high ambitions, it should be noted, however, that only 26% of SESAR solutions have been deployed (SESAR Joint Undertaking, 2020), demonstrating the difficulties of introducing operational changes in the sector.

To achieve the timeline set out in the masterplan, it was recognised that there is a need for a review of the incentivisation programme. Rewarding actors who implement innovative solutions, strengthening the synchronisation and coordination efforts already made by the SESAR Deployment Manager and promoting the deployment programme are among the proposed mitigation actions (SESAR Joint Undertaking, 2020). Via calls for digital sky demonstrators by the European Climate, Infrastructure and Environment Executive Agency (CINEA) under the Connecting Europe Facility, the SESAR Joint Undertaking targets early movers to accelerate the delivery of SESAR solutions (SESAR Joint Undertaking, 2022b).

Figure A8.6 Target roll-out of SESAR solutions



Source: SESAR Joint Undertaking (2020).

A8.4 Expected environmental impacts

Using the taxonomy set out in Chapter 3 the following higher order environmental impacts of ATM improvements can be identified.

A8.4.1 Indirect effects — efficiency effects

It is estimated that CO_2 emissions savings from ATM improvements could range between 13 million tonnes and 25.5 million tonnes by 2030, achieving 8.3-12.4% of potential CO_2 reductions (Eurocontrol, 2022b). In the long run, the potential ATM improvements will become slightly less pronounced but could still contribute 6-9% of overall CO_2 emission reductions by 2050 (Figure A8.7) (NLR et al., 2021; Eurocontrol, 2022b).

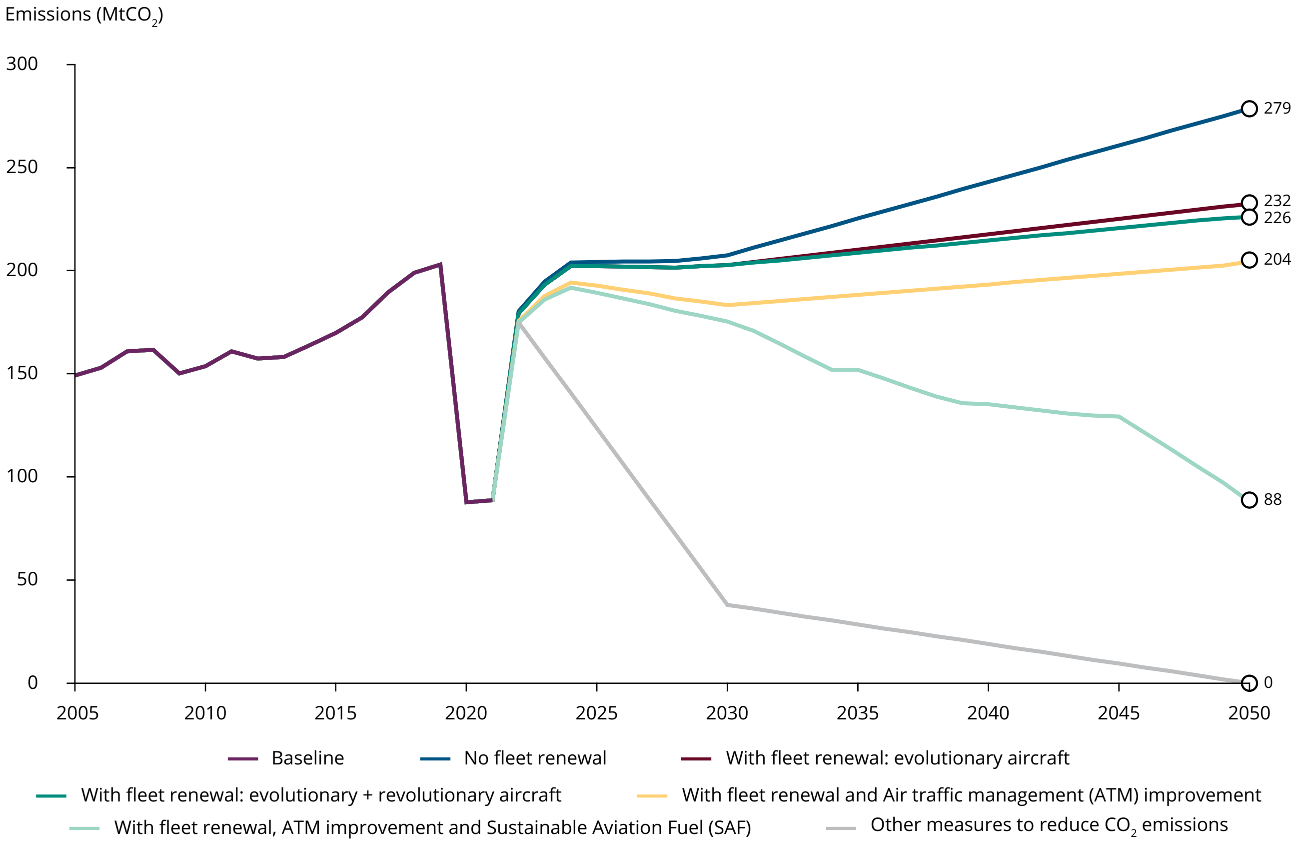
Others estimate that the SESAR programme could deliver a reduction of 5.6% in CO_2 emissions by 2035 and an extra 2% by 2040 compared to emission levels in 2020. Improved flight planning has the potential to reduce CO_2 emissions by 1.5% (NLR et al., 2021; see table 39). For contrail formation, Teoh et al. (2020) estimated that rerouting 15.3% of flights can reduce the impact of contrails significantly but that this comes with an increase in fuel consumption of 0.70%. It should also be noted that diversions come with a modest loss of airspace capacity, which is normally a scarce resource. Avila et al. (2019) show that in the United States, on average 15% of flights produce contrails, and an increase in flight altitudes can reduce the radiative impact by 92% with little impact on fuel consumption. All this requires improved ATM services to be able to communicate accurate weather forecasts and compute optimal flight routes. The use of sustainable aviation fuels could further help reduce the formation of contrails, as such fuels produce less soot particles when burned, which leads to reduced formation of ice crystals. However, the extent of this reduction is still subject to research (Lee, 2021).

Due to the complexity of air travel, there are a lot of interdependencies between externalities, and trade-offs are numerous. Although the optimisation of flight routes and airport operations have an important potential for reducing CO_2 emissions, they can have negative impacts on other externalities. The report by NLR and SEO Amsterdam Economics (2021) and references therein list some examples:

- Noise versus emissions (GHG and pollutants): a particular departure or landing trajectory might reduce noise for the surrounding population but might be less fuel efficient. Flights that avoid highly populated areas to reduce noise nuisance may increase the distance flown and fuel consumption.
- Safety versus emissions (GHG and pollutants): guaranteeing separation limits the capacity of a given airspace, creating congestion and might lead to aircraft choosing a non-optimal flight trajectory.
- Contrail formation versus emissions (GHG and pollutants): it is sometimes better to take longer routes or fly at different altitudes to avoid areas where contrails form more easily. This, however, may imply following less fuel-efficient routes and increasing CO_2 emissions.
- Capacity versus emissions (GHG and pollutants): if airlines follow optimised routes, this could increase the use of some airspace, leading to capacity problems and congestion with longer delays for aircraft and passengers.

The quantification of these trade-offs is not straightforward, as pointed out in various contributions during the research workshop 'Climate change and the role of air traffic control' (Baltic FAB et al., 2021). There is a need for more and diverse data and new metrics to be able to evaluate the impacts of technological advances on emissions and to quantify their interdependencies.

Figure A8.7 Estimated CO_2 emissions of aviation between 2005 and 2050 in Europe, base case scenario



Source: Eurocontrol (2022a).

A8.4.2 Structural and behavioural effects — direct rebound effects

Flexibilities and improvements in the use of the airspace can lead to positive effects such as an increase in the efficiency of asset use and a decrease in the costs of delays. However, this will always be limited by overall capacity: a CO_2 emission-optimal route choice can lead to increased use of some sectors of the airspace, increasing congestion.

A8.4.3 Structural and behavioural effects — indirect rebound effects

As mentioned before, airlines sometimes choose a longer, non-optimal route to avoid airspaces with high air navigation service charges. If airlines are constrained to follow the CO_2 emission-optimised routes, this could lead to a change in revenues for both the airlines and the ANSPs.

Changes in fuel burn costs and in air navigation service charges will be passed on, at least partially, to passengers through reduced or increased airfares. Changes in delays will also affect passengers directly and might encourage or discourage air travel, directly impacting the demand for it.

It should be noted that a delayed flight could be the more environmentally friendly solution, depending on the situation.

A8.5 Policy corner

The complexity of ATM operations can lead to a slow uptake of new technologies as reported in Delhaye et al. (2021). Some of the main challenges identified relate to the numerous stakeholders with different objectives (revenues, increasing capacity, safety) that are not always aligned. This leads to an articulate decision-making process, in an environment in which stringent safety requirements are of paramount importance. Other issues are that ATM investments are often very expensive and budget constraints can hinder their uptake, certainly when the investing party will not directly benefit from them (the 'split incentive problem'). In general, it is important to clearly signal the priorities for the whole sector. These must include environmental concerns.

Despite the numerous barriers, Delhaye et al. (2021) also identify ways that can encourage the aviation sector to implement further digitalisation technologies. They explore a number of policy options that could be adopted to promote investments in the sector, such as: (1) a flexible charging regulation that allows agents to charge different rates to their service users according to the technologies implemented, (2) giving subsidies to ANSPs when investment costs are very high but the technology is of more benefit to the airlines, and (3) introducing a 'best equipped-best served' charging mechanism that allows agents (ANSPs, airports, etc.) to provide a better service to airlines using a particular technology. A need for more and better demonstration of technologies to show their potential and the involvement of all stakeholders was also identified as necessary to ensure a good uptake of innovative technologies. The SESAR Deployment Manager and the SESAR Joint Undertaking digital European sky demonstrators are examples of tools that contribute to solving these issues.

Similar to what happens in other sectors, internalising transport externalities and managing demand could help to reduce the environmental impact of the sector and avoid some of the distortions currently seen in the market discussed above.

A8.6 Bottom line

Digitalisation potentially improves the overall operational efficiency of air traffic by reducing taxi time at airports and by optimising flight routes and landing and take-off trajectories. This will reduce emissions through a decrease in the fuel burned and the potential to avoid contrail formation. Due to the complexity of air travel, there are numerous trade-offs and reducing one externality can exacerbate another. Other technological innovations and the use of sustainable fuels in aviation are expected to have a greater impact on reducing GHG emissions. However, to achieve significant results, collaboration between the various actors is necessary and the creation of a digital single European sky is an important tool for this. As extensively discussed in other factsheets (e.g. Factsheet 7), internalising the externalities and managing the constantly increasing demand are necessary and complementary actions to reduce the environmental impact of the sector and avoid neutralising the benefit of other technological advancements.

A8.7 Case study 8.1: Airport collaborative decision-making

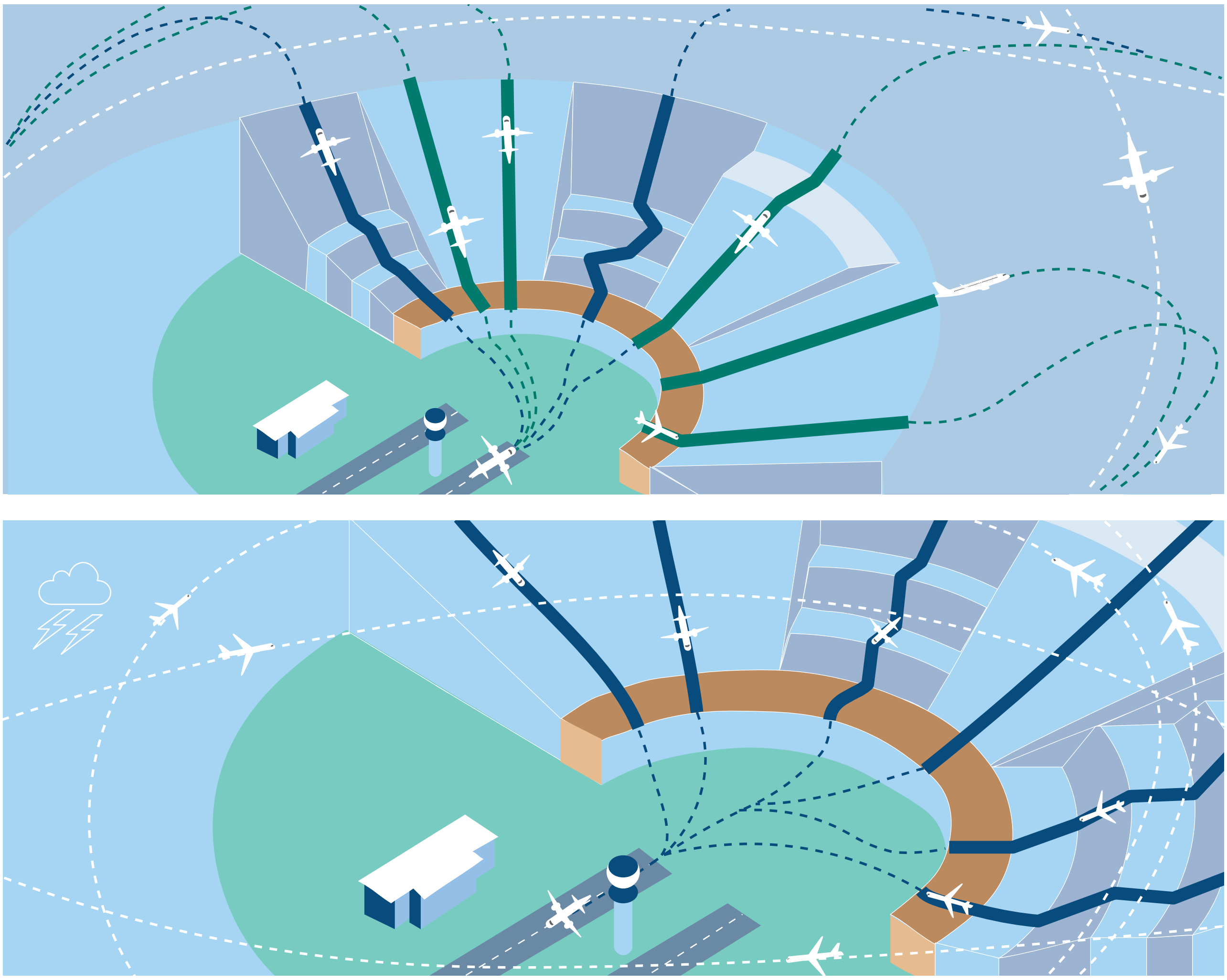
The objective of A-CDM is to improve data and information exchange, which is essential to improve operational efficiency, to optimise the use of resources and to improve the predictability of air traffic. Increased predictability can significantly improve traffic flow management, decreasing taxi times and related fuel burn.

A-CDM is currently fully implemented in 33 airports across Europe (Eurocontrol, 2023). In 2016, Eurocontrol performed an impact assessment of 17 A-CDM airports and identified a reduction in taxi minutes of 7% and in ATFM delay minutes of 10.3%, resulting in a reduction in CO_2 emissions of 102.7 kilotonnes and a reduction in sulphur dioxide emissions of 28.7 tonnes, which represent an overall 7.7% of reduction in emissions (Eurocontrol, 2016).

A8.8 Case study 8.2: Continuous climb and descent operations

Continuous climb and descent operations (CCO/CDO) allow aircraft to optimise their flight path when taking off and landing, leading to environmental benefits, thanks to reduced fuel burn and noise (Figure A8.8). In 2018, Eurocontrol conducted a European Civil Aviation Conference-wide study of the current implementation of CCO/CDO. The study concluded that CCO has the potential to save 48kg CO_2 per flight, while CDO saves a potential 145kg CO_2 per flight. Deployment throughout Europe could reduce CO_2 emissions by up to 1.1 million tonnes. Furthermore, the study concludes that CCO/CDO also has a positive impact on noise and could reduce noise levels by 1-5dB. It is, however, important to note that a full-scale deployment is probably not likely because of safety issues, weather, and capacity or air traffic controllers' workload. At the moment, this is a decision commonly taken by the pilot and the controller (Eurocontrol, 2018).

Figure A8.8 Schematic representation of continuous climb and descent operations



Source: FABEC (Functional Airspace Block Europe Central).

A8.9 Case study 8.3: Free route airspace

The free route airspace (FRA) concept allows airlines to freely plan routes between origin and destination, taking into account variables such as weather and wind speeds. This could allow aircraft in principle to take a more direct and fuel-efficient route and to reduce delay times and make more efficient use of the airspace. In 2017, 20% of flown flight times in the EU flew in FRA, and it is estimated that the fuel saved since 2014 due to FRA has reduced CO_2 emissions by 2.6 million tonnes. Once fully implemented in the EU, FRA could save up to 20 million tonnes of CO_2 (EASA et al., 2019; Eurocontrol, 2022c).

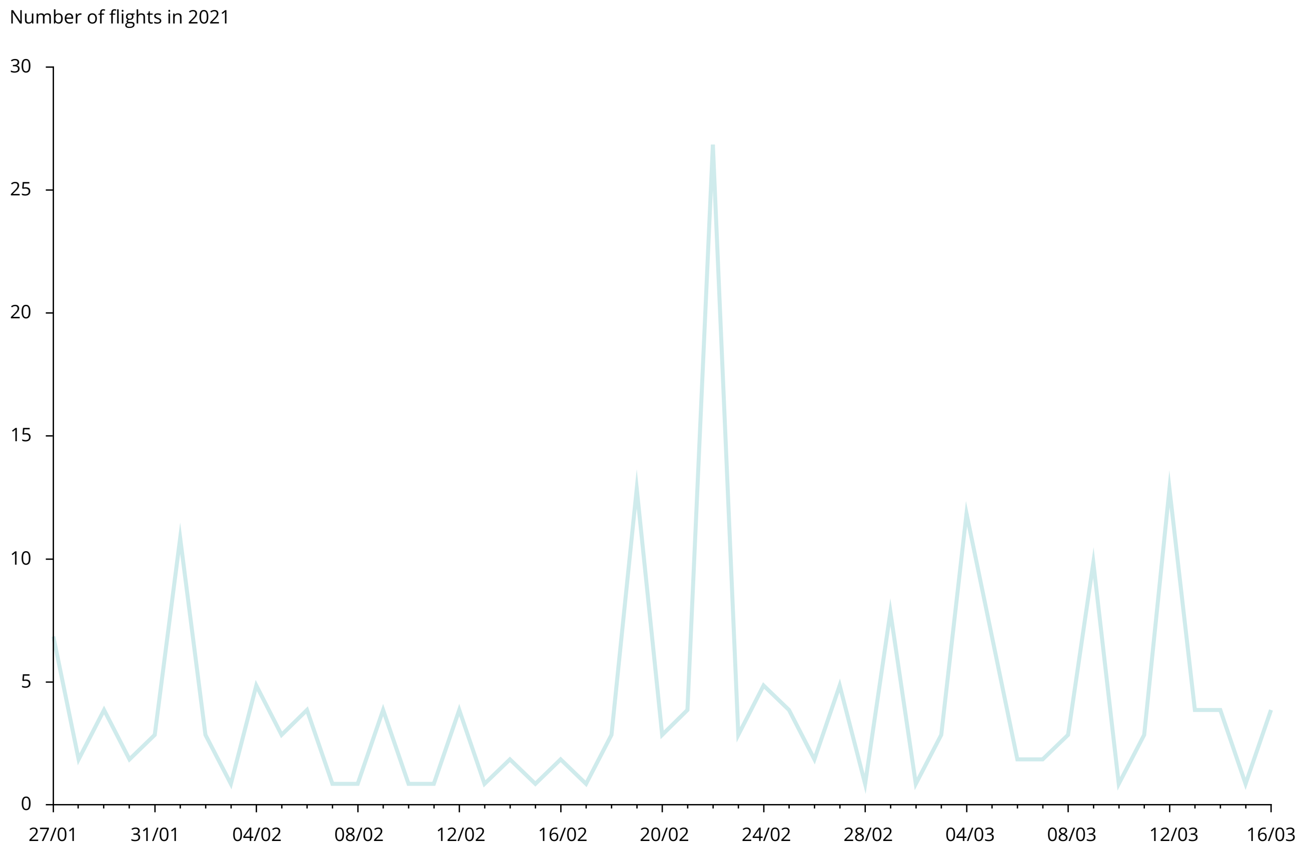
A8.10 Case study 8.4: Mitigating contrail formation — Eurocontrol live trial 2021

Non-CO_2 effects such as those generated by contrail formation can have a significant effect on climate change. Eurocontrol's Maastricht Upper Area Control Centre is currently running a pilot project aiming to investigate the operational feasibility of mitigating such effects though ATC. The main idea is as follows: by implementing minor operational changes such as diverting from the normal flight trajectory by 2,000 feet up or down to avoid flying planes through regions with a high probability of developing stable cirrus clouds or contrails (i.e. ice-supersaturated regions). Among other things, this involved creating a reliable persistent contrail prediction algorithm, developed in partnership with DLR, the German Aerospace Centre.

The trial started at the beginning of 2021 and, in the first 10 months, 209 flight trajectories were included in the project (Figure A8.9). It was operational on selected dates, after 18.00 local time and during the night, when contrail formation can have a warming effect.

The net assessment of environmental effects is still not available, but the project has highlighted a number of challenges and opportunities. An accurate model to forecast the location of ice-supersaturated regions is necessary as well as models to evaluate the usefulness of contrail prevention in specific weather contexts. These models can be supported by sensors mounted on the aircraft, ground-based cameras or satellite imaging, but these options are currently under investigation and not implemented . Aside from accurate weather forecast models, the trade-off between the reduction in non-CO_2 effects and the additional CO_2 emissions due to modifying aeroplane trajectories must be carefully evaluated, taking account of the different uncertainties affecting the two impacts. This is also challenging because the time horizons of the two are significantly different and comparing them on a common base is not necessarily easy. Despite the challenges, interest in this trial has been considerable among the large variety of stakeholders in the aviation sector, including policymakers.

Figure A8.9 Daily number of flights recorded during the trial



Source: Eurocontrol (2021b).