European Aviation Environmental Report 2019

European Environment Agency

EASA
European Union Aviation Safety Agency

EUROCONTROL

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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 along with other relevant sources.

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European Aviation Environmental Report

2019

WELCOME MESSAGE

Violeta Bulc

European Commissioner for Transport

Aviation is both a strong sector for the European Union's economy, and an increasingly important means of transport for EU citizens and businesses. Enhanced connectivity, cheaper tickets and more flying options have made it easier than ever before for Europeans to connect with their relatives, develop their business or simply take a spontaneous holiday! The growth of aviation is also providing the EU with a consistently growing pool of jobs, and helps regional development by attracting activity and investments. The success story of European aviation is destined to go on for the upcoming decades! All trends indicate a sustained increase in demand from EU citizens for air travel until 2040.

But growth for the sake of growth cannot be an objective in itself. Aviation has externalities that cannot be overlooked. Indeed, as air traffic increases year on year, the same holds true for environmental and health impacts. This is why the European Commission considers it a priority that the future growth of aviation goes hand in hand with sustainability policies. The EU is firmly committed to the goals of the Paris Agreement. To achieve its objectives, the Commission has put forward 'A Clean Planet for all', a strategic long-term vision for a prosperous, modern, competitive and climate neutral economy by 2050. We are making an irreversible shift to low and ultimately no-emission mobility – Vision Zero by 2050! The commitment shown by governments to support the sustainable development of aviation, and more largely to create an eco-civilisation hand in hand with the industry, only confirms our longstanding efforts for European citizens to be able to travel by air while leaving a minimal footprint. As a society, we should act together and take smart decisions and bold actions for a cleaner society, to tackle pollution and stay safe in this changing world. In the European Commission, as you can see, we put people at the heart of the common vision.

The second edition of the European Aviation Environmental Report provides a scientific and comprehensive overview of the environmental challenges of aviation in the EU. It gives valuable insight on critical matters in aviation and helps us see the progress achieved and where more work needs to be done. More importantly, it sheds light on the need for Europe to pursue its efforts to invest in developing and deploying innovative solutions in the years to come for our planet and ourselves.

The quality of this report is a good illustration of the excellent collaboration of the European Union Aviation Safety Agency, the European Environment Agency, EUROCONTROL and other stakeholders. The Commission highly values this precious cooperation, and I am confident that it will allow at the same time to inform European citizens, and to enlighten the policy decisions in the years to come.

Aviation is a global industry and all parts of the EU aviation network create value. Only a competitive and sustainable air transport sector will allow Europe to maintain its leadership position, in the interest of its citizens and its industry. EU must deliver, and I am confident that we will deliver.

While the benefits of air transport for EU citizens are clear in terms of mobility and connectivity, the sector represents a growing challenge for the environment in the years to come. Indeed, aviation currently accounts for 3% of global carbon emissions and long-term forecasts indicate that air traffic is expected to continue increasing. More than ever, Europe needs to be ambitious in order to meet its climate objectives, and notably to reach the targets set under the Paris Agreement.

Solutions do already exist. The European regulators and industry are acting on multiple fronts to reduce the environmental footprint of aviation. New energy solutions such as sustainable fuels and electrification are on their way. EU funding is enabling research and deployment to optimise aircraft technology as well as air traffic management operations.

In the years to come, the European Union and its Member States will need to continue taking ambitious steps. We can do more! The sector will need enhanced coordination between all aviation actors, an ambitious budget towards reducing environmental externalities, as well as real incentives for the industry to favour sustainable fuels over conventional fossil fuels.

Karima Delli

Member of the European Parliament and Chair of Committee on Transport and Tourism

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This second European Aviation Environmental Report has been prepared by the European Union Aviation Safety Agency (EASA), the European Environment Agency (EEA) and EUROCONTROL. Its development was coordinated by a Steering Group made up of representatives of these three organisations as well as the European Commission, the Swiss Federal Office of Civil Aviation, the Swedish Transport Agency and the Spanish Aviation Safety and Security Agency who all separately contributed to the report.

The Steering Group gratefully acknowledges the support of the Stakeholder Group, whose representatives[1] provided valuable input and comments on the report. The latest information on actions being undertaken by all parts of the aviation sector is provided within the 'Stakeholder Actions' boxes. The collaboration with this diverse set of organisations continues to help ensure that the report provides a balanced perspective.

Finally, we wish to acknowledge the financial support provided by EASA, as well as the provision of expert resources from all contributing organisations. This support has made it possible to build on the 2016 European Aviation Environmental Report, and provide a comprehensive assessment of how the environmental performance of the aviation sector is evolving over time.

European Aviation Environmental Report website

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

1 Aerospace and Defence Industries Association of Europe, Airports Council International Europe, Airlines for Europe, Airport Regions Conference, Austrocontrol, Clean Sky Joint Undertaking, Deutsches Zentrum für Luft- und Raumfahrt, European Business Aviation Association, European Express Association, International Air Transport Association, Manchester Metropolitan University, SESAR Joint Undertaking, Transport & Environment and Union Européenne Contre les Nuisances Aériennes.

FOREWORD

Tim Peake

European Space Agency astronaut

It's impossible not to be mesmerised by the view of Earth from space. From a distance, our planet appears a vibrant, blue oasis of life. Yet our existence depends upon a tiny strip of gas, just 16 km high, which protects us from the harsh environment of space and for billions of years has created the conditions for life to evolve on our planet. Our atmosphere is what differentiates Earth from the barren, hostile conditions of Mars or Venus.

From the unique vantage point of the International Space Station, orbiting the planet sixteen times a day, astronauts get to enjoy a stunning view of our atmosphere, best viewed at sunrise and sunset where the curvature of the Earth meets the blackness of space. But from space it's immediately apparent just how fragile our ecosystem is.

On Earth, looking up on a clear day we see lovely blue skies, but the view from space is not warm and welcoming – the Earth is set against a vast, black abyss and you suddenly realise how vulnerable and isolated we are on this small rocky planet. A myriad of complex systems churn away perpetually on the ISS to provide something that many of us take for granted on Earth – clean air and water.

Many astronauts report a phenomenon called the 'Overview Effect' – a cognitive shift in awareness while viewing Earth from orbit or the lunar surface. William Anders was one of the crew of Apollo 8, the first manned spacecraft to leave the Earth's orbit and circle the Moon. On Christmas Eve 1968, he and his fellow crewmen emerged in their spacecraft from behind the Moon's dark side, and they saw in front of them an astounding sight – an exquisite blue sphere hanging in the blackness of space. The photograph Anders took is known as "Earthrise".

At this moment in the history of human culture, we truly saw ourselves from a distance for the very first time, and this wonderful image is credited with inspiring a greater respect for our environment.

In this same spirit, the European Aviation Environmental Report aims to help protect our home by providing critical information on the environmental performance of the European aviation sector in order to focus efforts that spur innovation and help address the environmental challenges that we all face.

We only have one home – we would do well to look after it.

EXECUTIVE SUMMARY

This second European Aviation Environmental Report (EAER) provides an updated assessment of the environmental performance of the aviation sector published in the first report of 2016. The continued growth of the sector has produced economic benefits and connectivity within Europe, and is stimulating investment in novel technology. This draws on a wider pool of expertise and innovative approaches from other sectors, thereby creating potential new opportunities to address the environmental impacts from aviation. However, it is recognised that the contribution of aviation activities to climate change, noise and air quality impacts is increasing, thereby affecting the health and quality of life of European citizens.

Significant resources are being invested at both the European and Member State level, as well as by industry, to address this environmental challenge. While improvements are being made across various measures (technology, operations, airports, market-based measures), their combined effect described in this report has not kept pace with the recent strong growth in the demand for air travel, thereby leading to an overall increase in the environmental impact.

Effective coordination between stakeholders is of the utmost importance to build on existing measures and address the environmental challenges, thus ensuring the long-term success of the aviation sector. This report aims to publish clear, reliable and objective information to inform these discussions and support cooperation within Europe.

EAER DASHBOARD[2]

	Indicator	Units	2017	% change since 2014	% change since 2005
Traffic	Passenger kilometres flown by commercial flights(1)	billion	1,643	+20%	+60%
	Number of city pairs served most weeks by scheduled flights(1)		8,603	+11%	+43%
Noise	Number of people inside L_{den} 55 dB noise contours(2)	million	2.58	+14%	+12%
	Average noise energy per flight(3)	10^9 Joules	1.24	-1%	-14%
Emissions	Full-flight CO_2 emissions(1)	million tonnes	163	+10%	+16%
	Full-flight 'net' CO_2 emissions with ETS reductions(1)	million tonnes	136	+3%	n/a(4)
	Full-flight NO_x emissions(1)	thousand tonnes	839	+12%	+25%
	Average fuel consumption of commercial flights(1)	litres fuel per 100 passenger kilometres	3.4	-8%	-24%

(1) All departures from EU28+EFTA
(2) 47 major European airports
(3) All departures and arrivals in EU28+EFTA
(4) ETS not applicable to aviation in 2005

2 Red shading indicates a worsening of the relevant indicator and green shading an improvement.

Overview of Aviation Sector

- The number of flights increased by 8% between 2014 and 2017, and grows by 42% from 2017 to 2040 in the most-likely forecast.
- Technological improvements, fleet renewal and increased operational efficiency have been able to partially counterbalance the impact of recent growth, but there has still been an increase in overall noise and emissions since 2014.
- In 2016, aviation was accountable for 3.6% of the total EU28 greenhouse gas emissions and for 13.4% of the emissions from transport.
- In 2011, aviation accounted for 3.2% of the total population exposed to L_{den} levels above 55 dB from all sources covered by the EU Environmental Noise Directive.
- The number of people exposed to significant noise around 47 major European airports shows potential stabilisation, but under an assumption of no change in population and no airport expansion.
- The number of major airports that handle more than 50,000 annual aircraft movements is expected to increase from 82 in 2017 to 110 in 2040, and therefore aviation noise may well affect new populations.
- The environmental efficiency of aviation continues to improve and, by 2040, further improvements are expected in average fuel burn per passenger kilometre flown (-12%) and noise energy per flight (-24%).
- By 2040, CO_2 and NO_X emissions are predicted to increase by at least 21% and 16% respectively.

Technology and Design

- Recent certification data demonstrates that advanced technologies continue to be integrated into new designs.
- New aircraft noise standard became applicable on 1 January 2018, and new aeroplane CO_2 and engine PM standards will become applicable on 1 January 2020.
- The average noise level of the twin-aisle aircraft category in the European fleet has significantly reduced since 2008 due the introduction of the Airbus A350 and Boeing 787.
- New technologies (e.g. supersonic and urban mobility aircraft) need to be carefully integrated into the aviation system to avoid undermining progress in mitigating environmental impacts.

Sustainable Aviation Fuels

- The use of sustainable aviation fuel is currently minimal and is likely to remain limited in the short term.
- Sustainable aviation fuels have the potential to make an important contribution to mitigating the current and expected future environmental impacts of aviation.
- There is interest in 'electrofuels', which potentially constitute zero-emission alternative fuels. However, few demonstrator projects have been brought forward due to high production costs.
- Six bio-based aviation fuels production pathways have been certified, and several others are in the approval process.
- The EU has the potential to increase its bio-based aviation fuel production capacity, but the uptake by airlines remains minimal due to various factors, including the cost relative to conventional aviation fuel and low priority in most national bioenergy policies.
- Recent policy developments and industry initiatives aim to have a positive impact on the uptake of sustainable aviation fuels in Europe.

Air Traffic Management and Operations

- En route horizontal flight efficiency is on track to meet the SES Performance Scheme 2019 target of no more than 2.60% additional distance flown.
- Airport arrival flow and taxi-out operational efficiencies have remained fairly stable over the past years.
- The introduction of Free Route Airspace has saved more than 2.6 million tonnes of CO_2 since 2014 (approximately 0.5% of total aviation CO_2 emissions).
- Continuous descent operations have potential for reducing both noise and CO_2, especially in the European core area.
- The full potential from operational initiatives is not always achieved due to conflicting air navigation requirements (e.g. safety, environment, economic, capacity).

Airports

- New processes to verify aircraft noise data and collect aircraft noise certificates are being put in place by EASA to support a harmonised approach to managing aircraft noise.
- Marginally compliant 'Chapter 3' aircraft, as used in the 'Balanced Approach', represented less than 5% of operations in Europe during 2017.
- Noise and emissions charges are used extensively, but the low level of charges (less than 1% of airline operating costs) is unlikely to affect the fleet operating at airports.
- Between 2015 and 2018, the number of European airports participating in the Airport Carbon Accreditation programme has increased from 92 to 133, and airports reaching CO_2 neutral status rose from 20 to 37.
- Involvement of stakeholders is crucial to identifying balanced mitigation measures, and can be done through a process such as Collaborative Environmental Management, which has already been implemented at 25 airports.

Market-Based Measures

- Market-based measures are instruments designed to address the climate impact of aviation, beyond what operational and technological measures or sustainable aviation fuels can achieve.
- Between 2013 and 2020, an estimated net saving of 193.4 Mt CO_2 (twice Belgium's annual emissions) will be achieved by aviation via the EU ETS through funding of emissions reduction in other sectors.
- In 2016, an agreement was reached at ICAO to set up the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). As of November 2018, 76 States intend to volunteer to offset their emissions from 2021, representing 76% of the international aviation activity.
- Emissions trading systems (e.g. ETS) and offsetting schemes (e.g. CORSIA) both address aviation emissions but differ in how they function. ETSs generally work towards economy-wide emission reduction targets, while offsetting schemes also compensate for emissions by reductions in other sectors but without the associated cap.
- The environmental effectiveness of offsets depends on robust implementation to ensure that the emission reductions delivered would not have occurred in the absence of the scheme.

Aviation Environmental Impacts

- Long-term exposure to aircraft noise is linked with a variety of health impacts, including ischaemic heart disease, sleep disturbance, annoyance and cognitive impairment.
- The annoyance reported by residents from a given level of aircraft noise has been shown to be greater than that caused by other transport sources.
- There are good estimates for most pollutants emitted by aviation related activities that influence air quality and subsequent health effects, although knowledge gaps remain (e.g. on the impact of ultrafine particles).
- A high level of scientific understanding of the long-term climate effect from aviation CO_2 emissions make it a clear and important target for mitigation efforts.
- Climate impacts from non-CO_2 emissions (e.g. NO_X, particles) cannot be ignored as they represent warming effects that are important in the shorter term, but the level of scientific understanding of the magnitude of the effects is medium to very low.
- More States and organisations are taking action to adapt and build resilience to the impacts that climate change will have on the aviation sector (e.g. higher temperatures, rising sea-levels).

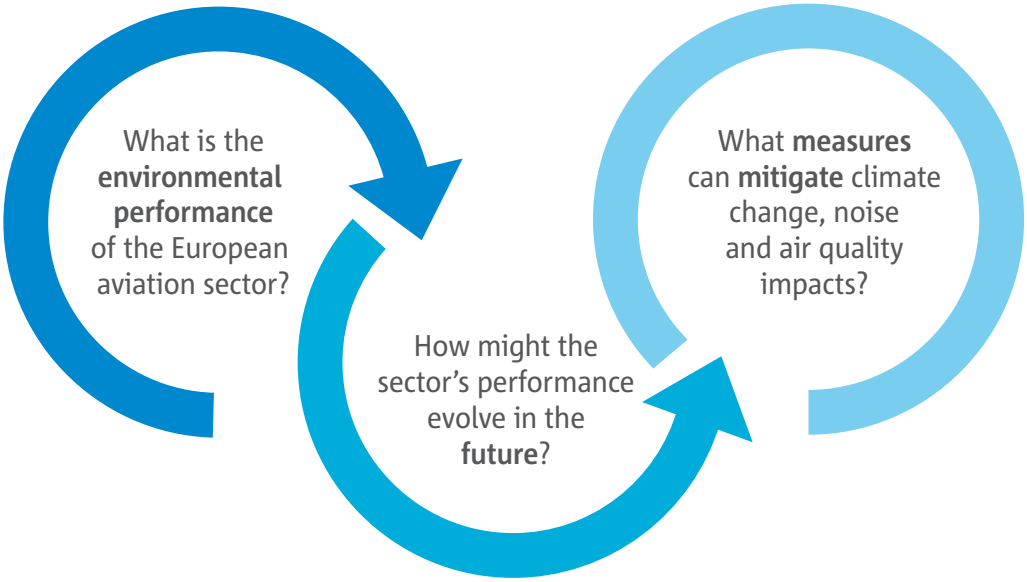
INTRODUCTION

Welcome to the second European Aviation Environmental Report! The core aim of the report is to provide an objective, clear and accurate source of information on the environmental performance of the aviation sector at the European level every three years.

In doing so, it also supports performance-based regulation focusing on measureable outcomes; informs strategic discussions on prioritisation of future work and resources (policy, legislative, operational, research); and facilitates effective coordination of this comprehensive approach across the different initiatives [1].

While Europe's aviation sector brings significant economic and social benefits, its activities contribute to climate change, noise and local air quality impacts, and consequently affect the health and quality of life of European citizens [2]. These impacts are currently forecast to increase. Therefore the ability of the European aviation sector to grow is directly linked to how effectively it responds to the major environmental challenges ahead.

Innovative, smart and environmentally sustainable solutions to these challenges provide an economic opportunity for the European aviation sector to increase its competitiveness in a global market – in this respect 'green is gold'. In order to seize this opportunity and overcome the challenges, Europe employs a comprehensive set of measures that come together to support an overarching strategy. Their current status has been summarised within the various chapters of this report.


What is the **environmental performance** of the European aviation sector?
How might the sector's performance evolve in the **future**?
What **measures** can **mitigate** climate change, noise and air quality impacts?


CHAPTER 7
Aviation Environmental Impacts
CHAPTER 5
Airports
CHAPTER 3
Sustainable Aviation Fuels

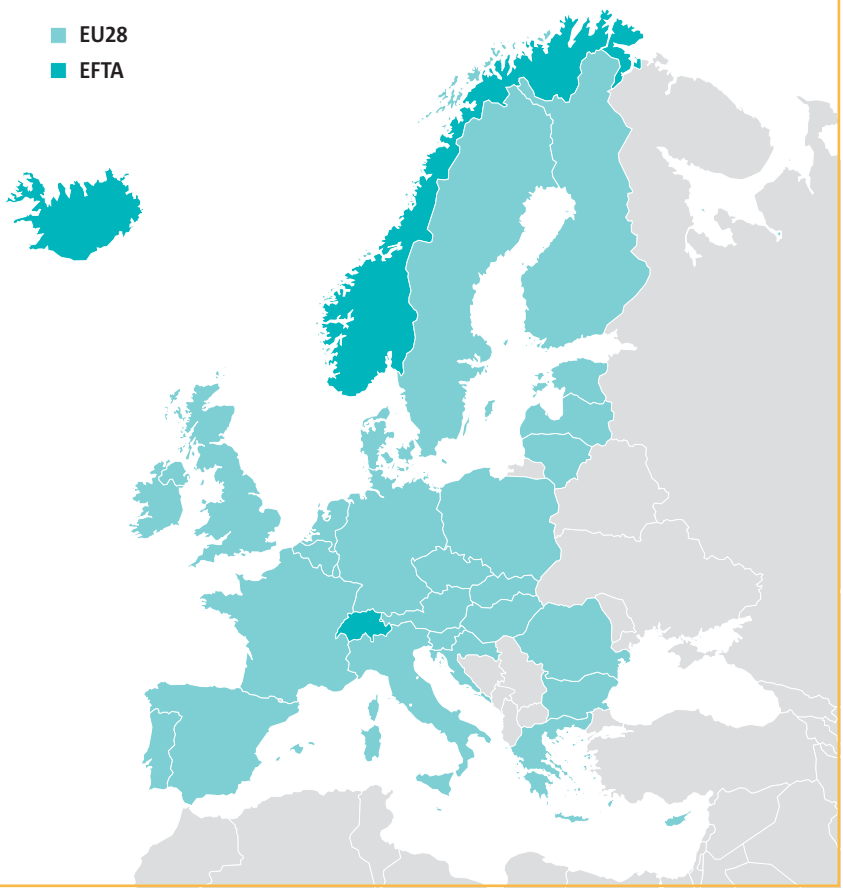

Munich
Salzburg
Linz
Wels
Augsburg
AUSTRIA
Klagenfurt
Innsbruck
Ljubljana
SLOVENIA
Zagreb
CROATIA
Karlovac
Sisak
Banja Luka
Rijeka
Pula
Gospic
Udine
Pordenone
Trieste
Treviso
Venice
Vicenza
Padua
Dolomites
Balaton
Kaposvar
Pécs
Danube
Szekesfehervar
Budapest
Nitra
Bratislava
Krakow
Katowice
Zadar

1. OVERVIEW OF AVIATION SECTOR

- **The number of flights in EU28+EFTA increased by 8% between 2014 and 2017, and grows by 42% from 2017 to 2040 in the most-likely forecast.**
- **Technological improvements, fleet renewal and increased operational efficiency have been able to partially counterbalance the impact of recent growth, but there has still been an increase in overall noise and emissions since 2014.**
- **In 2016, aviation was accountable for 3.6% of the total EU28 greenhouse gas emissions and for 13.4% of the emissions from transport.**
- **In 2011, aviation accounted for 3.2% of the total population exposed to L_{den} levels above 55 dB from all sources covered by the EU Environmental Noise Directive.**
- **The number of people exposed to significant noise around 47 major European airports shows potential stabilisation, but under an assumption of no change in population and no airport expansion.**
- **The number of major airports that handle more than 50,000 annual aircraft movements is expected to increase from 82 in 2017 to 110 in 2040, and therefore aviation noise may well affect new populations.**
- **The environmental efficiency of aviation continues to improve and, by 2040, further improvements are expected in average fuel burn per passenger kilometre flown (-12%) and noise energy per flight (-24%).**
- **By 2040, CO_2 and NO_x emissions are predicted to increase by at least 21% and 16% respectively.**

Analysis scope and assumptions

Historical air traffic data in this section comes from Eurostat and EUROCONTROL, whose 20-year STATFOR traffic forecast provided the future traffic scenarios representing 'high', 'base' (most likely) and 'low' growth rates. The coverage is all flights from or to airports in the European Union (EU) and European Free Trade Association (EFTA). 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

Recent strong growth, but flight counts still just below previous peak

In 2017, the number of flights in Europe was 1% below the all-time high reached in 2008. With the economic crisis, 2009 saw the biggest annual fall in flights of recent decades. The recovery in 2011 was temporary, but since 2014 a sustained return to growth is observed. In recent years, growth in low-cost flights has continued, while since 2015 the number of traditional scheduled flights has also increased (Figure 1.1 and 1.2).

Passenger numbers have grown even faster, and are 50% higher in 2017 than 2005. This is partially due to a gradual shift towards flying further in larger aircraft with the average distance flown up 16% since 2005. Other contributions come from an increase in load factors (the fraction of seats that are occupied) from 70.2% to 80.3%, and the use of lighter and slimmer seats so that more passengers can be accommodated on the same aircraft. All of the above have resulted in a reduction in fuel burn per passenger kilometre flown (see emissions section).

Figure 1.1 An increase in both low-cost and traditional scheduled flights has driven the recent return to growth

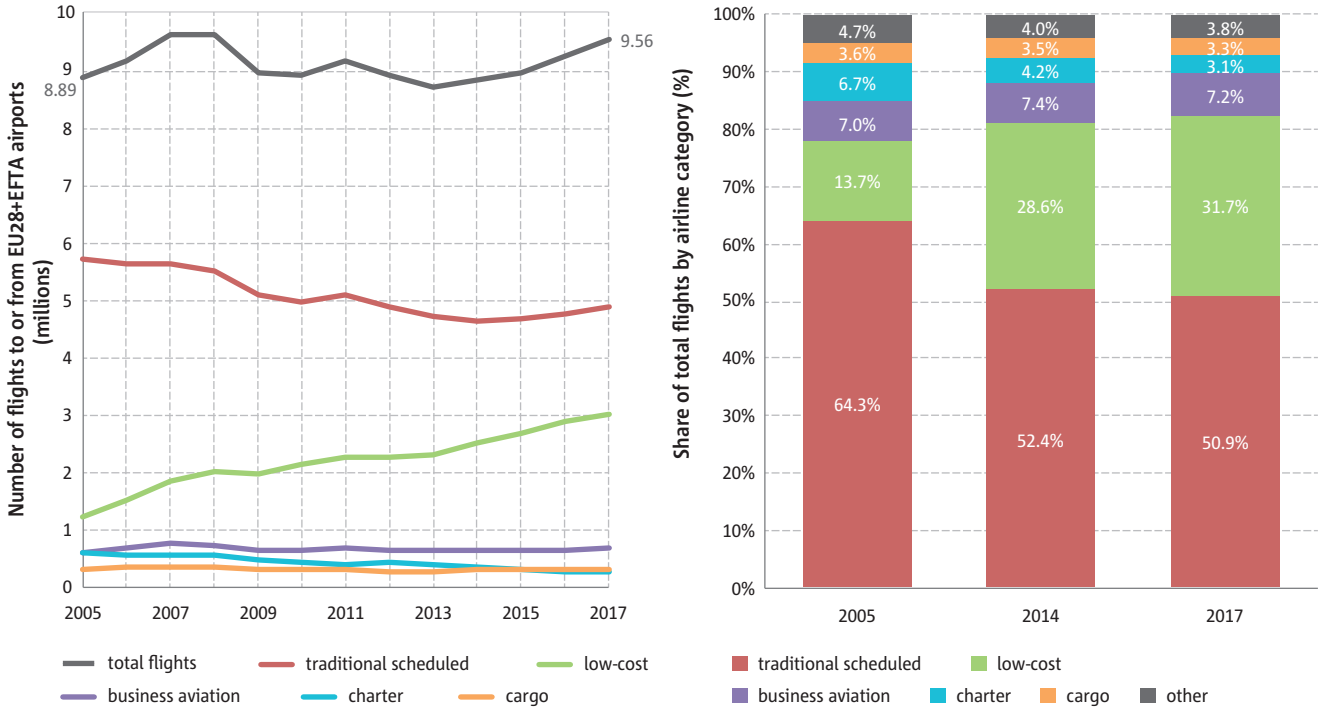
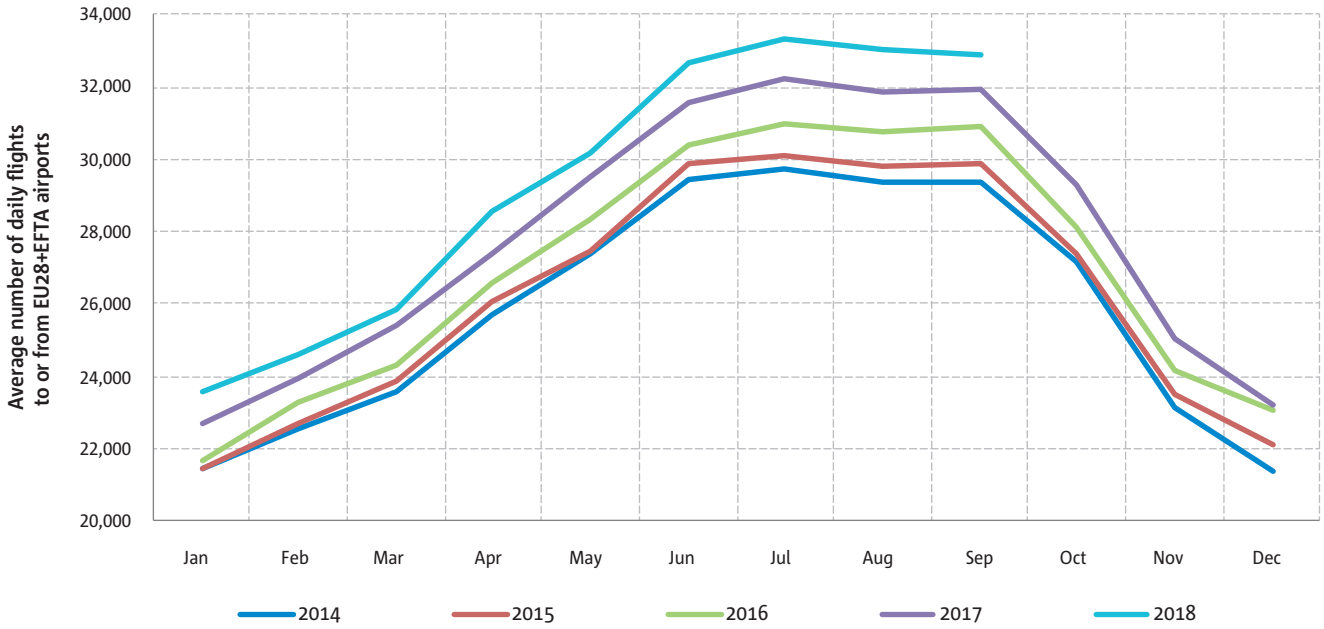


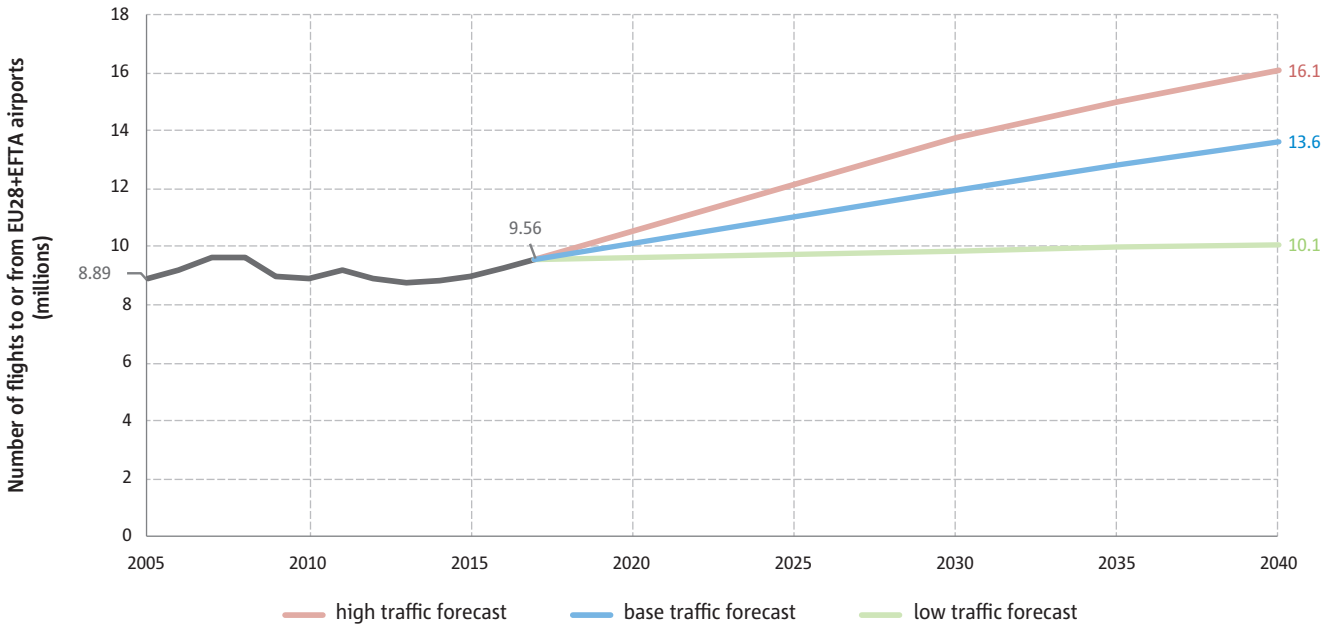
Figure 1.2 Number of daily flights increases every year between 2014 and 2018



The total cargo tonnage on all-cargo flights and in the belly hold of passenger flights went up by 55% from 2005 to 2017. However, the number of all-cargo flights decreased by 2% over the same period, indicating a shift towards belly cargo. In addition, smaller all-cargo aircraft with a take-off weight less than 50 tonnes had one of the sharpest reductions in number of flights over that period, indicating a shift to larger all-cargo aircraft.

Under the most-likely future scenario, hereafter referred to as the 'base' forecast, the total number of flights using EU28+EFTA airports is expected to reach 13.6 million in 2040, compared to 9.6 million in 2017 (Figure 1.3). This represents an average annual growth rate of 1.5% over this period. Although the forecast has been updated since the previous report, actual traffic growth has followed the base forecast, which explains why the 2035 figure remains unchanged.

Figure 1.3 Number of flights increases by 42% between 2017 and 2040 under the base traffic forecast

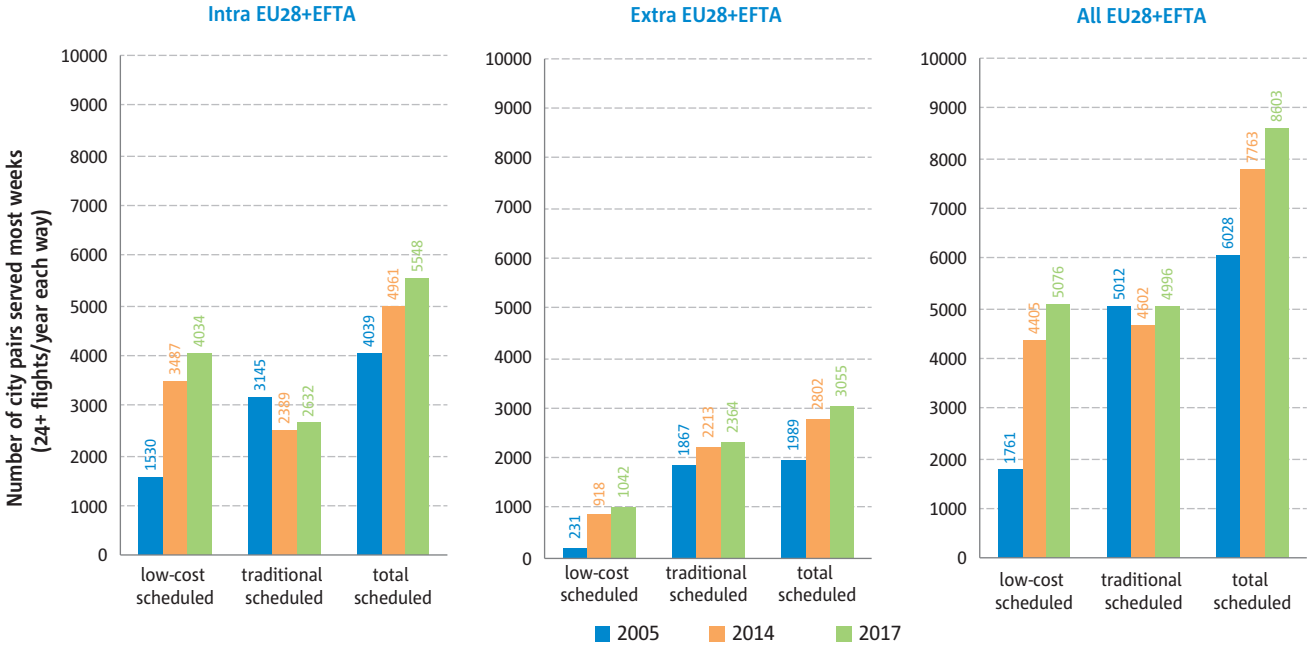


Low-cost airlines now provide the majority of the scheduled network

From 2005 to 2017, the number of scheduled flights increased by 14%, whereas the number of city pairs with scheduled flights most weeks of the year increased by 43% from 6,000 to 8,600 (Figure 1.4). This is due to airline operators reducing the number of city pairs with high-frequency connecting flights, with the median number of flights each way decreasing from 4.2 per week to 3.2 per week. The traditional scheduled carriers have also reduced the number of city pairs that they serve infrequently (less than 3 times per week), although this was compensated elsewhere by low-cost carriers adding new connections on other city pairs. Indeed, the low-cost carriers now serve more city-pairs than the traditional scheduled airlines.

More city pairs in the network means a greater dispersion of local impacts such as noise. The reduction in high-frequency connections is linked to the increase in aircraft size, and the fact that traditional carriers have reduced their short-haul, intra EU28-EFTA connections rather than their long-haul. This will also have been influenced by competition from road and the high-speed rail network that continues to expand within Europe.

Figure 1.4 Overall the scheduled network connects more city pairs in 2017

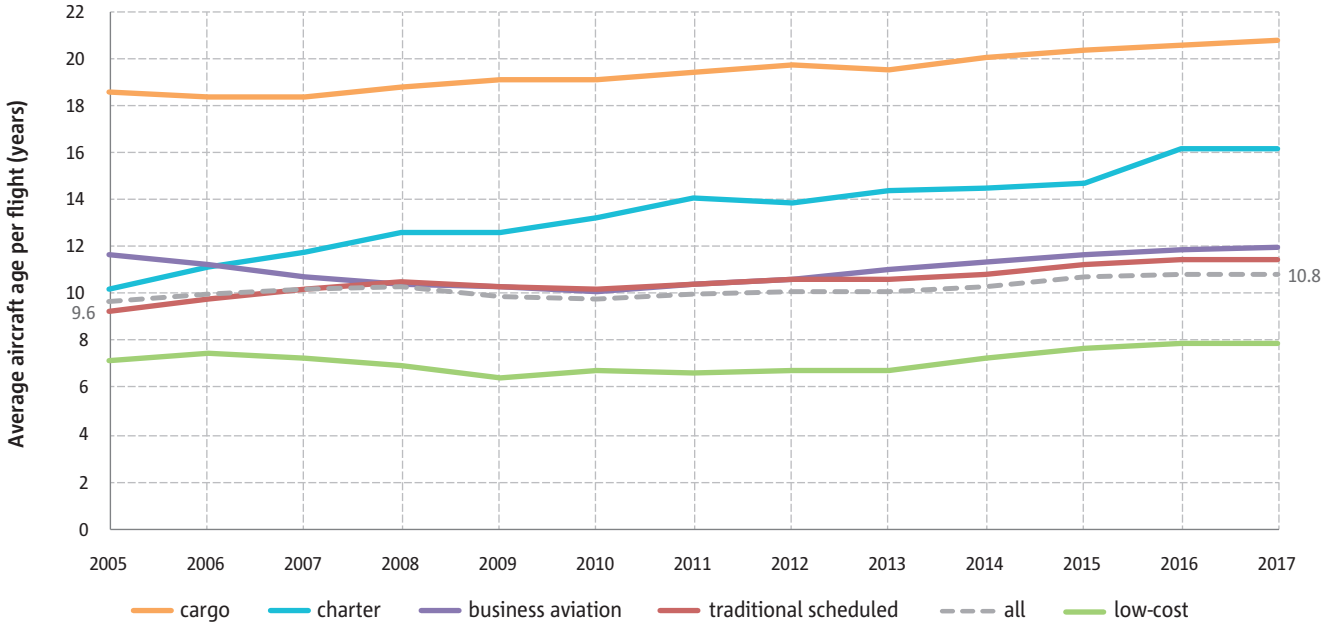


European fleet is young, but ageing slowly

Every year, new state-of-the-art aircraft join the European fleet to accommodate growth and replace old aircraft that are approaching the end of their operational life. Figure 1.5 shows the evolution of the average aircraft age per flight in Europe over time. Following the economic downturn in 2008, retirement of aircraft jumped to over 6% of the fleet in 2008 and 2009 from less than 3% between 2004 and 2007, and low cost carriers had a rapid expansion. This resulted in a reduction in the average aircraft age per flight.

The average aircraft age remained stable for a period, but has increased from 10.3 years in 2014 to 10.8 years in 2017. This increase in average age has been limited, despite a return to growth, by low-cost and traditional scheduled carriers investing in new aircraft such as the A320neo and B737 MAX families. The non-scheduled charter fleet has aged most rapidly, reflecting the decline of this segment and the switch to scheduled operations. The rapid expansion of business aviation up to 2008 was accompanied by the entry into service of new aircraft, but business aviation declined sharply with the economic downturn, which led to more frequent use of the existing aircraft and a gradual ageing in the fleet. The average age of aircraft used for all-cargo operations (i.e. not counting the passenger flights that often carry cargo too) is the highest of all, now reaching 21 years in 2017. It should be noted that new aircraft represent significant costs for operators, and a sufficient operational lifetime is required to ensure a return on their investment.

Figure 1.5 Average aircraft age per flight has crept up towards 11 years



The daily distribution of flights remains stable

The annual share of flights in the day, evening and night time periods at EU28+EFTA airports has not changed significantly between 2005 and 2017, with 72% of departures and landings occurring between 07:00 and 19:00 local time, 19% between 19:00 and 23:00 and 9% between 23:00 and 07:00. Consequently, the total number of night time departures and landings follows the same trend as the total traffic, and has been increasing since 2013. The situation varies between airports, with some increasing their number of night flights and some decreasing.

Table 1.1 Summary of air traffic indicators

	Units	2005	2014	2017
			(% change since 2005)	
Number of flights[1]	millions	8.89	8.85	9.56
			(-0.4%)	*(+8%)*
Actual flown distance[1]	billion km	13.1	14.6	16.4
			(+11%)	*(+25%)*
Average distance per flight[1]	km	1,478	1,649	1,714
			(+12%)	*(+16%)*
Passengers on commercial flights[2]	millions	592	742	890
			(+25%)	*(+50%)*
Passenger load factor[2]	%	70.2	76.7	80.3
			(+9%)	*(+14%)*
Passengers per flight[2]		86	113	124
			(+31%)	*(+43%)*
Passenger kilometres[2, 3]	billion	1,030	1,364	1,643
			(+32%)	*(+60%)*
Cargo on all-cargo and passenger aircraft[2]	million tonnes	6.4	8.3	10.0
			(+29%)	*(+55%)*
Number of all-cargo flights[1]	thousands	319	305	312
			(-4%)	*(-2%)*
Average aircraft age[1]	years	9.6	10.3	10.8
			(+7%)	*(+13%)*

1 Arrivals and departures

2 Departures only

3 Kilometres represent the shortest (or great circle) distance between origin and destination

1.2 Noise

Noise exposure is typically assessed by determining a noise contour. This represents an area around an airport inside which noise levels exceed a given decibel (dB) threshold, as shown in Figure 1.6. This section provides trends in the total noise contour areas, and number of people inside the noise contours of 47 major European airports. These are based on the indicators of L_{den} 55 dB and L_{night} 50 dB, as defined in the EU Environmental Noise Directive [6], and were derived using the STAPES airport noise model.

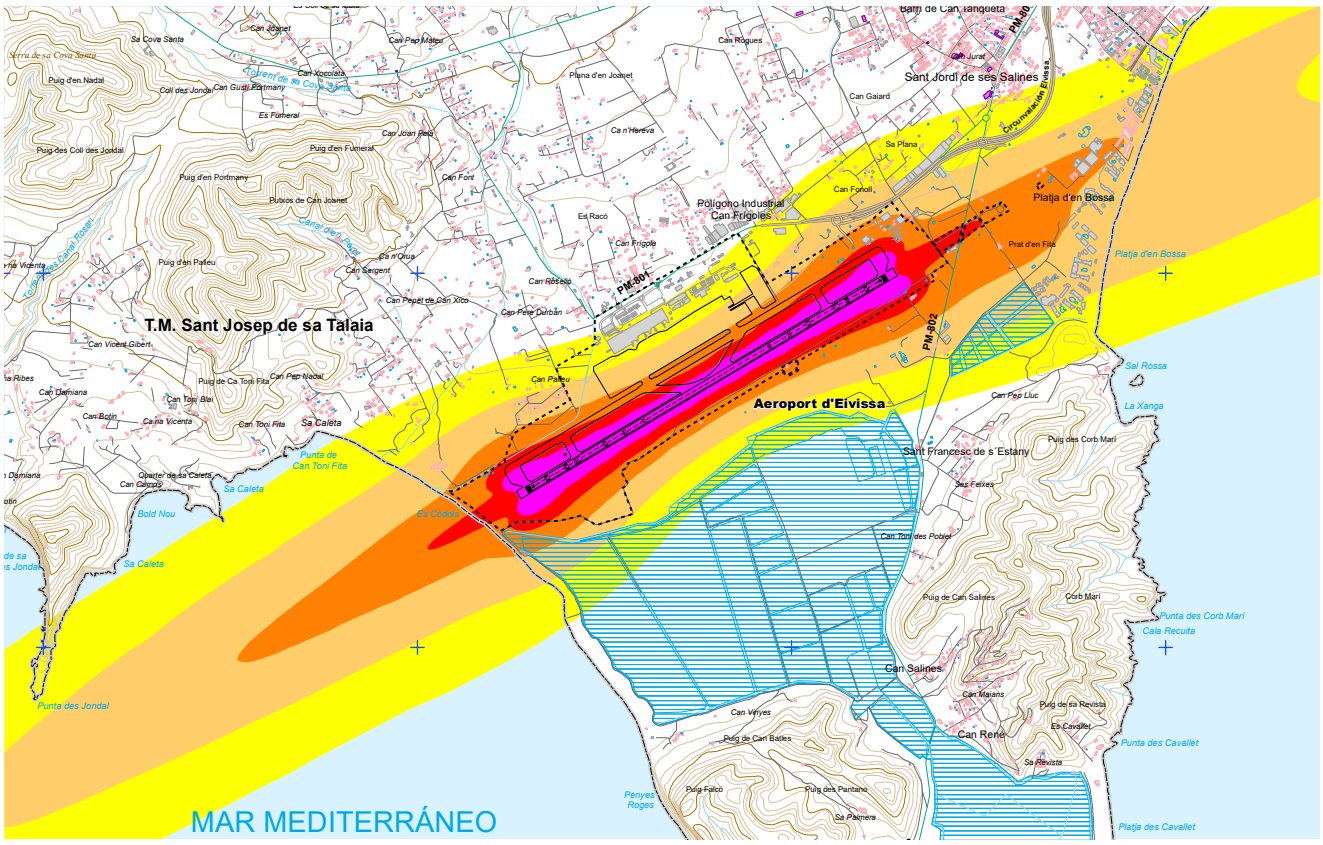
Complementary noise metrics assessed for this report include: the population exposed to aircraft noise events exceeding 70 dB during day and night; the noise-induced annoyance and sleep disturbance based on the latest exposure-response guidance; and the noise energy index computed annually for all flight operations at EU28+EFTA airports.

What are L_{den} and L_{night}?

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.

Due to the nature of decibels, if the traffic doubles at an airport but the noise of each aircraft movement is reduced by 3 dB, then L_{den} and L_{night} levels will be unchanged. Likewise, the new Airbus 'A320neo' aircraft are about 6 dB quieter than the older 'A320ceo' during take-off, and consequently **four** take-offs by an A320neo create similar L_{den} or L_{night} levels as **one** take-off by an A320ceo.

Figure 1.6 Example of an airport noise contour (Source: Aeropuertos Españoles y Navegación Aérea)



New, quieter aircraft could help stabilise noise levels around major airports, but noise nuisance may spread to other airports

Average noise levels around airports are still close to what they were in 2005, but are on an upwards trend again since 2013. The total population residing inside the L_{den} 55 dB and L_{night} 50 dB contours of the 47 major European airports were 2.58 and 0.98 million people respectively in 2017 (Figure 1.7, Table 1.2). This is 12% and 13% more than in 2005 for L_{den} and L_{night} respectively, but 14% and 20% more than in 2014. However, some airports within the 47 have seen their L_{den} and L_{night} contours reduced. The total noise energy in the EU28 and EFTA region follows flight counts closely (Figure 1.11) but was 5% lower in 2017 than in 2005, indicating that noise technology has managed to compensate for the increase in average aircraft size. The average noise energy per flight indeed went down by 14% over this period.

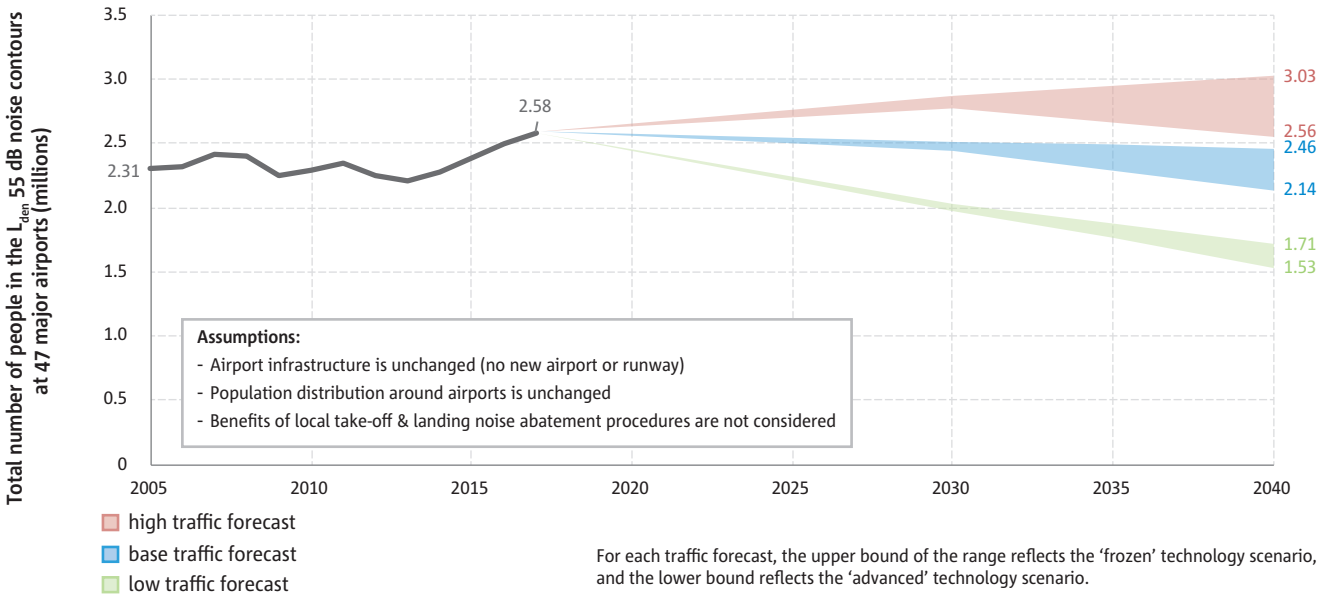
The latest World Health Organization Europe guidance [16] recommends to assess aircraft noise annoyance above L_{den} 45 dB and sleep disturbance above L_{night} 40 dB. Using this guidance, it is estimated that around 3.2 million people were highly annoyed by aircraft noise, and 1.4 million suffered from high sleep disturbance in 2017 around the 47 major airports. The number of people exposed to more than 50 aircraft noise events exceeding 70 dB per day was estimated to be 1 million in 2017 for the same airports; this is 60% more than in 2005.

What is the noise energy index?

When an aircraft flies to an airport, and later departs again, the area around an airport is exposed to a certain amount of noise energy. The 'noise energy' index uses certified aircraft noise data to calculate a proxy for the total noise energy received on the ground during an aircraft landing and take-off, irrespective of how the aircraft is operated. The individual noise energy from each flight operation is then summed at the European level.

If the latest aircraft types now entering the fleet deliver their expected noise benefits, the total population exposed to L_{den} 55 dB and L_{night} 50 dB noise levels around the 47 major airports could stabilise and even start to decrease by 2030. This forecast assumes that there will be no further airport expansion and no change in population around these airports. Furthermore, around 110 airports could handle more than 50,000 annual aircraft movements by 2040, compared to 82 airports in 2017, thereby affecting new populations.

Figure 1.7 Fleet renewal could stabilise average noise levels at today's 47 major airports by 2030



For each traffic forecast, the upper bound of the range reflects the 'frozen' technology scenario, and the lower bound reflects the 'advanced' technology scenario.

Table 1.2 Summary of noise indicators

	Units	2005	2014	2017	2040 Base forecast	
					Advanced Tech	Frozen Tech
			(% change since 2005)			
L_{den} 55 dB area (47 major airports)	km²	2,250	2,251	2,421	2,172	2,383
			(0%)	*(+8%)*	*(-3%)*	*(+6%)*
L_{den} 55 dB population (47 major airports)	millions	2.31	2.27	2.58	2.14	2.46
			(-2%)	*(+12%)*	*(-7%)*	*(+7%)*
L_{night} 50 dB area (47 major airports)	km²	1,134	1,145	1,240	1,014	1,119
			(+1%)	*(+9%)*	*(-11%)*	*(-1%)*
L_{night} 50 dB population (47 major airports)	millions	0.87	0.81	0.98	0.70	0.83
			(-6%)	*(+13%)*	*(-19%)*	*(-4%)*
Noise energy index (all EU28+EFTA airports)	10^{16} Joules	1.05	0.93	1.00	0.88	1.06
			(-12%)	*(-5%)*	*(-16%)*	*(+1%)*
Average noise energy per flight (all EU28+EFTA airports)	10^{9} Joules	1.45	1.26	1.24	0.79	0.94
			(-13%)	*(-14%)*	*(-46%)*	*(-35%)*

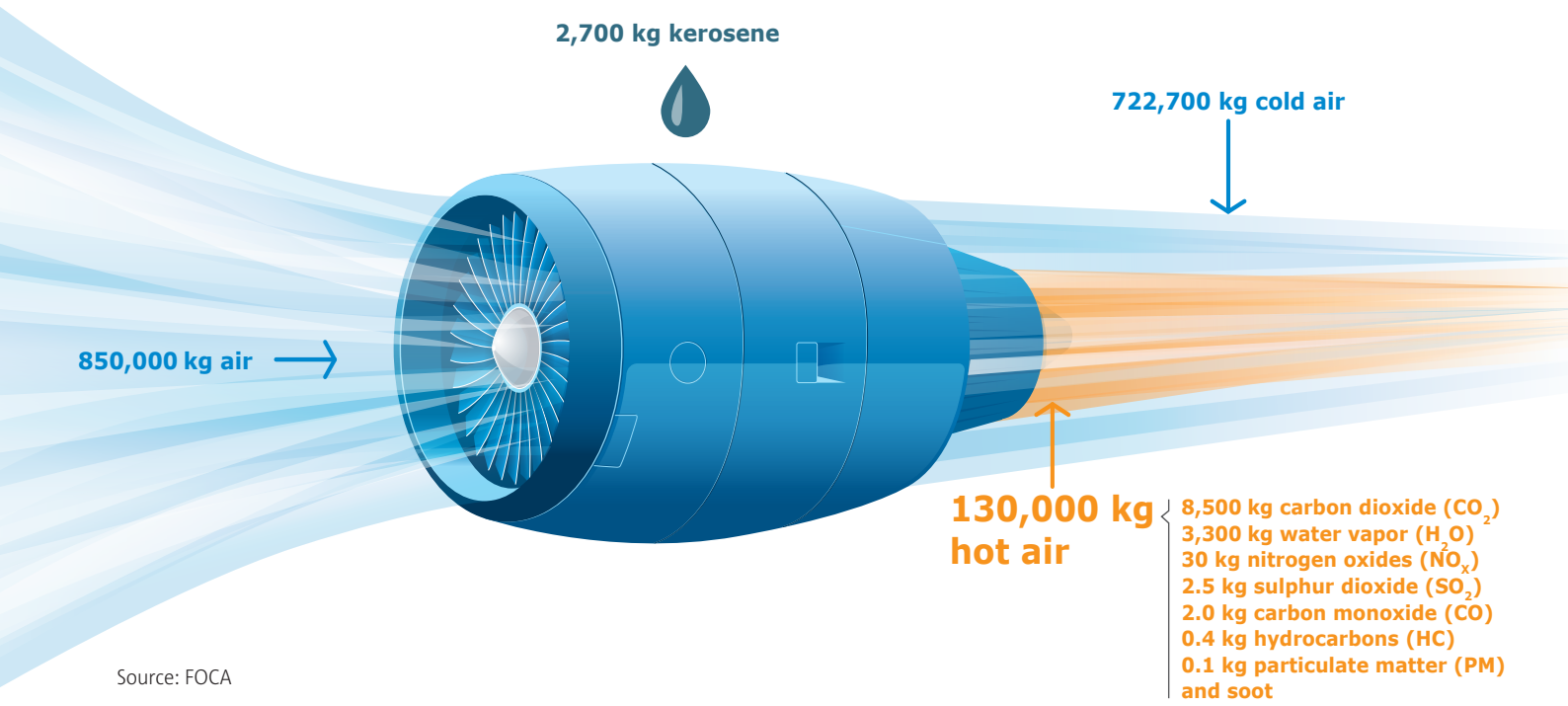
Aircraft noise in context

While individual aircraft have become less noisy due to technological improvements, the growing amount of air traffic in Europe means that an important part of the population is still exposed to problematic noise levels. In the EU, aircraft noise is the third biggest source of noise exposure after road and rail traffic. The European Environment Agency has estimated that more than 4.1 million people were exposed to L_{den} levels above 55 dB from aircraft at 85 major airports (over 50,000 movements per year) in 2011, which accounted for 3.2% of the total population exposed to this noise level from all sources covered by the EU Environmental Noise Directive [4].

1.3 Emissions

The main pollutants emitted by aircraft engines in operations are carbon dioxide (CO_2), nitrogen oxides (NO_X), sulphur oxides (SO_X), unburnt hydrocarbons (HC), carbon monoxide (CO), particulate matter (PM) and soot (Figure 1.8). This section provides trends in full-flight emissions of all flights departing from EU28 and EFTA airports.

Figure 1.8 Emissions from a typical two-engine jet aircraft during 1-hour flight with 150 passengers



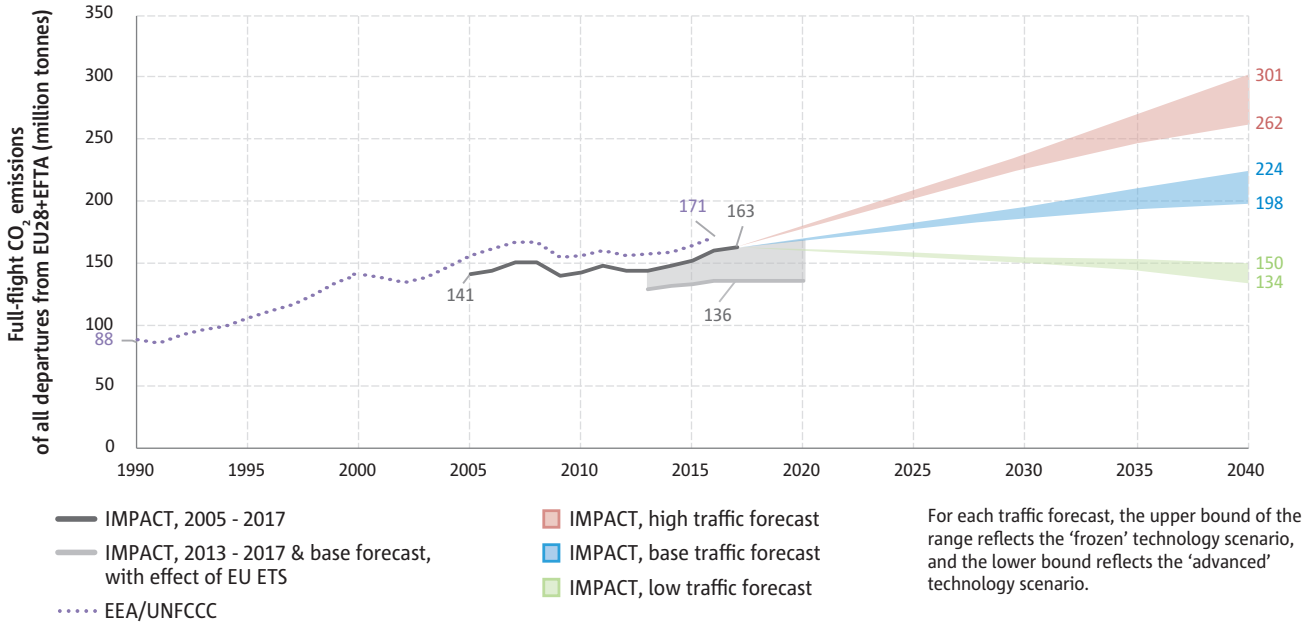
Source: FOCA

CO_2 and NO_x emissions are continuing to grow

According to the data reported by Members States to the United Nations Framework Convention on Climate Change (UNFCCC), the CO_2 emissions of all flights departing from EU28 and EFTA increased from 88 to 171 million tonnes (+95%) between 1990 and 2016 (Figure 1.9). In comparison, CO_2 emissions estimated with the IMPACT model reached 163 million tonnes (Mt) in 2017, which is 16% more than 2005 and 10% more than 2014. Over the same period, the average fuel burn per passenger kilometre flown for passenger aircraft, excluding business aviation, went down by 24%. This has reduced at an average rate of 2.8% per annum between 2014 and 2017.

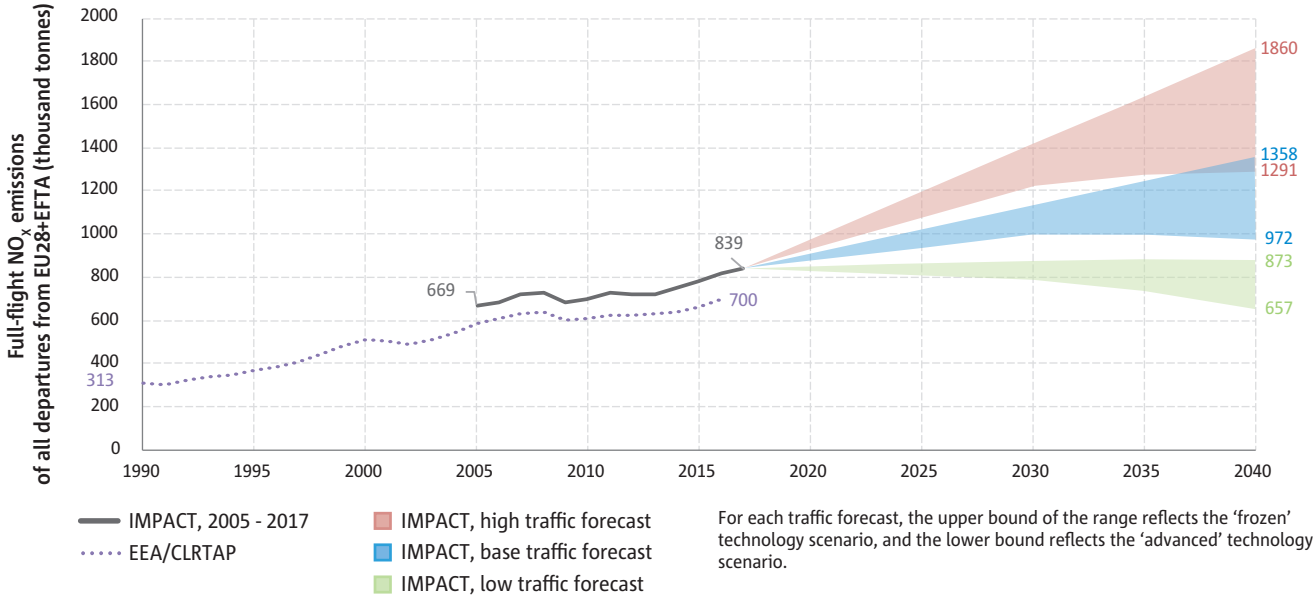
However, this efficiency gain was not sufficient to counterbalance the increase in CO_2 emitted due to the growth in the number of flights, aircraft size and flown distance. Future CO_2 emissions under the base traffic forecast and advanced technology scenario are expected to increase by a further 21% to reach 198 Mt in 2040. The annual purchase of allowances by aircraft operators under the EU Emissions Trading System (ETS) since 2013 resulted in a reduction of 27 Mt of net CO_2 emissions in 2017, which should rise to about 32 Mt by 2020.

Figure 1.9 CO_2 emissions are steadily increasing again since 2013



NO_x emissions have followed a steeper upwards trend than CO_2 in recent years (Figure 1.10). They increased from 313 to 700 thousand tonnes between 1990 and 2016 according to the Convention on Long-Range Transboundary Air Pollution (CLRTAP) data from the UN Economic Commission for Europe, and by 25% between 2005 and 2017 according to estimates from the IMPACT model. Unlike the CO_2 trend, current predictions indicate that the advanced engine NO_x technology scenario could lead to a downward trend after 2030. However, NO_x emissions would still reach around 1 million tonnes in 2040 under the base traffic forecast (+45% compared to 2005).

Figure 1.10 NO_x emissions will increase further, but advanced engine combustor technology could help curb their growth after 2030



Aviation emissions in context

In 2016, aviation was accountable for 3.6% of the total EU28 greenhouse gas emissions and for 13.4% of the emissions from transport, making aviation the second most important source of transport GHG emissions after road traffic [17]. Greenhouse gas emissions from aviation in the EU have more than doubled since 1990, when it accounted for 1.4% of total emissions. As emissions from non-transport sources decline, the emissions from aviation become increasingly significant [10]. European aviation represented 20% of global aviation's CO_2 emissions in 2015.

Aviation is also an important source of air pollutants, especially of nitrogen oxides (NO_X) and particulate matter (PM). In 2015, it accounted for 14% of all EU transport NO_X emissions, and for 7% of the total EU NO_X emissions. In absolute terms, NO_x emissions from aviation have doubled since 1990, and their relative share has quadrupled, as other economic sectors have achieved significant reductions. The carbon monoxide (CO) and oxides of sulphur (SO_X) emissions from aviation have also gone up since 1990, while these emissions from most other transport modes have fallen [18].

It should be noted that the aviation sector is not fully comparable to other sectors of the economy, as emissions reductions can be more difficult to achieve in aviation. This is partially due to the relatively long lifespan of aircraft, which could remain in operation for 25 years or more. Cap-and-trade systems, as well as offsetting schemes, allow to compensate emissions from aviation through reductions achieved more easily in other sectors. However, aviation will need to deliver more in-sector emissions reductions.

Due to fleet renewal, emissions of HC, CO and PM have been relatively stable between 2005 and 2014. However, PM emissions are expected to increase over the next twenty years if engine technology remains as it is today (Table 1.3).

Table 1.3 Summary of full-flight emission indicators based on IMPACT model

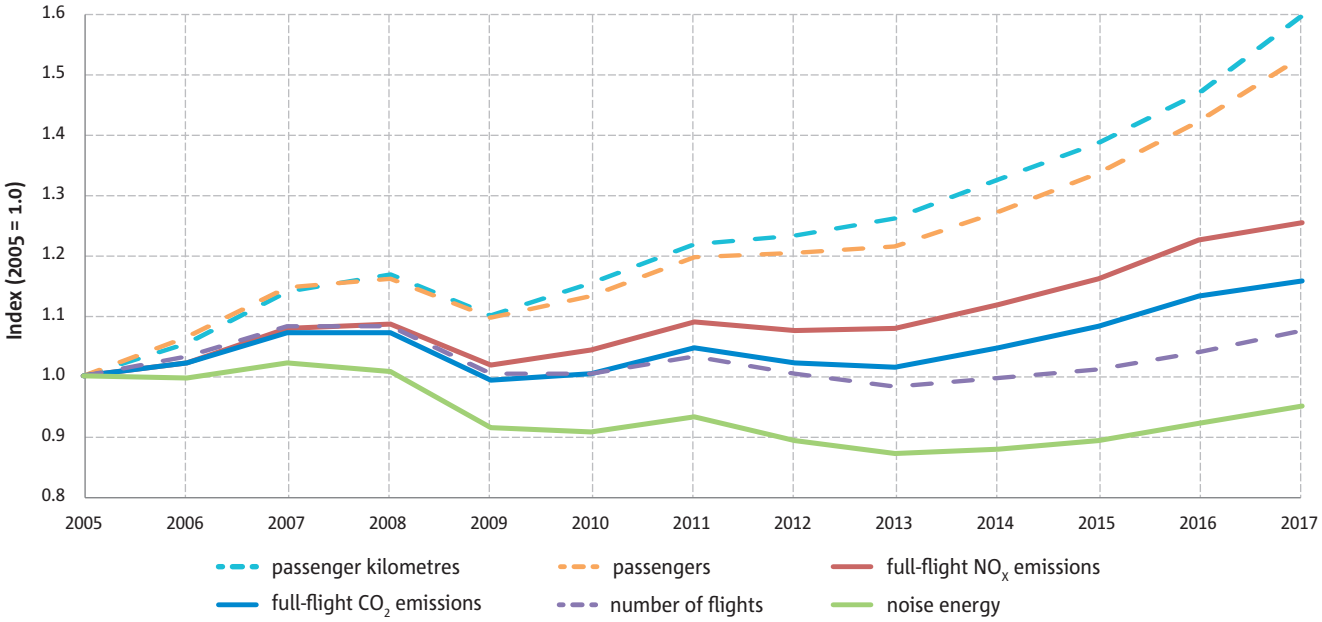
	Units	2005	2014	2017	2040 Base forecast	
					Advanced Tech	Frozen Tech
			(% change since 2005)			
Average fuel consumption of commercial flights	kg per passenger kilometre[1]	0.0355	0.0294	0.0270	0.0210	0.0238
	litres per 100 passenger kilometres[1]	4.4	3.7	3.4	2.6	3.0
			(-17%)	*(-24%)*	*(-41%)*	*(-33%)*
CO_2	million tonnes	141	148	163	198	224
			(+5%)	*(+16%)*	*(+40%)*	*(+59%)*
NO_x	thousand tonnes	669	749	839	972	1358
			(+12%)	*(+25%)*	*(+45%)*	*(+103%)*
HC	thousand tonnes	55	53	57	58	
			(-4%)	*(+3%)*	*(+6%)*	
CO	thousand tonnes	110	102	108	99	
			(-7%)	*(-2%)*	*(-9%)*	
volatile PM	thousand tonnes	126	123	136	157	
			(-3%)	*(+8%)*	*(+25%)*	
non-volatile PM	thousand tonnes	76	55	53	71	
			(-27%)	*(-30%)*	*(-5%)*	

1 Kilometres represent the actual flown distance between origin and destination

1.4 Combining indicators

Figure 1.11 presents the relative evolution of key air traffic and environmental indicators since 2005. This shows an increase in economic and connectivity benefits from aviation (measured in passenger kilometres flown) with a lower rate of increase in environmental impacts.

Figure 1.11 Noise and emissions grow slower than passenger kilometres but emissions grow faster than number of flights



Member State actions on climate change and noise

Climate change

In 2010, EU and EFTA States agreed to work through the International Civil Aviation Organization (ICAO) to achieve a global annual average fuel efficiency improvement of 2%, and to cap the global net carbon emissions of international aviation at 2020 levels. During 2012, Member States submitted Action Plans to the ICAO for the first time, outlining their respective policies and actions to limit or reduce the impact of aviation on the global climate. Updated and extended State action plans were subsequently provided in 2015 and 2018.

Noise

The EU Environmental Noise Directive [6] requires noise action plans to be drawn up by Member States addressing the main sources of noise, including aviation, with the aim of reducing the impact of noise upon populations. The first action plans were developed in 2008 and thereafter again in 2013 and 2018. Member States have identified a range of specific measures in their action plans to address noise from aviation-related sources. These include operational measures which reduce noise from aircraft operations (e.g. optimised flight procedures, airport night time flight restrictions, charges for noisier aircraft), and measures focused on reducing noise at the receiver (e.g. sound insulation of houses). Out of the 85 major airports in the EU (airports with more than 50,000 movements in 2011), approximately two thirds had adopted an action plan at the end of 2018.

European policy on noise

The European Union has a target in the 7th Environment Action Programme to significantly decrease noise pollution, moving closer to World Health Organization (WHO) recommended levels [3]. The Environmental Noise Directive (END) and Balanced Approach Regulation [4, 5, 6, 7, 8] are the overarching European Union (EU) legislative instruments under which environmental noise is monitored, communicated to the public and actions are taken. Member States are applying common criteria for noise mapping as well as developing and implementing local policies and action plans to reduce noise exposure in large cities and in the vicinity of major transport infrastructure.

European policy on emissions

Climate change. The EU plays a leading role in international efforts to limit climate change, and increased its climate finance contributions to €20.2 billion in 2016. This is backed up by a legally binding commitment and legal framework at EU level to reduce greenhouse gas emissions, increase the use of renewable energy and improve energy efficiency [9, 10, 11, 12]. These 'climate and energy' targets for 2020, which the EU is on track to meet, and 2030 are summarised below:

2020

- 20% cut in greenhouse gas emission (from 1990 levels)
- 20% of EU energy from renewables
- 20% improvement in energy efficiency

2030

- At least 40% cut in greenhouse gas emission (from 1990 levels)
- 32% of EU energy from renewables, with an upwards revision clause by 2023
- 32.5% improvement in energy efficiency, with an upwards revision clause by 2023

The EU has also agreed on a '2050 low carbon economy' roadmap that suggests the following targets:

- 60% cut in greenhouse gas emission by **2040** (from 1990 levels)
- 80% cut in greenhouse gas emission by **2050** (from 1990 levels), including a 60% reduction in transport emissions.

At the request of the European Council and the European Parliament, the European Commission presented its vision for long-term EU greenhouse gas emissions reductions in accordance with the Paris Agreement in November 2018, showing that decarbonisation is possible by 2050, including aviation.[3] The goal agreed under the Paris Agreement is to limit the global temperature increase to well below 2 degrees Celsius compared to pre-industrial levels, while pursuing efforts to limit the increase to 1.5 degrees. While this covers all man-made emissions, including aviation, measures to reduce these emissions are covered by the Nationally Determined Contributions under the Paris Agreement as well as global measures developed through the relevant international organizations, such as ICAO.

From an aviation perspective, the EU has invested approximately €5 billion over the last 10 years to support these commitments through various programmes (e.g. Clean Sky, SESAR, Life, Horizon 2020, Connecting Europe Facility) and a basket of measures (e.g. EU ETS, CORSIA, aeroplane CO_2 certification standard) that are summarised in the chapters of this report.

Air pollution. EU air pollution legislation follows a twin-track approach of implementing both local air quality standards [13, 14] 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 [15].

3 A Clean Planet for all: A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy.

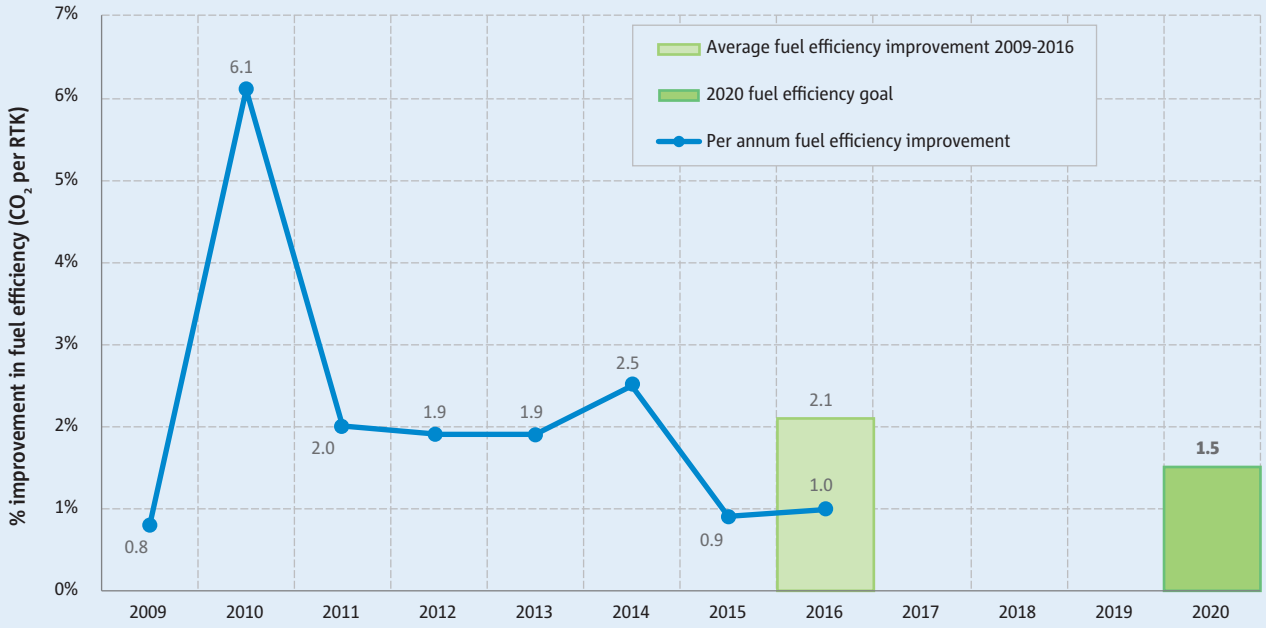
STAKEHOLDER ACTIONS

Industry goals and actions on climate change

In 2008 the global stakeholder associations of the aviation industry (Airports Council International, Civil Air Navigation Services Organization, International Air Transport Association and International Coordinating Council of Aerospace Industries Associations), under the umbrella of the Air Transport Action Group, committed to addressing the global challenge of climate change and adopted a set of ambitious targets to mitigate CO_2 emissions from air transport:

- A cap on net aviation CO_2 emissions from 2020 (carbon-neutral growth)
- A reduction in net aviation CO_2 emissions of 50% by 2050, relative to 2005 levels
- An average improvement in fuel efficiency (CO_2 per Revenue Tonne Kilometre) of 1.5% per year from 2009 to 2020.

Figure 1.12 Global commercial aviation fuel efficiency improvement (Source: IATA)



To achieve these targets, all stakeholders agreed to work closely together along a four-pillar strategy:

- Improved technology, including the deployment of sustainable low-carbon fuels
- More efficient aircraft operations
- Infrastructure improvements, including modernized air traffic management systems
- A single global market-based measure, to fill the remaining emissions gap.

2. TECHNOLOGY AND DESIGN

- **Recent certification data demonstrates that advanced technologies developed in the 2010-2015 period continue to be integrated into new designs since 2015.**
- **The average noise level of the twin-aisle aircraft category has significantly reduced since 2008 due the introduction of the Airbus A350 and Boeing 787.**
- **Supersonic aircraft, and other new technologies, need to be carefully integrated into the aviation system to avoid undermining progress in mitigating environmental impacts.**
- **Investment in novel technology is drawing on a wider pool of expertise and innovative approaches from other sectors, thereby creating new opportunities to address the environmental impacts from aviation.**
- **New aircraft noise standard became applicable on 1 January 2018.**
- **New aeroplane CO_2 and engine PM standards will become applicable on 1 January 2020.**

The growth in the aviation sector since the 1950s has delivered major benefits. However, there have been increasing concerns over the associated environmental impacts. Development of new aircraft technology, and its incorporation within advanced designs that are cleaner and quieter, is one of the key ways to mitigate the environmental impact from aviation.

The EU and EFTA have aircraft and engine environmental certification standards [19] which refer directly to the equivalent International Civil Aviation Organization (ICAO) standards [20, 21, 22]. ICAO's Committee on Aviation Environmental Protection (CAEP) is responsible for maintaining these standards, and an overview of the noise and emissions certification measurement procedures can be found in Appendix D.

This section of the report contains certified data for aircraft and their engines, which allows to compare the environmental performance of different products. Additional interactive graphs are available on the European Aviation Environmental Report website.

2.1 Aircraft noise

Jet and heavy[4] propeller-driven aircraft

These types of aircraft must comply with noise certification requirements and the associated noise limits referred to as Chapters 2, 3, 4, 5 and 14[5]. These Chapters represent the increasingly stringent standards that have been agreed over time.

Figure 2.1 illustrates the differences between the noise certification standards with noise contours for four hypothetical 75-tonne jet aircraft that just meet the various Chapter limits. The contours represent areas that are exposed to noise levels greater than 80 dB during one landing and take-off, and can be seen to reduce over time from the first Chapter 2 standard applicable before 1977 to the latest Chapter 14 standard applicable in 2018.

4 Maximum take-off mass is equal to or greater than 8,618 kg.
5 These are chapters of ICAO Annex 16 Volume I, a document that contains international aircraft noise standards.

Figure 2.1 Single landing and take-off 80 dB noise contours for four hypothetical aircraft that just meet the noise limits of the various ICAO Annex 16 Volume I Chapters

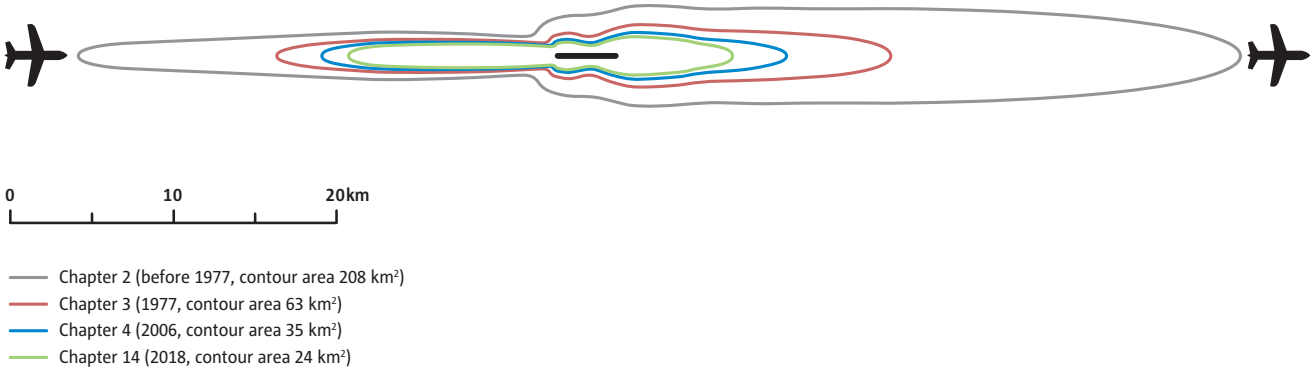


Figure 2.2 presents an overview of the improvement in aircraft noise technology-design performance over time in terms of the cumulative[6] margin to the Chapter 3 limits [23]. While recognising that aircraft are often sold in various configurations, Figure 2.2 only contains data for the heaviest weights and maximum engine thrust ratings. As the associated noise limits are higher for larger, heavier aircraft, this figure permits a comparison between the relative performance across a range of different aircraft types. The data has been reviewed, and new aircraft noise levels that have been certified by EASA during the 2016 to 2018 period have been added. Although these latest additions have a similar margin to aircraft from the period 2010 to 2015, they are still well below the applicable limit.

A view on future development goals that illustrate what the best technology could potentially achieve in 2020 and 2030, along with uncertainty bands, has been maintained in Figure 2.2. These are based on a review of noise technology by independent experts (IE) for the ICAO Committee on Aviation Environmental Protection that was performed between 2010 and 2013 [24]. The four categories cover most current jet aircraft families, except for the A380, which is added for information. An estimate is also provided for a small/medium range aircraft powered by two Counter-Rotating Open Rotor (CROR) engines which is expected to be able to just meet Chapter 14.

6 'Cumulative margin' is the figure expressed in EPNdB obtained by adding the individual margins (i.e. the differences between the certified noise level and the maximum permitted noise level) at each of the three reference noise measurement points in Chapter 3 of ICAO Annex 16, Volume I.

Figure 2.2 Improvement in aircraft noise performance has occurred over time

Aircraft categories as defined by ICAO/CAEP independent experts (IE)

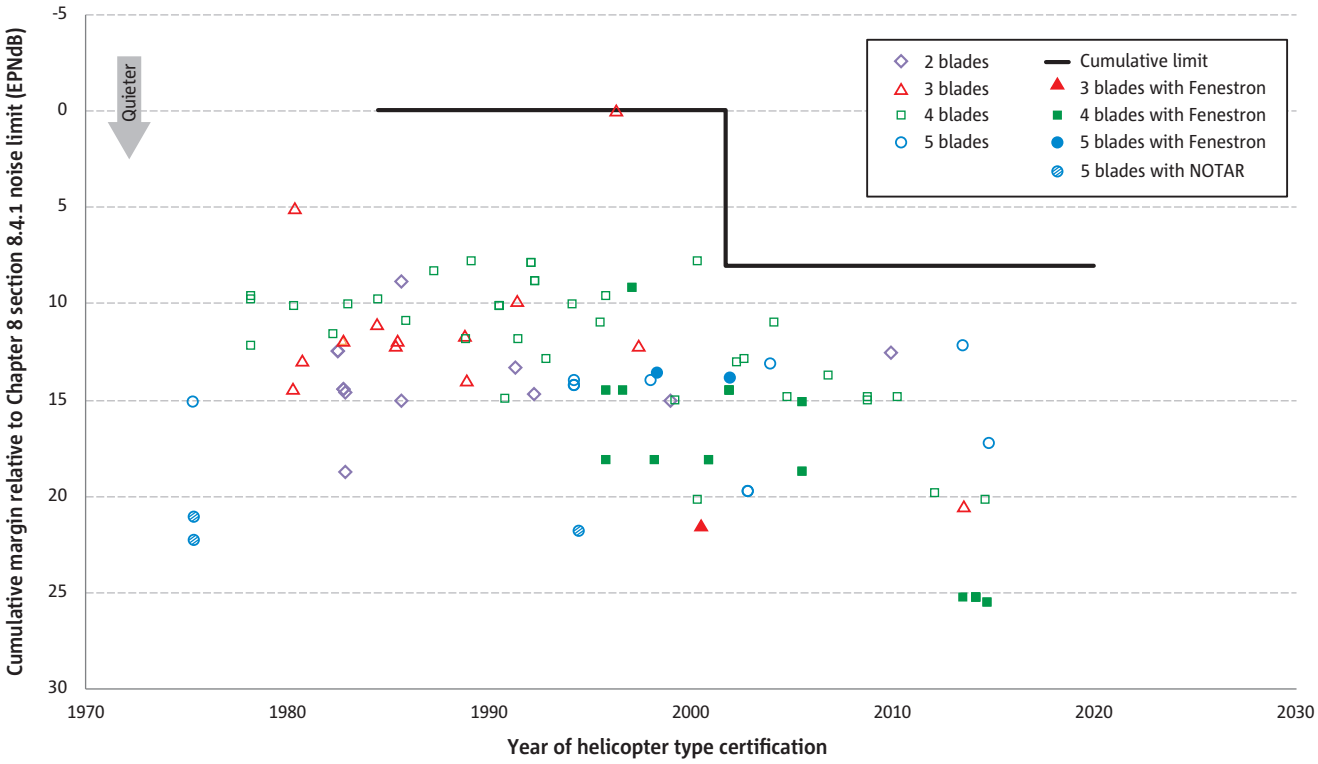
	Description	MTOW (tonnes)
RJ	Regional Jet	30 - 50
SMR2	Short/Medium Range 2-engine	58 - 98
CROR	Counter-Rotating Open Rotor	58 - 91
LR2	Long Range 2-engine	170 - 290
LR4	Long Range 4-engine	330 - 550

Airbus A380 plotted for information as outside weight range for LR4 (575 tonnes)

Helicopters

Heavy and light helicopters have to meet the noise standards of Chapters 8 and 11 respectively. Figure 2.3 illustrates the noise levels over time with respect to the cumulative margin relative to the original Chapter 8 limit [23]. The data has been categorized according to the number of main rotor blades and type of tail rotor configuration (e.g. no tail rotor - NOTAR, Fenestron), as these represent important design characteristics that influence noise levels. Note that no new technology has been certified since the previous report.

Figure 2.3 Some limited improvement in helicopter noise performance has occurred over time



Noise performance of the fleet registered in Europe

While previous sections look at certified data for specific products, this section presents information on the certified noise levels of aircraft that have actually been bought by airlines for use in operation. Figure 2.4 represents the average noise margin to the Chapter 3 limit for all aircraft built in a given year that have been registered in the EU or EFTA after 2000. In order to illustrate the trend of technology purchased over time, the data is plotted by build year and displayed in five categories as defined in Table 2.1.

Figure 2.4 Average cumulative noise margin to Chapter 3 for aircraft built in a given year and registered in EU28+EFTA after 2000

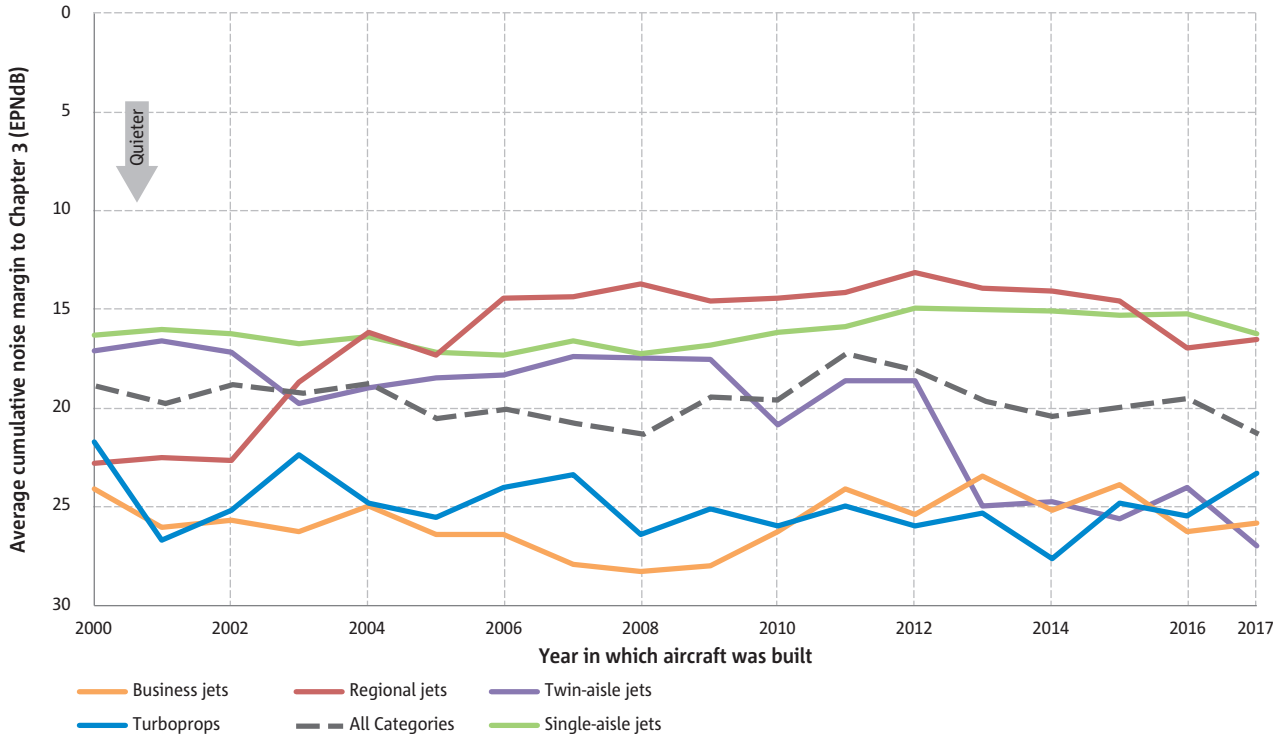


Table 2.1 Description of aircraft categories used in the analysis

Aircraft category	Definition	Examples of aircraft types
Twin-aisle jets	Large jet-powered aircraft for medium and long-range operations	Airbus A330; A340; A350; A380; Boeing 747; 757; 767; 777; 787
Single-aisle jets	Jet-powered aircraft intended for short to medium-range operations	Airbus A220; A319; A320; A321; Boeing 737-700; 737-800; 737-900
Regional jets	Jet-powered aircraft intended for short-range operations	Bombardier RJ700; RJ900; Embraer EMB145; ERJ-170; ERJ-190
Turboprops	Turboprop-powered aircraft (does not include small general aviation aircraft)	ATR 42; ATR 72; Bombardier DHC-8
Business jets	Small jet-powered aircraft with a seating capacity of 19 or less	Beech 400A; Cessna 525/650/750; Falcon 2000; Gulfstream 450/550

Figure 2.4 shows that the margin to the Chapter 3 limit actually decreases for regional jets, despite the general trend of improved aircraft type certification noise levels in Figure 2.2. This decrease in margin is primarily due to the market purchasing larger models and heavier weight variants (e.g. shifting from ERJ-145 to EMB-175 regional jets). The introduction of the Bombardier CS100 and CS300 aircraft in 2016, subsequently renamed the Airbus A220-100 and -300, appears to be responsible for the improved margin in that year. While the single-aisle trend has been relatively flat, the recent introduction of the re-engined Airbus A320neo and Boeing 737 MAX aircraft is expected to lead to future improvements in the margin. With respect to the twin-aisle category, the improvement in noise margin from 2008 is primarily associated with the introduction of the Boeing 787 and Airbus A350 aircraft types.

2.2 Aircraft engine NO_X emissions

Turbojet and turbofan engines

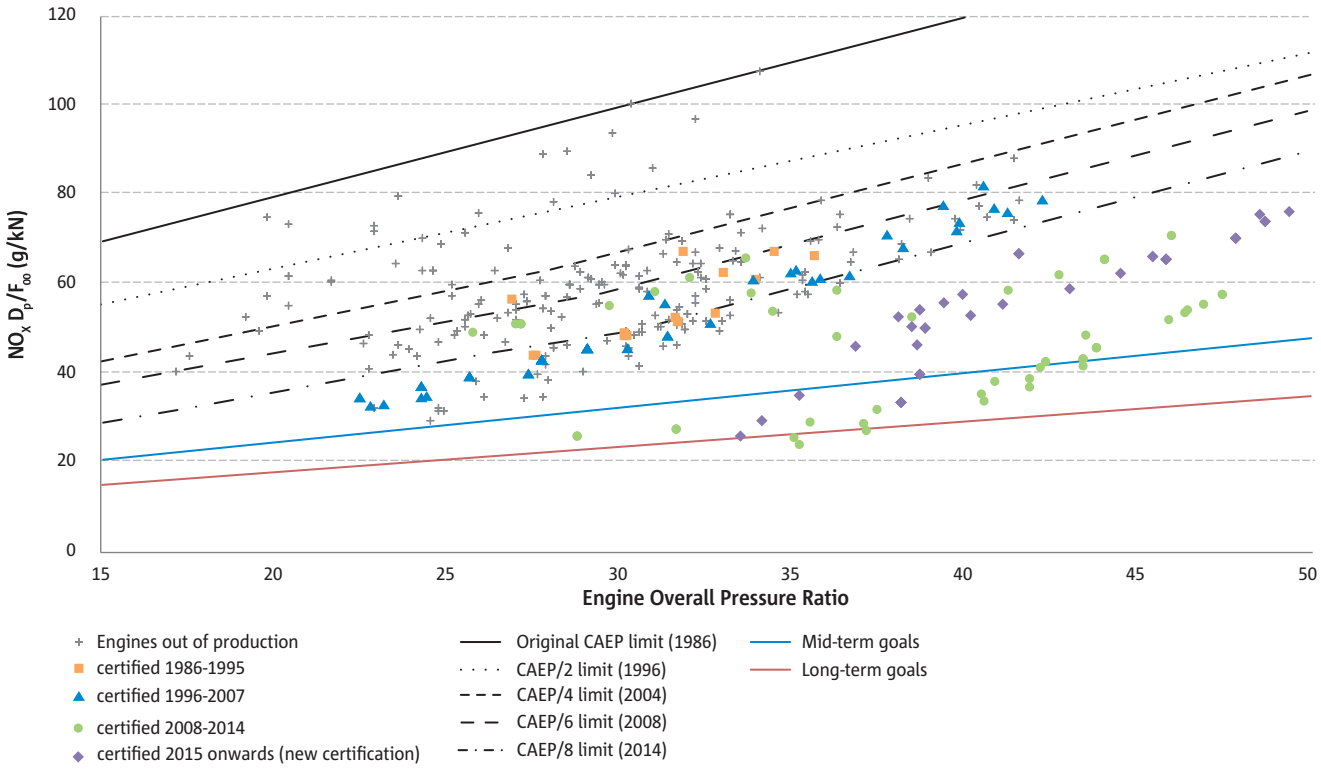
Engine technology has continuously evolved over the last 70 years, and reduction in fuel burn has always been a driving force behind this progress. More fuel efficient engine cycles, often made possible through the use of new materials, has led to increasing pressures and temperature within the combustor. Since this tends to increase the emissions of nitrogen oxides (NO_X), the control of these emissions through the combustor design is a significant challenge. The ICAO regulatory limits for engine NO_X emissions has been gradually tightened over time, and are usually referred to by the corresponding CAEP meeting number (CAEP/2, CAEP/4, CAEP/6 and CAEP/8). The engine NO_X standard, and the new aeroplane CO_2 standard, contribute in defining the design space for new products so as to address both air quality and climate change issues.

Figure 2.5 illustrates certified NO_X emissions data of aircraft engine models above 89 kN thrust in relation to the ICAO CAEP NO_X limits [25]. The regulatory NO_X limits are defined as the mass (D_p) of NO_X emitted during the Landing and Take-Off (LTO) test cycle and divided by the thrust of the engine (F_{00}). The limit also depends on the overall pressure ratio[7] of the engine. The current ICAO technology goals for NO_X are also shown. These goals, which were agreed in 2007, represent the expected performance of expected 'leading edge' technology in 2016 (mid-term) and 2026 (long term).

Each point in Figure 2.5 represents EASA certified data for an engine model, and the different colours provide insight into the trend over time. The dataset represents engine models typically fitted to single-aisle aircraft (e.g. A320, B737) and larger aircraft (e.g. A350, B777, A380). No further versions of the leading edge GEnx engines (lower green dots) have been certified since 2015. However, the most recent data (purple diamonds) illustrate that other manufacturers on different product development cycles have optimised new and existing combustor designs.

7 Ratio of total pressure at compressor exit compared to pressure at engine inlet.

Figure 2.5 Continued implementation of latest NO_x mitigation technology within certified engines



2.3 New standards

The latest global environmental standards were adopted by ICAO in 2017. These cover both aeroplane CO_2 emissions and aircraft engine non-volatile Particulate Matter (nvPM) mass concentration. EASA has subsequently supported the process to integrate these standards into European legislation [19], and will implement them as of the applicability date of 1 January 2020.

The CO_2 standard provides an additional requirement into the design process that increases the priority of fuel efficiency in the overall aeroplane design. It is an important step forward to address the growing CO_2 emissions from the aviation sector, and will contribute to the climate change mitigation objectives of the UNFCCC Paris Agreement [26].

The nvPM mass concentration standard is expected to ultimately replace the existing Smoke Number requirement. ICAO is also working on future standards for both nvPM mass and nvPM number, which are based on the emissions that occur during landing and take-off operations. These proposed standards will be discussed at the CAEP/11 meeting in 2019. If agreed, it is expected that they too will be implemented into the European legislative framework.

One of the substances considered to cause significant damage to the ozone layer is Halon. Additional measures for the protection of the ozone layer were adopted in 2008 under the Montreal Protocol. Consequently the European Commission and EASA are working with industry to conduct research that supports compliance with the on-going phase out of Halon in aircraft [27], while avoiding the risk of phasing in alternatives with high global warming potential.

2.4 Supersonic aircraft

Different types of new civil supersonic aircraft are currently under development, and may be in-service as early as the mid-2020s. The design process to develop and certify such aircraft faces various environmental challenges.

When an aircraft transitions through and flies faster than the speed of sound (Mach 1), the phenomenon of 'sonic boom' occurs. For this reason the Concorde was limited to subsonic speeds when flying over land and near coastlines. In recognition of this problem, the ICAO 39th Assembly adopted, in October 2016, an ICAO Resolution '*ensuring that no unacceptable situation for the public is created by sonic boom*'. A flight demonstrator is currently being built in the USA to research specifically shaped aircraft designs that may reduce the sonic boom, and to establish a noise dose-response relationship through community noise tests [28]. A European research study known as RUMBLE is also supporting the development of new regulations for low-level sonic booms [29].

Compared to subsonic aircraft, these supersonic aircraft will operate at higher cruise altitudes in the sensitive high troposphere and stratosphere (15-18 km altitude). Although future civil supersonic project aeroplanes will be more fuel-efficient than Concorde, their fuel burn is still expected to be higher in comparison with current subsonic aircraft of a similar size because drag increases with speed. Research also suggests that the climate change effects due to non-CO_2 emissions from supersonic aeroplanes, operating at significantly higher altitudes, could be considerably greater than the non-CO_2 effects from subsonic aeroplanes [30].

The noise and emissions produced from supersonic aircraft operations in and around airports is also a critical aspect. Engines optimised for supersonic operation typically have a trade-off between lower noise during take-off (high bypass ratio) and lower drag / higher fuel efficiency in supersonic cruise (low bypass ratio).

There are currently no noise or CO_2 certification requirements for supersonic aircraft in Europe, and the existing supersonic engine emissions standards are considered to be outdated according to ICAO guidance material. Europe is therefore actively working to update these standards.

2.5 New technology

The aviation industry is evolving into new areas, with existing and new start-up companies investing heavily in novel technology. In addition to recent developments of electric and hybrid engines, ideas to enhance urban mobility have also emerged including fully autonomous aircraft that can provide rapid point-to-point connectivity. New aircraft concepts and innovative types of operations have already applied for certification by EASA. These include the redesign of conventional aircraft as well as innovative electrical vertical take-off and landing (VTOL) aircraft. While the traditional noise certification procedure may be appropriate for the first category, drones and VTOL aircraft are more of a challenge. Based on an EASA Opinion, the European Commission is currently finalising proposals for noise requirements for drones that weigh less than 25 kg.

While these novel technologies bring new challenges, they also represent new opportunities to draw on a wider pool of expertise and innovative approaches from other non-aviation sectors to address the sector's environmental challenges. An in-depth life cycle analysis will be required to assess the environmental impacts of these new concepts in comparison to conventional aircraft. EASA is working closely with applicants to assess the environmental characteristics of these products, and put in place appropriate certification requirements. This will need to take into account new aircraft designs, required infrastructure and their operational characteristics which potentially brings aviation noise much closer to EU citizens [31].

Hybrid and electric aircraft

Various European companies, such as Pipistrel, are currently developing electric power plants for aircraft. The electricity can be generated through a variety of methods including batteries, solar cells, ultra-capacitors and fuel cells. In this case, the conventional engine is replaced by a hybrid or electric engine with similar performance. An evaluation of the conventional noise requirements and limits for these types of products will need to be performed.

Urban mobility - Air taxis and vertical take-off and landing (VTOL) aircraft

The number of active projects in this area has increased significantly over the last few years, such as Volocopter and Lilium. Different concepts have emerged with non-conventional designs. Specific studies of the design technologies, and operational procedures close to large populations, will need to be performed in order to identify appropriate noise certification requirements.

Drones

An Unmanned Aerial Vehicle (UAV), also known as a drone, is an aircraft without an onboard human pilot. UAVs are a component of an Unmanned Aircraft System (UAS) that includes a UAV, a ground-based controller and a system of communications between the two. There is a wide range of UAVs ranging from light and simple to heavy and complex aircraft, which operate with various degrees of autonomy and a diverse set of missions.

Clean Sky

The Clean Sky 2 initiative (2014-2024), part of the EU Horizon 2020 programme, is a Joint Undertaking of the European Commission and the European aeronautics industry [32]. It builds on the original Clean Sky 1 programme (2008-2017), and contributes towards achieving the 'Flightpath 2050' environmental objectives set out by the Advisory Council for Aviation Research in Europe [33]. Bringing together the aeronautics industry, small and medium sized enterprises, research centres and academia to drive forward innovative results, Clean Sky 2 also strengthens European aero-industry collaboration, global leadership and competitiveness. Clean Sky 2 has a total budget of €4 billion, and currently contains over 600 unique entities from 27 countries.

Clean Sky 1 envisioned technologies and procedures that would reduce CO_2 emissions per passenger kilometre by 75%, NO_X emissions by 90%, and perceived noise by 65% relative to the capabilities of a typical new aircraft in the year 2000. The objectives of Clean Sky 2 are to reduce CO_2, NO_X and noise emissions by 20 to 30% compared to "state-of-the-art" aircraft entering into service as from 2014.

Clean Sky 2 expects to develop innovative, cutting-edge technologies for more aerodynamic wings, advanced and lighter structures, more efficient engines including the emerging field of hybridization and electrification, advanced control, actuation and guidance systems (including increased digitization), brand-new aircraft configurations, and a more sustainable aircraft lifecycle. The scope of the programme includes large, regional, and commuter aircraft, and rotorcraft.

The Programme aims to accelerate the introduction of new technology in the 2025-2035 timeframe. By 2050, 75% of the world's fleet now in service (or on order) will be replaced by aircraft that can deploy Clean Sky 2 technologies. The direct economic benefits are estimated at €350-€400 billion and the associated indirect benefits of the order of €400 billion. Clean Sky 2 technologies are expected to bring a potential saving of 4 billion tonnes of CO_2 between 2025 and 2050. This is in addition to approximately 3 billion tonnes of CO_2 emissions savings that Clean Sky 1 should deliver [34].

STAKEHOLDER ACTIONS

AeroSpace and Defence Industries Association of Europe (ASD)

ASD is the European Aeronautics, Space, Defense and Security Industries with 16 major European companies and 24 national associations from 18 countries. In 2016, 843,500 people were employed by more than 3,000 companies generating a turnover of €220 billion. European Member States and ASD are working together, primarily through the Clean Sky 2 programme, to address aviation environmental challenges. An overview of some of these research projects is provided below.

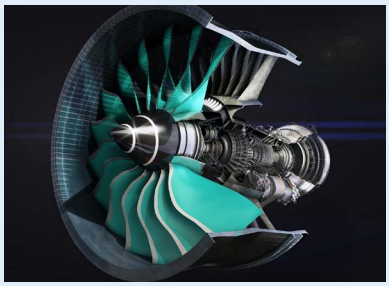
1. Hybrid-Electric E-Fan X

The Airbus, Rolls-Royce and Siemens 'E-Fan X' hybrid-electric technology demonstrator is anticipated to fly in 2020 following a comprehensive ground test campaign, provisionally on a BAe 146 flying testbed with one of the aircraft's four gas turbine engines replaced by a two megawatt electric motor. These types of propulsion systems are among the most promising technologies for reducing aviation's dependence on fossil fuels.

2. Sage2 Counter-Rotating Open Rotor (CROR)
In 2017, the Sage2 CROR successfully demonstrated new technologies including composite propeller blades, pitch control system, contra rotating reduction gearbox and aero acoustic optimization at the Safran test facility. This full scale demonstration confirmed the technical feasibility of a CROR, the expectation of significant fuel burn improvements (-30% vs year 2000) and the capability to satisfy the current ICAO Chapter 14 noise requirements.

3. Laminar wing demonstrator (BLADE)
The Airbus A340 laminar-flow Flight Lab test demonstrator aircraft has been engaged in successful testing to explore the wing's characteristics in flight since 2017. The test aircraft is the first in the world to combine a transonic laminar wing profile with a true internal primary structure. BLADE has been running since 2008 with 20 key partners and 500 contributors from all over Europe. It is tasked with assessing the feasibility of introducing laminar flow wing technology that aims to reduce aircraft drag by 10% and CO_2 emissions by up to 5%.

4. Ultrafan
Rolls-Royce is developing a new civil aviation propulsion architecture that allows the fan and the turbine to be independently optimized by introduction of a power gearbox capable of operating at anything up to 100,000 HP to deliver greatly improved propulsive efficiency. This architecture will be proven through a programme of engine demonstrators that will culminate in a flying test bed. It will deliver 25% improvement in fuel efficiency compared to the first Trent engines and is being designed to meet potential noise and emissions stringency levels for aircraft entering service before 2030.



5. Additive 3D manufacturing
This new technique for building aerospace parts involves adding material, layer upon layer, in precise geometric shapes. This enables complex components to be produced directly from computer-aided design information. It allows quicker and more flexible production, and reduces material waste compared to traditional approaches such as milling. It also results in much lighter parts which reduces aircraft weight and consequently fuel burn. 3D-printed parts are already flying on Airbus A320neo and A350 XWB test aircraft (e.g. cabin brackets, bleed pipes, combustor fuel nozzles on the CFM LEAP engine).

6. Electric green taxiing system
This system, jointly developed by Safran and Airbus, enables aircraft to pushback and taxi at airports without having to use their main engines or call upon airport towing services. Two of the main landing gear's wheels are equipped with an electric motor powered by the aircraft's auxiliary power unit. It improves both economic and operational efficiency, with up to 4% fuel savings on a short to medium range mission compared to current dual-engine taxi operation, plus reductions of other pollutants and noise. The on-going development of a hydrogen fuel cell to power the electric motor will further reduce the environmental impact of aircraft ground operations.

7. Circular economy
Advanced manufacturing capability is at the heart of the aerospace sector, which relies on essential skills to optimize resources and processes. European aviation has also been at the forefront of developing capabilities and processes for end-of-life aircraft dismantling and recycling of parts. TARMAC AEROSAVE, a jointly owned company of Airbus, Safran and Suez, has recycled over 135 aircraft since it was established in 2007. Today, 92% of the total weight of an aircraft is recycled.

3. SUSTAINABLE AVIATION FUELS

- **The use of sustainable aviation fuel is currently minimal and is likely to remain limited in the short term.**
- **Sustainable aviation fuels have the potential to make an important contribution to mitigating the current and expected future environmental impacts of aviation.**
- **There is interest in 'electrofuels', which potentially constitute zero-emission alternative fuels. However, few demonstrator projects have been brought forward due to high production costs.**
- **Fuels must be certified in order to be used in commercial flights. Six bio-based aviation fuels production pathways have been certified, and several others are in the approval process.**
- **The EU has the potential to increase its bio-based aviation fuel production capacity, but the uptake by airlines remains limited due to various factors, including the cost relative to conventional aviation fuel and low priority in most national bioenergy policies.**
- **Regular flights using blends of bio-based aviation fuel are already being performed from several airports in the EU, albeit at very low percentages of the total fuel uplift.**
- **Recent policy developments and industry initiatives aim to have a positive impact on the uptake of sustainable aviation fuels in Europe.**

3.1 Background

Over the past decades, significant technological developments have taken place in most areas of the aviation sector, except for the fossil-based fuel used by aircraft, which has remained relatively unchanged. Although alternative clean propulsion technologies are under development - such as electric-powered aircraft or cryogenic hydrogen fuel - these options are unlikely to be commercially ready before 2030 [35]. The last decade has seen considerable progress in developing Sustainable Aviation Fuels (SAFs) produced from bio-based feedstocks that have a lower carbon intensity, and which consequently could play an important role in mitigating the environmental impact of aviation.

Bio-based aviation fuels are obtained from sources other than petroleum, such as woody biomass, hydrogenated fats and oils, recycled waste or other renewable sources. In order for these fuels to be used in aircraft operations, they must have 'drop-in' characteristics, which means they have to meet strict fuel specifications and have comparable behaviour to fossil fuel during the *combustion* process. As such, the emissions reductions are achieved in their *production* process. These bio-based aviation fuels can be mixed with conventional fossil-based aviation fuel at a blending ratio that is dependent on how the fuel is produced.

There is not a single internationally agreed definition of SAF. The definitions used can cover a wide set of criteria including not only a reduction in greenhouse gas (GHG) emissions, but also other environmental and social aspects such as biodiversity, land use (forests, wetlands, peatlands), water, labour standards applied in production processes and support to the social and economic development of communities involved in fuel production. For the purposes of this chapter, SAFs are defined as bio-based aviation fuels that reduce GHG emissions relative to conventional aviation fuel, while avoiding other adverse sustainability impacts.

Significant interest exists also for non-bio-based feedstocks, in particular the so-called drop-in Power-to-Liquids 'electrofuels' [36]. This pathway allows the production of a synthetic alternative fuel to fossil kerosene through the use of renewable electricity to produce hydrogen from water by electrolysis and a combination with carbon from CO_2 (ideally captured from the air). The Power-to-Liquid process can present a favourable greenhouse gas balance relative to conventional and bio-based aviation fuel streams with close to zero emissions [37]. As of today, electrofuels are a technically viable solution to help decarbonise the aviation sector. However, few demonstrator projects are being brought forward due to the fact that electrofuels are 3 to 6 times more expensive than kerosene [38]. According to one

study, using electrofuels to meet the expected remaining fuel demand for aviation in 2050 would require 95% of the electricity currently generated using renewables in Europe [39].

3.2 Bio-based aviation fuels

Production pathways

The American Society for Testing and Materials (ASTM) International has developed standards [40, 41] to approve new bio-based aviation fuels, and currently six production pathways have been certified for blending with conventional aviation fuel. These include:

- **FT-SPK** (Fischer-Tropsch Synthetic Paraffinic Kerosene). Biomass is converted to synthetic gas and then into bio-based aviation fuel. Maximum blending ratio is 50%.
- **FT-SPK/A** is a variation of FT-SPK, where alkylation of light aromatics creates a hydrocarbon blend that includes aromatic compounds. Maximum blending ratio is 50%.
- **HEFA** (Hydroprocessed Fatty Acid Esters and Free Fatty Acid). Lipid feedstocks, such as vegetable oils, used cooking oils, tallow, etc. are converted using hydrogen into green diesel, and this can be further separated to obtain bio-based aviation fuel. Maximum blending ratio is 50%.
- **HFS-SIP** (Hydroprocessing of Fermented Sugars - Synthetic Iso-Paraffinic kerosene). Using modified yeasts, sugars are converted to hydrocarbons. Maximum blending ratio is 10%.
- **ATJ-SPK** (Alcohol-to-Jet Synthetic Paraffinic Kerosene). Dehydration, oligomerization and hydroprocessing are used to convert alcohols, such as iso-butanol, into hydrocarbon. Maximum blending ratio is 50%.
- **Co-processing**[8]**.** Biocrude up to 5% by volume of lipidic feedstock in petroleum refinery processes.

Additional pathways are currently in the ASTM certification process.

Defining the maturity level of the available bio-based aviation fuel production pathways, either from a technological or from a commercial point of view, is challenging. Despite the dynamism of the sector, only a few of the ASTM certified pathways are supplying fuel on a commercial scale. The technological maturity of each production pathway can be defined through a Technology Readiness Level - TRL [42], which ranges from 1 for basic ideas, to 9 for an actual system proven in an operational environment. Alongside the technology readiness, the commercial development of a certain fuel could be different due to various other drivers (e.g. certification issues, costs issues). To better clarify the progress of a specific fuel production pathway towards full commercialisation, the US Commercial Aviation Alternative Fuels Initiative has developed the Fuel Readiness Level (FRL) system, which has been endorsed by ICAO [43]. FRL also ranges from 1 for basic ideas to 9 for production capability established, but is tailored for approval of aviation fuel international standards.

8 This pathway has been approved in April 2018 and added to Annex A1 of ASTM D1655, Standard Specification for Aviation Turbine Fuels.

Table 3.1 TRL and FRL of the six production pathways certified by ASTM for use in commercial flights [44, 45, 46]

Process		Technology Readiness Level (TRL)	Fuel Readiness Level (FRL)
Fischer-Tropsch Synthetic Paraffinic Kerosene	*FT-SPK*	6-8	7
Fischer-Tropsch Synthetic Paraffinic Kerosene with Aromatics	*FT-SPK/A*	6-7	7
Hydroprocessed Fatty Acid Esters and Free Fatty Acid	*HEFA*	9	9
Hydroprocessing of Fermented Sugars - Synthetic Iso-Paraffinic kerosene	*HFS-SIP*	7-8	5-7
Alcohol-to-Jet Synthetic Paraffinic Kerosene	*ATJ-SPK*	6-7	7
Co-processing biocrude up to 5% by volume of lipidic feedstock in petroleum refinery processes	*Co-processing*	7-8	6-7

Production capacity

Europe is today a key player in the wider biofuel production technology sector, with several commercial-size plants currently in operation. The production capacity of bio-based aviation fuel in the EU relies on a small number of plants, accounting for a maximum potential output of approximately 2.3 million tonnes per year (Max-EU scenario[9]), which potentially corresponds to about 4% of the total EU conventional fossil aviation fuel demand. **It is important to note the distinction between potential bio-based aviation fuel production capacity that is discussed in this section, and the consumption of such fuels discussed in the next section, as several barriers are currently limiting market uptake.**

The largest potential share of EU bio-based aviation fuel relies on the processes able to convert various feedstocks and residues into a fuel suitable for commercial flights. The most developed process to date produces Hydroprocessed Fatty Acid Esters and Free Fatty Acid (HEFA). In this process, vegetable oils and/or animal lipid feedstocks can be used to produce a fully certified bio-based alternative to fossil-based aviation fuel. The certified HEFA is a portion of the Hydrotreated Vegetable Oil (HVO) product, which is currently used within the road sector. A pathway that would allow the use of a greater share of the HVO production, thereby increasing the EU production potential, is currently being certified (HEFA expansion or HEFA+).

Refineries producing biomass derived SAF can tune their process in order to increase the output for aviation, if demand increases (Max-EU scenario). However, in view of the relatively low profitability of producing aviation fuel and road fuels, it is reasonable to assume that the actual bio-based aviation portion from the HEFA process would account for a lower share of the processing plant output than the theoretical maximum. A share of 15% has been assumed in defining a moderate bio-based aviation fuel scenario (Mod-J scenario), which results in an estimate of the current EU potential bio-based aviation fuel output equal to 0.355 million tonnes per year (Table 3.2).

The current potential production capacity is substantially based on HEFA plants, but may increase by 2020 with the announcement of new facilities and the scaling-up of existing facilities within the EU. Moreover, the recently certified co-processing pathway may unlock a larger potential production capacity. However, significant investments into the other ASTM-certified pathways (e.g. ATJ and SIP) do not seem to be a priority at the moment for major industrial players in Europe, even if new actors are expected to become active in the market after 2020 and contribute to the growth in the moderate bio-based aviation fuel scenario.

9 The information provided in this section is based on the European Commission Directorate General Joint Research Centre (DG JRC) database on the European biofuels production plants [Prussi et al., 2019 – In press].

Table 3.2 Estimated EU bio-based aviation fuel potential production capacity (million tonnes per year)

Year	Max-EU scenario	Mod-J scenario
2017	2.32	0.355
2020	3.32	0.525
2025	3.50	0.550

Max-EU: Overall EU potential based on the full capacity of HVO plants plus other technologies today producing SAF.
Mod-J: Moderate bio-based aviation fuel scenario (15% share of bio kerosene from HVO plants).

Price and consumption

The price of bio-based aviation fuel relative to fossil-based kerosene is one of the major barriers to its greater market penetration. Today the feedstock price represents the major component of the final bio-based aviation fuel price, and its price volatility on the EU market can also create supply problems for fuel producers. While a typical price for fossil-based aviation fuel would be €600/tonne, the price of bio-based aviation fuel produced from used cooking oil can be in the range of €950-€1,015/tonne. In addition, feedstocks that comply with sustainability requirements, such as used cooking oil and tallow used in the HEFA process, are in demand by the road fuel sector for biodiesel and green diesel production. It is expected that this competition between road and aviation will further increase in the coming years.

There are various on-going initiatives at the European level aimed at increasing the market penetration of bio-based aviation fuels. However, despite the presence of these initiatives, the current consumption in Europe is very low when compared to the potential production capacity. Only Germany reported the use of bio-based aviation fuels as part of the official 2016 figures under the framework of the Emissions Trading Directive.

3.3 Sustainable Aviation Fuels

What is a Sustainable Aviation Fuel?

In order for a bio-based aviation fuel to be considered a SAF, it has to meet sustainability criteria. At present, there is currently not a single definition of SAFs agreed at the international level. In the European regulatory framework, sustainability is defined in the Renewable Energy Directive (RED) EC/2009/28. The Council and European Parliament have recently agreed on a revision of the RED, which sets new ambitious targets and includes revised sustainability criteria [47]. Table 3.3 provides an overview of the sustainability criteria agreed for the revised RED. At international level, discussions are ongoing to agree on criteria to assess the sustainability of aviation fuels, which would be eligible for the purposes of ICAO's CORSIA scheme (see Market-Based Measures chapter).

Table 3.3 Sustainability criteria in regulatory frameworks

Scheme	Sustainability criteria
EU RED Recast (2018)	*GHG reductions* – Greenhouse gas emissions from biofuels must be lower than from the fossil fuels they replace: at least 50% for installations older than 5 October 2015, 60% for installations after that date and 65% for biofuels produced in installations starting operation after 2021. *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 and can be covered by certification schemes on a voluntary basis.
Future 'CORSIA'	Sustainability criteria under approval at ICAO[1]

1 The EAER website will provide an update on the CORSIA SAF sustainability criteria as soon as they are officially approved at ICAO level.

Reduction in greenhouse gas emissions

Bio-based aviation fuels may have lower GHG emissions in comparison with traditional fossil fuels. Indeed, the emissions from biofuel combustion are often considered as being zero, given that the fuels are produced from biomass. These are referred to as 'biogenic emissions', and they are assumed to be zero on the basis that the growth of the biomass absorbs the same amount of CO_2 released during combustion. Conversely, 'non-biogenic emissions' are used to refer to production emissions from bio-based aviation fuels, resulting from the cultivation, harvesting and transport of the biomass, as well as from its conversion into fuel. These 'non-biogenic emissions' are not offset, and consequently constitute a direct impact of the bio-based aviation fuels. The difference between the 'non-biogenic emissions' of the bio-based aviation fuel, and the emissions from using a standard fossil derived fuel, constitutes the potential bio-based aviation fuel GHG saving.

There is ongoing discussion about the most appropriate methodology to assess the emissions reduction performance of the different pathways through a Life-Cycle Assessment. This is particularly relevant for those pathways that are currently entering the market. In many processes more than one product is produced, and it is necessary to divide the GHG impacts between these products. There is also much debate about how to account for indirect emissions such as cultivation emissions closely related to the farming practices and soil types (i.e. forest dynamic) [48]. Depending on these indirect effects, the emissions of a bio-based aviation fuel as compared to the emissions from the production and combustion of conventional aviation fuel can be lower, comparable or even higher.

Induced indirect effects of Sustainable Aviation Fuel production and use

The environmental benefit of using bio-based aviation fuel can be significantly reduced by induced indirect effects related to their production. The best known indirect effect relates to the impact on land use. Biomass production typically takes place on cropland that was previously used for other agriculture such as growing food or feed. Since this agricultural production is still necessary, it may be, at least partly, displaced to previously non-cropland such as grasslands and forests. This process is known as indirect land use change.

Another widely accepted indirect effect relates to the competition with food and feed production, when agricultural feedstocks are used. An example is the use of rapeseed oil as feedstock for producing bio-based aviation fuel, which by increasing the demand for rapeseed oil can contribute to increasing its price on the food and feed markets.

One option to limit these induced indirect effects is to use waste materials as feedstock. Recycled household waste (Municipal Solid Wastes) is a good example, as today the non-recycled part is mainly sent to landfill or is incinerated. However, it is not always easy to define a production stream as 'waste', as other industrial sectors may already be using this by-product for other purposes. This is the case with sugar molasses, which are processed and reused for the production of animal feed. If residual molasses are used to produce bio-based aviation fuel, and the feed industry increases its demand for low cost sugar sources, this would generate again a land use change effect.

The European Commission's Joint Research Centre is actively contributing to on-going discussion on the quantification of GHG emissions reduction potential from bio-based aviation fuels. While the GHG emissions from the production of HEFA based on feedstocks such as sunflower and soybean oils can be estimated at around 40 gCO_2eq/MJ, the same HEFA process fed by rapeseed oil is estimated to result in higher GHG emissions, of around 51 gCO_2eq/MJ due to differences in production chains. In order to calculate the potential GHG reductions from bio-based aviation fuel, it is worth noting that ICAO have defined a reference level of GHG emissions from a fossil-based aviation fuel as 89 gCO_2eq/MJ. Table 3.4 provides an overview of direct emissions savings for a variety of bio-based aviation fuel pathways.

Table 3.4 Greenhouse gas emission savings (excluding carbon emissions from land use change)

Conversion technology	Fuel feedstock	% direct emissions savings compared to fossil-based aviation fuel baseline of 89 gCO_2eq/MJ
Fischer-Tropsch (FT)	Agricultural residues	89-94%*
	Forestry residues	88%
	Municipal Solid Waste (MSW)	68%
	Short-rotation woody crops	81%
	Herbaceous energy crops	87%
Hydroprocessed esters and fatty acids (HEFA)	Tallow	78%
	Used cooking oil	85%
	Palm fatty acid distillate	76%
	Soybean	53%
	Rapeseed/Canola	48%
	Camelina	54%
	Palm oil - closed pond	61%
	Palm oil - open pond	29%
Synthesized iso-paraffins (SIP)	Sugarcane	62%
	Sugarbeet	68%
Alcohol (iso-butanol) to jet (ATJ)	Agricultural residues	71%
	Forestry residues	74%
	Sugarcane	69%
	Corn grain	54%
	Herbaceous energy crops (switchgrass)	66%
	Molasses	69%
Alcohol (ethanol) to jet (ATJ)	Sugarcane	69%
	Corn grain	26%

*More than one feedstock considered

3.4 Policy actions

European Union

The EU sees an important role for SAF in contributing to reduce the environmental impact of aviation. This is why it is taking action in a number of areas to support a greater uptake of SAF within the European market, including research within the 'Horizon 2020' programme that supports the development and pre-commercial production of SAF. From 2013 to 2020, a total budget of €464 million is available to study advanced biofuels and other renewable sources, of which €25 million has been specifically allocated to SAF.

The Renewable Energy Directive (RED), which was adopted in 2009, established an overall policy framework for the production and promotion of energy from renewable sources in the EU. The RED requires all EU countries to ensure that at least 10% of their transport energy comes from renewable sources by 2020. The RED also includes multipliers which count the contribution of biofuels by a factor greater than 1 in order to encourage the use of advanced biofuels and meet future targets, while capping the contribution of bio-based fuels derived from food/feed-competing crops. The RED targets do not apply to aviation fuel. However, in 2015, the RED was amended [49] to recognise the possibility of a so-called 'voluntary aviation opt-in' to implement in national legislation, which was taken up by the Netherlands[10] and the UK.

An agreement has recently been reached on an update to the RED that now requires fuel suppliers to ensure that at least 14% of energy used in the EU transport sector comes from renewable sources by 2030. Under this revision, SAF can contribute to the achievement of the RED targets in all Member States, on condition that they comply with the associated sustainability criteria. In addition, a specific multiplier of 1.2 is to be applied to the quantity of SAF supplied, in calculating its contribution towards the renewable energy targets. The contribution of bio-based fuels from food or feed crops to the targets in each Member State will be capped at around its level in 2020. The contribution of any high-indirect land use change risk food or feed crop-based biofuels, produced from food or feed crops for which a significant expansion of the production area into land with high carbon stock is observed, towards the targets in each Member State will be capped at the 2019 level of consumption of such fuels until 2023, after which their contribution will gradually be reduced to 0% by 2030 at the latest. Biofuels certified as low indirect land use change risk will be excluded from this limit.

The EU Emissions Trading System (EU ETS) provides an incentive to aircraft operators to use SAF that comply with the sustainability criteria defined in the RED by attributing them zero emissions under the scheme. The use of SAF thereby reduces an aircraft operator's reported emissions, and the number of ETS allowances it has to purchase. This provides a financial incentive for aircraft operators to use SAF instead of conventional aviation fuels.

The European Advanced Biofuels Flightpath was launched in 2011 as a partnership between the European Commission and major European stakeholders, with the aim to accelerate the speed at which SAF are brought to market. It is clear that the goal previously set by the group for 2 million tonnes of SAF to be produced annually by 2020 will not be met. The European Advanced Biofuels Flightpath is working on an updated roadmap towards 2030.

Global level

The UN International Civil Aviation Organization (ICAO) recognises SAF as an important element in reducing GHG emissions from aviation. Following ICAO's 39th Assembly in 2016, Resolution A39-2 requested Member States to put in place coordinated policy actions to accelerate the development, deployment and use of SAF. The second ICAO Conference on Aviation and Alternative Fuels in 2017 subsequently adopted a 2050 Vision for SAFs that called on States and all stakeholders to ensure that a significant proportion of fossil-based aviation fuels be substituted with SAF by 2050. Quantified targets are to be agreed at the next conference due to take place by 2025.

ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) will be implemented as of 2021, and will allow aircraft operators to reduce their offsetting obligations by using SAFs and fossil-based 'lower carbon aviation fuels'. These fuels must comply with sustainability criteria, which as noted in section 3.3 are still the subject of ongoing discussions. The extent to which SAF eligible under CORSIA will make a positive contribution to mitigating the environmental impacts of international aviation will depend on the sustainability criteria for their eligibility. ICAO has

10 The Netherlands had allowed the use of SAF to contribute to fulfilling the RED targets since 2013.

not yet adopted these. The reduction in offsetting requirements that can be claimed is equal to the emissions reductions calculated for the specific fuel used. This is based on the difference between the baseline life cycle emissions of 89 gCO_2eq/MJ and the calculated life cycle emissions of the specific bio-based fuel. Work is still on-going to quantify induced land use change reference values that will be used to calculate the total life cycle emissions of the fuels.

3.5 Looking to the future

There is broad agreement that SAFs have a potentially important role to play in reducing the environmental impact of European aviation, and in reducing the sector's exposure to crude oil price volatility.

The current consumption of SAF remains very low in Europe. However, recent developments, including policy actions at the EU and global level, are intended to create incentives to increase the uptake of SAF in Europe. Nevertheless, the uptake of SAF is likely to remain limited to below 1% of total EU aviation fuel consumption in the near future, and its evolution in the mid/long term within the European market is still difficult to predict.

Fry to Fly!

Eating French fries when you are waiting for your flight at the gate may not be good for your health, but it may be good for reducing the environmental impact of your trip as the recycled oil used for cooking is an excellent feedstock for producing SAF through the HVO/HEFA pathway. Recovering used cooking oil (UCO) is also important as its inappropriate disposal can result in harmful environmental effects. The current collectable volume of UCO within Europe from both restaurants and households theoretically allows a SAF production of about 1 million tonnes per year [50], which is about 2% of the current annual aviation fuel use in EU28+EFTA.

STAKEHOLDER ACTIONS

1. Airport initiatives on SAF
During 2016 and 2017 Avinor's Oslo and Bergen airports became the first in the world to offer SAF to all airlines on a commercial basis, and a total of 1.325 million litres of SAF was uplifted. The bio-based SAF consumption at Swedavia airports in 2016 was 450 tonnes, and currently new SAF initiatives are planned from 2018 onward. Other initiatives include the French 'Green Deal', and the 'Fly Green Fund' that is offering travellers the opportunity to contribute to the extra-cost associated with using SAF. The Fly Green Fund has a supply contract with SkyNRG, which in turn sources SAF from AltAir in the USA.

2. IAG Sustainable Aviation Fuels - Turning waste into fuel
IAG is part of a project with UK renewable fuels specialist Velocys to produce aviation fuel from household waste which will then be supplied to British Airways. Production should start in 2022, making it one of the first plants in the world dedicated to producing bio-based aviation fuel on a commercial scale. Ultimately, IAG hopes biofuels could provide up to 25% of its fuel by 2050. The fuel emits 60% less greenhouse gases and 90% fewer particulates than fossil fuels, and the planned plant will produce around 30,000 tonnes a year – delivering CO_2 savings of some 60,000 tonnes annually.

Recent changes to the UK Renewable Transport Fuel Obligation, which sets targets for sustainable fuel use in transport, means the new fuel will qualify for government incentives to help develop the technology. The incentives will make it more price competitive with conventional fuels, helping make the business case for its adoption. The government has shown further support for the project by awarding Velocys a grant on the grounds of sustainable fuel's potential to help meet the UK's low-carbon vision.

3. Delivery of new Airbus aircraft
Since May 2016, Airbus has offered customers the option of taking delivery of new aircraft using a blend of SAF. More than 25 aircraft have been delivered to date with 3 different airlines. Airbus, along with its partners are currently investigating how to scale-up sustainable fuel deployment across its sites and operations.

4. AIR TRAFFIC MANAGEMENT AND OPERATIONS

- **En route horizontal flight efficiency is on track to meet the SES Performance Scheme 2019 target of no more than 2.60% additional distance flown.**
- **Airport arrival flow and taxi-out operational efficiencies are fairly stable.**
- **Key deliverables from the Single European Sky ATM Research Programme (SESAR) are now being deployed, with the aim to improve efficiency, reduce emissions and mitigate noise.**
- **The introduction of Free Route Airspace has saved more than 2.6 million tonnes of CO_2 since 2014 (approximately 0.5% of total aviation CO_2 emissions).**
- **Airport Collaborative Decision Making has been implemented at 28 airports.**
- **Continuous descent operations have potential for reducing both noise and CO_2, especially in the European core area.**
- **The full potential from operational initiatives is not always achieved due to conflicting air navigation requirements (e.g. safety, environment, economic, capacity).**

4.1 Single European Sky

There were 9.6 million flights to or from EU28+EFTA airports during 2017, and they are forecasted to increase by 42% between 2017 and 2040 under the base traffic forecast. The Single European Sky (SES) initiative [51] has introduced regulatory instruments at the EU level to help address the environmental challenges associated with this expected growth.

Performance Scheme

The SES 'Performance Scheme' [52, 53] defines key performance indicators and sets mandatory local and EU targets in the fields of environment, safety, efficiency and capacity, while taking into account their interdependencies. The scheme captures the relationship between flight routing and environmental impacts through two Key Performance Indicators (KPIs). These involve measuring horizontal flight efficiency by comparing the great circle (shortest) distance against (1) the trajectory in the last filed flight plan (KEP) and (2) the actual trajectory flown (KEA). These KPIs are regarded as reasonable proxy measures of Air Navigation Service Provider efficiency.

Considering the complexity of the route structure, interface procedures and air traffic control operations, horizontal en route flight efficiency is not considered an appropriate performance indicator for the airport and terminal manoeuvring area. Instead, the additional taxi-out time and the additional transit time in the Arrival Sequencing and Metering Area (ASMA)[11] is monitored against an unimpeded time based on periods of low traffic demand. Likewise, in order to measure the performance of aircraft ground operations at airports, the actual taxi-out time of a flight is compared to an unimpeded taxi-out time during periods of low traffic demand. At present, the performance scheme does not cover non-CO_2 emissions, vertical flight efficiency, noise levels or air quality.

The European Commission is currently conducting a review of the Performance and Air Traffic Management (ATM) Charging Schemes which is due to be completed by the start of 2020. This will in particular respond to the findings of the recent European Court of Auditors report [54], and better capture the responsiveness of the ATM System to requests for preferred flight trajectories of airspace users.

11 ASMA is measured as a cylinder of airspace centred on the airport with a radius of 40 nautical miles.

Network Manager

The European Commission nominated EUROCONTROL as Network Manager in July 2011 until the end of 2019 [55, 56]. The SES Network Manager coordinates between operational stakeholders to effectively manage imbalances between capacity and demand, and thereby optimise the performance of the European aviation network. The aim is to prevent congestion in the air through the design, planning and management of the European ATM network and to limit unnecessary fuel burn and emissions through flow and capacity management.

Single European Sky ATM Research (SESAR)

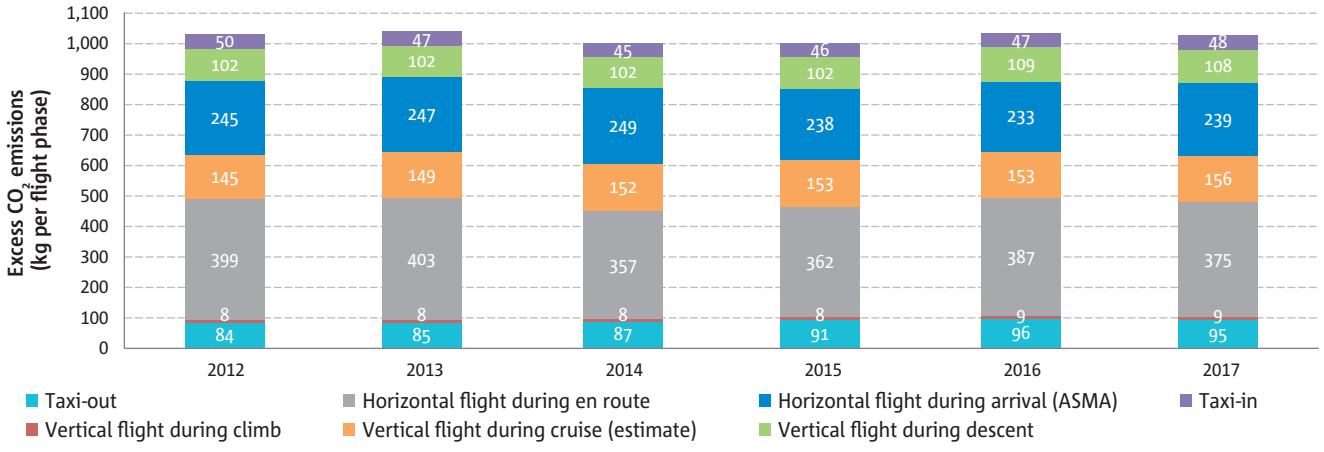
SESAR is the technological pillar of the Single European Sky [57] funded by the European Union, EUROCONTROL and industry partners, with a total budget of €2.1 billion for the original SESAR programme (2008-2016) and €1.6 billion for the SESAR 2020 programme (2014-2024). It aims to improve ATM performance by modernising and harmonising systems through the definition, development, validation and deployment of innovative technological and operational solutions. These solutions are defined in the European ATM Master Plan, along with required operational changes and a roadmap for their implementation. The solutions are developed and validated by the SESAR Joint Undertaking (SJU), and deployed through 'Common Projects' supported by dedicated SESAR deployment governance and incentive mechanisms. All of these processes actively involve the stakeholders and the Commission in different forms of partnerships.

The implementation of the deployment framework [58] will allow SESAR to fully deliver its environmental benefits from concept to implementation. The European Union has contributed €1.5 billion from the Connecting Europe Facility Programme to support operational stakeholders in this process.

4.2 Excess CO_2 emissions due to network flight inefficiency

When comparing the gate-to-gate actual trajectories of all European flights in 2017 against their unimpeded trajectories[12], there is an additional 5.8% gate-to-gate CO_2 emissions at European level. Figure 4.1 illustrates the average excess CO_2 emissions per flight broken down into the different flight phases. The average excess CO_2 emissions has remained stable over the last 6 years, even though traffic has increased.

Figure 4.1 Breakdown of gate-to-gate excess CO_2 emissions for an average flight in Europe



12 Unimpeded trajectories are characterised by: zero additional taxi-out time, no level-off during climb (full fuel CCO), no sub-optimal cruise level, en route actual distance equal to great circle distance, no level-off during descent (full fuel CDO), no additional time in the Arrival Sequencing and Metering Area (ASMA), zero additional taxi-in time.

It should be noted, however, that there are a number of reasons why the actual trajectory flown can vary from the unimpeded trajectory, and therefore 100% efficiency is not achievable (e.g. due to adverse weather, avoidance of 'Danger Areas', need to maintain minimum separation, lack of capacity leading to diversions, avoidance of relatively high route charges). Some inefficiency is unrecoverable due to necessary operational constraints and interdependencies [59].

The 2018 European ATM Master Plan [60] ambition is to continue reducing the additional gate-to-gate flight time and additional gate-to-gate CO_2 emissions to reach 3.2% and 2.3% respectively by 2035.

4.3 Environmental performance and targets

Horizontal en route flight efficiency

The total additional distance flown in 2017 within the SES area was 222.8 million kilometres, which resulted in approximately 3 million tonnes of additional CO_2 emissions. The SES Performance Scheme includes two binding targets at the EU level for 2019 set at 4.1% for the en route flight inefficiency of the last filed flight plan (KEP) and 2.6% for the actual trajectory (KEA).

Figure 4.2 Horizontal en route flight inefficiency for 2009 to 2017 (Source: SES PRB [61])

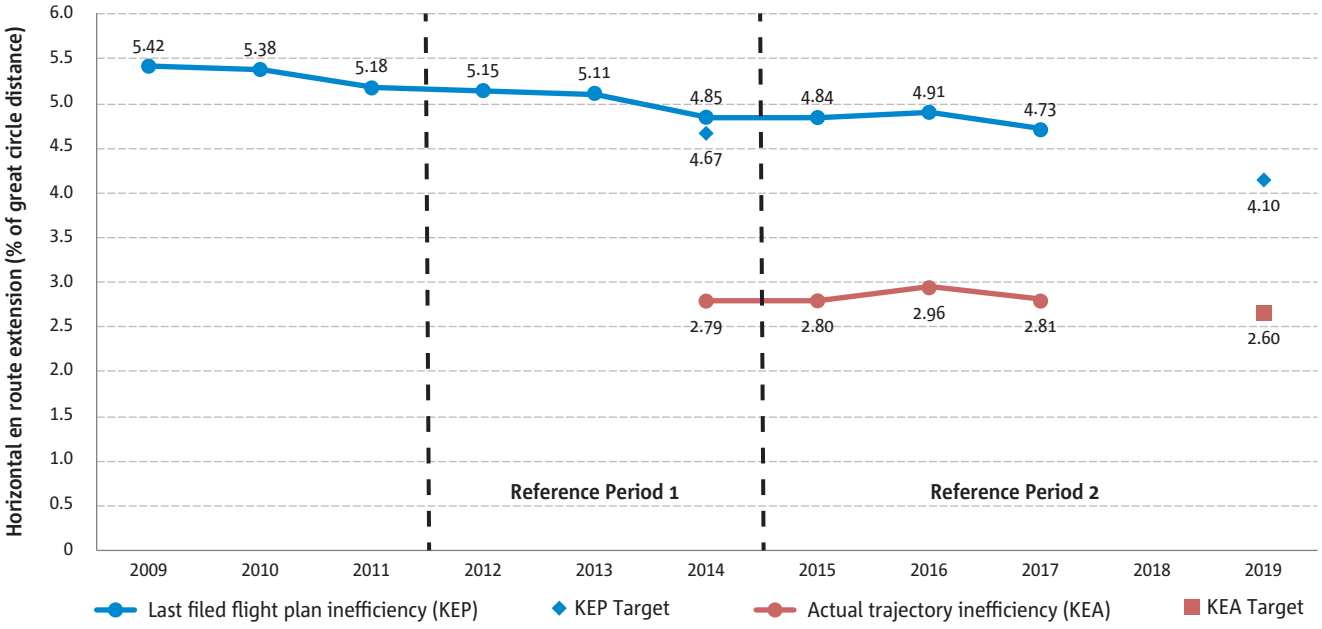
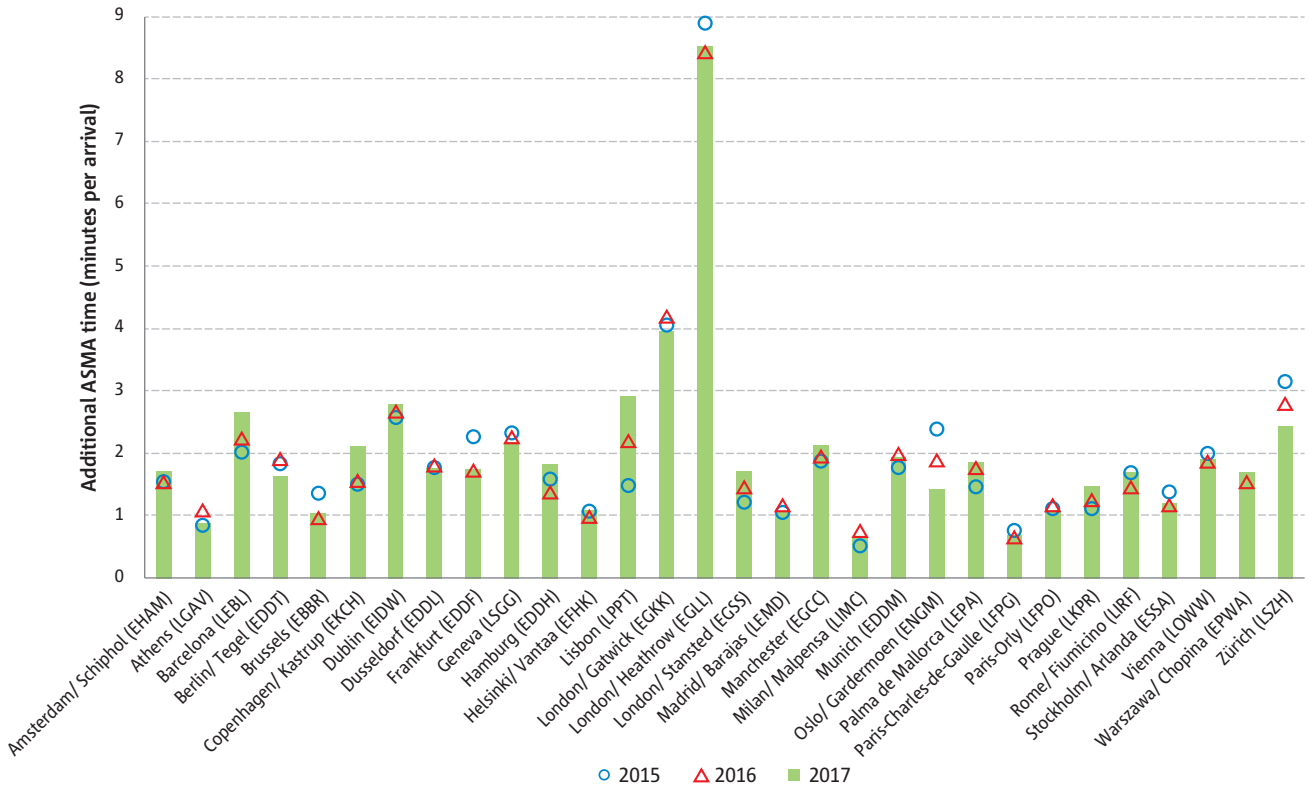


Figure 4.2 shows that KEA decreased to 2.81% and is on track to reach the target by 2019. This is largely due to the simplification of the airway structure in the en route airspace, thereby moving towards a free route airspace (see Section 4.4). KEP decreased from 4.91% in 2016 to 4.73% in 2017. This improvement was due to better flight planning and the reduction of unnecessary route restrictions (e.g. military areas). It is expected that most of the European airspace would have implemented free route airspace by 2019. Consequently, there may be limited scope for further reduction beyond the 2.6% target.

Airport operational efficiency

While the average additional Arrival Sequencing and Metering Area (ASMA) time is about 1.24 minutes per arrival in 2017, significant variations can be seen at an airport level (Figure 4.3). In 2017, inefficiencies in the arrival flow at the top 30 airports resulted in 8.33 million minutes of additional ASMA time. The main contributor being London Heathrow, which accounted for 23% of the total minutes, while its traffic share was less than 6%. This is a consequence of the mode of operations at Heathrow, which prioritises full use of runway capacity.

Figure 4.3 ATM related inefficiencies on the arrival flow (ASMA) at the top 30 busiest airports



In comparison to the additional ASMA time, the average additional taxi-out time per departure improved slightly at the 30 busiest airports in the SES area from 3.82 minutes in 2016 to 3.77 minutes in 2017, with some variation at an airport level (Figure 4.4). Waiting in a queue for take-off generates unnecessary CO_2 emissions and unpredictability.

The implementation of departure manager, in combination with the integration of Airport Collaborative Decision Making (A-CDM) systems, aims to improve the departure sequencing. This provides optimised taxi-time, and improves predictability of take-off times, by monitoring surface traffic. However, this effect is not always fully visible as some A-CDM implemented airports (Figure 4.9) show similar taxi-out performance as non A-CDM airports. Arrival Management (AMAN) now extends into en route airspace as far as 180-200 nautical miles from the arrival airport, and should support better traffic sequencing.

Figure 4.4 Additional taxi-out time at the top 30 busiest airports

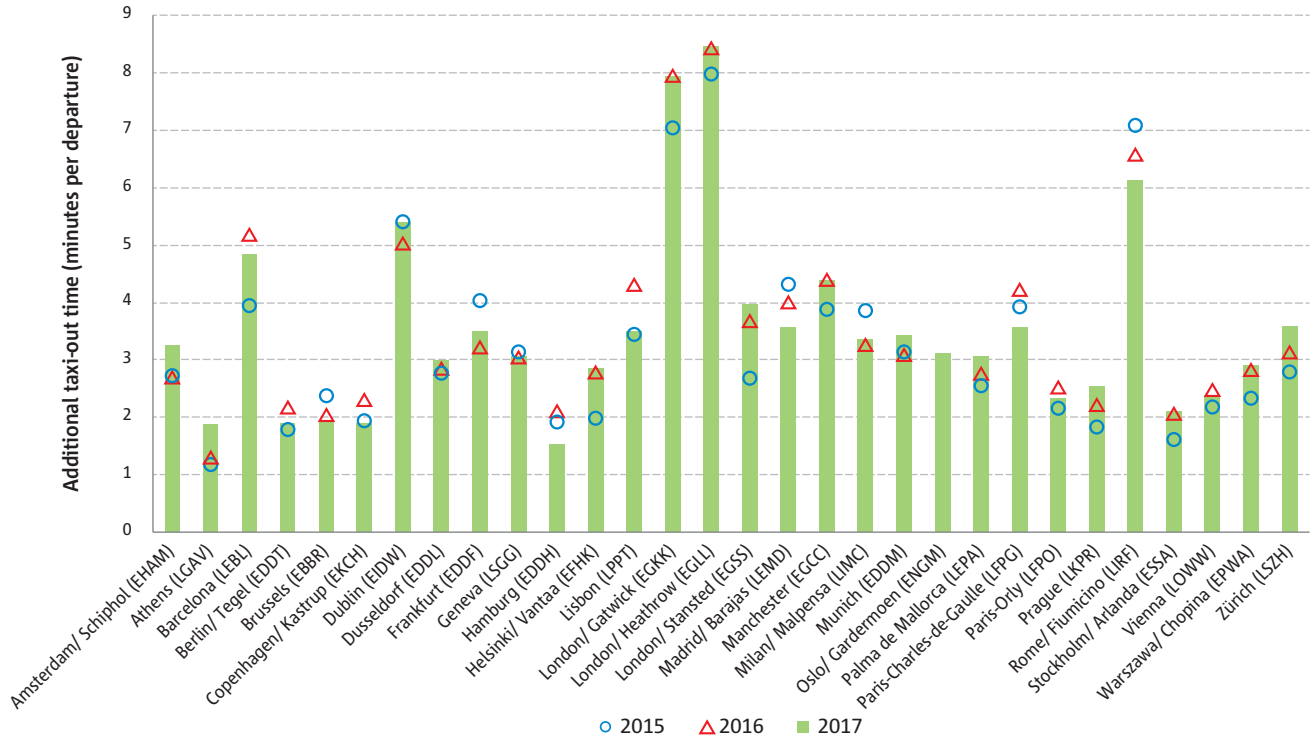
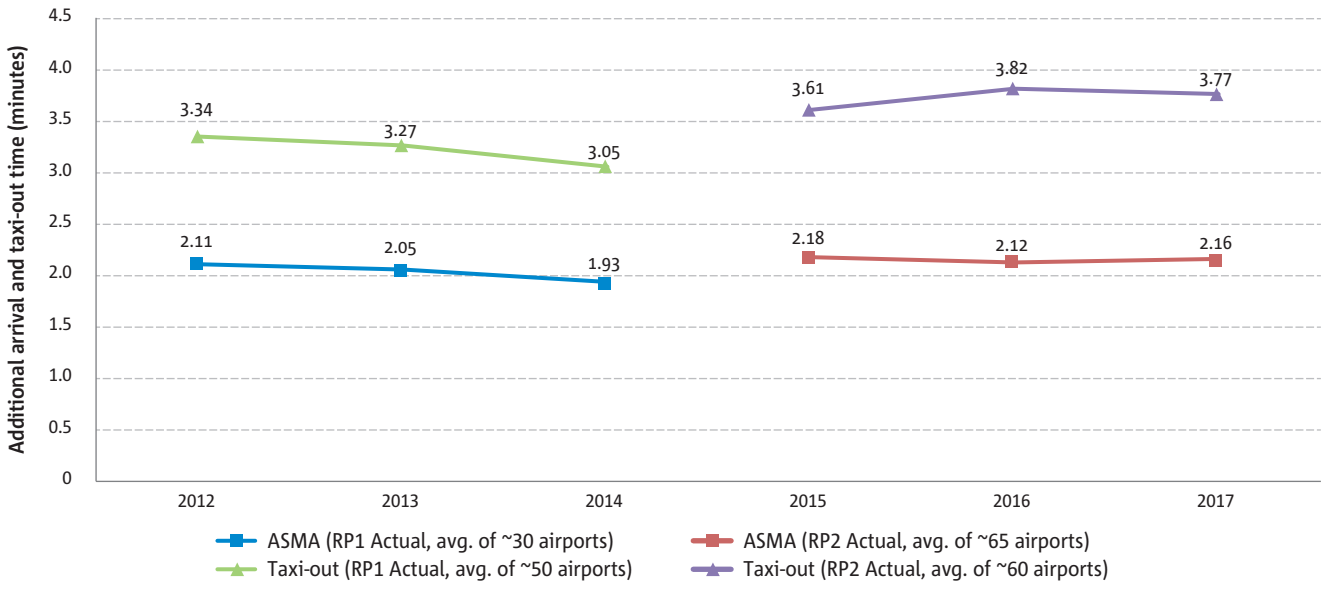


Figure 4.5 illustrates the trend over time of the average additional ASMA and taxi-out times for the busiest airports in the SES area. Note that the sets of airports changed between the 2012-2014 and 2015-2017 periods, and are therefore presented separately.

Figure 4.5 Evolution of additional ASMA and taxi-out times in the SES area[13]



13 The disconnect in the trend line is due to a change in criteria for 'ASMA' airports between Reference Period 1 (RP1 - 2012 to 2014) and Reference Period 2 (RP2 - 2015 to 2019).

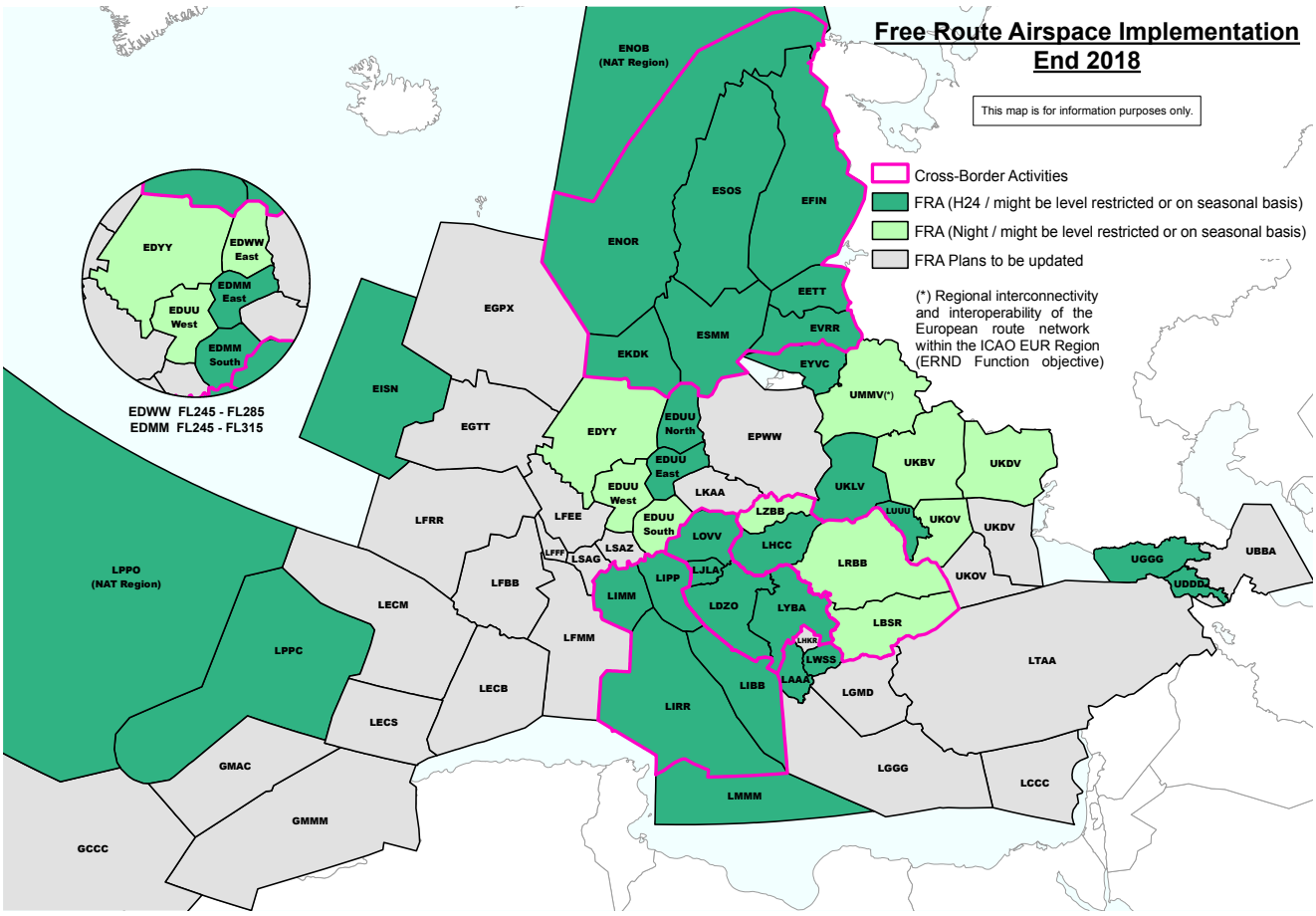
4.4 Operational initiatives

The 2035 ambition level (section 4.2) is to be reached by implementing various operational initiatives.

Free Route Airspace

Free Route Airspace is defined as that airspace within which users may freely plan a route between any defined entry and exit point, subject to airspace availability. Figure 4.6 provides an overview of Free Route Airspace (FRA) and direct routing implementation in Europe as of the end of 2018. It fosters the implementation of shorter routes and more efficient use of the European airspace. The proportion of flight time flown in Free Route Airspace during 2017 was 20% compared to 8.5% in 2014. Since 2016, it should also be noted that cross-border free route activities have been implemented in Estonia, Latvia, Italy, Malta, Slovenia and Croatia. The Network Manager estimates 2.6 million tonnes CO_2 savings from the implementation of FRA since 2014.

Figure 4.6 Free Route Airspace (24 hours or at night) implementation (Source: Network Manager)



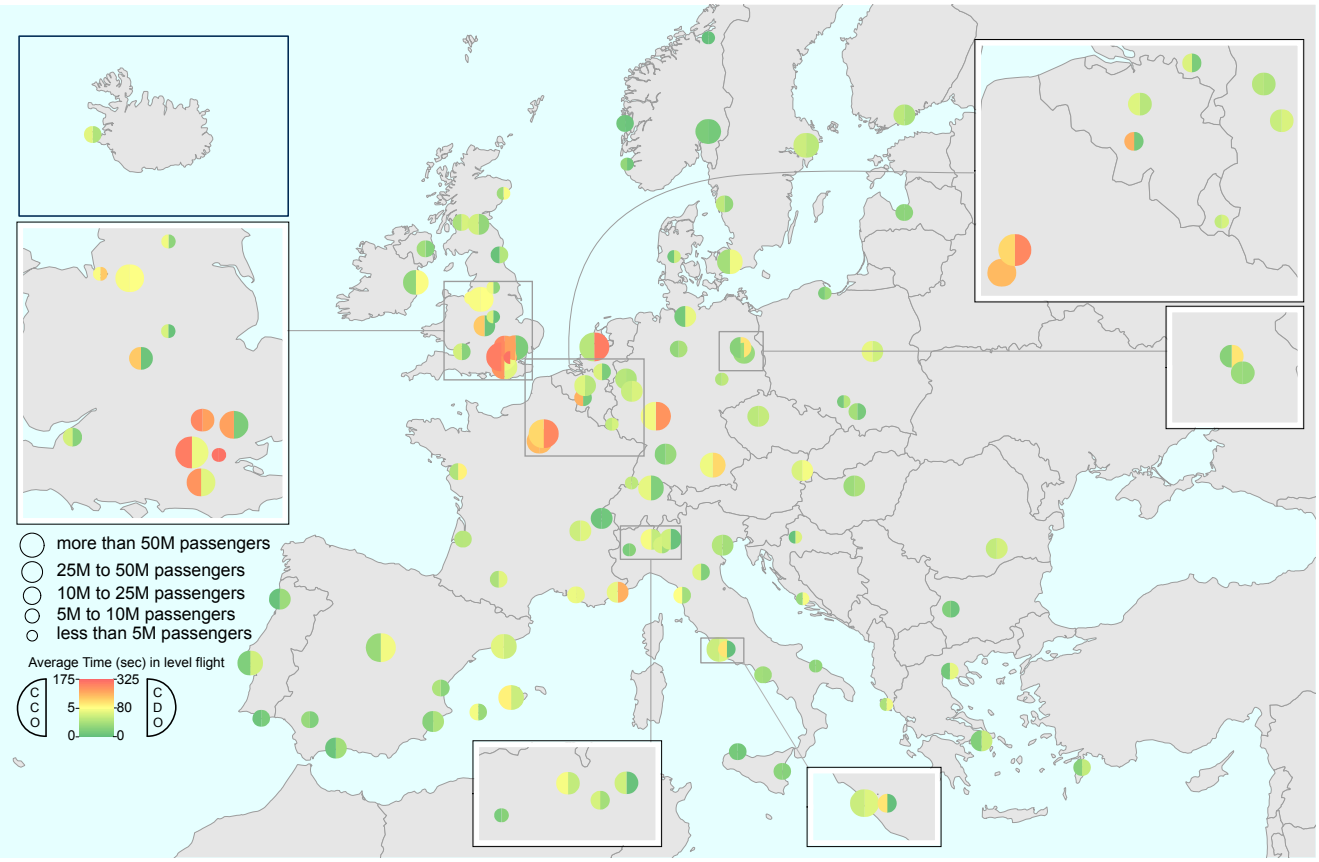
Continuous Climb Operations / Continuous Descent Operations

In 2015, harmonised definitions, metrics and parameters to measure Continuous Climb Operations (CCO) and Continuous Descent Operations (CDO) in Europe were agreed by a Task Force of European ATM Stakeholders. These included the definition of a 'noise CCO/CDO' and of a 'fuel CCO/CDO'. The fuel CCO/CDO measures the vertical flight efficiency, in terms of fuel and CO_2, for the entire climb and descent profile respectively. The noise CCO/CDO measures the vertical flight profile efficiency to 10,500 ft for CCO and from 7,500 ft for CDO, which are the phases of flight where the primary impact is considered to be noise.

A European-wide study [62] of current CCO/CDO implementation, based upon the agreed definitions, was subsequently performed in 2017 where flights with level segments (a proxy for inefficiencies in the climb and descent phases of flight) were measured and their fuel burn, CO_2 and financial impact estimated.

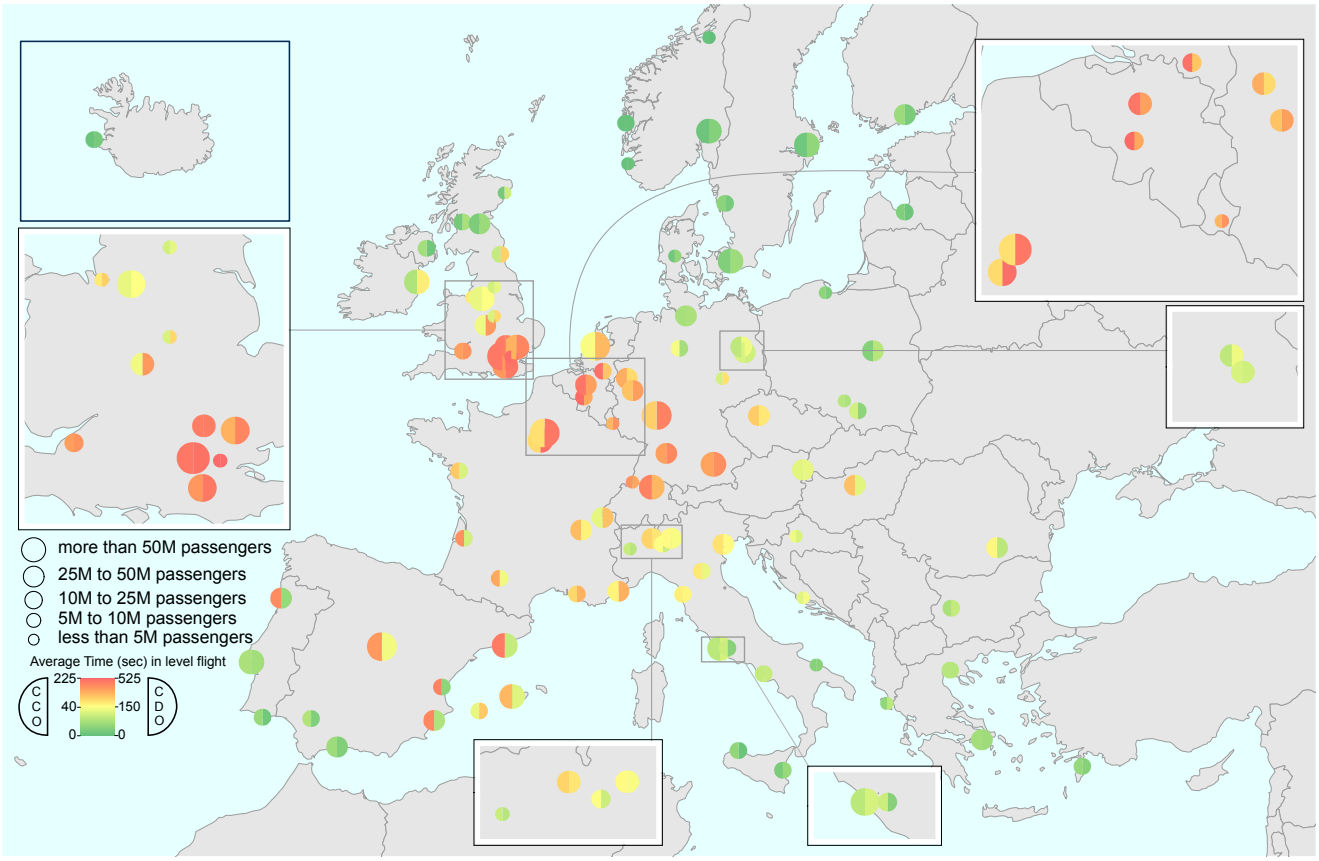
Figures 4.7 and 4.8 use a sliding scale to indicate the average amount of time flown in level flight for both the noise and the fuel CCO/CDO at selected European airports in 2017. The scales for the noise and fuel CCO/CDOs are different, based on minimum, average and maximum values, illustrating the relative performance between the airports. Note that the average amount of level flight flown on departure (noise CCO) is relatively low at 5 seconds compared to 67 seconds for arrivals (CDO).

Figure 4.7 Noise CCO/CDO level flight in 2017



Within the scope of the fuel CCO and CDO definition, the average amount of level flight flown by all European flights is 44 seconds for departures (CCO) and 165 seconds for arrivals (CDO). Figure 4.8 shows that there is there is a relatively high amount of level flight within the European core area, indicating a link between CCO/CDO and airspace complexity.

Figure 4.8 Fuel CCO/CDO level flight in 2017



The results indicate a greater potential to reduce noise and fuel use during descent (CDO) compared to climb-out (CCO), and overall the room for improvement is less in the noise CCO/CDO compared to the fuel CCO/CDO. The ability to perform CCO/CDO profiles also appears to be linked to airspace complexity rather than airport capacity.

The results also indicate that a typical flight with level segments could benefit on average from CO_2 savings of up to 48 kg for a CCO and 145 kg for a CDO, reflecting the higher CO_2 penalties caused by inefficiencies in the descent phase. The potential CO_2 benefits from optimising European wide CDOs were estimated to be ten times more than those of optimising CCOs. Furthermore, there is a much smaller potential to optimise the noise CCO/CDO compared to the fuel CCO/CDO. Acknowledging that the optimisation of environmental benefits depends upon local conditions, it was concluded that CCO/CDO implementation should, where possible, focus on the optimisation of the flight profile from top of descent.

The total potential savings in Europe is up to 350,000 tonnes of fuel, which is equivalent to 1.1 million tonnes of CO_2 emissions per year. However, it should be noted that the ability to fly 100% CCO or CDO may not be possible for a number of reasons such as safety (i.e. time or distance separation), weather or capacity.

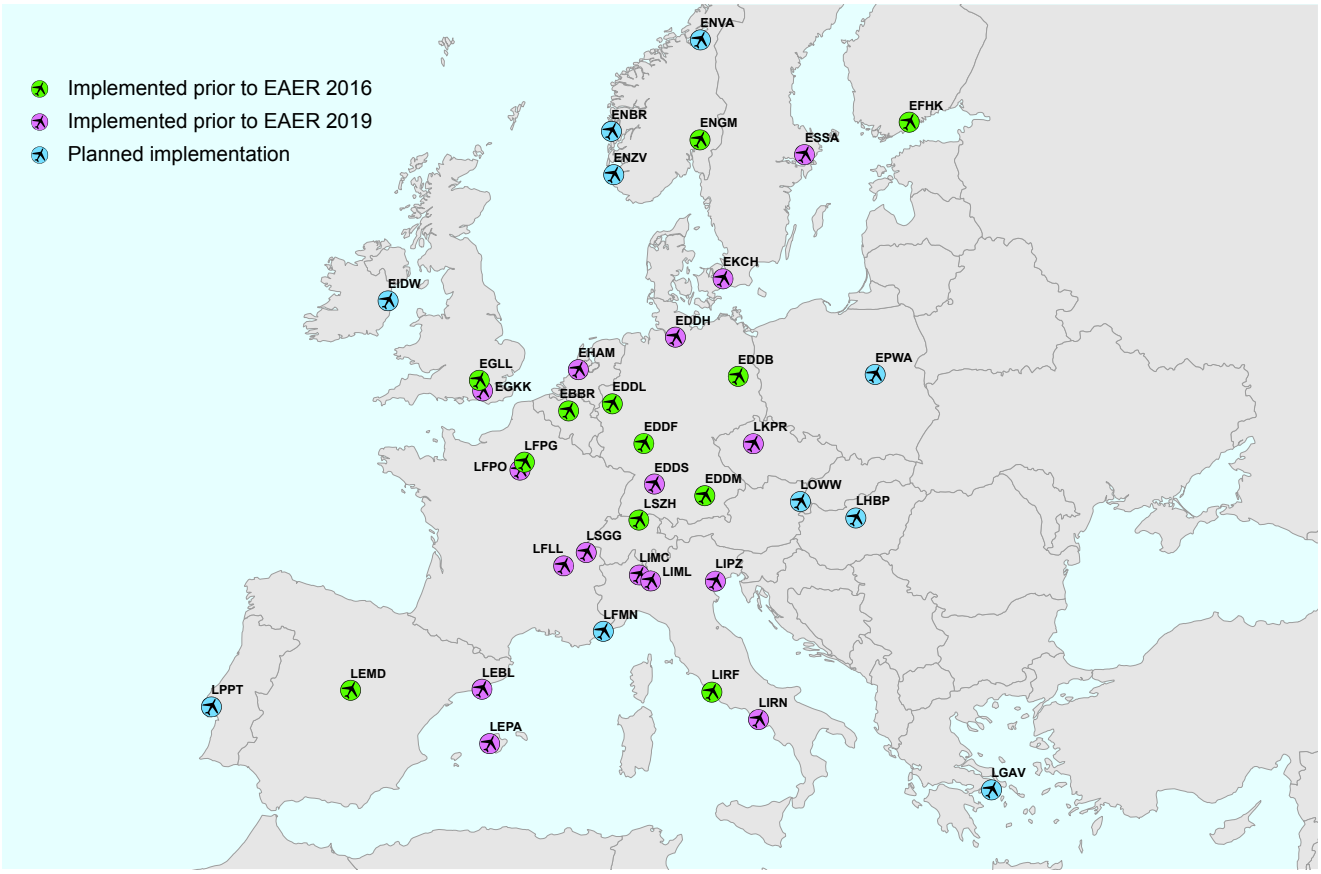
Implementation of Airport Collaborative Decision Making

Airport Collaborative Decision Making (A-CDM) aims at improving the overall efficiency of airport operations, especially on aircraft turn-round and pre-departure sequencing processes.

Increased predictability can be of significant benefit for all major airport and network operations by improving flow management and sector planning. This is achieved by the Network Manager receiving more accurate target take-off times from the airport. On average, the implementation of A-CDM enables a reduced taxi time of 1 to 3 minutes per departure [63].

A further 16 airports (Figure 4.9) have implemented A-CDM since 2016, resulting in 40.9% of European departures operating from a A-CDM airport. The 2016 A-CDM impact assessment report [64] identified savings generated from 13 of the 17 A-CDM airports that have demonstrated tangible taxi-time performance improvements of 108,072 tonnes of CO_2 emissions.

Figure 4.9 Airport Collaborative Decision Making (A-CDM) in the SES area



Additional operational initiatives

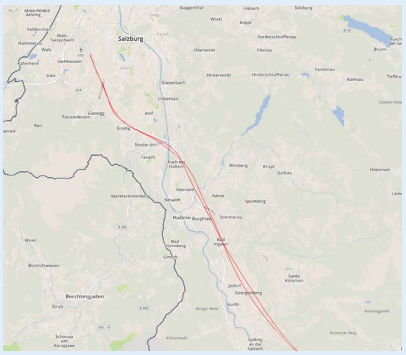
Further solutions which are expected to provide substantial environmental savings are highlighted in Table 4.1.

Table 4.1 Examples of SESAR solutions deployed or soon to be deployed in Europe

SESAR solutions	Environmental benefits
Arrival Management extended to en route Airspace (AMAN) Allows for smoother traffic management by earlier sequencing of arrival traffic at a point further away from the airport.	Less fuel burn from reduced vectoring at lower levels, reduced holding and maintaining more fuel efficient flight levels for longer
Enhanced Terminal Airspace using RNP-Based Operations This allows aircraft to follow precision flight paths to reduce distance flown and avoid noise sensitive areas.	Less fuel burn and lower noise
Departure Management Synchronised with Pre-departure Sequencing Pre-departure management delivers optimal traffic flow to the runway by factoring in accurate taxi time forecasts and route planning derived from static data.	Reduced waiting time at the runway holding point, which saves fuel and allows air navigation service efficiency
Departure Management integrating Surface Management Constraints The solution integrates surface planning and routing functions to build a very accurate departure sequence, taking the tactical changes into account.	Less fuel burn and emissions
Time-Based Separation for Final Approach Current distance separations replaced with time intervals in order to adapt to weather conditions and maintain runway approach capacity.	Less fuel burn due to reduction in holding times
Automated Assistance to Controller for Surface Movement Planning and Routing The route planning functionality allows controllers to graphically edit routes and automatically compute estimated taxi times, contributing to more predictable surface operations.	Improved taxi times resulting in less fuel burn

STAKEHOLDER ACTIONS

Air Navigation Service Providers



Austro Control has developed and implemented radio navigation procedures to reduce both noise and emissions at Salzburg airport. The airport is located on the northern edge of the Alps, and airlines generally prefer to approach from the south, stay high and descend to a reasonable approach altitude of around 5,000 ft after being clear of mountains. This was followed by an ILS approach from the north, as long as wind conditions allow. This flight extension of approximately 46 km results in additional fuel burn, gaseous emissions and noise over densely populated areas. In order to reduce these impacts, Austro Control has developed a direct approach procedure from the south that enables airlines to safely descend through the valley even in poor weather (IMC) conditions.

Airline Operators

1. Lufthansa case study: Vortex Generators for Quieter Approaches

'Vortex generators' have been developed to reduce noise tones generated by two overpressure relief outlets located on the lower wing surface of A320 aircraft. These vortex generators are mounted in front of the cavities to prevent the generation of these tones, thus resulting in a four decibel noise reduction at distances between 17 and 10 kilometres from the runway. These are now fitted as standard on new A320 aircraft and can also be retrofitted to in-service aircraft. In addition to a noise reduction, the vortex generators help to reduce noise related airport charges.

2. Austrian Airlines case study: Crew Transport by Train

Alongside the transportation of passengers using classic intermodal travel situations, Austrian Airlines is now cooperating with the Austrian Federal Railway Company (ÖBB) to transport cockpit- and cabin-crews to work. Each month ÖBB receives the number of required seats on specific trains from Austrian Airlines and puts in place the respective seat reservations. Austrian Airlines incorporates the train details into the crew duty roster. As well as reducing costs and CO_2 emissions, the crew experience a more comfortable and flexible journey compared to road shuttle services.

3. IAG case study: Flying the fuel efficiency flag

Aviation fuel typically comprises 25% or more of airline costs and accounts for over 97% of airline CO_2 emissions, so focusing on fuel efficiency makes both commercial and environmental sense. IAG has set ambitious targets to improve fuel efficiency by 10% in 2020 compared to 2014, thereby achieving an average fuel efficiency of 87.3 gCO_2 per passenger kilometre.

Big wins have come from new aircraft such as the Boeing 787 and the Airbus A350 / A320neo that deliver up to 20% better fuel efficiency compared to the aircraft they replace. However, small measures also add up, including weight reduction, regular maintenance and optimizing flight operations. During 2017, IAG's flight carbon efficiency improved by 2.6% versus 2016, which saved over 80,000 tonnes of CO_2 through more than 25 separate fuel efficiency initiatives including using electric push back tugs, reduced engines for taxiing and reducing aircraft drag by reducing the time when landing lights are extended into the airflow.

During 2017 IAG also began implementing the Honeywell 'GoDirect' fuel efficiency software. This will enable mining of big data to identify further fuel efficiencies, and will allow IAG to benchmark fuel use across its fleet and share best practice among the Group's five airlines. IAG's focus is now on developing innovative ways to communicate fuel efficiency information to flight crews in a way that engages and inspires them to change behaviour and minimize excess emissions.


B

5. AIRPORTS

- **New processes to verify aircraft noise data and collect aircraft noise certificates are being put in place by EASA to support a harmonised approach to managing aircraft noise.**
- **Between 2015 and 2018, the number of European airports participating in the Airport Carbon Accreditation programme has increased from 92 to 133, and the number of airports reaching CO_2 neutral status rose from 20 to 37.**
- **Marginally compliant Chapter 3 aircraft represented less than 5% of operations in Europe during 2017.**
- **Noise and emissions charges are used extensively, but the low level of charges (less than 1% of airline operating costs) is unlikely to affect the fleet operating at airports.**
- **Involvement of stakeholders, through a process such as Collaborative Environmental Management, is crucial to identifying balanced mitigation measures.**
- **Airports are applying a range of mitigation measures to reduce their environmental impact.**

ACI EUROPE Environmental Survey

This Chapter utilises information gathered from an environmental survey that ACI EUROPE undertook in 2018. Responses were received from 51 airports which is approximately 10% of members. Although this is a small portion of airports, this included about half of the busiest EU28+EFTA airports with over 5 million passengers per year and approximately 60% of annual EU28+EFTA airport passengers.

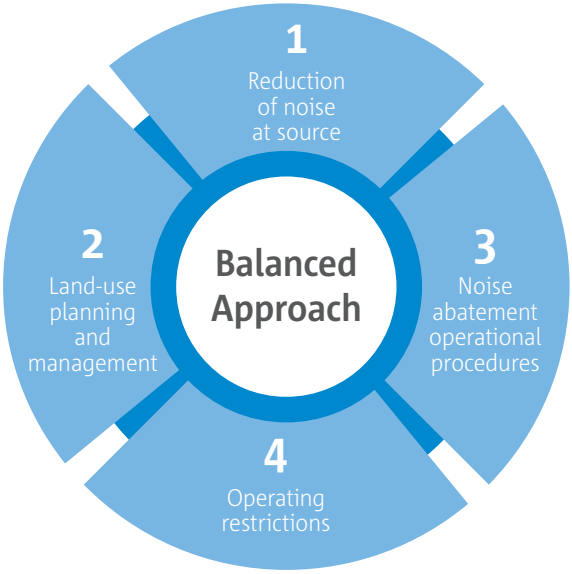
5.1 Noise management strategies

The regulatory environment has evolved over the last three years with the entry into force of Regulation (EU) 598/2014 on the establishment of rules and procedures with regard to the introduction of noise-related operating restrictions at Union airports within a Balanced Approach [8]. This regulation, and the EU Environmental Noise Directive [6], promote effective management techniques to manage noise pollution around airports and are complementary to the implementation of national and local initiatives.

As part of the Regulation 598/2014, EASA has been asked to implement two new roles on aircraft noise data collection. The first role is to verify and publish aircraft noise and performance data for use in calculating airport noise contours and assessing the noise situation. This provides a robust and common set of data that further enhances and harmonises the modelling approach within Europe. It builds upon the database [65] that has been maintained and hosted by EUROCONTROL. In addition, EASA is to collect aircraft noise certificates from operators using European airports. This central database will be made available to competent authorities, air navigation service providers and airport operators for operational purposes. It provides a process at a European level whereby this information can be shared between all appropriate stakeholders in a much more efficient manner.

The principle of a 'balanced approach' [66] to aircraft noise management at airports involves assessing (modelling) and monitoring (measuring) the situation, defining a baseline, future objectives and an associated noise action plan. The balanced approach consists of the following core elements:

Figure 5.1 Balanced approach to airport noise management



1. **Reduction of noise at source** through research studies, technology programmes and standard setting.

2. **Land-use planning and management policies** to prevent incompatible development into noise-sensitive areas. This action unites planning (zoning, easement), mitigation (building codes, insulation, real estate disclosure) and financial aspects (tax incentives, charges).

3. The practical application of **noise abatement operational procedures** [67], to the extent possible without affecting safety. These procedures enable the reduction or the redistribution of the noise around the airport and the full use of modern aircraft capabilities.

4. **Operating restrictions on aircraft** defined as any noise-related restriction that limits access to or reduces the operational capacity of an airport, for instance noise quotas or flight restrictions. This is used only after consideration of other elements of the balanced approach.

It is recognised that involvement of all stakeholders in the discussions on a balanced approach to noise management is a critical factor in mitigating aircraft noise and the annoyance to communities near airports. Regulation 598/2014 requires that technical cooperation be established between the airport operators, aircraft operators, ground handlers and air navigation service providers to examine measures to mitigate noise. In addition, local resident representatives, and relevant local authorities, are to be consulted and technical information on noise mitigation measures provided to them.

Such stakeholder consultation and collaboration is often referred to as 'Collaborative Environmental Management' (CEM) and is adopted to suit local needs and capabilities. The CEM working arrangement provides a platform for discussion between core operational stakeholders, such as airports, airlines, air navigation service providers; and as appropriate, local authorities and local communities. This facilitates the identificaiton of synergies, quantification of impacts including trade-offs (e.g. noise and fuel burn), and the understanding of potential constraints within the aviation system in order to reach compromises from an operational perspective, which all stakeholders can collaborate in implementing. EUROCONTROL updated its CEM Specification in 2018 [68], and 25 respondents to the ACI EUROPE survey stated that they have implemented a CEM-type collaborative approach since 2014.

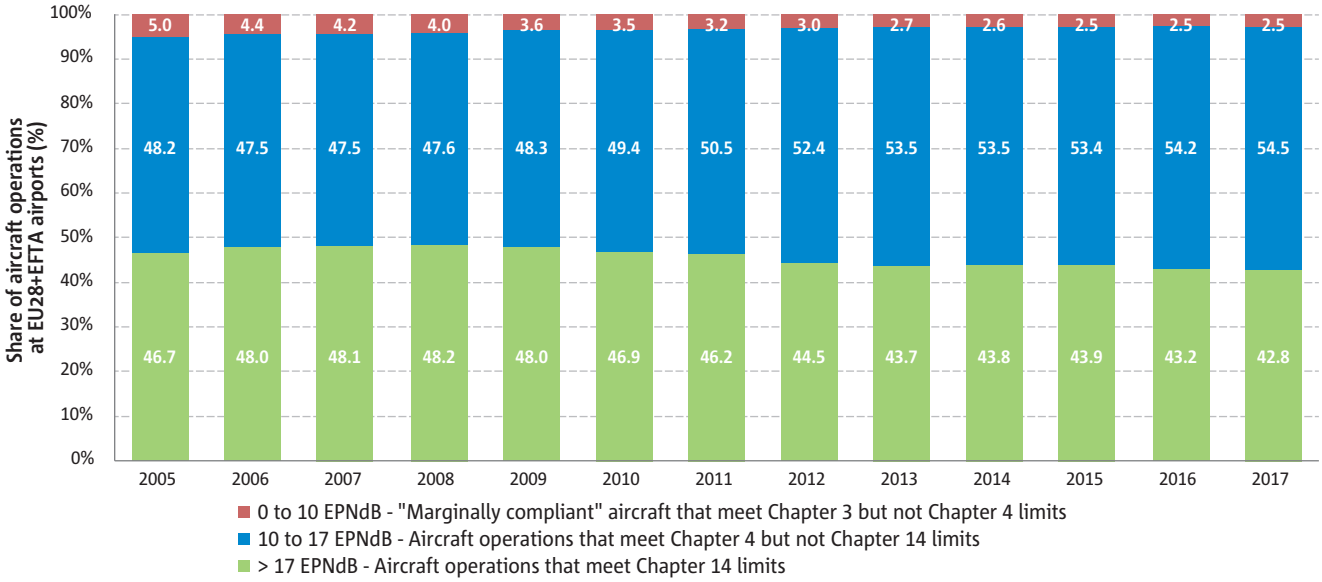
Operational stakeholders may place greater emphasis in certain elements of the balanced aproach than others, depending on the airport objectives with regard to noise abatement and the cost effectiveness of potential mitigation measures. 84% of survey respondents indicated that local and/or national authorities defined land-use planning noise zones around the airport, and that the airport is involved in land-use planning processes. In addition, 65% of survey respondents have implemented sound insulation schemes for local communities. To reduce noise impacts, 90% have implemented noise abatement operational procedures with 43% employing all of the following: enhanced departure procedures, arrival procedures, ground-based procedures, preferential runway procedures and procedures for engine test run-ups.

Whilst recognising that operating restrictions should be used only after consideration of other elements of the balanced approach, 79% of the airports surveyed indicated that they employ various approaches including restrictions on noisier aircraft (78% of respondents), night flight restrictions (75%), runway restrictions (48%), noise budgets (18%) and movement caps (18%) amongst others.

5.2 Aircraft noise performance at European airports

Aircraft that were only compliant with ICAO Annex 16, Volume I, Chapter 2 noise certification limits were no longer permitted to operate in Europe from 1 April 2002 [69]. Following the implementation of the balanced approach in 2002 [8], operating restrictions are now considered at an airport level rather than a regional level. The Balanced Approach Regulation (EU) 598/2014 defines an 'operating restriction' as a noise-related action that limits access to or reduces the operational capacity of an airport. This includes the banning of operations by so-called 'marginally compliant' aircraft that are defined as having a cumulative margin[14] of less than 10 EPNdB[15] to the ICAO Annex 16, Volume I, Chapter 3 noise certification limits. Figure 5.2 illustrates the share of EU28+EFTA aircraft operations split into three categories based on their margin to the Chapter 3 limits.

Figure 5.2 Share of EU28+EFTA operations by cumulative margin to Chapter 3 limits



14 'Cumulative margin' is the figure expressed in EPNdB obtained by adding the individual margins (i.e. the differences between the certified noise level and the maximum permitted noise level) at each of the three reference noise measurement points in Chapter 3.

15 The definition of a marginally compliant aircraft is currently 8 EPNdB and will increase to 10 EPNdB on 14 June 2020. This is equivalent to the Chapter 4 noise certification limits.

The ICAO Resolution A39-1 Appendix E [70], which was adopted in 2016, urges States not to permit the introduction of any operating restrictions aimed at aircraft that comply with the noise standards in Chapter 4 and Chapter 14 and any further stringency levels adopted by the ICAO Council. Currently less than 5% of EU28+EFTA aircraft operations do not comply with these standards.

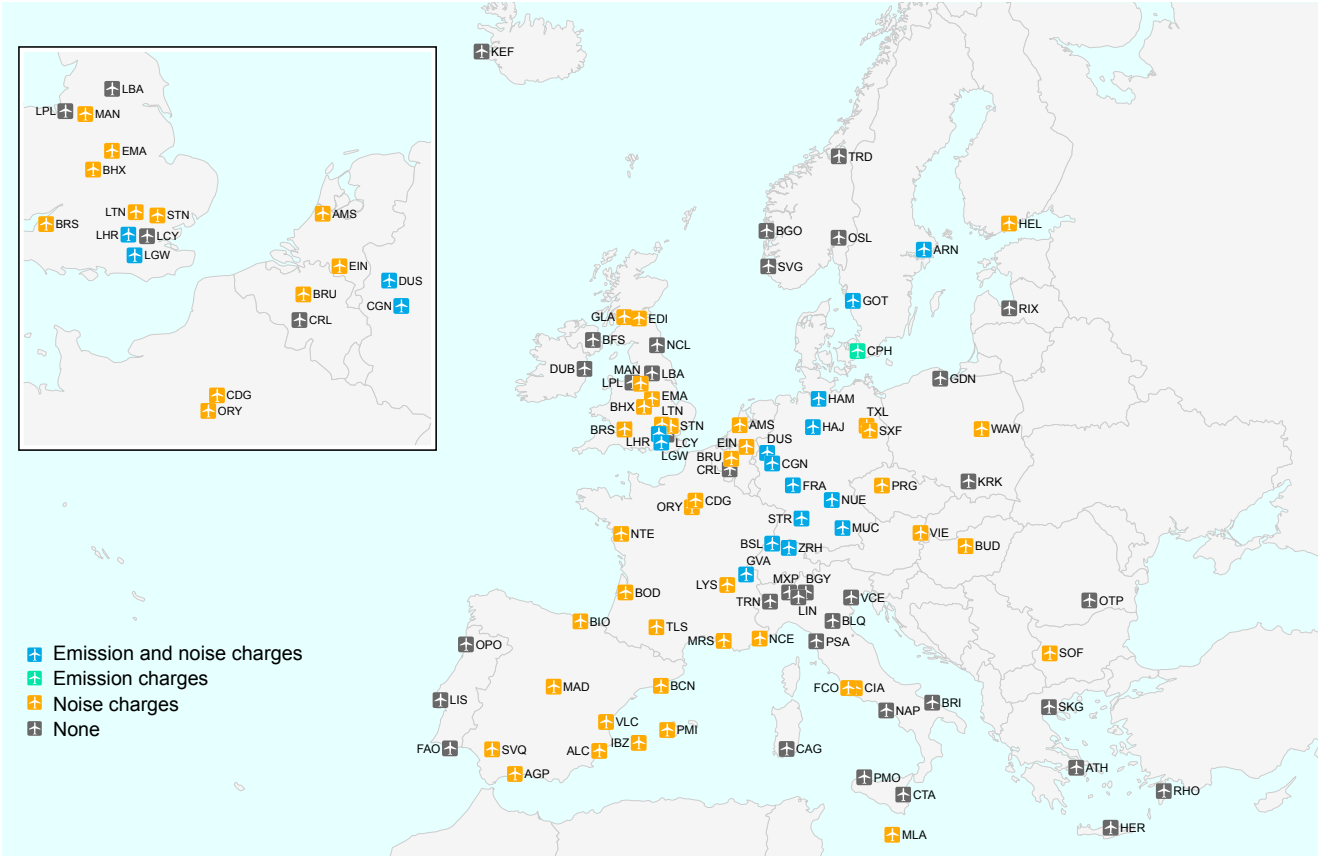
5.3 Environmental charges

Some airports levy environmental charges, either separate or integrated into other ones (e.g. landing charges), in order to incentivise the use of quieter or lower-emission aircraft by airlines or fund local mitigation measures.

A recent evaluation of Directive 2009/12/EC on Airport Charges [71], together with an analysis of publicly available information, revealed that approximately 60% of the busiest EU28+EFTA airports have implemented environmental charges. In line with ICAO guidance, these charges are focused on local noise and/or air quality (NO_X) impacts and not global climate change impacts (CO_2), and are dependent on numerous factors including the aircraft and engine type, the certified noise and emission levels and time of the day. The overall proportion of environmental charges relative to total airport charges is increasing, but remains small as of 2016 (approximately 4% for long haul and 1% for short haul flights). As airport charges represent 15-20% of low-cost carrier costs and 4-8% of network carrier costs, the evaluation report concluded that it is questionable whether those charging schemes influence the fleet operating at the airports.

Although there are significant differences in the structure of the environmental charging systems across Europe, the evaluation of the Airport Charges Directive concluded that it had provided a common framework for a transparent consultation on the charging setting process, remedies, non-discrimination and the establishment of independent supervisory authorities.

Figure 5.3 Environment related charging schemes at 100 busiest EU28+EFTA airports in terms of flight movements



5.4 Environmental impact mitigation measures

Airports have been active in improving their environmental performance in various areas. This section provides an overview of some of these actions based on the 51 airport responses to the ACI EUROPE survey in 2018, which represent 60% of total EU28+EFTA passenger numbers.

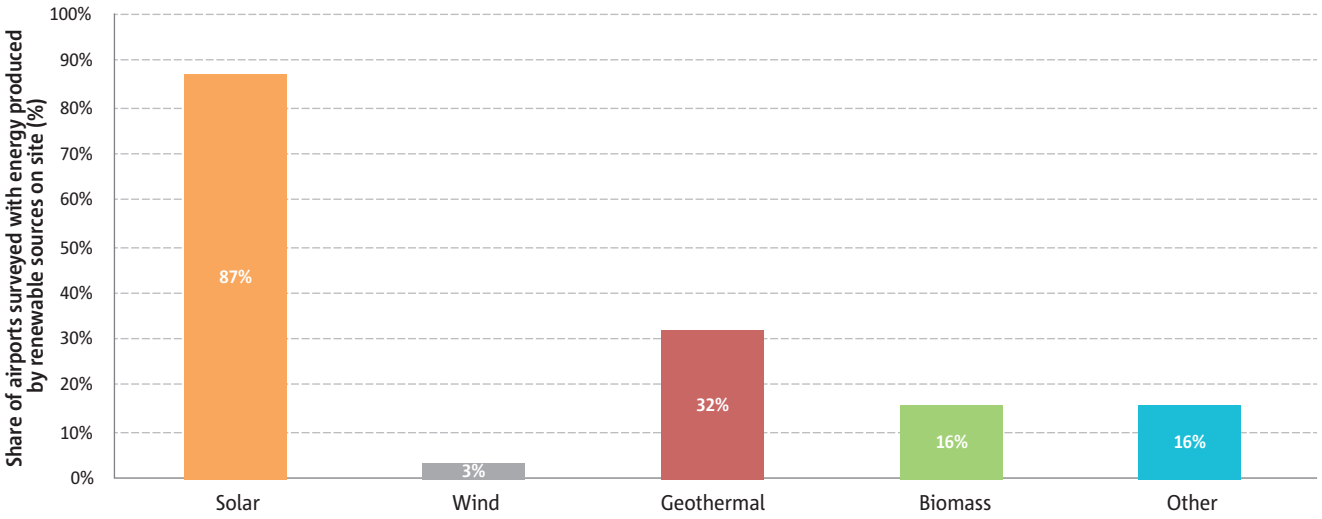
Vehicle fleet

86% of the respondents reported that their vehicle fleet included electric vehicles, 47% have hybrid models and 35% have vehicles that run on sustainable alternative fuel. In addition, 18% of airports indicated that they provide incentives for taxis to also use these types of 'green' vehicles.

Energy

61% of survey respondents indicated that renewable energy is produced on site (Figure 5.4) while 40% have established an energy management system certified according to the ISO 50001 standard. 89% of these airports indicated that the renewable energy produced on site covers 1-20% of their energy needs, 3% stated the energy covers 21-40% of their needs, 5% stated the energy covers 41-60% of their needs and 3% stated the energy covers more than 61% of their needs. In addition, 65% of airports purchase electricity from renewable sources.

Figure 5.4 Share of airports that produce renewable energy on site



Airport infrastructure

The provision of Fixed Electrical Ground Power (FEGP) and Pre-Conditioned Air (PCA) to aircraft at the airport gate reduces emissions by allowing the pilot to obtain electricity direct from the local grid and use the airport's air conditioning system to control the temperature on board. The aircraft Auxiliary Power Unit, which uses normal jet fuel, can then be kept switched off until just before the aircraft is ready to depart when it is needed to start the main engines. 82% of respondents provide FEGP to aircraft on-stand and 58% of respondents provided PCA.

Airport surface access

A large part of the indirect emissions at airports originate from surface access transport (e.g. the road access to the airport). The development of improved public transport systems to reduce the use of individual vehicles, and improve local air quality, is one of the key challenges for airports and the local authorities. While 98% of airports indicated that public transport was available, a majority of airports also reported that less than 20% of their employees actually use it to travel to work. In a separate analysis, on average, 36% of passengers travelled to airports by public transport in 2018, compared to 43% in 2016[16].

Environmental Management Systems

82% of surveyed airports, representing 53% of total EU28+EFTA passengers, were certified against an international standard to effectively monitor and manage their environmental performance (e.g. EU EMAS, ISO 14001) or energy management (ISO 50001).

16 2016 and 2019 data was based on airport reports representing 56% and 64% of European traffic respectively.

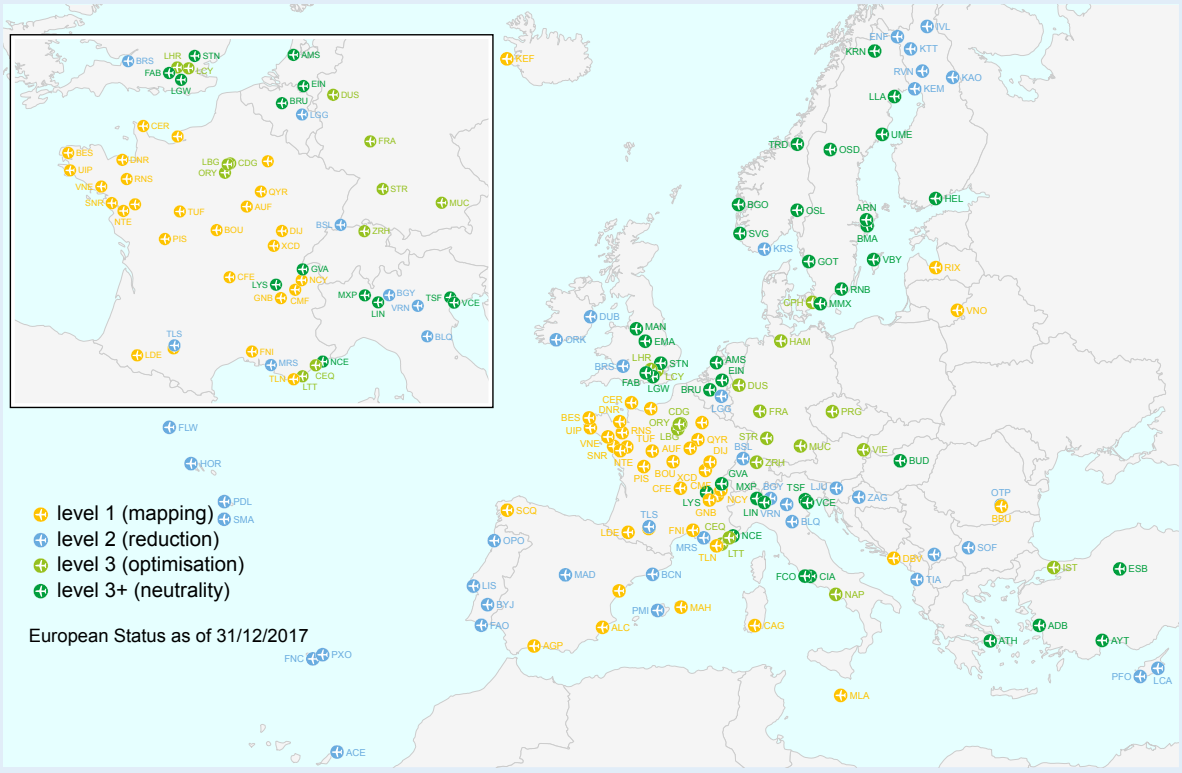
STAKEHOLDER ACTIONS

Airport Carbon Accreditation Programme

The Airport Carbon Accreditation programme [72] was launched by the Airports Council International Europe in 2009 and has now expanded to include 237 airports worldwide. It is a voluntary industry led initiative, that provides a common framework for carbon management with the primary objective to encourage and enable airports to implement best practices. It is run by an independent Programme Administrator who manages the application and approval process, and is overseen by an independent Advisory Board that reviews the progress and relevance of the programme. All data submitted by airport companies via Airport Carbon Accreditation are externally and independently verified.

The programme is structured around four levels of certification (Level 1: Mapping, Level 2: Reduction, Level 3: Optimisation and 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). As of the latest 2017-2018 reporting period, there are **133 European airports**[17] participating in the programme.

Figure 5.5 European airports participating in the ACA programme



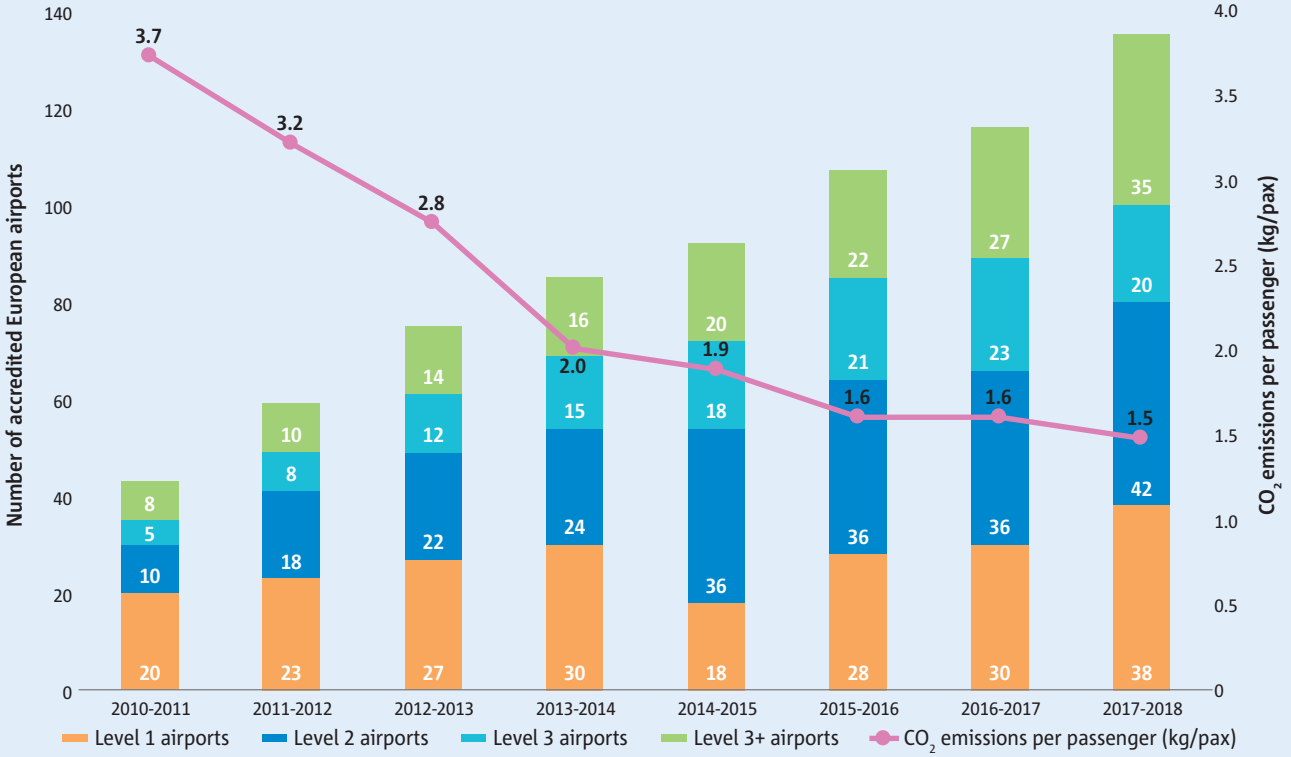
(Source: Airport Carbon Accreditation [72])

These airports correspond to **1.343 billion passengers (65% of passengers in Europe)** in 2017-2018, compared to 1.105 billion passengers (64% of passengers in Europe) in the 2014-2015 period. Total direct emissions which were under the full control of the airport were reported as 1.985 million tonnes of CO_2 in 2017-2018, down from 2.089 million tonnes

17 The figures presented on this page contain six non-EU28+EFTA airports (Istanbul Ataturk, Antalya, Ankara, Izmir, Pristina and Tirana) which are included in the European values provided in the Annual Reports.

of CO_2 in the 2014-2015 period. The carbon emission per passenger travelling through European airports at all levels of Airport Carbon Accreditation has stabilised over the last 3 years at about 1.5 kg CO_2/passenger (Figure 5.6).

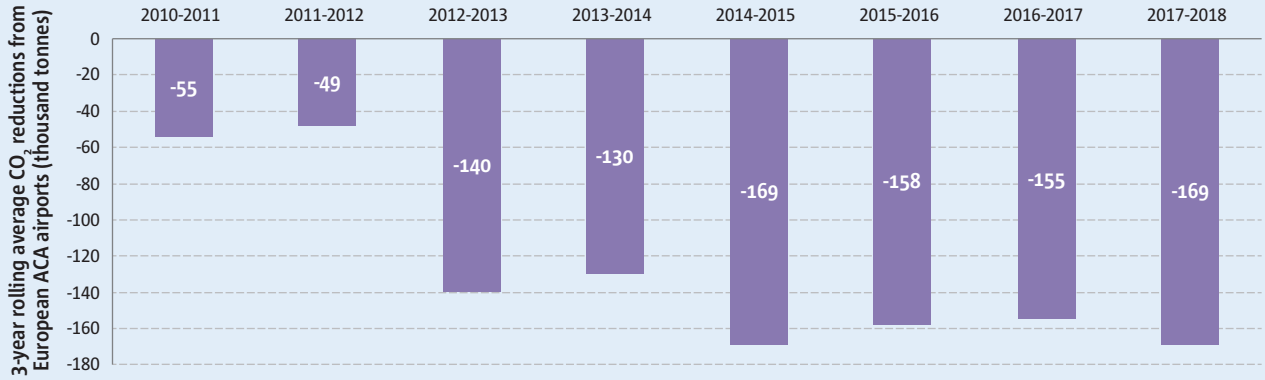
Figure 5.6 Increasing number of accredited European airports and stabilised CO_2 emissions per passenger



(Source: Airport Carbon Accreditation [72])

In Scope 1 and 2 emissions, a total reduction[18] of **0.169 million tonnes of CO_2** (Figure 5.7) for all accredited airports at Level 2 and above was also reported in 2017-2018. This represents about 7.9% of the average annual emissions during the 2014-2017 period. The Scope 3 emissions increased by **1.159 million tonnes of CO_2** in 2017-2018, compared to a reduction of 0.551 million tonnes in the 2014-2015 period.

Figure 5.7 Reductions in airport Scope 1 and 2 CO_2 emissions



(Source: Airport Carbon Accreditation [72])

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

STAKEHOLDER ACTIONS

Airports Council International Europe (ACI EUROPE)

ACI EUROPE represents over 500 airports in 45 European countries, which accounts for over 90% of commercial air traffic in the region. It works to promote professional excellence and best practice amongst its members, including in the area of environmental protection.

Measures to reduce emissions from airport-related activities include improving the energy efficiency of infrastructure, facilitating the transition to electric vehicles, both airside and landside, and the adoption of SAFs by airlines, to name a few. A growing number of airports generate renewable energy on-site, such as Athens International (solar), Reus (geothermal) and La Palma (wind). It is increasingly recognised that collaboration between all partners operating at the airport is essential to reduce emissions, as shown by Budapest Airport through its Greenairport programme. 35 European airports have achieved carbon neutral status for their operations, and ACI EUROPE has set the target of reaching 100 carbon neutral airports by 2030. Ronneby Airport in Sweden is the first European airport to completely eliminate carbon emissions, without offsetting, from activities under its direct control through significant investment in renewable energy and energy efficiency measures.

Aircraft noise is another significant environmental challenge and airports play a crucial role in facilitating coordination between all relevant stakeholders to identify the most suitable noise mitigation measures based on the specific local circumstances and residents' needs. Airports can also play an important role in the implementation of these measures, for example by establishing or contributing to sound insulation schemes, which can involve investments of millions of euros. In addition to reducing aircraft noise, transparent and regular communication with residents has its own added value, enhancing trust and potentially reducing annoyance. The Dialogue Forum at Vienna Airport, which involves communities in noise-related decision-making, is one of the most successful examples of such engagement.

Innovation also drives activities of European airports in the environmental sphere. For example, London Gatwick Airport became the first airport worldwide to construct a plant onsite that converts cabin waste into energy, while Amsterdam Airport Schiphol is applying circular economy principles to the refurbishment of its car parks and lighting systems. Finally, the Norwegian airport operator Avinor has set the objective of enabling all Norwegian short-haul flights to become electric by 2040.

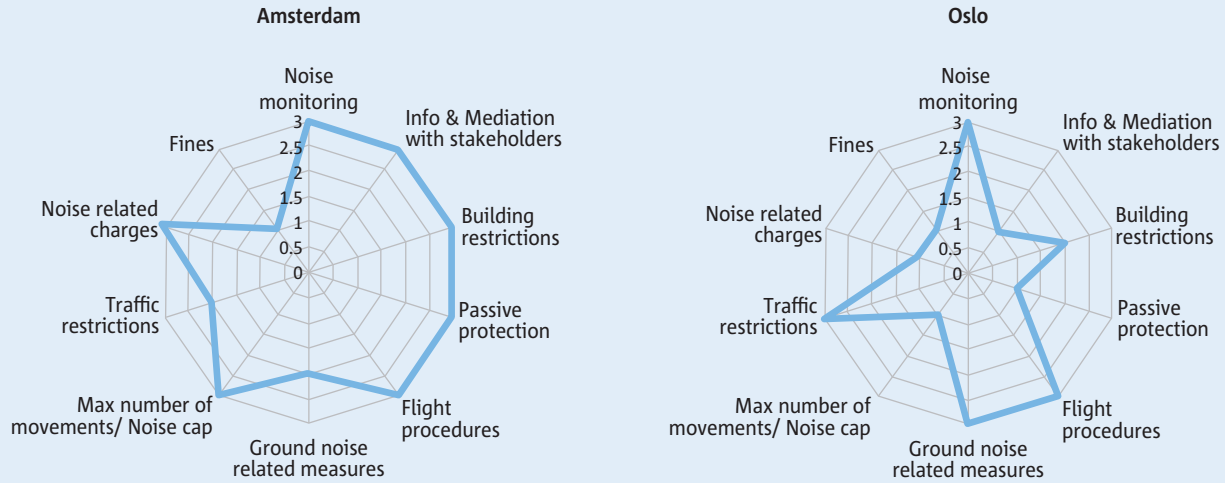
Airport Regions Conference (ARC)

ARC is an association of local and regional authorities with an international airport on their territories. It has over 30 members, representing nearly 70 million European citizens. More than half of European air traffic goes through an ARC airport. ARC Members are dedicated to balancing the economic benefits generated by the airport with their environmental impact.

Benchmarking noise policies: improving airport noise management and going beyond the balanced approach

ARC has developed a methodology to help decision-makers assess the implementation of noise policies at airports, taking into account both acoustical and non-acoustical factors. By comparing the implementation of mitigation measures that go beyond just the balanced approach, it is possible to 'map' the situation at an airport. Such mapping does not rank one airport against another, but allows for identification of actions that could be further developed.

For example, below is a comparison of noise policies at two different airports. Using this methodology, one can identify where there are areas and opportunities for improvement.



Some lessons from this benchmarking exercise:

- The balanced approach does not cover all the available tools for noise management.
- No situation is ever entirely comparable to another, and this tool supports decision-makers in identifying what can still be done.
- A comprehensive noise policy requires the cooperation of all stakeholders using an appropriate governance structure.
- No airport area is using all available tools, so there is always room for improvement.

Non-Governmental Organisations (NGOs)

Environmental NGOs[19] in Europe are actively involved in policy-making discussions to address the increasing environmental impacts of aviation. They communicate wider civil society views on concerns and positions associated with noise, air pollution, climate change and social justice.

Union Européenne Contre les Nuisances Aériennes (UECNA)

UECNA was created in 1968 and is a pan-European NGO representing citizens impacted from the nuisance of noise and air pollution associated with aviation. UECNA represents its members in expert work groups, mainly at the European level, and keeps them informed of new developments.

Aviation is growing and this trend will continue in the coming years. The consequences of noise and pollution on the health of populations overflown by aircraft are often not internalised within market prices. An awareness of these environmental challenges by all stakeholders, at the European, national and local level, is essential in order to identify and implement plans that will significantly reduce these impacts.

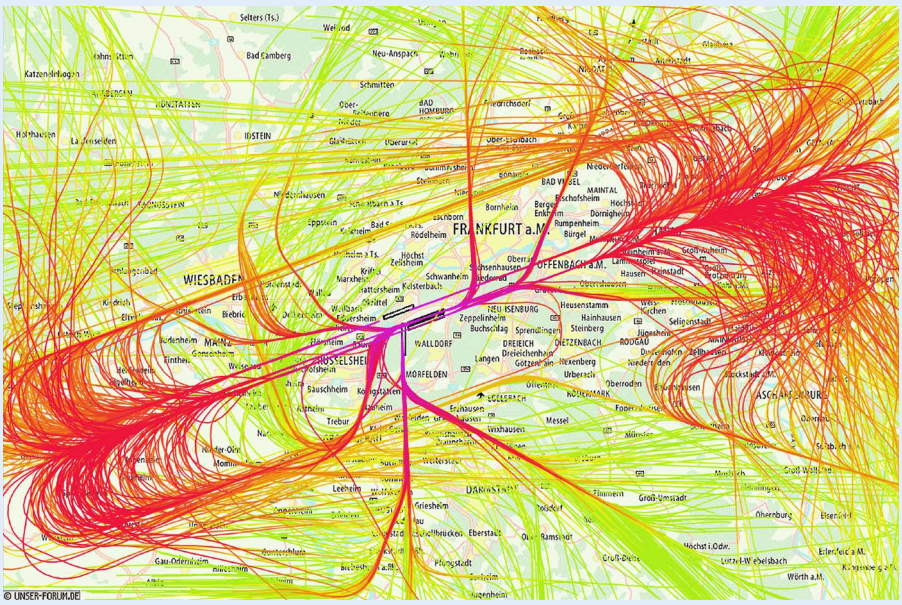
UECNA works continuously with this objective in mind. A constructive comparison process is an important element of progress that UECNA promotes. Through systematic benchmarking and positive comparisons of the solutions put in place at various airports, best practise solutions can be shared in order support general measures to reduce noise

19 This includes Transport & Environment, Aviation Environment Federation, Carbon Market Watch and UECNA who are members of the International Coalition for Sustainable Aviation. There is also a range of national NGOs such as RAC (France), Bund (Germany) active in the aviation area as well as many local action groups.

and air pollution. UECNA works closely with the European Aircraft Noise Measurement System (EANS) in this area.

Case Study: European Aircraft Noise Measurement System

The public can sometimes find it difficult to obtain information on aircraft noise in their area (e.g. noise levels, flight tracks). As a result, one such community near Frankfurt Airport decided to monitor aircraft noise itself. This led to the founding of the European Aircraft Noise Measurement System (EANS) as an NGO in 2002. Today, the EANS offers free online information about aircraft noise covering 54 airports with 697 noise monitoring stations in 8 European countries. The EANS system is financed by citizens and municipalities through membership fees and donations, and managed by Eidgenössische Materialprüfungsanstalt (EMPA) in Switzerland. It provides expert advice to technical working groups, and works closely with UECNA.



24 hours of flights at Frankfurt Airport on 13 July 2018

6. MARKET-BASED MEASURES

- **Market-based measures are instruments designed to address the climate impact of aviation, beyond what operational and technological measures or sustainable aviation fuels can achieve.**
- **Between 2013 and 2020, an estimated net saving of 193.4 Mt CO_2 (twice Belgium's annual emissions) will be achieved by aviation via the EU ETS through funding of emissions reduction in other sectors.**
- **In 2016, an agreement was reached at ICAO to set up the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). As of November 2018, 76 States intend to volunteer to offset their emissions from 2021, representing 76% of the international aviation activity.**
- **Emissions trading systems (e.g. ETS) and offsetting schemes (e.g. CORSIA) both address aviation emissions but differ in how they function. ETSs generally work towards economy-wide emission reduction targets, while offsetting schemes also compensate for emissions by reductions in other sectors but without the associated cap.**
- **The environmental effectiveness of offsets depends on robust implementation to ensure that the emission reductions delivered would not have occurred in the absence of the scheme.**

Market-based measures are part of the comprehensive approach needed to reduce aviation's emissions, as technological and operational measures alone are currently not sufficient to tackle the growing impact of the aviation sector on climate change. Market-based measures, comprising both cap and trading as well as offsetting schemes are designed to mitigate climate change through in-sector emission reductions or through incentivizing efforts outside of the aviation sector. This section provides an overview of the EU Emissions Trading System and ICAO's Carbon Offsetting and Reduction Scheme for International Aviation, as well as a brief comparison of the two approaches.

6.1 The EU Emissions Trading System

The EU Emissions Trading System (EU ETS) [73] is the cornerstone of the EU's policy to combat climate change. It is the EU's key tool for reducing, in a cost-effective manner, greenhouse gas emissions from the power and heat, industry and aviation sectors. This means that emissions are cut where the costs are lowest. Working as a cap and trade system with an ambitious reduction of emissions over time, the EU ETS either incentivises CO_2 mitigation within the sector, or through trading of allowances with other sectors of the economy where more options for reductions are available and abatement costs can be lower.

Aviation and the EU Emissions Trading System

In 2008, the EU decided to include aviation activities in the EU ETS [74]. Emissions from aviation are therefore subject to the EU's domestic greenhouse gas emission reduction targets of 20% and 40% for 2020 and 2030 respectively, and are thereby part of the EU's contribution to meeting the Paris Agreement objectives. In 2017, CO_2 emissions from aviation accounted for 3.6% of the EU's total CO_2 emissions and 13.4% of the EU's total transport greenhouse gas emissions [17].

The initial scope of the EU ETS covered all flights arriving at, and departing from, airports in the European Economic Area which includes the EU Member States, Norway, Iceland, Liechtenstein and closely related territories. However, flights to and from airports in non-European Economic Area countries have subsequently been excluded from the EU ETS until the end of 2023 through a temporary derogation. This exclusion, first resulting from the 'stop the clock' decision in 2013 [75], and subsequently extended [76, 77], was made to facilitate negotiation of a global market-based measure for international aviation emissions at the International Civil Aviation Organization (ICAO). ICAO decided on a roadmap for the development

of a global market-based measure at its 2013 Assembly, and agreed on a resolution containing the main parameters of the measure at its 2016 Assembly. The implementation of the offsetting requirements is foreseen from 2021.

Therefore, at present only flights between airports located in the European Economic Area are included in the EU ETS. Flights to and from the outermost regions of the EU are covered only if they occur in the same outermost region. This temporary scope derogation until the end of 2023 may be reviewed in the light of developments in the international context, also in view of CORSIA.

EUROCONTROL works with the European Commission, States and aircraft operators to support the implementation of the aviation element of the EU ETS, in particular to harmonise data and reduce compliance costs. The ETS Support Facility provides 24 States with access to ETS-related data, and provides traffic and emissions data to over 300 aircraft operators. The ETS List, which allocates aircraft operators to their administering States, is developed by EUROCONTROL and published annually by the European Commission.

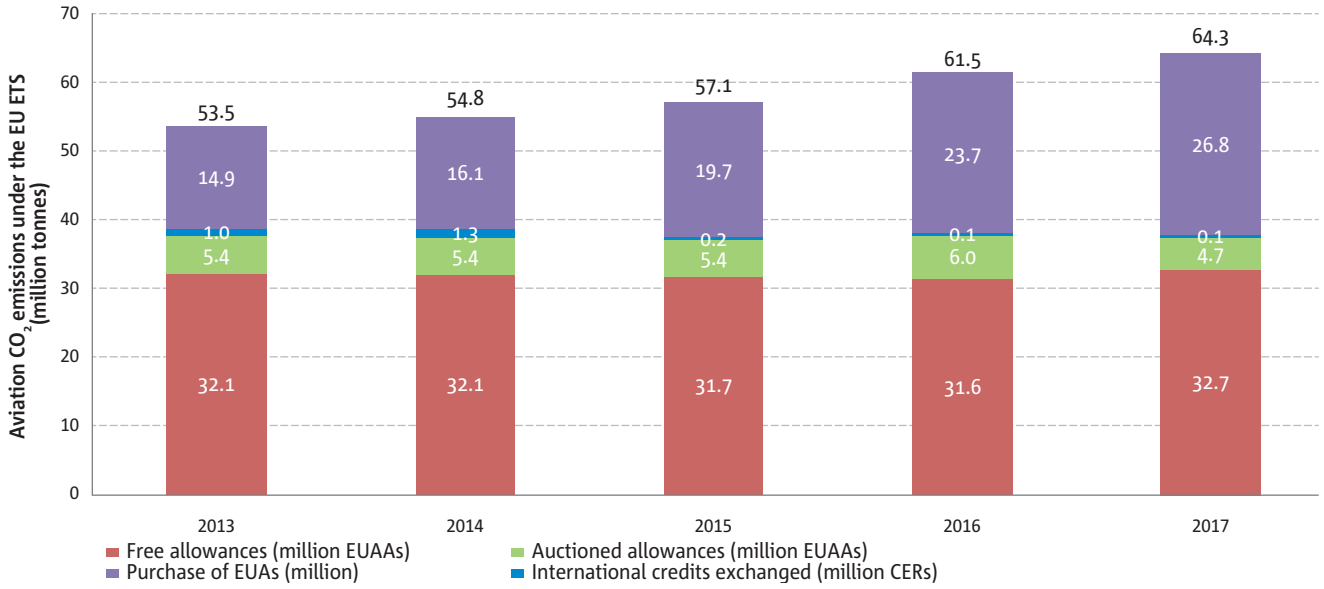
Aviation emissions under the ETS current phase (2013-2020)

The initial cap for aviation in the EU ETS was based on average historic aviation emissions between 2004 and 2006, representing 221.4 million tonnes (Mt) of CO_2 per year for all participating countries. The cap for aviation activities set for the current phase of the ETS (2013-2020) was set to 95% of these historical aviation emissions, adjusted for the change in applicability scope related to the 'stop the clock' decision. While aircraft operators may use aviation allowances as well as EU Allowances (EUAs) from the stationary sectors, stationary installations are not permitted to use aviation allowances for compliance. In addition, some international credits can be used by aircraft operators for up to 15% of their verified emissions in 2012. Since 2013, each aircraft operator is entitled to use certain international credits up to a maximum of 1.5% of its verified emissions during the current phase, in addition to any residual entitlement from 2012. In 2017, 677 operators, which included more than 200 non-European carriers, operated under the scope of the system.

During the 2013-2017 phase, the total verified CO_2 emissions from aviation covered by the EU ETS have increased from 53.5 Mt in 2013 to 64.3 Mt in 2017 [78]. This implies an average increase in CO_2 emissions of 4.7% per year.

Since 2013, with the scope of intra-European Economic Area flights in the EU ETS, the amount of annual EU Aviation Allowances (EUAAs) issued is around 37.5 Mt. The EUAAs cover emissions under the EU ETS cap for aviation. About 15% of these allowances are auctioned, while 85% are allocated for free. For CO_2 emissions exceeding the EU ETS aviation cap, aircraft operators have to purchase EU Allowances. The purchase of EU allowances by the aviation sector has gone up from 14.9 Mt in 2013 to 26.8 Mt in 2017. Over this period, there has been a total mitigation of over 100 Mt of CO_2 emissions in the European Economic Area achieved by incentivising emission reductions in all sectors covered by the ETS (Figure 6.1).

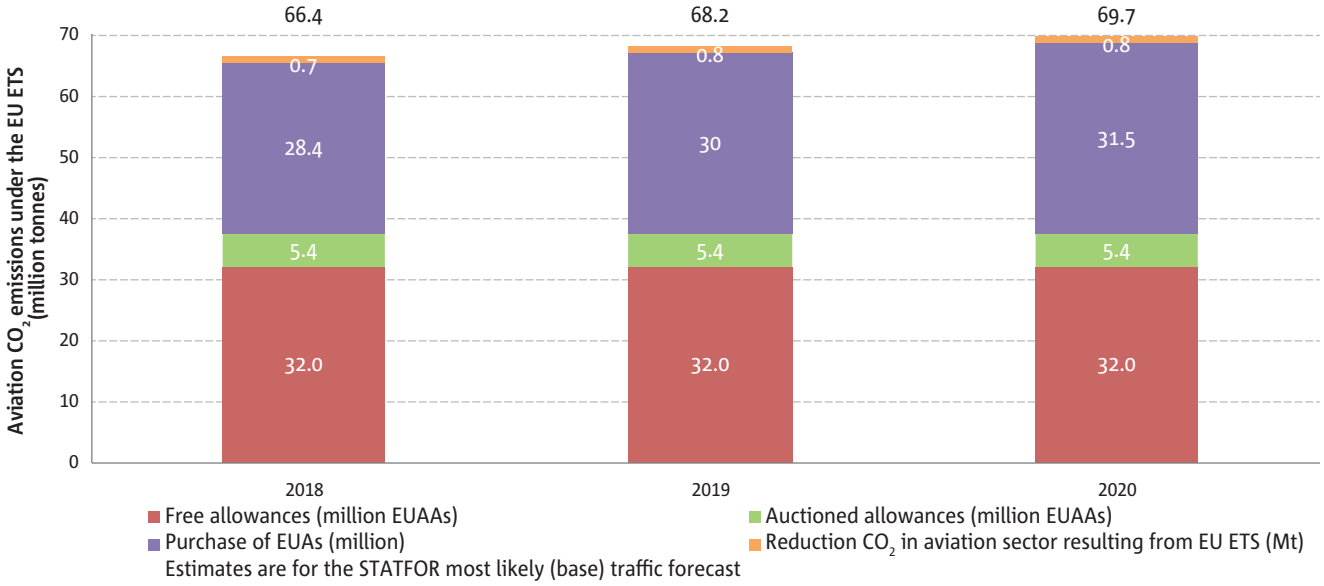
Figure 6.1 Aviation CO_2 emissions under the EU ETS in 2013-2017 (1 EUAA or EUA equals 1 tonne of CO_2)



EU ETS carbon prices varied between €4 and €6 per tonne of CO_2 during the 2013-2017 period [79]. Consequently, total aircraft operator costs linked to purchasing EU Allowances (EUAs) have gone up from around €89 million in 2013 to €189 million in 2017. For 2017, it is estimated that these EUA costs represent about 0.3% of total operating costs for aircraft operators on flights within the scope of the EU ETS. As of September 2018, EU Allowances representing one tonne of CO_2 were being traded at over €20, and consequently the fraction of operating costs is expected to be higher.

As shown in Figure 6.2, the total CO_2 emissions are expected to increase to 69.7 Mt in 2020 (+8.5% relative to 2017) and the purchase of EUAs by the aviation sector increases from 28.4 Mt in 2018 to 31.5 Mt in 2020. Moreover there could be a relative demand reduction within the aviation sector over the years 2018-2020 of 2.3 Mt, resulting in an overall aviation related emission reduction of 92.2 Mt for this period. In total, the net reduction in aviation related emissions for the entire 2013-2020 phase is estimated to be 193.4 Mt of CO_2 emissions.

Figure 6.2 Forecasted aviation CO_2 emissions under the EU ETS in 2018-2020 (1 EUAA or EUA equals 1 tonne of CO_2)



Aviation emissions under the ETS fourth phase (2021-2030)

For the fourth phase of the EU ETS, from 2021 to 2030, the system will see a number of modifications that will also affect the aviation sector [77, 80]. The linear reduction factor of 2.2% per year will also be applied to the aviation cap. Emission reductions will have to be exclusively domestic; therefore only EU Aviation Allowances (EUAAs) and EU Allowances (EUAs) will be eligible for compliance, as will be the case for all other sectors under the EU ETS.

The 2017 revision to the EU ETS Directive [77] includes a mandate from the European Parliament and the Council to the Commission to consider ways for CORSIA to be implemented in the EU through a revision of the Directive, consistent with the EU 2030 climate objectives. To that end, the Commission will conduct a comprehensive assessment including all relevant aspects of CORSIA's ambition and environmental integrity and, where appropriate, make a legislative proposal. Environmental integrity includes the need for proper mechanisms to prevent an offset from being counted twice.

6.2 Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

Background

In October 2016, the 39th General Assembly of ICAO Contracting States reconfirmed the 2013 objective of stabilising CO_2 emissions from international aviation at 2020 levels. In addition, the States adopted Resolution A39-3 [81], aiming to introduce a global market-based measure, namely the 'Carbon Offsetting and Reduction Scheme for International Aviation' (CORSIA), to offset international aviation's CO_2 emissions above 2020 levels through international credits. This major milestone, almost 20 years after the Kyoto Protocol to the UN Framework Convention on Climate Change, had called on States to work through ICAO to address international aviation emissions, and after the entry into force of the Paris Agreement, came as a result of the strong and sustained support by European States to address international emissions from aviation at a global level.

Since the end of 2016, international experts have been working in ICAO on the technical elements necessary for CORSIA's implementation. In June 2018, the ICAO Council approved the associated Standards and Recommended Practices (SARPs). To date, work is continuing on the additional 'Implementation Elements', which notably include rules on eligible fuels and emission units that can be used to comply with CORSIA offsetting requirements. Participating States will have to adopt the necessary national law in order to implement the provisions of CORSIA.

Europe's commitment towards CORSIA

On 3 September 2016, before the 2016 ICAO Assembly, the Directors General of Civil Aviation of EU Member States and the other Member States of the European Civil Aviation Conference (ECAC) signed the 'Bratislava Declaration'. This signalled their intention to fully implement CORSIA from the start of the pilot phase, provided that certain conditions were met, notably on the environmental integrity of the scheme and global participation. The Bratislava Declaration illustrated the commitment of the EU and ECAC States to address the growth of CO_2 emissions from international air transport and to achieving overall carbon neutral growth from 2020.

CORSIA scope and timeline

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, regardless of whether their administering State is participating or not in the offsetting phases, will be required to monitor, verify and report their CO_2 emissions during 2019 and 2020. Humanitarian, medical and firefighting operations are exempted. The average yearly CO_2 emissions reported during that period will represent the baseline for carbon neutral growth from 2020. Beyond 2020, the aviation sector will be required to offset its international CO_2 emissions above this level.

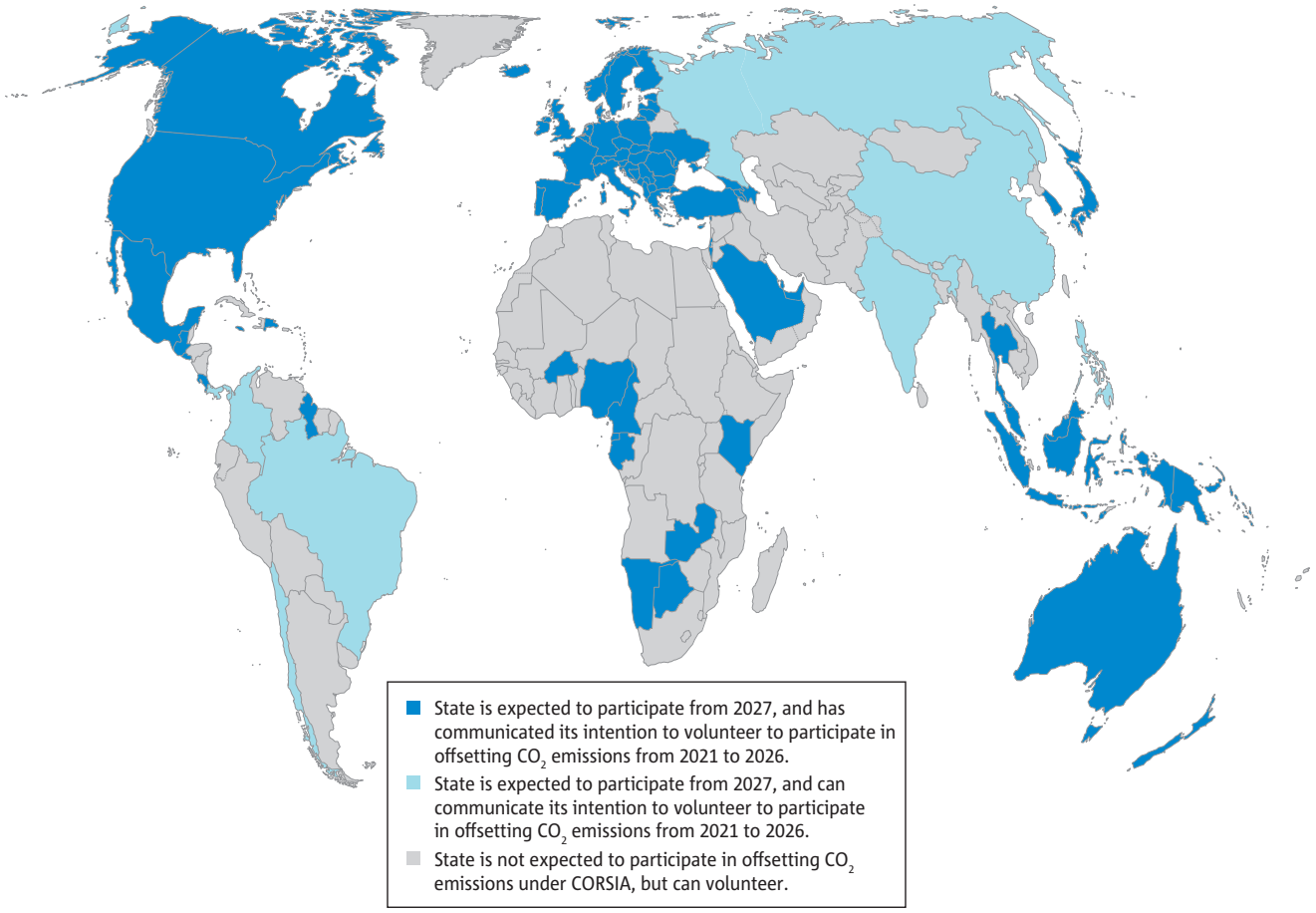
CORSIA operates on a route-based approach and applies to international flights, i.e. flights between two ICAO States. A route, defined by a pair of States, is covered by CORSIA offsetting obligations if both the State of departure and the State of destination are participating in the Scheme, and in this case the obligations are applicable to all aeroplane operators on the same route.

CORSIA comprises of three implementation phases: the pilot phase (2021-2023), a first phase (2024-2026) and a second phase (2027-2035). During the pilot phase and first phase, offsetting requirements will only be applicable to flights between States that have volunteered to participate. As of 5 November 2018, 76 States have officially notified ICAO that they intend to voluntarily participate in the pilot and first phase of CORSIA, representing approximately 76% of international aviation activity in terms of Revenue Tonne Kilometres (RTKs). States can notify their intentions for the year 2021 up until 30 June 2020, and thereafter on an annual basis during the voluntary period. The second phase will apply to all ICAO Member States within the agreed applicability scope, with certain exemptions:

- States with an individual share of international aviation activities in RTKs in year 2018 below 0.5% of total RTKs;
- States that are not part of the list of States that account for 90% of total RTKs when sorted from the highest to the lowest amount of individual RTKs; or
- Least Developed Countries (LDCs), Small Island Developing States (SIDS) and Landlocked Developing Countries (LLDCs).

However, States covered by the exemption criteria above can volunteer to participate. The contribution of CORSIA to stabilise international aviation emissions at 2020 levels is to some extent reliant on the level of participation of States in CORSIA.

Figure 6.3 ICAO Member States expected to join CORSIA in the various phases[20]



CORSIA in practice

Each international flight within the scope of CORSIA is attributed to an aeroplane operator, and each aeroplane operator is attributed to a State to which it has to submit an Emissions Monitoring Plan. Aeroplane operators monitor, verify and report their fuel use according to the approved plan, while their annual emissions offsetting requirements are calculated by the State. The monitoring of emissions applies to all flights, including those not subject to offsetting requirements. Offsetting requirements are calculated according to a dynamic approach to take into account the growth of the aviation sector and that of an individual aeroplane operator.

Aeroplane operators meet their offsetting requirements on a 3-year compliance period basis by purchasing and cancelling CORSIA eligible emissions units. Details on the cancellation of units, which must be verified by an independent verification body, are finally submitted by the aeroplane operator to its State. Aeroplane operators can reduce their offsetting requirements by using CORSIA eligible fuels that meet CORSIA sustainability criteria.

Capacity building activities

In 2013 the European Commission launched a project entitled "Capacity building for CO_2 mitigation from international aviation", with a total budget of €6.5 million covering 12 African States and 2 Caribbean States. This 4.5-year project, implemented by ICAO, improved the capability of less developed countries to measure, manage and reduce their aviation

20 Based on the information from ICAO website on States that have communicated their intention to volunteer to participate in offsetting CO_2 emissions from 2021 to 2026, accessed 5 November 2018, and latest 2016 ICAO data on States' individual share of the total international RTKs.

emissions in order to support their submission of ICAO State Action plans. The project contributed to international, regional and national efforts to address growing emissions from international aviation through a complementary set of activities.

Preceding the ICAO Assembly of October 2016, a declaration of intent was signed between Transport Commissioner Violeta Bulc and ICAO Secretary General Dr Fang Liu, announcing their intention to continue cooperation in addressing climate change, which included the implementation of CORSIA. Various EU international cooperation projects have subsequently been put in place during 2017 and 2018 to provide capacity building and technical assistance in the regions of China, South Asia, South East Asia, Africa and Latin America, including the Caribbean. While operating in different contexts each with their specificities, these projects all share the objective to pave the way for the practical implementation of CORSIA and the establishment, or further development, of effective State Action Plans targeting aviation emissions.

EASA and EUROCONTROL are also supporting the European Commission on the implementation of CORSIA both within Europe and internationally. This includes developing CORSIA functionality based upon the ETS Support Facility with a focus on collecting and harmonising data for monitoring, reporting and verification processes, and the execution of international cooperation programmes to continue capacity building that addresses aviation's climate impact around the world.

What is the difference between the EU ETS and CORSIA?

The EU Emissions Trading System (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 (heat and power as well as industry) and aircraft operators. The total number of emissions allowances is limited ('capped') and decreases over time, thus ensuring that the objective of an **absolute reduction of the level of CO_2 emissions** is met at the system level. In the case of the EU ETS, this is expected to lead to an economy-wide emissions reduction of 43% in 2030 compared to 2005 levels for the sectors covered by the ETS. The gradually more limited supply of allowances drives operators in need of additional allowances to buy them on the market from other sectors in the system – hence cap-and-*trade*. The need for additional allowances is determined by an operator's free allocation of allowances and actual emissions. The supply and demand for allowances establishes their price under the ETS, and the higher the price, the stronger the incentive to reduce emissions. As of September 2018, EU Allowances for CO_2 emissions were being traded at over €20 per tonne.

The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is an **offsetting** scheme. An offsetting scheme is a cost-effective solution for the aviation industry, as emissions reductions that cannot be achieved in the aviation sector can be compensated through emission reductions in other sectors where the potential for quicker reductions is greater and the associated costs are lower. This is based on the premise that greenhouse gas emission reductions benefit the climate irrespective of the sector in which they occur. The objective of CORSIA is to reach Carbon Neutral Growth 2020 - that is, to ensure that the emissions from international aviation do not exceed the 2020 levels. To that end, aeroplane operators will be required to purchase offset credits in order to compensate for emissions exceeding the 2019-2020 baseline. These offsets, also known as emission units, will be made eligible under CORSIA for purchase by aeroplane operators, provided that they comply with an established set of Emission Unit Criteria adopted at ICAO level. The eligible units contribute to achieving emissions reduction in various sectors of the economy, such as renewable energy or waste management. Each offset credit represents the certification that a tonne of CO_2 has been reduced or avoided compared to a scenario without CORSIA, meaning that the reduction would not have occurred in the absence of the offset-generating activity.

It is worth noting that ETS allowances are not currently accepted under CORSIA, and international offset credits, including those deemed to be eligible under CORSIA, will not be accepted under the ETS as of 1 January 2021.

7. AVIATION ENVIRONMENTAL IMPACTS

- **Long-term exposure to aircraft noise is linked with a variety of health impacts even at relatively low noise levels, including ischaemic heart disease, sleep disturbance, annoyance and cognitive impairment.**
- **The annoyance reported by residents for a given level of aircraft noise has been shown to be greater than that caused by other transport sources.**
- **Aviation is one of many sources that influence air quality, both in the vicinity of the airport and further afield. Although there remain knowledge gaps (e.g. impact of ultrafine particles), there are generally good estimates for the amount of pollutants emitted by aircraft and their health effects.**
- **A high level of scientific understanding of the long term climate effect from aviation CO_2 emissions make it a clear and important target for mitigation efforts.**
- **Climate impacts from non-CO_2 emissions (e.g. NO_x, particles) cannot be ignored as they represent warming effects that are important in the shorter term, but the level of scientific understanding of the magnitude of the effects is medium to very low.**
- **More States and organisations are taking action to adapt and build resilience to the impacts that climate change will have on the aviation sector (e.g. higher temperatures, rising sea-levels).**

A robust scientific understanding of the environmental impacts from aviation is an essential basis for informed policy discussions, and for the development of effective mitigation measures that achieve the desired outcome in a cost-effective way. This chapter provides an overview of the latest scientific understanding on the noise, air quality and climate change impacts from the aviation sector.

7.1 Noise

Impact of aviation noise

Millions of people in Europe are exposed to aircraft noise at residential communities in the vicinity of airports, and long-term exposure to these noise levels affects the health of individuals.

In 2018, the World Health Organization Europe summarised the scientific evidence in a guidance document [16] on the maximum acceptable outdoor noise levels to avoid health effects. The main World Health Organization Europe findings that link aviation noise and health effects are presented in Table 7.1. Additional health effects were reported, but the relationship with aircraft noise was considered inconclusive.

Table 7.1 Main health effects of aviation noise (Source: WHO Europe, 2018)

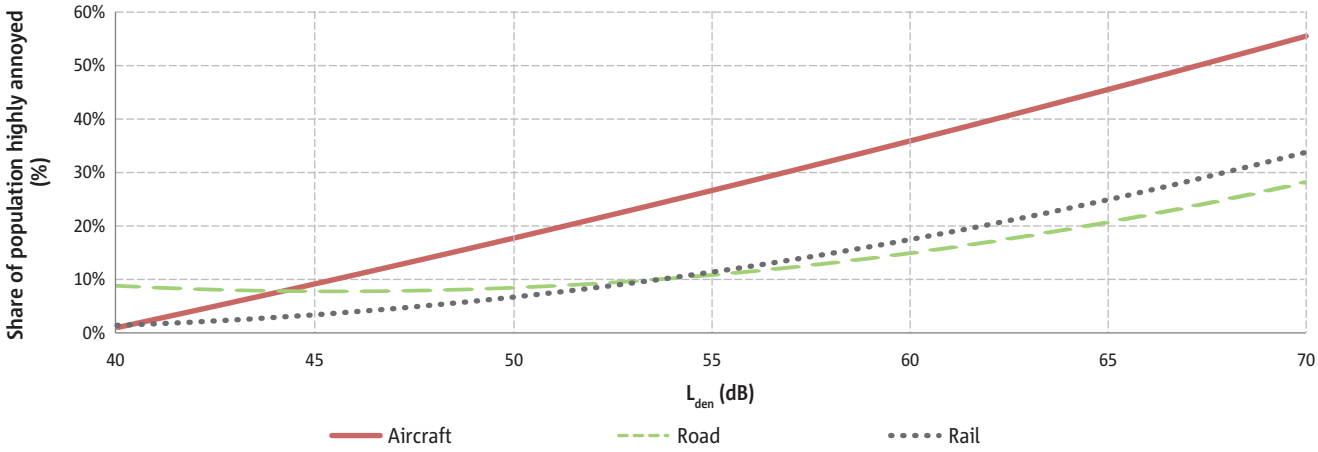
Health effect	Relationship
Annoyance	The effect is confirmed starting from L_{den} 45 dB and the estimate of the magnitude is quite reliable.
Sleep disturbance	The effect is confirmed starting from L_{night} 40 dB and the estimate of the magnitude is quite reliable.
Ischaemic heart disease	The effect is confirmed starting from about L_{den} 52 dB, but the estimate of the magnitude is not reliable.
Cognitive impairment in children	The effect is confirmed starting from L_{den} 55 dB and the estimate of the magnitude is reliable.

Aircraft noise annoyance

Annoyance is one of the most prevalent effects of noise [82, 83]. A high level of annoyance is considered to be a good indicator that there are health impacts resulting from environmental noise in a community.

The predicted community annoyance from aircraft noise is generally assessed through an 'exposure-response' relationship showing the expected percentage of people highly annoyed due to a range of aircraft noise exposure levels [84]. In Europe, noise exposure is assessed with the L_{den} noise indicator. Figure 7.1 illustrates the exposure-response relationships from the World Health Organization Europe guidelines for noise from various transportation modes.

Figure 7.1 Estimated percentage of people highly annoyed by noise from aircraft, road and rail (Source: WHO Europe, 2018)



As shown in Figure 7.1, aircraft noise is considered more annoying at the same noise exposure level than road or railway noise [85]. The tonality of the source noise, the frequency content or a negative attitude towards aircraft could be potential causes for this difference in reactions. Furthermore, while most buildings are not surrounded by roads or railways on all sides, aircraft noise arrives from above and may be harder to avoid.

It should be kept in mind that the above exposure-response curve for aircraft noise represents the average response over a range of studies conducted since the early 2000s. As circumstances and communities around airports can differ, local and scientifically robust exposure-response relationships may be preferred, if available, when assessing annoyance from aircraft noise around specific airports [86].

Noise-Related Annoyance, Cognition, and Health (NORAH) study

The NORAH study examined a range of health effects in the area around Frankfurt airport, both before and after a fourth runway was built [87, 88]. After the opening of the new runway, the reported annoyance initially increased but dropped again in the subsequent two years. However, the annoyance levels remained higher than the levels seen prior to the runway opening.

The study also captured the effects of a night flight ban. The introduction of a six-hour night flight ban from 23:00 to 05:00 had a positive overall effect on sleep. The ban reduced the number of awakenings in people that went to bed between 22:00-22:30 and got up between 06:00-06:30, although participants felt increasingly tired and sleepy in the mornings. Thus the introduction of the curfew on scheduled flights between 23:00 and 05:00 had not led to people making a more positive subjective evaluation of their sleep [89]. Furthermore, it was observed that people who had a critical attitude towards aircraft traffic were found to sleep less well than those supporting it.

7.2 Air quality

Air pollution has significant impacts on the health of the European population, particularly in urban areas [13]. The most significant pollutants in terms of harm to human health are particulate matter (PM), nitrogen dioxide (NO_2) and ground-level ozone (O_3).

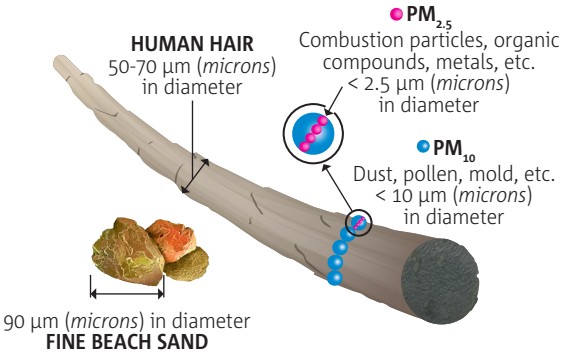
Aviation and air pollution

Air quality in the vicinity of airports is not just influenced by the emissions from aircraft engines, but also from other sources such as ground operations, surface access road transport and airport on-site energy generation and heating [90]. The most significant emissions related to health impacts from aviation activities are particulate matter (PM), nitrogen oxides (NO_X) and volatile organic compounds (VOCs). Some of these primary pollutants undergo chemical and physical transformations in the atmosphere that in turn produce other pollutants such as secondary particulate matter[21] and ground-level ozone.

Nitrogen oxides (NO_X)

NO_X emissions are primarily produced by the combustion of fossil fuels, especially at high temperatures such as those experienced in aircraft engine combustors. In the atmosphere, nitrogen monoxide (NO) is rapidly oxidised to nitrogen dioxide (NO_2), which is associated with adverse effects on human health such as lung inflammation. NO_2 also plays a key role in the formation of secondary particles and ground-level ozone. Thus, nitrogen oxides have both a direct and an indirect impact on air quality.

Particulate matter (PM)



Particulate matter is a general term used to describe very small solid or liquid particles. Emissions from aviation related activities, in a similar manner to other sources using carbon-based fuels, contain PM_{10} and $PM_{2.5}$ emissions[22], as well as ultrafine particles (PM_1, $PM_{0.1}$) that have very small diameters [91]. Such small particles, irrespective of the combustion source, can deposit in the human lung, pass natural barriers in human cells and enter the bloodstream. Solid ultrafine particles can trigger inflammation and act as carriers for toxic substances that damage the genetic information in cells. The EU Ambient Air Quality Directives [14] contain regulatory limits for PM_{10} and $PM_{2.5}$ in ambient air, but not for ultrafine particles. However, $PM_{2.5}$ is considered to be a good indicator of general risk associated with exposure to particulate matter. As the mass of the ultrafine particle emissions is so low, measurements of aircraft engine emissions have also focused on the number of emitted particles.

Ozone

The presence of ozone in the high-altitude stratosphere provides an essential natural shield against harmful ultraviolet radiation from the sun. However, ground-level ozone can cause several respiratory problems, including reduced lung function, bronchitis, emphysema and asthma.

Evaluating the impact of aviation emissions

Most evaluations of air quality impacts from aviation have focused on the health impacts of $PM_{2.5}$ formation attributable to aviation, with some others including the impact of ozone as well. Some studies [92, 93] have focused on landing and take-off emissions, as these happen at relatively low altitudes and therefore closest to local populations. A limited number of studies [94, 95] have also attempted to evaluate the impact of aviation emissions on human health at a global scale by including aircraft emissions at high altitude.

21 Secondary particulate matter is formed from chemical reactions in the atmosphere from the gases ammonia (NH_3), sulphur dioxide (SO_2) and nitrogen oxides (NO_x), and from organic compounds.

22 The subscript '10' in PM_{10} refers to particles with a diameter of less than 10 microns (0.01 millimetres).

Research Studies

1. Schiphol and Copenhagen airports

The emissions of air pollutants from Amsterdam Schiphol airport have been found to contribute less than 5% to ambient concentrations of PM_{10} and NO_2 near the airport, which suggest a limited impact on air quality [96]. However, in 2014 continuous measurements of ultrafine particles (total particle number per cubic centimetre of air), including condensed particles from gaseous precursors was performed at two different sites located 7 km and 40 km from the main airport site. While the emissions from aircraft did not lead to elevated particle concentrations in ambient air, it was found that they were the most important source of ultrafine particles during periods in which the predominant wind direction was from Schiphol.

A long-term occupational health study (1990-2012) at Copenhagen airport tracked the exposure to ultrafine particles and assessed the health of almost 70,000 people working in ground operations and other positions [97]. The results found no increased incidence of conditions linked to chronic exposure to air pollution such as heart disease, cerebrovascular disease, asthma, cancer or chronic obstructive pulmonary disease.

The results of both studies point to a knowledge gap in the formation, exposure and health effects of ultrafine particles from aviation that needs to be filled with additional research.

2. Medical faculty of the University of Bern

The REHEATE Project (Respiratory Health Effects of PM generated by Aircraft Turbine Engines) investigated the health effects of aircraft exhaust emissions on the human respiratory system. The study used a replicated human lung that provided realistic deposition of particles on normal and diseased lung cells from human donors.

The research thus far has focused on the characterization of the response to a high level of particle emissions from a common mid-sized turbofan engine, and a comparison to exposure of cells to filtered exhaust emissions. The tests were performed with both conventional and bio-based aviation fuels. Initial results suggest, as with other combustion sources (e.g. cars), significant responses of the lung cells. It supports the notion that control of the number of particles emitted, especially at low engine power settings, is important for health protection.

7.3 Climate change

Aviation emissions

The Intergovernmental Panel on Climate Change (IPCC) is the international body responsible for assessing the science related to climate change. It was set up in 1988 by the World Meteorological Organization and United Nations Environment Programme to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation. In October 2018, the IPCC published its Special Report into the impacts of global warming of 1.5°C above pre-industrial levels to support the Paris Agreement process. It concluded that climate warming due to human activities is currently estimated to increase by 0.2°C per decade due to past and ongoing emissions. In order to stabilise warming at 1.5°C, global net CO_2 emissions from human activities would have to decline to 45% of 2010 levels by 2030, reaching net zero by around 2050 [98].

The IPCC considers carbon dioxide (CO_2) as the principal greenhouse gas. Aviation represents approximately 2 to 3% of the total annual global CO_2 emissions from human activities and, in addition to CO_2, has impacts on climate from its non-CO_2 emissions (e.g. NO_x, particles).

How to quantify climate impacts?

Greenhouse gases and other emissions have complex effects on climate [99, 100, 101, 102]. The most common indicator of climate impact is a metric called 'Radiative Forcing (RF)', measured in watts per square metre (W/m^2). It represents the change since pre-industrialization, taken as 1750, in the balance between the energy received by the Earth from the Sun and the energy the Earth radiates back into space. RF is used as there is a good relationship between a change in global mean RF and climate warming in the form of a change in global mean equilibrium surface temperature [103]. It is also simpler to calculate than changes in global mean surface temperature, with positive values implying warming and negative values cooling.

Overall radiative forcing and aviation's contribution

Since the late 19th century, an overall climate warming of 0.78°C from man-made greenhouse gas emissions has resulted from a total RF increase of 2.29 W/m^2 [100]. A comprehensive assessment of aviation RF effects was last undertaken in 2009 [104] for a base year of 2005. The overall RF was 0.078 W/m^2, which represented 4.9% of the total RF increase as assessed by the IPCC for the Fourth Assessment Report [103].

Climate effects from aviation emissions

CO_2

Carbon dioxide (CO_2) emissions from burning fossil fuel accumulate in the atmosphere and can remain there for hundreds to thousands of years. Thus, in accounting for aviation CO_2 RF, emissions from the beginning of 'significant' civil aviation activities, usually taken as 1940, are used in the calculations of the marginal contribution of aviation to overall CO_2 concentrations in the atmosphere. Of the overall aviation RF for 2005, CO_2 RF was approximately 40%. The other 60% originates from non-CO_2 emissions.

The level of scientific understanding for this effect is 'high' [104].

NO_x

The overall RF effect from aircraft nitrogen oxides (NO_x) emissions at cruise altitude, via atmospheric chemistry, has a warming effect from the formation of short-term tropospheric ozone (O_3) and a near counterbalancing cooling effect from a reduction in ambient methane (CH_4). The overall balance is a positive RF and warming effect. Since 2009, smaller additional negative RF effects (cooling) associated with the CH_4 reduction have been identified and quantified, but the overall balance still remains one of warming.

The level of scientific understanding for this effect is 'medium – low' [104].

Contrail-cirrus clouds

Contrails are the line-shaped ice clouds formed behind cruising aircraft, and their presence and longevity are a function of the conditions of the background atmosphere. If the atmosphere is sufficiently cold and ice-supersaturated, these linear contrails can spread into large cirrus-cloud like structures. Such individual clouds can have both warming and cooling effects, although the overall global mean response is considered to be warming.

Improvements have been made in the quantification of both linear contrail RF and contrail-cirrus RF. As can be observed, contrails can spread into large cirrus cloud-like structures, which are estimated to have a larger RF impact than linear contrails. The IPCC [100] estimated that

persistent contrails had an RF of around 0.010 W/m^2, and a combined RF with contrail-cirrus of around about 0.050 W/m^2. This is 2 to 3 times the RF from historical aviation CO_2 emissions, but has a much wider uncertainty range than that of CO_2.

The level of scientific understanding for this effect is 'very low' [104].

Particles (direct effects)

Particles of soot and sulphate have a very small direct RF in terms of warming and cooling, respectively.

The level of scientific understanding for these effects are 'low' [104].

Cloudiness

The more recently discussed 'indirect' effects on cloud formation are also potentially important. It is not known whether the overall effect of soot particles on high-level clouds is warming or cooling, or if the magnitude is substantial or negligible in comparison with other non-CO_2 effects of aviation. The sulphate particles, however, have a well-understood negative RF effect, due to the lower-level cloud modification of droplet size distribution and optical brightness, but with an associated high level of uncertainty. Clearly much more work needs to be done to understand the magnitude and potential sign of these indirect cloudiness effects.

The level of scientific understanding for these effects are assessed as 'very low', by analogy to [104]*, based on underlying original research papers* [105, 106, 107, 108].

Conclusions

CO_2 emissions from aviation continue to increase steadily, and so does the CO_2 RF. Non-CO_2 impacts are also expected to have increased, roughly in proportion to fuel use. The non-CO_2 impacts still have larger uncertainties than those associated with CO_2, particularly impacts on clouds.

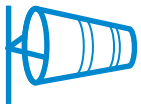
The high level of scientific understanding of the climate effect from aviation CO_2 emissions, combined with the long-term impacts of CO_2, make it a clear and important target for mitigation efforts. Nonetheless, non-CO_2 impacts cannot be ignored as they potentially represent approximately 60% of total climate impacts that are important in the shorter term (excluding cloudiness impacts). However, it worth noting that the level of scientific understanding of the magnitude of non-CO_2 impacts is medium to very low, and these knowledge gaps remain to be addressed.

Adapting aviation to a changing climate

1. Impacts on European aviation

Climate change continues to be a growing risk to the aviation sector, and stakeholders will need to consider this as part of their planning process and future investments (Table 7.2). The impacts of climate change on the European aviation sector will vary according to geography, climate zone and local circumstances [109, 110].

Table 7.2 Key potential risks for the European aviation sector from climate change [111]

Climate Effect		Aviation Impact
Temperature		
	Europe continues to warm more quickly than the global average: Scandinavia more in winter, southern Europe in summer	Aircraft performance Seasonal and geographical changes in tourism demand patterns Heat damage to infrastructure
Changes to rain & snow patterns		
	Less snow overall, but heavier events Less rain in the South, more in the North More heavy rainfall events	Delays and cancellations Flooding of airports and access routes Change in snow clearance needs
Changes to storm patterns		
	More uncertainty in the climate modelling here, but increase in frequency of strong and damaging storms	Delays, re-routing, increased fuel burn Loss of en route capacity Convective weather affecting multiple airports simultaneously
Sea level		
	Over longer term, sea level rise Uncertainty over storm surges	Permanent or temporary loss of airport capacity, infrastructure and access Network disruption
Changes to wind patterns		
	Change in jet stream strength, position and curvature Shifts in prevailing wind direction Increase in extreme wind speeds in the North and centre of Europe	Increase in clear air turbulence Increased variability in trans-Atlantic times and routes Crosswind changes affecting airport capacity Operational disruption

The understanding of the potential impacts of climate change on the aviation sector is continuing to evolve. During the period 2015-2018, the following new research results on climate adaptation have been published:

More turbulence: Climate change is expected to strengthen the North-Atlantic jet stream, thereby causing an increase in both the frequency and strength of moderate and severe en route clear-air turbulence along transatlantic flight paths [112]. However, new technologies are under development to both improve detection of potential areas of turbulence, and to exchange information between airspace users.

Changes in trans-Atlantic flight times: Changes to the strength of the North-Atlantic jet stream are likely to cause eastbound flights to be quicker and westbound flights to be slower. However, the overall effect is expected to be an increase in flight times and therefore fuel burn, emissions and costs [113, 114]. In early 2018 a new record of 5 hours 13 minutes was set for a New York-London flight time due to the temporarily increased strength of the jet stream.

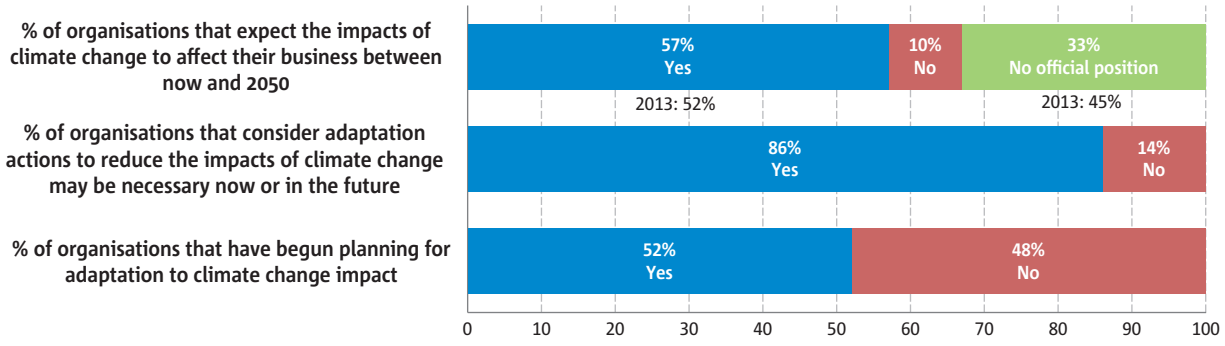
Heat restrictions: Higher average and extreme temperatures will have an impact on the general performance of aircraft. This is due to the fact that, as air temperature increases, air density decreases and lift is reduced so more thrust and runway length are required for take-off. It is not a new issue, and several airports around the globe already schedule departures for heavier aircraft at cooler times of the day to account for higher temperatures, higher altitudes or shorter runways. However, as the impact of climate change increases, such situations would become more common and require changes in schedules or reductions in payloads (cargo and passengers) [115].

2. Adaptation action in Europe

The EU Strategy on Adaptation to Climate Change [116, 117] provides a framework for adaptation with the purpose of increasing resilience and enhancing capacity to address climate change impacts. It includes three main objectives: (i) promote action by Member States, (ii) carry-out 'climate-proofing' action at EU level and (iii) facilitate better-informed decision-making. The Strategy is accompanied by a European Climate Adaptation online platform, which contains information on aviation infrastructure impacts and potential adaptation measures [118]. In September 2016, the Commission launched an evaluation of the Strategy which is due to be completed by the end of 2018.

An increasing number of organisations are starting to take action to adapt aviation to a changing climate, with initiatives at European, national, and organisational levels. In 2018, EUROCONTROL conducted a follow-up to its 2013 survey[23] asking European aviation stakeholders' views on climate adaptation, and the results are summarised in Figure 7.2. It highlights that while organisations are becoming more aware of the risks from climate change, not all of them have begun planning to adapt to this impact [111].

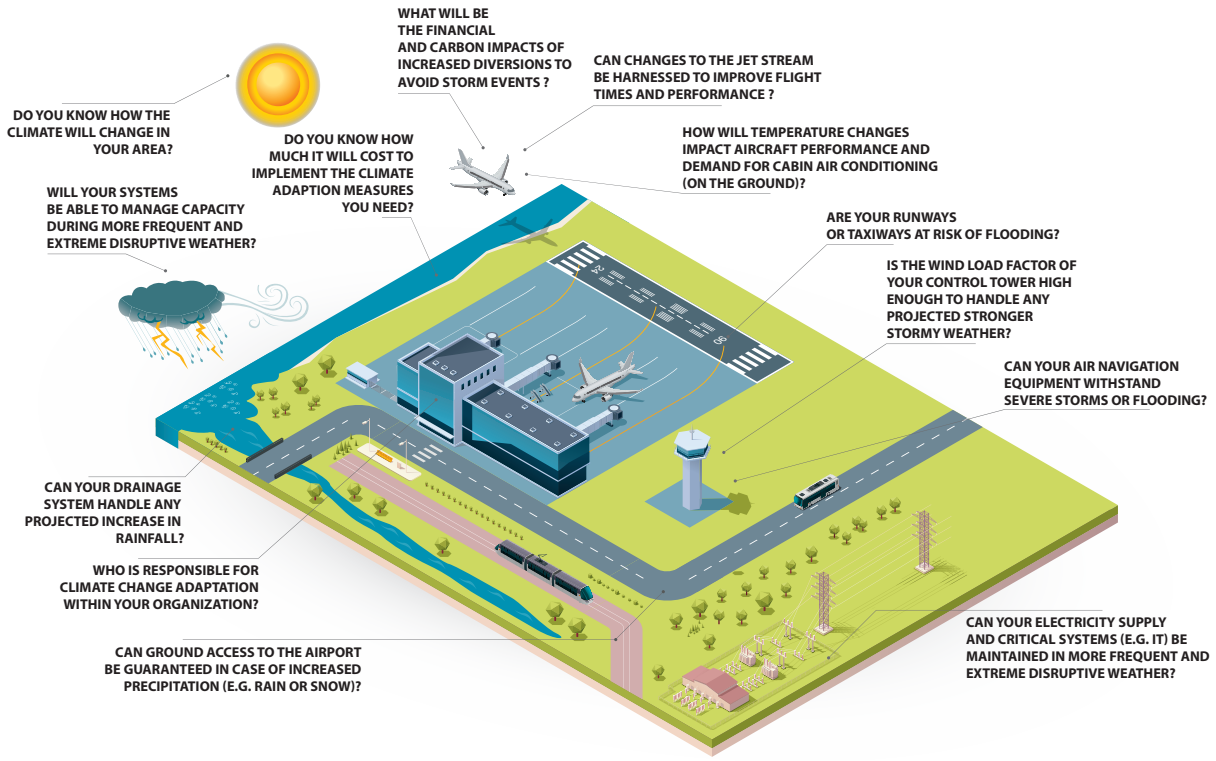
Figure 7.2 Responses to consultation on climate change impacts and adaptation



23 The survey was sent to about 200 organisations and 90 responded. Feedback covered all of the main European climate zones. Respondents were from a range of aviation stakeholders including civil aviation organisations, airport operators, ANSPs and airlines.

Some Member States include transport in their National Adaptation Plans, whilst others have launched specific aviation adaptation programmes. Industry organisations, such as airports and air navigation service providers, are also carrying out climate change risk assessments and putting adaptation plans in place (Figure 7.3) [119, 120]. Pre-emptive action is often considered as the best way to avoid future costs and damage. Potential risks and impacts will also vary greatly according to the specific local situation.

Figure 7.3 Getting started with risk assessment: a few key questions [119]



APPENDICES

APPENDIX A: LIST OF RESOURCES

Introduction

[1] EC, 2015, An Aviation Strategy for Europe.

[2] EEA, 2017, Aviation and Shipping – impacts on Europe's environment, Transport and Environment Reporting Mechanism (TERM) 2017, EEA Report No 22/2017.

[3] EU, 2013, Decision No 1386/2013/EU on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet'.

[4] EEA, 2014, Noise in Europe, EEA Report No 10/2014.

[5] EC, 1996, Future noise policy, European Commission Green paper, COM 96 (540).

[6] EC, 2002, Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise.

[7] EEA, 2010, Good practice guide on noise exposure and potential health effects, EEA Technical report No 11/2010.

[8] EU, 2014, Regulation (EU) 598/2014 of the European Parliament and the Council of 16 April 2014 on the establishment of rules and procedures with regard to the introduction of noise related operating restrictions at Union airports within a Balanced Approach and repealing Directive 2002/30/EC.

[9] EU, 2018, European Semester – Europe's growth strategy and 2020 targets.

[10] EEA, 2017, Trends and projections in Europe 2017, EEA Report No 17/2017.

[11] EU, 2018, EU climate and energy framework for 2020, 2030 and 2050.

[12] EC, 2011, White Paper, Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system, COM(2011) 144 final.

[13] EEA, 2017, Air quality in Europe – 2017 report, EEA Report No 13/2017.

[14] EC, 2008, Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe.

[15] EU, 2016, Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC new National Emission Ceilings Directive 206/2284.

Overview of Aviation Sector

[16] World Health Organization Europe, 2018, Environmental Noise Guidelines for the European Region.

[17] EEA, 2018, Greenhouse gas - data viewer.

[18] EEA, 2017, Transport and Environment Reporting Mechanism (TERM) 2017.

Technology and Design

[19] EU, 2018, Regulation (EU) No 2018/1139 of the European Parliament and of the Council of 4 July 2018 on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency.

[20] ICAO, 2017, Annex 16 to the Convention on International Civil Aviation — Environmental Protection, Volume I, 8th Edition — Aircraft Noise.

[21] ICAO, 2017, Annex 16 to the Convention on International Civil Aviation — Environmental Protection, Volume II, 4th Edition — Aircraft Engine Emissions.

[22] ICAO, 2017, Annex 16 to the Convention on International Civil Aviation — Environmental Protection, Volume III, 1st Edition — Aeroplane CO_2 Emissions.

[23] EASA, 2018, EASA certification noise levels.

[24] ICAO, 2014, Report of the Second CAEP Noise Technology Independent Expert Panel — Novel Aircraft-Noise Technology Review and Medium- and Long-term Noise Reduction Goals, Doc 10017, International Civil Aviation Organization.

[25] ICAO, 2018, ICAO Aircraft Engine Emissions Databank.

[26] UNFCCC, 2015, COP 21 Paris Agreement.

[27] EC, 2009, Regulation (EC) No 1005/2009 of the European Parliament and of the Council of 16 September 2009 on substances that deplete the ozone layer.

[28] NASA, 2018, Low Boom Flight Demonstration.

[29] EU, 2018, Horizon 2020 RUMBLE research and innovation project.

[30] Grewe V., Plohr M. et al., 2010, Estimates of the climate impact of future small-scale supersonic transport aircraft – results from the HISAC EU-project, the Aeronautical Journal, March 2010, Volume 114 No 1153.

[31] EU, 2018, SESAR U-space.

[32] EU, 2018, Clean Sky 2 Joint Undertaking.

[33] EC, 2011, Flightpath 2050, Europe's Vision for Aviation, Report of the High Level Group on Aviation Research, Publications Office of the European Union, Luxembourg.

[34] Clean Sky, 2017, Clean Sky 2 Joint Undertaking Development Plan.

Sustainable Aviation Fuels

[35] IRENA, 2017, Biofuels for aviation technology brief.

[36] Germany, 2017, Power-to-Liquids (PtL): Sustainable alternative fuels produced from renewable electricity.

[37] Roth, Schmidt, 2017, Power-to-Liquids: A new pathway to renewable jet fuel.

[38] F. Müller-Langer, S. Hausschild, C. Marquardt, T. Schripp, C. Wolf, 2018, Research and Demonstration Project on the Use of Renewable Jet fuel at Airport Leipzig/Halle.

[39] T&E, 2018, Roadmap to decarbonising European aviation.

[40] ASTM D4054, 2017, Standard Practice for Evaluation of New Aviation Turbine Fuels and Fuel Additives.

[41] ASTM D7566, 2018, Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons.

[42] EC, 2014, Technology Readiness Levels (TRL), Horizon 2020, Work Programme 2014-2015, General Annexes.

[43] CAAFI, 2018, Fuel Readiness Level definition.

[44] Vásquez, M. C., Silva, E. E., & Castillo, E. F., 2017, Hydrotreatment of vegetable oils: A review of the technologies and its developments for jet biofuel production.

[45] Mawhood, R., Gazis, E., de Jong, S., Hoefnagels, R., & Slade, R., 2016, Production pathways for renewable jet fuel: a review of commercialization status and future prospects.

[46] EC, 2015, State of the Art on Alternative Fuel Transport System in the European Union, Final Report.

[47] General Secretariat of the Council of the European Union, 2018, ST 15090/1/16 REV1 + ADD1REV1.

[48] Grassi, G., Camia, A., Fiorese, G., House, J., Jonsson, R., Kurz, W. A.,... & Vizzarri, M., 2018, Wrong premises mislead the conclusions by Kallio et al. on forest reference levels in the EU. Forest Policy and Economics, 95, 10-12.

[49] EU, 2015, Directive (EU) 2015/1513 of the European Parliament and of the Council of 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources.

[50] Greenea, 2018, And do you recycle your used cooking oil at home?

Air Traffic Management and Operations

[51] EC, 2004, Regulation (EC) No 549/2004 of the European Parliament and of the Council of 10 March 2004 laying down the framework for the creation of the single European sky (the framework Regulation).

[52] EU, 2013, Commission Implementing Regulation (EU) No 390/2013 of 3 May 2013 laying down a performance scheme for air navigation services and network functions.

[53] EU, 2014, Commission Implementing Decision 2014/132/EU of 11 March 2014 setting the Union-wide performance targets for the air traffic management network and alert thresholds for the second reference period 2015-19.

[54] European Court of Auditors, 2017, Single European Sky: a changed culture but not a single sky, Special report No 18/2017.

[55] EU, 2011, Commission Regulation (EU) No 677/2011 of 7 July 2011 laying down detailed rules for the implementation of air traffic management (ATM) network functions and amending Regulation (EU) No 691/2010.

[56] EU, 2011, Commission Decision C(2011) 4130 of 7 July 2011 on the nomination as the Network Manager for the air traffic management (ATM) network functions of the single European sky.

[57] EU, 2014, Council Regulation (EU) No 721/2014 of 16 June 2014 amending Regulation (EC) No 219/2007 on the establishment of a Joint Undertaking to develop the new generation European air traffic management system (SESAR) as regards the extension of the Joint Undertaking until 2024.

[58] EU, 2013, Regulation (EU) 409/2013 of 3 May 2013 on the definition of common projects, the establishment of governance and the identification of incentives supporting the implementation of the European Air Traffic Management Master Plan.

[59] CANSO, 2012, ATM Global Environment Efficiency Goals for 2050.

[60] SESAR JU, 2015, eATM Portal – European ATM Master Plan.

[61] SES, 2018, Performance Review Body.

[62] European ATM stakeholders, 2018, European CCO and CDO Task Force Report.

[63] SES Network Manager, 2018, Airport Collaborative Decision Making.

[64] SES Network Manager and EUROCONTROL, 2016, A-CDM Impact Assessment.

Airports

[65] ANP Database, 2018, An international data resource for aircraft noise modellers.

[66] ICAO, 2008, Guidance on the Balanced Approach to Aircraft Noise Management, Doc 9829 AN/451, International Civil Aviation Organization.

[67] ICAO, 2014, PANS-OPS Procedures for Air Navigation Services — Aircraft Operations, Doc 8168, Volume I — Flight Procedures, Part V, Chapter 3, International Civil Aviation Organization.

[68] EUROCONTROL, 2018, Specification for Collaborative Environmental Management.

[69] EC, 2006, Directive 2006/93/EC of the European Parliament and of the Council of 12 December 2006 on the regulation of the operation of aeroplanes covered by Part II, Chapter 3, Volume 1 of Annex 16 to the Convention on International Civil Aviation, second edition (1988).

[70] ICAO, 2016, Resolution A39-1, Consolidated Statement of continuing ICAO policies and practices related to environmental protection – General provisions, noise and local air quality.

[71] EC, 2017, Support study to the ex-post evaluation of Directive 2009/12/EC on Airport Charges.

[72] Airport Carbon Accreditation, 2018, Airport Carbon Accreditation Annual Reports.

Market-Based Measures

[73] EC, 2003, Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC.

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

[75] EU, 2013, Decision No 377/2013/EU of the European Parliament and of the Council of 24 April 2013 derogating temporarily from Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community.

[76] EU, 2014, Regulation (EU) No 421/2014 of the European Parliament and of the Council of 16 April 2014 amending Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community, in view of the implementation by 2020 of an international agreement applying a single global market-based measure to international aviation emissions.

[77] EU, 2017, Regulation (EU) 2017/2392 of the European Parliament and of the Council of 13 December 2017 amending Directive 2003/87/EC to continue current limitations of scope for aviation activities and to prepare to implement a global market-based measure from 2021.

[78] EEA, 2018, EU ETS data viewer. Data extracted on 31/5/2018.

[79] EEX Group, 2018, Market Data - Environmental markets.

[80] EU, 2018, Directive (EU) 2018/410 of the European Parliament and of the Council of 14 March 2018 amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments, and Decision (EU) 2015/1814.

[81] ICAO, 2016, Resolution A39-3: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Global Market-based Measure (MBM) scheme.

Aviation Environmental Impacts

[82] Basner M, Babisch W, Davis A, Brink M, Clark C, Janssen S, Stansfeld S., 2013, Auditory and non-auditory effects of noise on health.

[83] World Health Organization Europe, 2011, Burden of disease from environmental noise — Quantification of healthy life years lost in Europe.

[84] H.M.E. Miedema, 2007, Annoyance caused by environmental noise: Elements for evidence-based noise policies.

[85] H.M.E. Miedema, C.G.M. Oudshoorn, 2001, Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals.

[86] Basner M, Clark C, Hansell A, Hileman JI, Janssen S, Shepherd K, et al., 2017, Aviation noise impacts: state of the science.

[87] Forum Flughafen & Region Umwelt-und Nachbarschaftshaus, 2015, NORAH Knowledge No. 14 - NORAH Noise Impact Study Overview of Results.

[88] Guski, R., Klatte, M., Moehler, U., Muller, U., zur Nieden, A., Schreckenberg, D., 2016, NORAH (Noise Related Annoyance, Cognition and Health): Questions, designs and main results.

[89] Forum Flughafen & Region Umwelt-und Nachbarschaftshaus, 2015, NORAH Knowledge No. 10 - Aircraft noise and nocturnal sleep.

[90] Zurich Airport, 2013, Zurich Airport Regional Air Quality Study 2013.

[91] ACI EUROPE, 2018, Ultrafine Particles at Airports.

[92] Zurich Airport, 2017, Taxi-Emissions at Zurich Airport - Calculation Analysis and Opportunities.

[93] Zurich Airport, 2018, Ultrafine Particle Measurements at Zurich Airport.

[94] Barrett et al., 2010, Global Mortality Attributable to Aircraft Cruise Emissions.

[95] Yim et al., 2015, Global, regional and local health impacts of civil aviation emissions.

[96] Keuken et al., 2015, Total and size-resolved particle number and black carbon concentrations in urban areas near Schiphol airport (the Netherlands), Atmospheric Environment 104 (2015), p. 132-142.

[97] Syddansk Universitet et al., 2016, Helbredsskader og partikelforurening i Københavns Lufthavn, Kastrup.

[98] IPCC, 2018, IPCC special report on the impacts of global warming of 1.5°C.

[99] IPCC, 1999, Special Report on Aviation and the Global Atmosphere.

[100] IPCC, 2013, Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report.

[101] IPCC, 2014, Climate Change 2014: Impacts, Adaptation, and Vulnerability Part A: Global and Sectoral Aspects. Working Group II Contribution to the Fifth Assessment Report.

[102] IPCC, 2014, Climate Change 2014 Mitigation of Climate Change Working Group III Contribution to the Fifth Assessment Report.

[103] IPCC, 2007, Climate Change 2007. The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report.

[104] Lee D. S., Fahey D., Forster P., Newton P.J., Wit R.C.N., Lim L.L., Owen B., Sausen R., 2009, Aviation and global climate change in the 21st century.

[105] Righi M., Hendricks J., and Sausen R., 2016, The global impact of the transport sectors on atmospheric aerosol in 2030 – Part 2: Aviation.

[106] Pitari G., Iachetti D., Di Genova G., De Luca N., Amund Søvde O., Hodnebrog Ø., Lee D.S. and Lim L., 2015, Impact of Coupled NOx/Aerosol Aircraft Emissions on Ozone Photochemistry and Radiative Forcing.

[107] Kapadia Z. et al., 2016, Impacts of aviation fuel sulfur content on climate and human health.

[108] Zhou C. and Penner J., 2014, Aircraft soot indirect effect on large-scale cirrus clouds: Is the indirect forcing by aircraft soot positive or negative?

[109] EEA, 2014, Adaptation of transport to climate change in Europe, EEA Report No 8/2014.

[110] EEA, 2017, Climate change, impacts and vulnerability in Europe 2016, EEA Report No 1/2017.

[111] EUROCONTROL, 2018, European Aviation in 2040: Challenges of Growth.

[112] Williams, P. D., 2017, Increased Light, Moderate, and Severe Clear-Air Turbulence in Response to Climate Change.

[113] Williams, P. D., 2016, Transatlantic flight times and climate change.

[114] Irvine, E., Shine, K. Stringer, M., 2016, What are the implications of climate change for trans-Atlantic aircraft routing and flight time?

[115] Coffel, E.D., Thompson, T.R. and Horton, R.M., 2017, The impacts of rising temperatures on aircraft take-off performance.

[116] EU, 2013, The EU Strategy on adaptation to climate change.

[117] EC, 2013, Adapting infrastructure to climate change, Commission Staff Working Document.

[118] EC and EEA, 2015, Climate-ADAPT — European Climate Adaptation Platform.

[119] EUROCONTROL, ACI EUROPE, AENA, Avinor, DGAC, Heathrow, NATS, Manchester Metropolitan University, 2014, Adapting Aviation to a Changing Climate Factsheet.

[120] EC and EEA, 2015, Climate-ADAPT — European Climate Adaptation Platform: Adaptation Support Tool.

APPENDIX B: ACRONYMS AND UNITS

ATM	Air Traffic Management
CAEP	Committee on Aviation Environmental Protection
CO / CO_2	Carbon monoxide / dioxide
dB	decibel
EASA	European Union Aviation Safety Agency
EC	European Commission
ECAC	European Civil Aviation Conference
EEA	European Environment Agency
EFTA	European Free Trade Association
EPNdB	Effective Perceived Noise decibel
ETS	EU Emissions Trading System
EU	European Union
EU28	28 Member States of the European Union
ft	feet
gCO_2eq	gram of carbon dioxide equivalent
GHG	Greenhouse gas
HC	Hydrocarbons
ICAO	International Civil Aviation Organization
kg	kilogram
km	kilometre
kN	kilonewton
lbf	pound (force)
L_{den} / L_{night}	Day-evening-night / Night-time sound pressure level
LTO	Landing and Take-Off
MJ	megajoule
Mt	megatonne, million metric tonnes
MTOW	Maximum take-off weight
NO_x	Nitrogen oxides
PM	Particulate matter
RTK	Revenue tonne kilometre
SES	Single European Sky
SESAR	Single European Sky ATM Research
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 Chapter 1 (Overview of Aviation Sector) and Chapter 2 (Technology and Design). These modelling capabilities have been developed and used to support various European initiatives, including SESAR and Clean Sky, as well as international policy assessments in ICAO CAEP.

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 28 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, Sweden and the United Kingdom. EFTA members are Iceland, Liechtenstein, Norway and Switzerland.

Data sources

PRISME[24]

Historical 2005-2017 flight operations were extracted from the EUROCONTROL database of filed flight plans called PRISME. PRISME covers all Instrument Flight Rules 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 (PRISME Fleet).

Eurostat[25]

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 Chapter 1 are based on Eurostat directly, on analysis of other Eurostat flows and on data from PRISME. The great circle (i.e. shortest) distance between airport pairs is used when reporting passenger kilometres, while the actual flown distance is used when calculating the average fuel consumption.

STATFOR[26]

The EUROCONTROL STATFOR 20-year forecast that was published in 2018 provided the traffic volumes from 2017 to 2040 used in this report. In this report, we focused on three of the four forecast scenarios: Regulation & Growth is the most-likely or 'base'; Global Growth gives the 'high'; and Fragmenting World gives the 'low'. The forecast was prepared as part of the Challenges of Growth 2018[27] study. 112 airports provided future capacity plans to this study, and the forecast traffic respects the capacity constraints implied by these plans.

24 www.eurocontrol.int/service/operator-fleet-airframe-data
25 ec.europa.eu/eurostat/data/database
26 www.eurocontrol.int/statfor
27 www.eurocontrol.int/articles/challenges-growth

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 aircraft types operating in the European region. The latest BADA 4 family provides increased levels of precision in aircraft performance parameters over the entire flight envelope, and covers 70% of aircraft types operating in the European region. This report uses BADA 4, complemented by BADA 3 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 the US Department of Transportation, EUROCONTROL and EASA. It provides the noise and performance characteristics for over 150 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 and European bodies. EASA is responsible for collecting, verifying and publishing ANP data for aircraft which fall under the scope of Regulation (EU) 598/2014.

EASA Certification Noise Levels[28]

EASA maintains a database of all aircraft noise certification levels which the Agency has approved. The database provides certified noise levels for over 34,000 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 chapter.

ICAO Aircraft Engine Emissions Databank (EEDB)[29]

The ICAO Aircraft Engine Emissions Databank (EEDB) hosted by EASA contains Landing and Take-Off (LTO) emissions data for NO_X, HC, CO as well as smoke number for over 400 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[30]

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.

CODA Taxi Times Database[31]

EUROCONTROL's Central Office for Delay Analysis (CODA) collects flight-by-flight data from around 100 airlines and 130 airports, such as actual off-block and take-off times, and delay causes. Largely this is on a voluntary basis in return for performance and benchmarking information, but increasingly the data collection is influenced by the EU performance regulations [52]. 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.

28 www.easa.europa.eu/easa-and-you/environment/easa-certification-noise-levels
29 www.easa.europa.eu/easa-and-you/environment/icao-aircraft-engine-emissions-databank
30 www.foi.se/en/our-knowledge/aeronautics-and-air-combat-simulation/fois-confidential-database-for-turboprop-engine-emissions.html
31 www.eurocontrol.int/coda

Population Data[32]

The JRC Global Human Settlement population grid was used to calculate the number of people exposed to aircraft noise. This spatial dataset, developed in the European Copernicus Program, depicts the distribution and density of residential population. The dataset is generated using the 2011 censuses provided by Eurostat/GEOSTAT and the best available sources by country. The initial 1 km resolution has been further disaggregated to 100 m based on information from Corine Land Cover Refined 2006 and the European Settlement Map 2016.

Models and methods

IMPACT

IMPACT is a web-based modelling application used to assess the environmental impacts of aviation, and whose development, initiated in the context of the SESAR 1 programme, has since been steered and carried out by EUROCONTROL. It allows the consistent assessment of trade-offs between noise and full-flight gaseous emissions thanks to a common advanced aircraft performance-based trajectory model using a combination of the ANP database and the latest release of the BADA family. CO_2, NO_X, HC, CO and PM emissions are computed using the LTO emission indices in the ICAO EDB and FOI Turboprop Emissions database combined with the Boeing Fuel Flow Method 2 (BFFM2). PM emission indices of jet engines are estimated using the First Order Approximation (FOA3.0) method[33]. Both BFFM2 and FOA3.0 methods are detailed in the ICAO Airport Air Quality Manual (Doc 9889). The IMPACT methodology and data to assess fuel burn and emissions may differ from that 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 ECAC Doc 29 modelling methodology, combined with a database of airports with information on runway and route layout, as well as the distribution of aircraft movements over these runways and routes. The 47 European airports within EU28 and EFTA modelled in STAPES are estimated to cover approximately three quarters of the total population exposed to aircraft noise levels of L_{den} 55 dB and above in this region.

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 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 now an integral part of the STATFOR 20-year forecast methodology. The forecast operations are processed through the IMPACT and STAPES models to assess the fuel burn, emissions and noise data in 2025, 2030, 2035 and 2040 presented in the Sector Overview chapter.

AERO

AERO is an application owned by EASA that is used to examine the impacts of different policies intended to reduce international and domestic aviation greenhouse gas emissions. AERO can assess the consequences of a wide range of policy measures aimed at reducing aviation emissions, including technological, operational and market-based measures. For this report, AERO was used to assess the impact of the EU Emissions Trading System in years 2018, 2019 and 2020 based on the STATFOR medium-term 'Base' forecast (see Sector Overview and Market-Based Measures chapters) and traffic data supplied by EUROCONTROL. No analysis was conducted beyond 2020 due to on-going discussions on ways to implement CORSIA in the EU through a revision of the ETS Directive, which would be consistent with the EU 2030 climate and energy framework.

32 European Commission, Joint Research Centre (JRC) [Dataset]

33 Due to the lack of smoke number data for turboprop engines, PM estimates currently exclude this category. As an indication, turboprop aircraft represented approximately 1.5% of the total fleet fuel burn in 2017.

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 EU28 or EFTA, i.e. flights coming from outside EU28 or EFTA are not included. In contrast, emissions below 3,000 feet and noise indicators include all departures and all arrivals. Historical fuel burn and emission calculations are based on the actual flight plans from PRISME, including the actual flight distance and cruise altitude by airport pair. Future year fuel burn and emissions are based on actual flight distances and cruise altitudes by airport pair in 2016. Future taxi times are assumed to be equal to the 2017 taxi times; where non available, ICAO default taxi times are applied. Helicopter operations are excluded from the assessment.

For the STAPES noise assessments, the number of airports, together with their respective runway and route layout, 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 [6] 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. Population density around airports was also assumed to remain unchanged throughout the analysis period. 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 47 airports modelled in STAPES, the noise generated by aircraft take-offs and landings at all airports in the EU28 and EFTA area was estimated via the noise energy index, defined as:

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

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[34].

Noise exposure-response curves

To estimate the total population highly annoyed (HA) and highly sleep disturbed (HSD) by aircraft noise, the following exposure-response regression curves recommended by WHO for the European region were used [16]:

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

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

The total population at the 47 major airports in STAPES was assessed for L_{den} 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.

34 For Chapter 6 and 10 aircraft (light propeller), the unique overflight or take-off level is used for the three values.

Future fleet technology scenarios

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

The most conservative 'frozen technology' scenario assumes that the technology of new aircraft deliveries between 2017 and 2040 remains as it was in 2017. Under this scenario, the 2017 in-service fleet is progressively replaced with aircraft available for purchase in 2017. 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 2017 onwards following a single 'advanced' technology scenario. This technology scenario was derived from analyses performed by groups of Independent Experts for the ICAO CAEP, and is meant to represent the maximum noise and emission reductions that can be expected from aircraft and engine technology by 2040.

For noise, the advanced technology scenario modelled for this report assumes a reduction of 0.1 EPNdB per annum at each noise certification point for new aircraft deliveries. The previously reported 0.3 EPNdB reduction per annum scenario was considered too optimistic given the recent improvement in aircraft noise technology and the general trend towards heavier aircraft, and was therefore left aside.

For fuel burn and CO_2, the advanced technology scenario assumes a 1.16% improvement per annum for new aircraft deliveries[35]. For NO_X, the scenario assumes a 100% achievement of the CAEP/7 NO_X Goals by 2036[36]. No technology improvement was applied when estimating future HC, CO and PM emissions.

Lastly, the technology improvement assumptions do not take into account potential future aircraft designs like supersonic or counter-rotating open rotor powered aircraft.

Future ATM improvements

The existing ATM system efficiency is assumed to remain unchanged despite future increases in overall air traffic. As a first order approximation, fuel burn and emission gains can be directly deducted from the projected ATM-related fuel efficiency gains (e.g. a 3% fuel efficiency improvement can be assumed to generate a 3% reduction in total fuel burn and emissions).

35 ICAO Environmental Report 2010 (p. 33).
36 ICAO Environmental Report 2010 (p. 29).

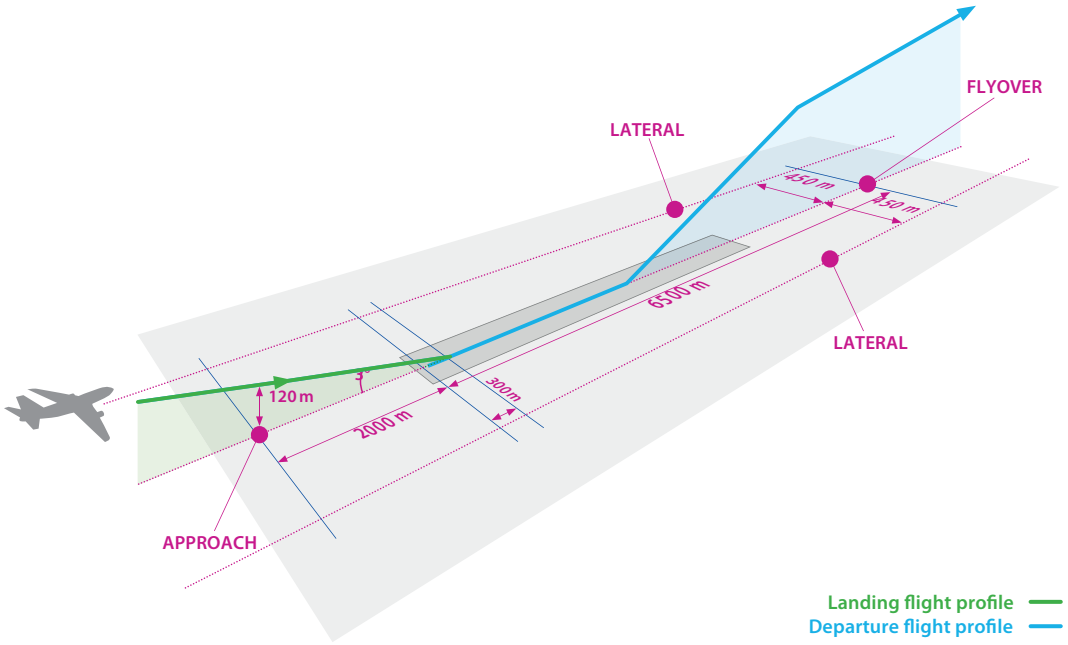
APPENDIX D: CERTIFICATION MEASUREMENT PROCEDURES

This appendix provides an overview of the EASA certification measurement procedures for aircraft noise, aircraft engine emissions and aeroplane CO_2 emissions, which are based on ICAO Annex 16 Volumes I, II and III respectively.

1. Aircraft noise

The noise of jet and heavy propeller-driven aircraft is measured at three different measurement points (approach, lateral and flyover – see Figure D.1) in order to characterise the aircraft noise performance around an airport. The certified noise levels are measured in Effective Perceived Noise decibels (EPNdB) which is a metric that represents the human ear's perception of aircraft noise.

Figure D.1 Three noise certification measurement points

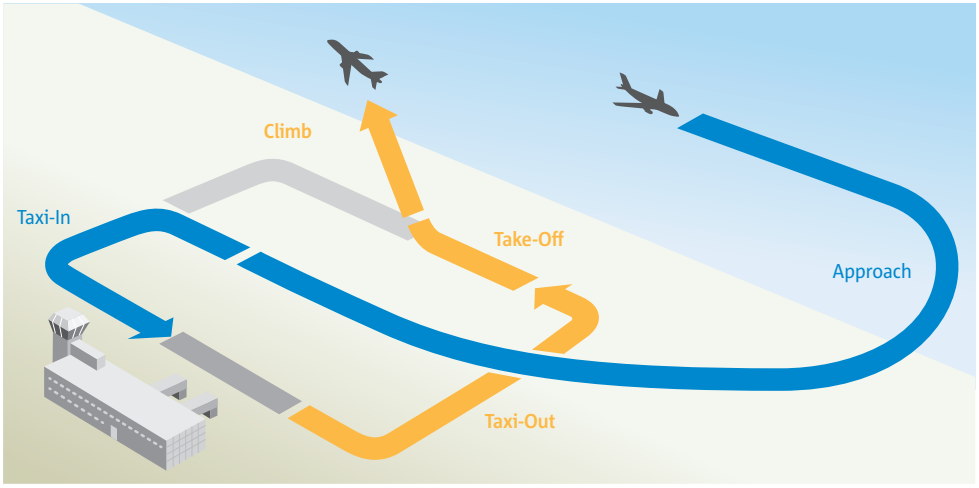


The certification requirements define noise limits that shall not be exceeded at each of the three measurement points and, in the case of the latest standards, an additional limit based on the sum of the three noise levels (cumulative limit). These noise limits are referred to as Chapters 2, 3, 4, 5 and 14 of the ICAO noise requirements, and represent the increasingly stringent standards developed over time.

2. Aircraft engine emissions

The ICAO emissions certification standards are designed to regulate smoke and various gaseous emissions from aircraft engines, including unburned hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x) and non-volatile particulate matter (nvPM). The smoke limit was set to control visible emissions, whereas the limits for gaseous emissions were set to address local air quality issues in the vicinity of airports using a reference Landing and Take-Off (LTO) cycle as the basis for the calculation of the mass of gaseous emissions (Figure D.2). The standards apply to all turbojet and turbofan engines in the case of smoke, but only to those engines with a thrust greater than 26.7 kilonewtons (kN)[37] in the case of gaseous emissions.

Figure D.2 Standard engine emissions LTO cycle



LTO cycle

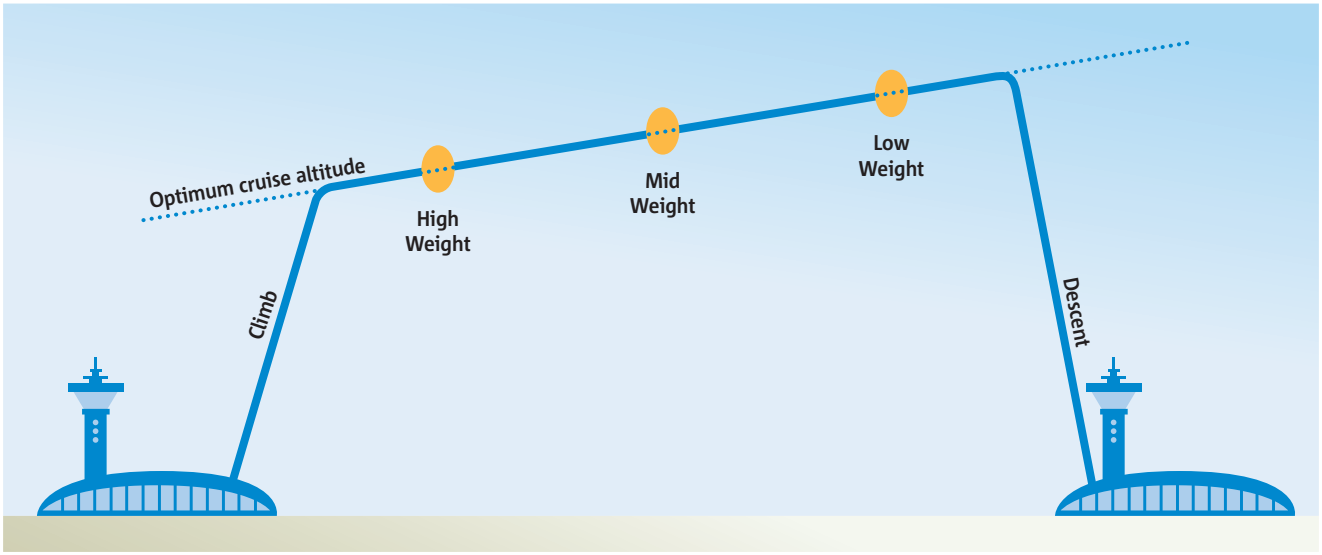
Mode	Thrust	Time
Take-off	100%	0.7 min
Climb	85%	2.2 min
Approach	30%	4.0 min
Taxi	7%	26 min

37 Greater than 26.7 kN (6,000 lbf) generally represents engine types fitted to business jets and larger jet aircraft.

3. Aeroplane CO_2 emissions

Every kg of fuel burnt produces 3.16 kg of CO_2 emissions, and so aircraft CO_2 emissions are directly related to the fuel efficiency of an aircraft. The CO_2 standard measures the average fuel burn (kg) per unit distance travelled (km) at three points during the cruise flight phase, which represents a range of weights used in day-to-day aeroplane operations.

Figure D.3 Illustrative example of the CO_2 cruise measurement points



In order to account for a wide variety of aeroplanes, the CO_2 standard also takes into account transport capability to allow a fair and direct comparison between different aeroplane types. This adjustment is made through a factor that accounts for differences in aeroplane sizes.

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