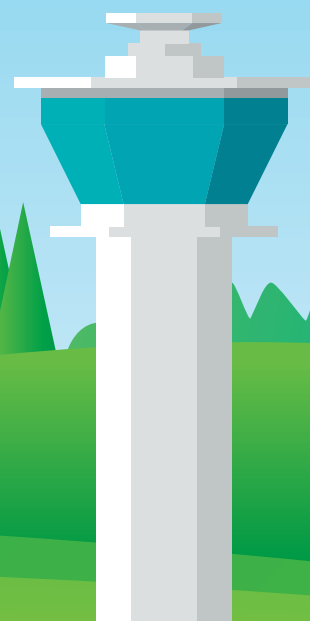
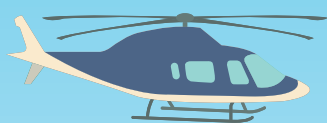




European Aviation Environmental Report 2016



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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.

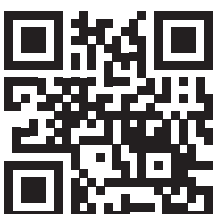
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**European Aviation
Environmental Report
2016**

WELCOME MESSAGE



Violeta Bulc

European
Commissioner for
Transport

It is my pleasure to welcome you to this first edition of the European Aviation Environmental Report. It is a valuable initiative to monitor, promote and strengthen the EU's efforts for a more sustainable European aviation sector. This report is the result of a close collaboration between the European Commission, the European Aviation Safety Agency, the European Environment Agency and EUROCONTROL.

The European Commission's main ambition is to strengthen the EU air transport value network in order to enhance its competitiveness and make the sector more sustainable, which is why the Commission adopted 'An Aviation Strategy for Europe' in December 2015.

Aviation needs concerted, co-ordinated and consistent policy support, which can be delivered by the EU, with a shift in mindset. Europe must take a collective stance to tackle common challenges. In this respect, the task of finding many of the solutions lies as much with the industry as it does with the regulators who have the responsibility to provide an appropriate regulatory framework.

Europe is a leading player in international aviation and a global model for sustainable aviation, with a high level of service and ambitious EU standards. However the aviation sector's contribution to climate change, air pollution and noise levels is under increasing scrutiny. In 2011, the Commission adopted a White Paper setting out ambitious

decarbonisation objectives for the transport sector. This was taken one step further under the leadership of President Jean-Claude Juncker, by making a forward looking climate policy and a strong Energy Union one of the Commission's top priorities.

I am confident that European aviation is taking on the challenge to contribute as much as possible to these efforts and I am convinced that innovation, both in technologies and business models will offer solutions to make aviation more sustainable. Good coordination and collaboration between the different aviation stakeholders, including policy makers and regulators, manufacturers, airlines and airport operators, air navigation service providers, non-governmental organisations and the public, are crucial.

The foundation of such an approach requires published, reliable and objective information, accessible to all. This first report marks an important step towards the regular monitoring of the overall environmental performance of the European aviation system. It will also support better coordination and collaboration within Europe on future priorities by feeding discussions on the effectiveness of different policies and measures already in place. Moreover, the Commission has proposed in its new European Aviation Safety Agency Regulation that the European Aviation Safety Agency publishes updates of this report.

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The Steering Group gratefully acknowledges the support of the Stakeholder Group, whose representatives² provided comments and input from all parts of the aviation sector (see Stakeholder Input boxes). The collaboration of this diverse set of organisations helped to ensure a comprehensive and balanced report.

Finally, the financial support provided by EASA management is acknowledged, as well as the provision of expert resources within all the European organisations, which made it possible to take forward this initiative and complete the report on schedule.

Further information

For the latest information, and to find out more, visit the EASA website:

www.easa.europa.eu/eaer

Questions associated with this report should be sent to the EASA Environment Department:

eaer@easa.europa.eu

¹ Directorate-Generals for Mobility and Transport, Climate Action, Environment and Joint Research Centre.

² Airports Council International Europe, Association of European Airlines, Aerospace and Defence Industries Association of 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, National Air Traffic Services, SESAR Joint Undertaking and Transport & Environment.

FOREWORD

With each of their great ‘firsts’, the adventurers of the last century constantly pushed back the limits and changed our perception of the impossible. Today, the drive to make new discoveries goes on, with the aim of improving the quality of life on our planet. By facing the challenges that await us, new horizons for science will open up to help preserve the planet from today’s threats, in order to sustain and improve our quality of life.

So how do we perpetuate the pioneering spirit and build on the audacity of our predecessors to address these challenges? The Solar Impulse aircraft is writing the next pages in aviation history with solar energy, by voyaging around the world without fuel or pollution. Its ambition is to highlight how exploration and innovation can contribute to the cause of renewable energies, by demonstrating the importance of clean technologies for sustainable development, and restoring dreams and emotions at the heart of scientific adventure. The solutions developed for Solar Impulse employ the technologies of today, not those of the future. If they were used extensively in our world, they would allow us to halve the amount of fossil energy our society consumes and generate half of the rest with renewable sources.

Solar Impulse is a symbol that we hope inspires everyone. Are not all of us on Earth in the same situation as the pilot of Solar Impulse? If the pilot does not have the right technologies or wastes the aircraft’s energy, he will have to land before the rising sun enables him to continue his flight. Likewise, if we do not invest in the scientific means to develop new energy sources, we shall find ourselves in a major crisis which compromises the sustainability of the planet for the next generation.

Until now, renewable energies have lacked the impetus that would come from truly dynamic promotion and marketing. It is imperative to unite ecology with economy, environment with finance, and a long term vision with short-term political interest. Public attention must be drawn towards the changes necessary to ensure our planet’s energy and ecological future. Each and every one of us needs to become pioneers in our own lives, in the way we think and behave.

The objectives of the European Aviation Environmental Report are linked with those of Solar Impulse. By providing valuable information on the environmental performance of the European aviation sector, this report will help focus the efforts of current and future pioneers to spur innovation and address the environmental challenges that the sector faces.



Bertrand Piccard

Initiator, Chairman
and Pilot of Solar
Impulse



EXECUTIVE SUMMARY

It is recognised that Europe's aviation sector brings significant economic and social benefits. However its activities also contribute to climate change, noise and local air quality impacts, and consequently affect the health and quality of life of European citizens. The historic rate of improvement in various areas (e.g. technology and design) has not kept pace with past growth in the demand for air travel leading to increased overall pressures (e.g. emissions, noise) on the environment, and this trend is forecast to continue. Consequently the environmental challenge for the sector will increase, and future growth in the European aviation sector will be inextricably linked to its environmental sustainability.

A comprehensive and effective package of measures is required to continue to address this challenge in the coming years. The foundation of such an approach requires published, reliable and objective information, accessible to all, to inform discussions on how this challenge will be specifically addressed. This is the core objective of the European Aviation Environmental Report. Greater coordination to support subsequent editions will help to periodically monitor and report on the environmental performance of the European aviation sector.

Overview of Aviation Sector

- Number of flights has increased by 80% between 1990 and 2014, and is forecast to grow by a further 45% between 2014 and 2035³.
- Environmental impacts of European aviation have increased over the past 25 years following the growth in air traffic.
- Mean aircraft age was about 10 years in 2014, but fleet is slowly ageing.
- Due to technological improvements, fleet renewal, increased Air Traffic Management
- efficiency and the 2008 economic downturn, emissions and noise exposure in 2014 were around 2005 levels.
- About 2.5 million people were exposed to noise at 45 major European airports in 2014⁴, and this is forecast to increase by 15% between 2014 and 2035.
- CO₂ emissions have increased by about 80% between 1990 and 2014, and are forecast to grow by a further 45% between 2014 and 2035.
- NO_x emissions have doubled between 1990 and 2014, and are forecast to grow by a further 43% between 2014 and 2035.

Technology and Design

- Jet aircraft noise levels have generally reduced by about 4 decibels per decade. The progress has recently slowed to about 2 decibels per decade, and this rate of improvement is expected to continue in the future.
- The future trend in noise improvements may be adversely influenced by a new engine design known as a Counter-Rotating Open Rotor that is due to enter service around 2030.
- More stringent aircraft noise limits and engine NO_x emissions limits have been introduced over time to incentivise continuous improvement.
- Average NO_x margin to CAEP/6 limit for in-production engine types has increased by about 15% over the last 5 years.
- Additional standards for aircraft CO₂ emissions and aircraft engine particulate matter emissions are expected to enter into force in the near future.

³ 2035 figures in this section represent the most likely 'base' traffic forecast with a low technology improvement rate.

⁴ Population exposed to L_{den} ≥ 55 dB noise level.

Sustainable Alternative Fuels

- Uptake of sustainable alternative fuels in the aviation sector is very slow, but assumed to play a large role in reducing aviation greenhouse gas emissions in the coming decades.
- The European Advanced Biofuels Flightpath provides a roadmap to achieve an annual production rate of 2 million tonnes of sustainably produced biofuel for civil aviation by 2020.
- European commercial flights have trialed sustainable alternative fuels. However regular production of sustainable aviation alternative fuels is projected to be very limited in the next few years, and thus it is unlikely that the roadmap 2020 target will be achieved.

Air Traffic Management and Operations

- European network handles 27,000 flights and 2.27 million passengers per day.
- Europe is investing heavily in modernising the air traffic management system through the Single European Sky Air Traffic Management Research (SESAR) programme which is the technological pillar of the EU Single European Sky (SES) legislative framework.
- En route and arrival operational efficiencies show a moderate but steady reduction in additional distance flown, as does taxi-out times, thereby combining to reduce related excess CO₂ emissions.
- SESAR deliverables will form the core of the European deployment of new operational capabilities which will contribute to achieving the SES Performance Scheme targets and high level goals as well as enhance global harmonisation and interoperability.

Airports

- 92 European airports are currently participating in the Airport Carbon Accreditation programme, and 20 of these airports are carbon neutral.

- 80% of passengers in Europe are handled via an airport with a certified environmental or quality management system.
- Involvement of all local stakeholders in the implementation of the balanced approach to aircraft noise management is recognised as a crucial factor in reducing the annoyance for people living near airports.
- By 2035, in the absence of continuing efforts, it is anticipated that some 20 major European airports will face significant congestion and related environmental impacts due to air traffic growth.

Market-Based Measures

- Market-based measures are needed to meet aviation's emissions reduction targets as technological and operational improvements alone are not considered sufficient.
- The European Union Emissions Trading System (EU ETS) currently covers all intra-European flights. This will contribute around 65 million tonnes of CO₂ emission reductions between 2013 and 2016, achieved within the aviation sector and in other sectors.
- More than 100 airports in Europe have deployed noise and emissions charging schemes since the 1990s.

Adapting Aviation to a Changing Climate

- Climate change is a risk for the European aviation sector as impacts are likely to include more frequent and more disruptive weather patterns as well as sea-level rise.
- Aviation sector needs to prepare for and develop resilience to these potential future impacts. Actions have been initiated at European, national and organisational levels.
- Pre-emptive action is likely to be cost-effective in comparison to addressing impacts as they occur in the future.



INTRODUCTION

Europe's aviation sector brings significant benefits, both directly through the jobs it creates and indirectly through the facilitation of global trade and tourism. However, its activities also contribute to climate change, noise and local air quality impacts, and consequently affect the health and quality of life of European citizens.

While today's aircraft are much quieter and produce much less emissions than their equivalents thirty years ago, the rate of improvement has not kept pace with the historic growth in demand for air travel. This trend is forecast to continue, thereby increasing the environmental challenge for the sector.

Therefore, future growth in the European aviation sector is inextricably linked to its environmental sustainability.

The environmental and health impacts of the aviation sector clearly impose a cost on society as a whole. However, as with other transport modes, these external costs are typically not fully reflected within the sector itself. Consistent with the 'polluter pays' principle, there is increasing public and political pressure on the aviation sector to participate in the economy-wide effort to internalise environmental costs. At the same time, the research and development of innovative and environmentally sustainable solutions provides an economic opportunity for the European aviation sector, being an important factor in the competitiveness of the European economy.

A comprehensive set of measures have already been implemented within Europe to address these challenges. They include, but are not limited to, the measures in the below table.

Technology and Design	Air Traffic Management (ATM) and Operations	Airports
Reductions in aircraft noise and emissions via EU research programmes, Clean Sky, and environmental technical standards	EU Single European Sky framework SESAR ATM Research Programme Modernisation of ATM systems Optimisation of airspace use and aircraft operations	Participation in the Airport Carbon Accreditation programme Certified environmental and quality management systems Balanced approach to aircraft noise management
Market-Based Measures	Sustainable Alternative Fuels	Adapting Aviation to a Changing Climate
Internalisation of external costs via the European Union's Emissions Trading System (ETS) and airport charging schemes	Development of new sustainable fuels as a means to: <ul style="list-style-type: none"> • Improve air quality • Mitigate climate change • Diversify energy supply 	Actions within the aviation sector to adapt and develop resilience to the current and future impacts of climate change

Effective coordination [1] is required to support this comprehensive approach on aviation environmental protection, and it is important that the performance of the European aviation sector is regularly monitored and reported on in an objective, consistent and clear manner to address key questions such as:

- What is the environmental performance of the European aviation sector?
- How might the sector evolve in the future?
- What existing measures are in place to mitigate climate change, noise and air quality impacts?

This is the core objective of the European Aviation Environmental Report.

Noise impacts and European policy

Noise is generated by transport and industrial activities on land and in the air. It is a pervasive pollutant that directly affects the health of exposed humans and wildlife in terms of physical, mental and social well-being. Populations exposed to high noise levels can exhibit stress reactions, sleep-stage changes, and clinical symptoms like hypertension and cardiovascular diseases. All of these impacts can contribute to premature mortality [2, 3].

The Environmental Noise Directive (END) and Balanced Approach Regulation [4, 5, 6, 7] are the overarching European Union (EU) legislative instruments under which environmental noise is monitored and actions are taken. Member States are applying common criteria for noise mapping as well as developing and implementing action plans to reduce exposure in large cities and places close to major transport infrastructure.



Emissions impacts and European policy

Climate change. Aircraft engines emit various pollutants of which carbon dioxide (CO₂) is the most significant greenhouse gas (GHG) influencing climate change. Global climate change impacts will affect Europe in many ways, including changes in average and extreme temperature and rainfall, warmer seas, rising sea level and shrinking snow and ice cover on land and at sea. These have already led to a range of impacts on ecosystems, socio-economic sectors and human health, and will continue to do so [8].

In the context of international efforts to limit climate change, the EU is committed to cutting its GHG emissions by at least 20% in 2020 compared to 1990 levels, and by 40% in 2030 [9, 10, 11]. The transport sector is expected to contribute to these goals through the reduction of its GHG emissions by 20% in 2030 compared to 2008 levels⁵, and by 70% in 2050 [12]. These commitments have been backed by a basket of measures such as the inclusion of the aviation sector in the EU Emissions Trading System [13, 14, 15, 16] and the development of an aircraft CO₂ standard [17].

Air pollution. Local and regional air pollution is a top environmental risk factor of premature death in Europe. It increases the incidence of a wide range of diseases, and also damages vegetation and ecosystems [18]. Such impacts constitute a real economic loss for Europe in terms of its natural systems, agriculture, productivity of its workforce and health of its citizens. Two important air pollutants relevant to aviation are:

- **Nitrogen oxides (NO_x)** which are emitted from fuel combustion and can lead to the formation of other air pollutants which harm health such as particulates and ground-level ozone. They also cause the acidification and eutrophication of waters and soils, and are an indirect GHG which can contribute to the creation of ozone at altitude.
- **Particulate matter (PM)** which is one of the most harmful pollutants for health, as it penetrates into sensitive regions of the respiratory system, and can cause or aggravate cardiovascular and lung diseases and cancers.

EU air pollution legislation follows a twin-track approach of implementing both local air quality standards [19] 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 [20].

5 This corresponds to a 60% reduction in GHG emissions by 2030 compared to 1990 levels.



ation

Time

Flight

Destinatio

1. OVERVIEW OF AVIATION SECTOR

The environmental impacts of European aviation have increased following the growth in air traffic. Between 1990 and 2005 air traffic and emissions of CO₂ have both increased by about 80%. However due to technological improvements, fleet renewal, increased ATM efficiency and the 2008 economic downturn, both emissions and noise exposure in 2014 are around 2005 levels. Future improvements are not expected to be sufficient to prevent an overall growth in emissions during the next 20 years, but may stabilise noise exposure by 2035.

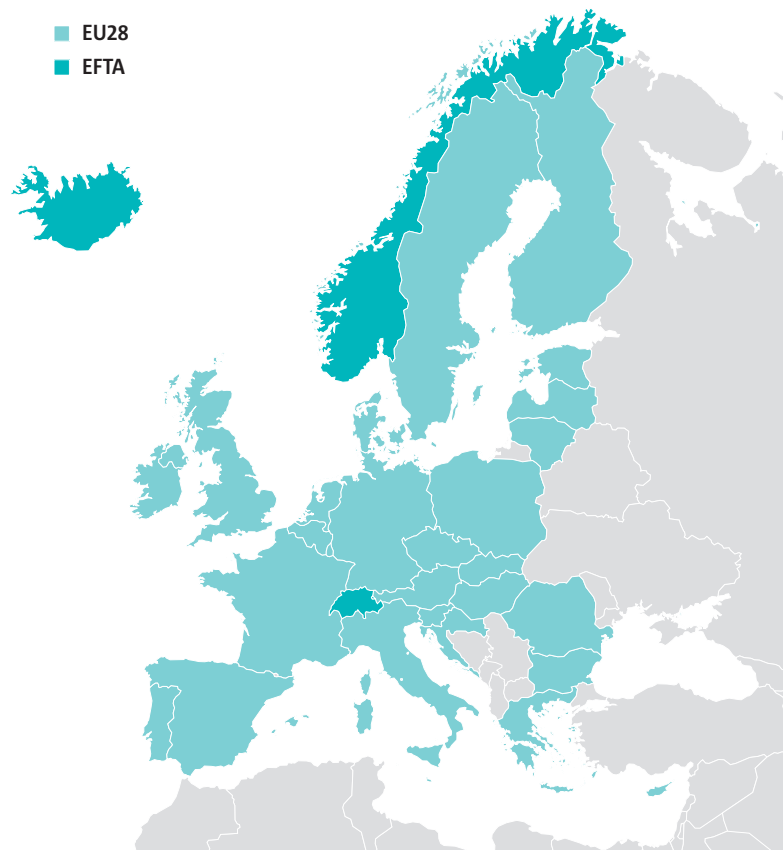
Analysis scope and assumptions

Historical air traffic data in this section comes from European Member States and aircraft operators. This is provided to EUROCONTROL and used as a basis for the three future traffic scenarios in their STATFOR 20-year traffic forecast representing 'high', 'base' (most likely) and 'low' growth rates [21]. The coverage is all flights from or to airports in the European Union (EU)⁶ and European Free Trade Association (EFTA)⁷.

Aircraft emissions were derived using the IMPACT model and aircraft noise indicators using the STAPES noise contour model. For each traffic forecast, CO₂, NO_x and noise trends are presented as a range based on various potential technology improvement rates. The upper forecast bound represents the 'low' technology improvement rate, and the lower forecast bound represents the 'advanced' technology improvement rate.

The efficiency of the ATM system and population around airports were considered constant in the analysis, although future capacity plans provided by airports were taken into account.

For more details on models, analysis methods, forecasts, supporting data sources and assumptions used in this analysis, please refer to Appendix C.



6 Austria, Belgium, Bulgaria, Croatia, 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.

7 Iceland, Liechtenstein, Norway and Switzerland.

1.1 Air traffic

Flight counts still below peak, but could see a 45% increase by 2035

The number of flights in Europe during 2014 was about 80% higher than in 1990. This is slightly lower than the previous 2008 peak in numbers of flights, passengers, and volume of cargo. With the economic downturn, 2009 saw the largest annual fall in flights of recent decades (-7% from 2008). As of 2014, the number of scheduled and charter passenger flights is similar to 2005 levels (Figure 1.1).

Passenger numbers however have recovered much more quickly, due to the average number of passengers per flight increasing from 87 in 2005 to 113 in 2014. The increase in the number of passengers per flight is, in part, due to the general trend towards longer flights and larger

aircraft being used in Europe. The passenger increase is also due to increasing load factors (the fraction of seats that are occupied) from 70.2% to 76.7% and to lighter and slimmer seats so that more seats can be accommodated on the same aircraft. The mean distance per flight has increased from 1,480 km to 1,650 km between 2005 and 2014. These combine to reduce fuel burn per passenger kilometre flown by 19%.

A similar pattern is seen for tonnes of cargo which are up about 30% from 2005 to 2014 although the number of all-cargo flights has declined by 4% over the same period. In particular, smaller cargo aircraft (less than 50 tonnes of take-off weight) saw some of the sharpest reductions in flights over that period.

By 2035, the total number of flights could reach 12.8 million under the base (most likely) traffic forecast, against 8.85 million in 2014 (Figure 1.2).

Figure 1.1 Growth in low-cost flights has compensated for the decrease of flights by traditional carriers

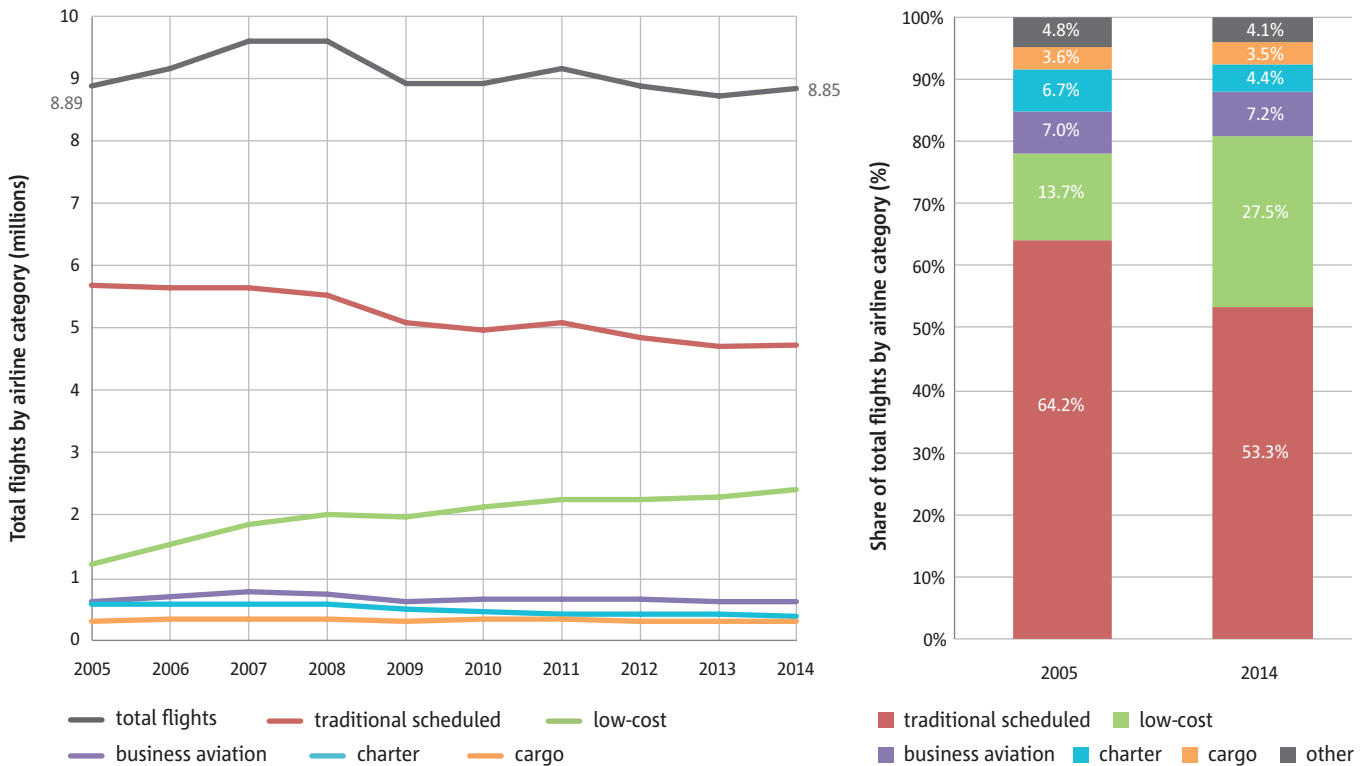
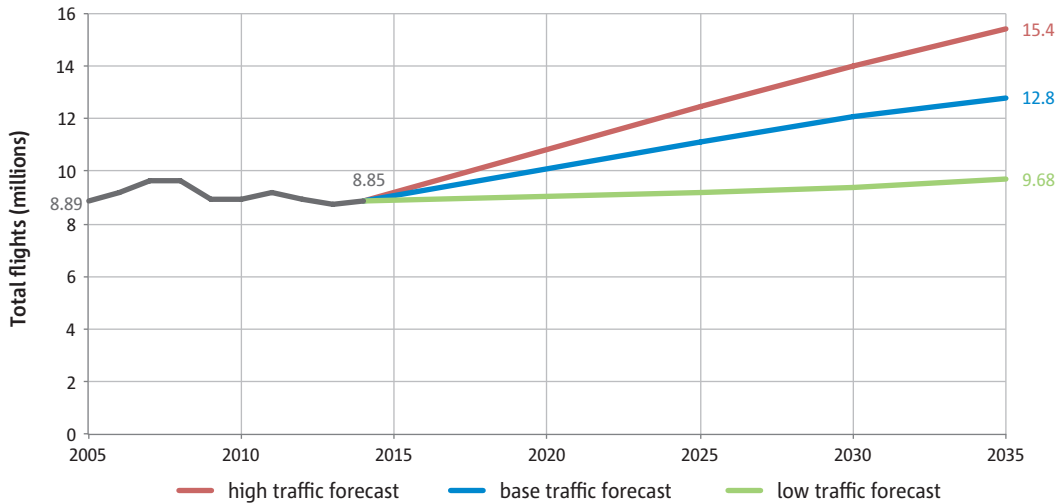


Figure 1.2 Flight counts in Europe peaked in 2008, and will increase further



Daily patterns: stretching the flying day

The economics of air transport have changed considerably in the last 10 years, not least because fuel prices increased 51% between 2005 and 2014, from an average of €445 to €672 per tonne of fuel. One way airlines have responded to this is to increase ticket prices, which since 2005 increased by 9.5% more than average

consumer prices [22]. Another is to maximise operational use of aircraft by performing as many flights as possible during the day. For example, the traditional scheduled carriers flew on average 3.1 flights/day with each aircraft in 2005 compared to 3.7 in 2014. This has led to increased numbers of flights in late morning and the later part of the evening (Figure 1.3).

Figure 1.3 Growth in flights has occurred in the evening and late morning

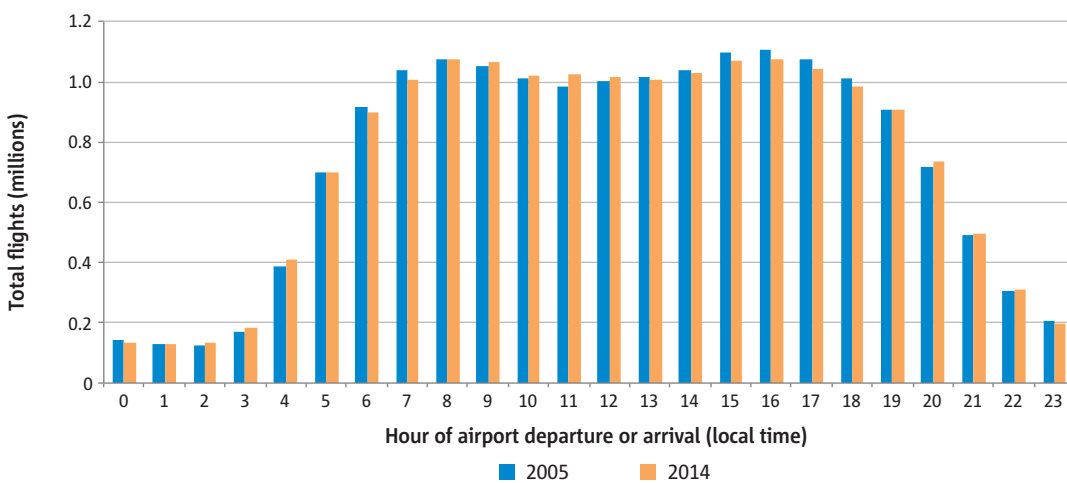
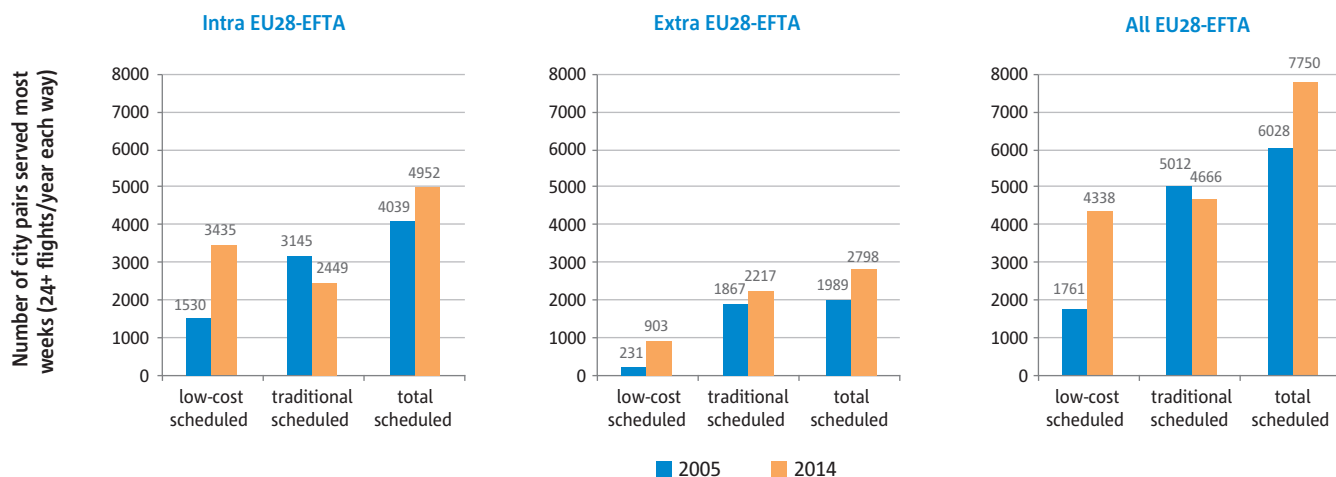


Figure 1.4 Overall the scheduled network connects more city pairs in 2014



Scheduled network: more city connections, lower frequencies

From 2005 to 2014, the number of scheduled flights increased by 3.2%, but the number of city pairs⁸ with scheduled flights most weeks of the year increased by 29%, from approximately 6,000 to 7,800 (Figure 1.4). This growth in the connectivity of the network, without adding many flights, has been achieved by reducing the number of city pairs which are served very frequently. The median number of flights each way on the total scheduled city pairs shown in Figure 1.4 dropped from 4.3/week to 3.2/week. The traditional scheduled carriers have also cut the number of city pairs that they served infrequently (i.e. less than 3 times/week); but this loss of connections has been compensated elsewhere by new connections established by low-cost carriers. The increase in the number of city pairs in the network is a high level indicator of the wider geographical coverage and greater dispersion of local impacts such as noise. The corresponding reduction in high-frequency connections is linked to the increase in aircraft size and the fact that it is short-haul, intra-EU28-EFTA connections that have been reduced by the traditional carriers, rather than long-haul. This is likely to have also been influenced by the expanding high-speed rail network within Europe.

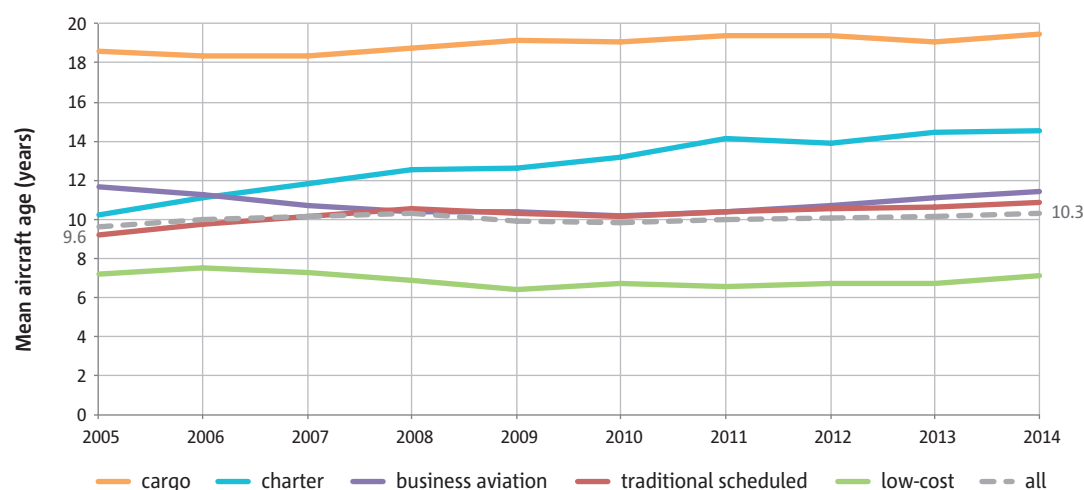
Slower growth brings a slowly ageing fleet

Newer aircraft and engines are more environmentally efficient, so the age of the

European aircraft fleet is an important indicator. The mean aircraft age (weighted by the number of flights made by each aircraft) has crept up from 9.6 to 10.3 years, with only 2009 and 2010 seeing reductions (Figure 1.5). These reductions were driven by the rapid expansion of the low-cost fleet, which is younger than average, and retirements of less fuel-efficient older aircraft by the traditional scheduled operators in response to higher fuel prices and falling demand (retirements jumped to over 6% of the fleet per year in 2008 and 2009). In more recent years, the fleet began to age again as a result of slower low-cost carrier growth, and very limited fleet renewal by the traditional-scheduled carriers. In 2014, about half of all flights were by aircraft built in 2005 or later. This figure increases to three quarters when considering only low-cost carriers.

The mean age of the non-scheduled charter fleet has increased 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 introduction of new aircraft, but business aviation declined sharply with the economic downturn, with the focus subsequently shifting to increased utilisation rather than buying new aircraft. The mean age of aircraft used for all-cargo operations (i.e. not including the passenger flights which often carry cargo too) is around 19 years during the whole of this period due to the generally lower daily aircraft utilisation.

⁸ A 'city pair' is two cities which have a direct flight between any of their airports.

Figure 1.5 Mean aircraft age has crept up beyond 10 years**Table 1.1** Summary of air traffic indicators

	2005	2014 (% change vs. 2005)
Number of flights (millions)	8.89	8.85 (-0.5%)
Flown distance (billion km)	13.1	14.6 (+11%)
Mean distance per flight (km)	1,480	1,650 (+12%)
Passengers on commercial flights (millions)	590	740 (+25%)
Passenger flight load factor	70.2%	76.7% (+9%)
Passenger kilometres (billion)	1,040	1,370 (+32%)
Mean fleet age (years)	9.6	10.3 (+7%)

1.2 Environment

Continued efforts may stabilise noise exposure by 2035 but it will continue to be a key challenge

Aircraft noise exposure is typically assessed by looking at the area of noise contours around airports, as well as the number of people within these contours. A noise contour represents the area around an airport in which noise levels exceed a given decibel (dB) threshold

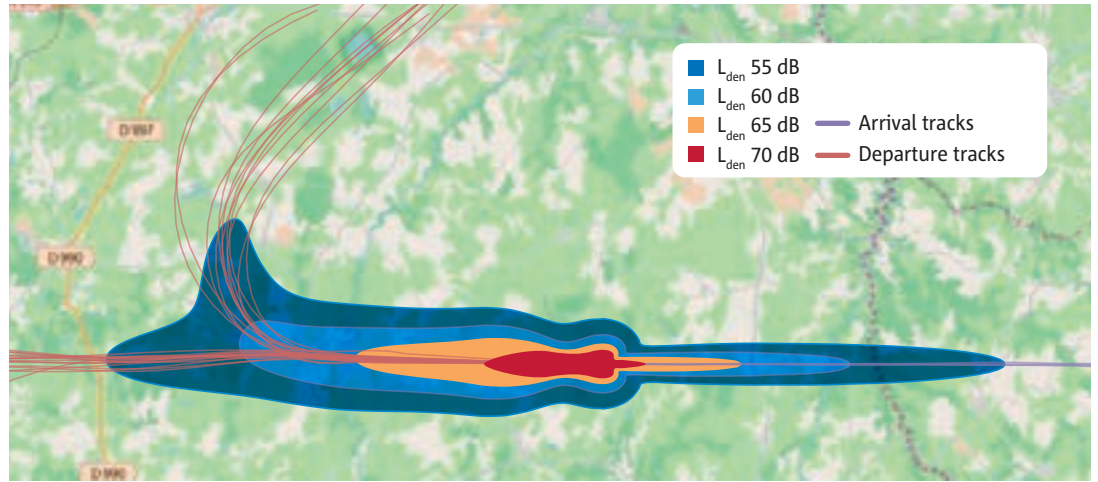
(Figure 1.6). The noise metrics and thresholds presented in this report are the L_{den} 55 dB⁹ and L_{night} 50 dB¹⁰ indicators, in line with what Member States are required to report under the EU Environmental Noise Directive (END) [5]. Total contour areas and populations were computed for 45 major European airports using the STAPES noise model. These two metrics were complemented by noise energy¹¹, which was computed for all airports in the EU28 and EFTA region (about 2100 airports in 2014).

9 L_{den} is defined as an equivalent sound pressure level averaged over a day, evening and night time period. The default time periods in Directive 2002/49/EC are 07:00 to 19:00 for day, 19:00 to 23:00 for evening and 23:00 to 07:00 for night with associated penalties during the evening (+5 dB) and night (+10 dB).

10 L_{night} is defined as an equivalent sound pressure level averaged over a night time period.

11 Noise energy is an indicator which combines the number of flights of aircraft with their respective certified noise levels (see Appendix C for actual definition). It is independent of how aircraft are operated at airports.

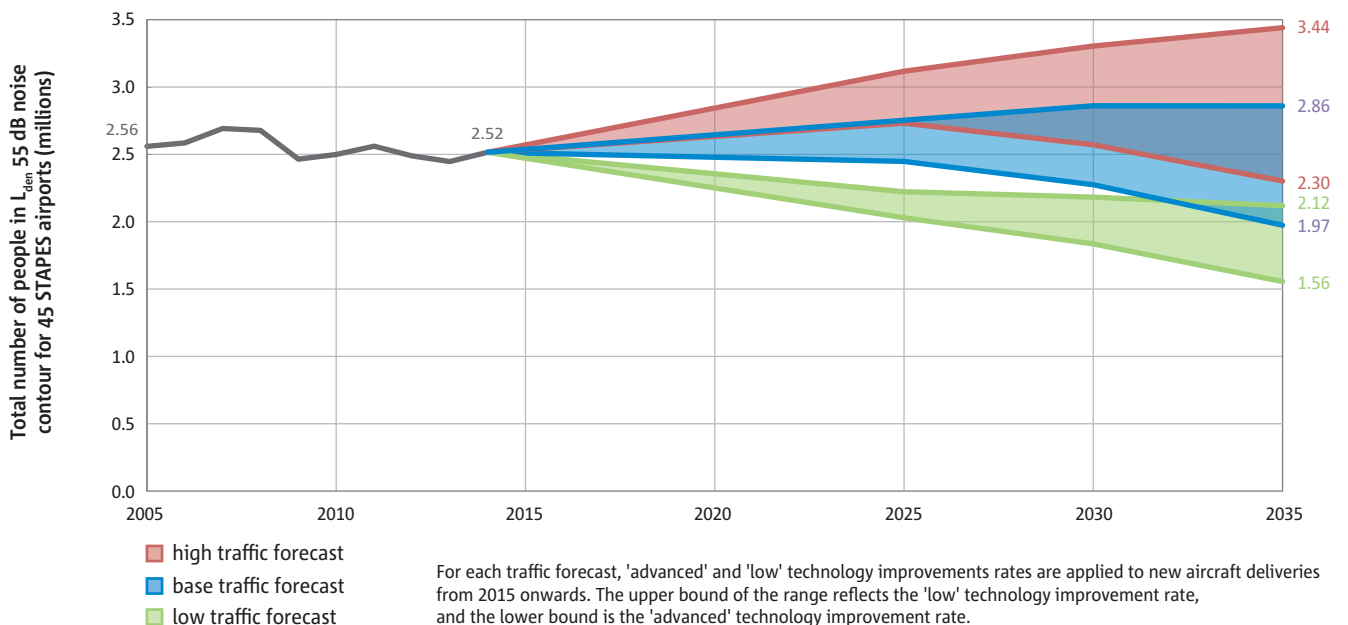
Figure 1.6 Example of notional airport noise contours



Noise exposure has stabilised over the past ten years. The total population inside the STAPES L_{den} and L_{night} contours decreased by only 2% (L_{den}) and 1% (L_{night}) between 2005 and 2014, to reach 2.52 and 1.18 million people respectively in 2014 (Figure 1.7, Table 1.2). A similar trend is observed for the total noise energy in the EU28 and EFTA region, which decreased by 5% during the same period. This overall noise reduction is due to technological improvements, fleet renewal, increased ATM efficiency and the 2008 economic downturn. Fleet renewal has led to a 12% reduction in the average noise energy per operation between 2005 and 2014.

Under the base (most likely) traffic forecast, a continued 0.1 dB reduction per annum for new aircraft deliveries (low technology improvement rate) could halt the growth of the overall noise exposure in the 2035 timeframe, while a 0.3 dB reduction per annum (advanced technology improvement rate) could lead to a net reduction of the exposure compared to 2014 even under the high traffic forecast. However, in the absence of continuing technology improvements for new aircraft, the population inside the increased L_{den} 55 dB contour areas could reach 2.58, 3.54 and 4.29 million in 2035 under the low, base and high traffic forecasts respectively.

Figure 1.7 Future technology improvements could stabilise overall aircraft noise exposure in the 2035 timeframe



Aircraft noise in context

Under the Environmental Noise Directive [5], aircraft noise data from 56 out of 91 airports having more than 50,000 movements/year, were reported by EU Member States. These data showed that for these 56 airports 2.4 million people were exposed to noise levels of 55 dB L_{den} and above in 2012. An analysis was conducted on the remaining 35 European airports having more than 50,000 movements/year and, combined with the reported data, showed that around 5 million people in Europe were exposed to noise above 55 dB L_{den} that year [23].

World Health Organization (WHO) noise research

The L_{den} and L_{night} indicators represent average noise over a given time period, so they do not capture the specific characteristics of each noise event or differences between sources of noise (e.g. noise from single events are smoothed out) [24].

In order to support Member States, the WHO regional office for Europe is reviewing the latest scientific evidence and is expected to propose revised dose-response¹² functions in 2016 to help better quantify the consequences of noise on health. As part of this work, WHO is also reviewing the harmful effects of aircraft noise at lower dB levels than the L_{den} 55 dB and L_{night} 50 dB indicators used in this report. Past work on noise dose-response curves and health effects shows that aircraft typically generate more annoyance and sleep disturbance than other sources at the same L_{den} levels.

Table 1.2 Summary of noise indicators

	2005	2014 (% change vs. 2005)	Base forecast 2035 Advanced – Low Technology (% change vs. 2005)
L_{den} 55 dB area, 45 STAPES airports (km ²)	2,251	2,181 (-3%)	1,983 – 2,587 (-12%) (+15%)
L_{night} 50 dB area, 45 STAPES airports (km ²)	1,268	1,248 (-2%)	1,058 – 1,385 (-17%) (+9%)
L_{den} 55 dB population, 45 STAPES airports (millions)	2.56	2.52 (-2%)	1.97 – 2.86 (-23%) (+12%)
L_{night} 50 dB population, 45 STAPES airports (millions)	1.18	1.18 (-1%)	0.78 – 1.19 (-34%) (+1%)
Noise energy, all EU28-EFTA airports (10 ¹⁵ J)	9.60	9.16 (-5%)	9.37 – 12.9 (-2%) (+34%)
Average noise energy per operation, all EU28-EFTA airports (10 ⁸ J)	7.29	6.41 (-12%)	4.14 – 5.70 (-43%) (-22%)

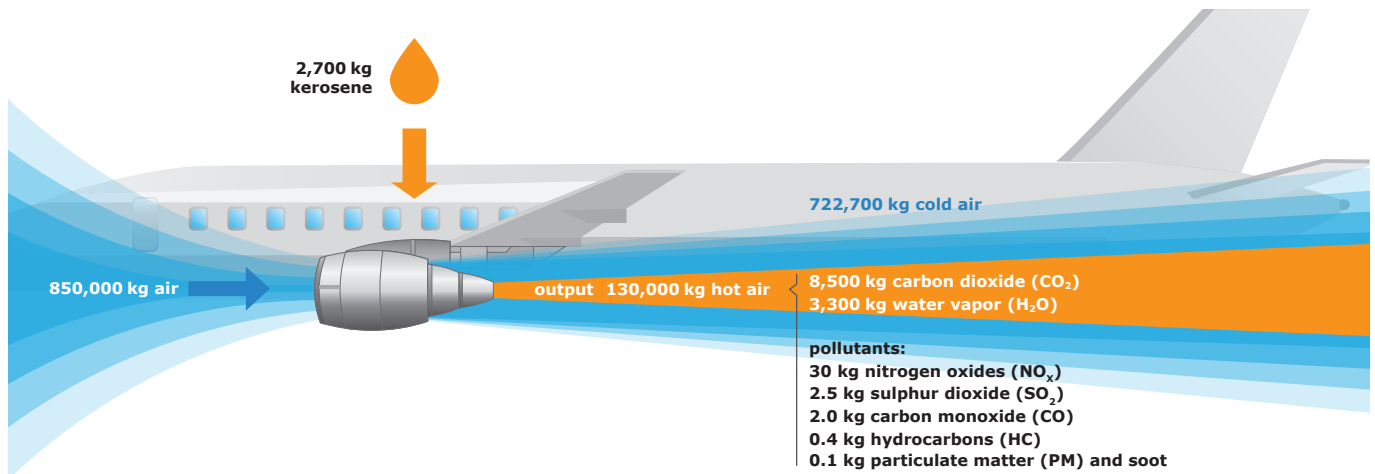
12 A dose-response function provides the likelihood of annoyance at different noise levels.

Emissions are expected to increase further

The main aircraft engine emission pollutants are (Figure 1.8): carbon dioxide (CO₂), nitrogen oxides (NO_x), sulphur oxides (SO_x), unburned

hydrocarbons (HC), carbon monoxide (CO), particulate matter (PM) and soot. They are considered here in terms of either full-flight (gate-to-gate), or a landing-take-off cycle below 3,000 feet for local air quality purposes.

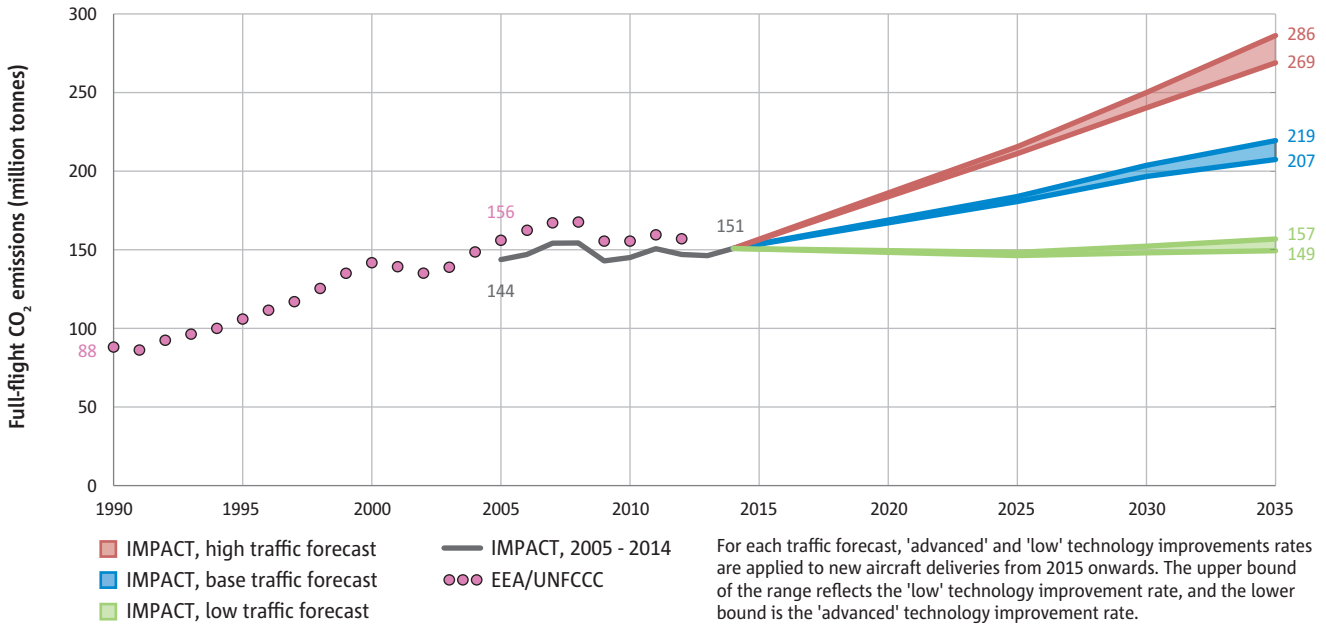
Figure 1.8 Emissions from a typical two-engine jet aircraft during 1-hour flight with 150 passengers (Source: FOCA)



Aircraft CO₂ emissions increased from 88 to 156 million tonnes (+77%) between 1990 and 2005 according to the data reported by EU28 and EFTA Members States to the United Nations Framework Convention on Climate Change (UNFCCC) (Figure 1.9). According to data from the IMPACT emissions model, CO₂ emissions increased by 5% between 2005 and 2014. The increase in emissions is however less than the increase in passenger kilometres flown over the same period (2005 to 2014). This was due to an improvement in fuel efficiency driven by

the introduction of new aircraft, removal of older aircraft, and improvements in operational practice. The average fuel burn per passenger kilometre flown for passenger aircraft, excluding business aviation, went down by 19% over this same period. However, projections indicate that future technology improvements are unlikely to balance the effect of future traffic growth. Under the base traffic forecast and advanced technology improvement rate, CO₂ emissions increases by 44% from 144 Mt in 2005 to 207 Mt in 2035.

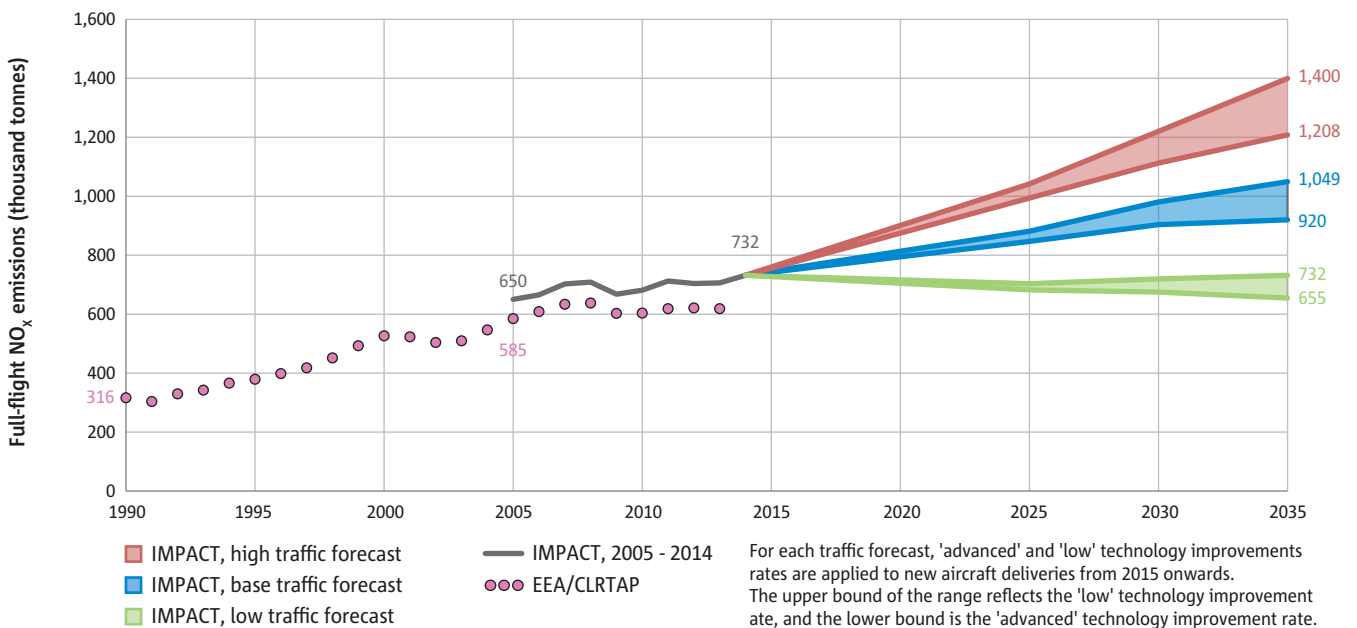
Figure 1.9 After remaining stable between 2005 and 2014, aircraft CO₂ emissions are likely to increase further



NO_x emissions have also increased significantly (Figure 1.10): +85% (316 to 585 thousand tonnes) between 1990 and 2005 according to the Convention on Long-Range Transboundary Air Pollution (CLRTAP) data from the UN Economic Commission for Europe, and +13% between

2005 and 2014 according to IMPACT data. Under the base air traffic forecast and assuming an advanced NO_x technology improvement rate, emissions would reach around 920 thousand tonnes in 2035 (+42% compared to 2005).

Figure 1.10 NO_x emissions are likely to increase in the future, but advanced engine combustor technology could help mitigate their growth



Aviation emissions in context

In 2012, aviation represented 13% of all EU transport CO₂ emissions, and 3% of the total EU CO₂ emissions. It was also estimated that European aviation represented 22% of global aviation's CO₂ emissions. Similarly, aviation now comprises 14% of all EU transport NO_x emissions, and 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 [25].

Emissions of HC, CO and non-volatile PM have decreased between 2005 and 2014, while full-flight emissions of volatile PM have increased by 7%. However, the total emissions of each of

these pollutants are forecast to increase over the next twenty years (Table 1.3).

Table 1.3 Summary of emission indicators based on IMPACT data

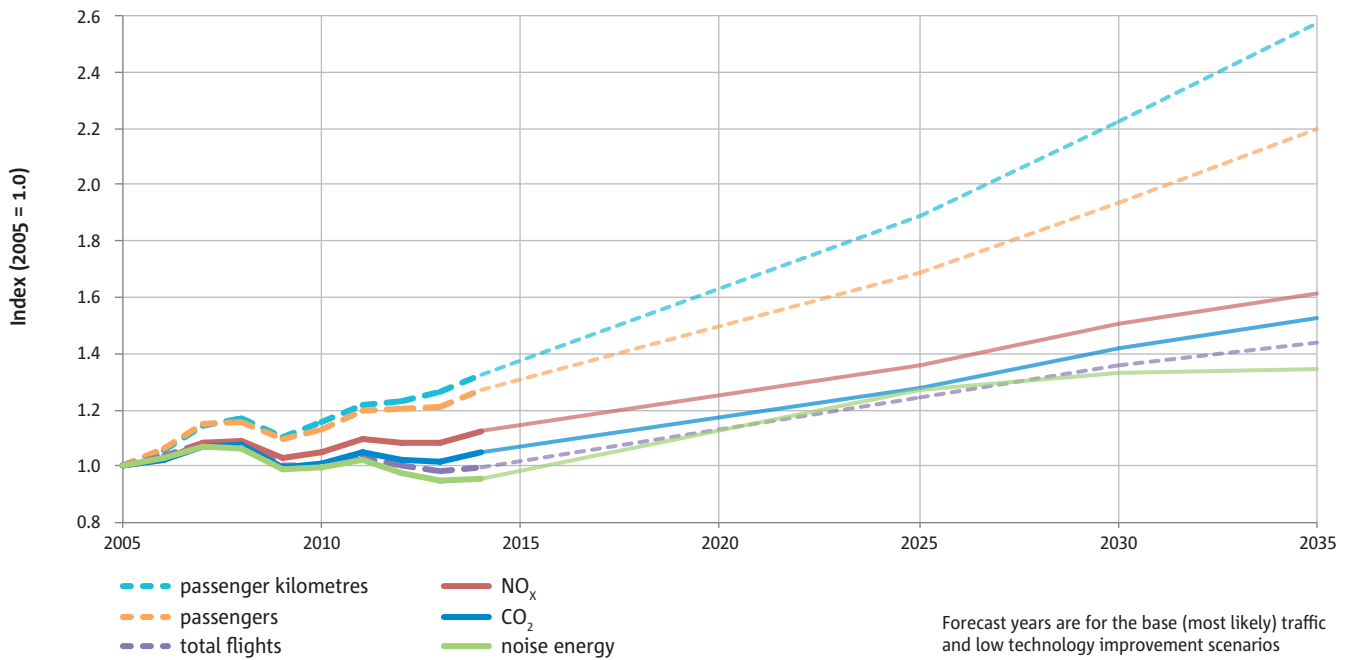
	2005	2014 (% change vs. 2005)	Base forecast 2035 Advanced – Low Technology (% change vs. 2005)
Average fuel burn (kg) per passenger kilometre	0.0388	0.0314 (-19%)	0.0209 – 0.0222 (-46%) (-43%)
CO ₂ (Mt)	144	151 (+5%)	207 – 219 (+44%) (+53%)
NO _x (1,000 t)	650	732 (+13%)	920 – 1049 (+42%) (+61%)
NO _x below 3,000 feet (1,000 t)	53.3	58.8 (+10%)	73.3 – 83.1 (+37%) (+56%)
HC (1,000 t)	20.8	17.0 (-18%)	22.9 (+10%)
HC below 3,000 feet (1,000 t)	7.8	6.4 (-18%)	11.0 (+40%)
CO (1,000 t)	143	133 (-7%)	206 (+44%)
CO below 3,000 feet (1,000 t)	52.4	48.2 (-8%)	85.5 (+63%)
volatile PM (1,000 t)	4.18	4.47 (+7%)	6.93 (+66%)
volatile PM below 3,000 feet (1,000 t)	0.27	0.27 (-1%)	0.41 (+50%)
non-volatile PM (1,000 t)	2.67	2.38 (-11%)	3.16 (+18%)
non-volatile PM below 3,000 feet (1,000 t)	0.15	0.13 (-14%)	0.17 (+11%)

1.3 Combining indicators

Combining air traffic and environmental indicators together shows some signs of growing economic and connectivity benefits from aviation (measured in passenger kilometres flown) without a proportionate increase in environmental

impacts (Figure 1.11). The diverging trends of passenger kilometres flown and noise energy between 2005 and 2014 have shown that this is possible, and that there is the potential for this to continue in the future. Nevertheless, the absolute noise energy and emissions of aviation are expected to grow further in the next twenty years.

Figure 1.11 Noise and emissions forecast to grow slower than passenger kilometres



Member State actions on climate change and noise

Climate change

In 2010, Member States agreed to work through the International Civil Aviation Organization (ICAO) to achieve a global annual average fuel efficiency improvement of 2%, and to stabilise the global net carbon emissions of international aviation at 2020 levels. During 2012, Member States submitted voluntary Action Plans to the ICAO outlining their annual reporting on international aviation CO₂ emissions and their respective policies and actions to limit or reduce the impact of aviation on the global climate. New or updated action plans were submitted during 2015, and are expected once every three years thereafter.

The 44 Member States of the European Civil Aviation Conference (ECAC), which includes the EU and EFTA Member States, recognise the value of submitting Action Plans on CO₂ emissions reductions to ICAO as an important step towards the achievement of the global collective goals. As of 2015, 38 out of the 44 ECAC Member States had submitted their Action Plans which included measures listed in this report.

The ECAC Member States share the view that a comprehensive basket of measures, as summarised in this report, is necessary to reduce aviation emissions. In Europe, many of the actions which are undertaken within the framework of this comprehensive approach are in practice taken at a supra-national level and led by the EU.

In relation to actions which are taken at a supra-national level, it is important to note that the extent of participation varies from one country to another, reflecting their priorities and circumstances (e.g. economic situation, size of the aviation market, historical and institutional context). The ECAC Member States are thus involved to different degrees and on different timelines in the delivery of these common actions. In addition, some of the component measures, although implemented by some but not all of ECAC Member States, will nonetheless provide emission reduction benefits across the whole of the region (e.g. research measures, technology development).

Noise

The EU Environmental Noise Directive [5] 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 affected populations. The first action plans were developed in 2008 and thereafter again in 2013, and are aimed at reducing noise exposure where it is excessive and where it is above national noise limits. See also 'Balanced Approach to Aircraft Noise Management' in Chapter 5.

Depending on available financial resources, Member States have identified a range of specific measures in their action plans to address noise from aviation-related sources. In the case of the 79 major airports in the EU (airports with more than 50,000 movements in 2006), 28 of them have adopted an action plan. These adopted plans include operational measures (e.g. optimised flight procedures, airport night-time restrictions) and measures focused on the receiver (e.g. noise insulation of houses).

STAKEHOLDER INPUT

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 Association), 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 CO₂ emissions from air transport:

- An average improvement in fuel efficiency of 1.5% per year from 2009 to 2020;
- A cap on net aviation CO₂ emissions from 2020 (carbon-neutral growth);
- A reduction in net aviation CO₂ emissions of 50% by 2050, relative to 2005 levels.

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

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

Non-Governmental Organisations (NGOs)

Environmental NGOs¹³ in Europe are actively engaged in efforts to address the environmental impacts of aviation. The importance of NGO work in helping to communicate wider civil society views, and to contribute to key policy decisions, has grown in light of the significant environmental challenges facing the aviation sector. While the initial focus of NGOs was on effective communication of concerns and positions associated with noise and air pollution from airport development plans, it has since expanded to include climate change and social justice concerns.

NGOs often work on limited budgets, or on a volunteer basis, but their efforts are supported by a dynamic and effective mode of operation with close cooperation across borders. This includes sharing and translating the latest research, campaign advice and coordinating messages, and close cooperation with research and academic organisations. Many of these organisations have large memberships, which gives them a direct connection to the communities and societies that they are representing. Environmental NGOs operate through a variety of methods which range from grassroots campaigns at a local and national level, to engaging directly with EU level decision makers. The International Coalition for Sustainable Aviation is the environmental NGO body which acts as an Observer to the ICAO Committee on Aviation Environmental Protection (CAEP).

The international aviation sector is exempted from fuel tax and Value Added Tax. Environmental NGOs have subsequently broadened their network to include collaboration with groups working on taxation, state aid issues and social justice concerns. These NGOs promote the concept that a green tax shift based on the 'polluter-pays principle' can benefit the environment and promote job creation.

Case Study 1: Climate Change

A wide international NGO coalition has been closely engaged in the discussions on the use of market-based measures within the aviation industry. This includes the integration of aviation into the EU ETS (see Chapter 6), and the ongoing issue of compliance which is delegated to each Member State. It is important that the reporting on compliance is 100% clear and transparent, and so NGOs have developed a network of national groups who are tracking this issue.

Case Study 2: Noise and Air Quality

Europe's population density, and the proximity of its airports to major urban centres, makes noise and local air quality a priority concern for local communities. As pressure has grown at airports to expand, a network of European environmental campaign groups has developed to ensure proper local consultation and environmental impact studies. This network is able to share best practices, and facilitate citizen engagement to communicate concerns in public consultations. This has sometimes led to agreements on the need to restrict noise pollution, night flights and airport expansion.

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



2. TECHNOLOGY AND DESIGN

Aircraft and their engines must meet international standards for noise and pollutant emissions. Over the past decades jet aircraft certified noise levels have generally reduced by about 4 decibels (dB) per decade. This progress has recently slowed to about 2 dB per decade, and this slower rate of improvement is expected to continue in the future. However, this trend may be adversely influenced by a potential new low fuel burn engine design known as a Counter-Rotating Open Rotor which is expected to begin operating beyond 2030 with significantly higher noise levels compared to conventional engines introduced in the same timeframe. Pollutant emissions from engines have also been significantly reduced by technological developments. This has been promoted by more stringent NO_x limits which have been introduced to avoid potential trade-offs due to the demand for more fuel efficient engines. The average NO_x margin to CAEP/6 limit for in-production engine types has increased by about 15% over the last 5 years. Additional standards for CO₂ and particulate matter are currently being developed and are expected to enter into force in the near future.

Flightpath 2050

Successive EU research programmes jointly funded by the EU and industry have played a large role in historic technology improvements. The European vision set out in 'Flightpath 2050' by the High Level Group on Aviation Research stresses the need to continue this partnership and achieve further ambitious reductions in noise, NO_x and CO₂ [27]. By 2050, it is envisioned that technologies and procedures will be available to reduce CO₂ emissions per passenger kilometre by 75%, NO_x emissions by 90%, and perceived noise by 65% relative to the capabilities of typical new aircraft in 2000.

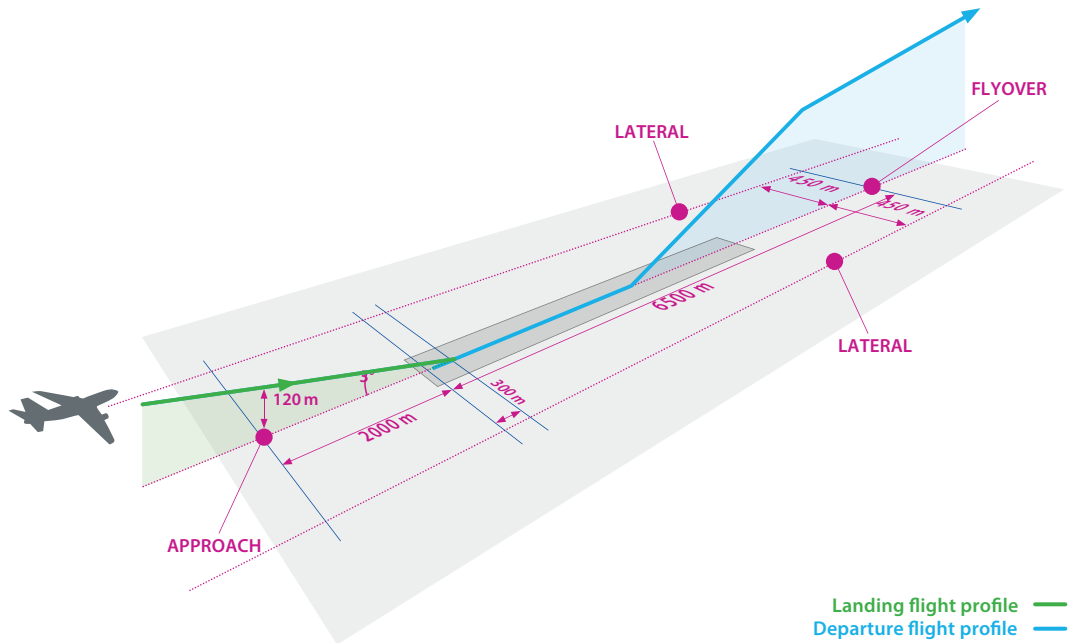
The rapid growth in aircraft flights during the 1960s led to growing public concern over aircraft noise. As a consequence the International Civil Aviation Organization (ICAO) agreed to an aircraft noise certification standard in 1971 [28, 29]. Ten years later the first aircraft engine emissions standard was also adopted to address local air quality issues [30, 31]. ICAO's Committee on Aviation Environmental Protection (CAEP) is responsible for maintaining these standards, and they form the basis for EU legislation [32].

2.1 Aircraft noise

2.1.1 Jet and heavy propeller-driven aircraft

All jet and heavy propeller-driven aircraft must comply with noise certification requirements. This involves the measurement of noise levels at three different measurement points (approach, lateral and flyover – see Figure 2.1) in order to characterise the aircraft noise performance around an airport. The EASA certified noise

Figure 2.1 Three noise certification measurement points

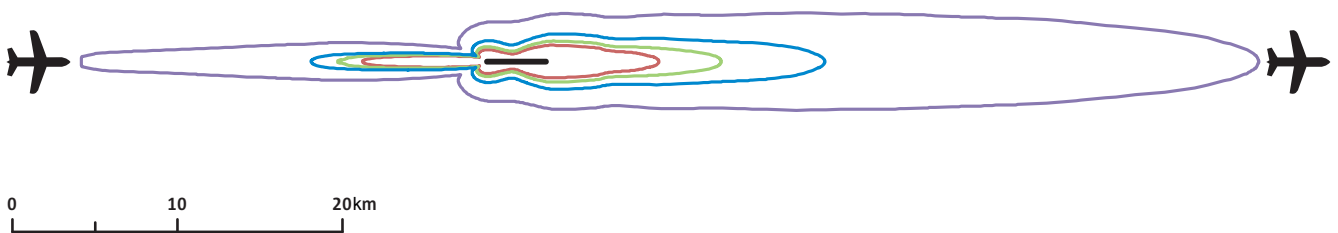


levels are measured in Effective Perceived Noise decibels (EPNdB) which is a metric that represents the human ear’s perception of aircraft noise.

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 and 14 of the ICAO noise requirements, and represent the increasingly stringent standards developed over time. Figure 2.2 shows the effect of the difference between the noise certification limits of the various chapters. It illustrates the areas that are exposed to noise levels greater than 80 dB during one landing and take-off for aircraft that just meet the various Chapter limits. The areas get smaller when aircraft get quieter.

Figure 2.2 80 dB Sound Exposure Level (SEL) contours for different aircraft that just meet the various ICAO Chapter limits



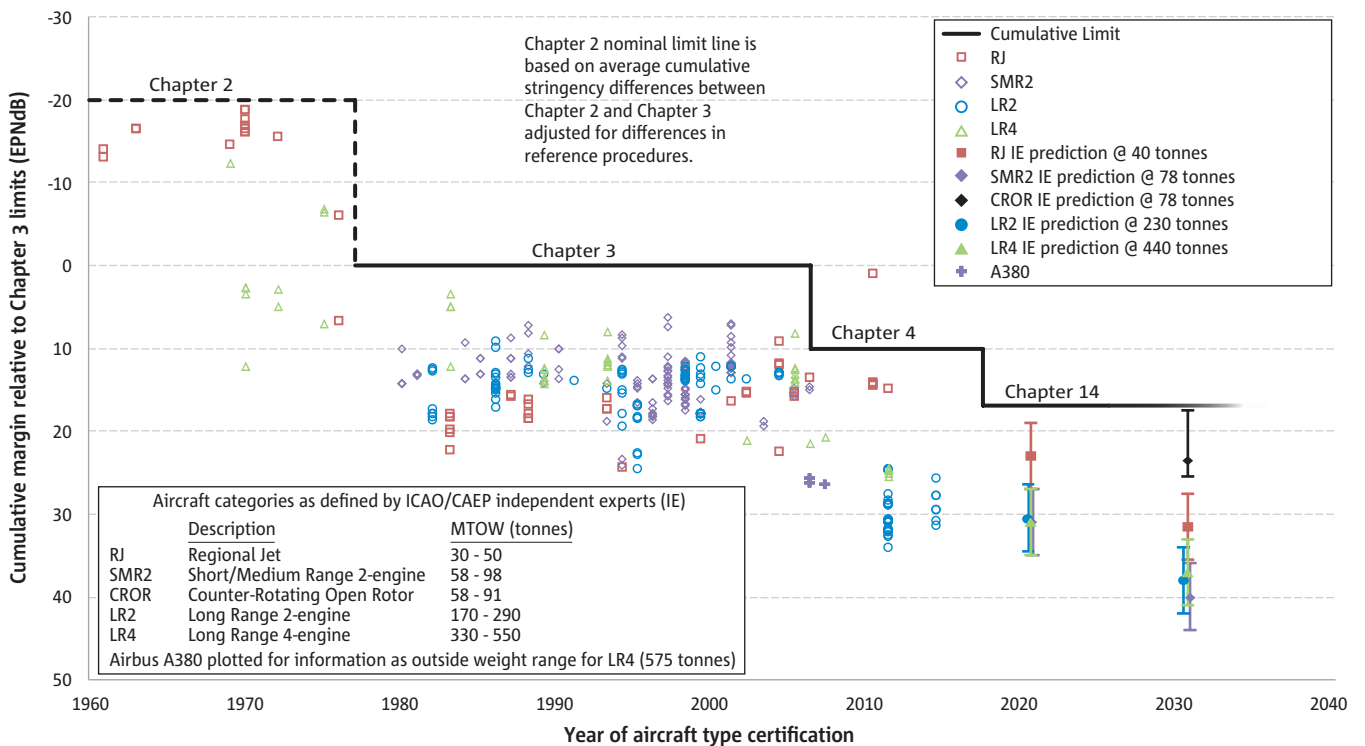
- Chapter 2 (before 1977), cumulative level: 309.0 EPNdB, 80 dB SEL contour area: 300 km²
- Chapter 3 (1977), cumulative level: 285.2 EPNdB, 80 dB SEL contour area: 67 km²
- Chapter 4 (2006), cumulative level: 275.2 EPNdB, 80 dB SEL contour area: 34 km²
- Chapter 14 (2017), cumulative level: 268.2 EPNdB, 80 dB SEL contour area: 21 km²

Figure 2.3 presents the evolution of aircraft noise technology-design performance over time against the noise limits. The figure shows the cumulative margin of the three certified aircraft noise levels relative to the associated Chapter 3 cumulative limit, plotted against the year the aircraft type was certified. This allows a comparison of different aircraft types across a range of weights as the associated limit values take into account the fact that larger, heavier aircraft make more noise. It should be noted that a specific aircraft configuration is often approved at various weights with different noise levels. Only the heaviest weights which represent the highest noise levels are plotted in Figure 2.3.

Work during the ICAO CAEP work programme from 2010 to 2013 included a review of noise

technology goals by independent experts (IE) for the intermediate (2020) and long-term (2030) timescales [33]. These goals are estimates with uncertainty bands of what the best technology is expected to achieve in four weight categories, namely Regional Jets (RJ), Short/Medium Range two-engine aircraft (SMR2), Long Range two-engine aircraft (LR2) and Long Range four-engine aircraft (LR4). The goals indicated on Figure 2.3 for 2020 and 2030 provide a reference for potential future developments and are combined with existing aircraft data for the same weight categories over the period 1960 to 2015. The four weight ranges cover most current jet aircraft families, except for the Airbus A380, which is added for information. A special data point is the estimate for an SMR2 aircraft powered by a Counter-Rotating Open Rotor (CROR).

Figure 2.3 Continuous improvement in aircraft noise performance has occurred over time across various weight categories



2.1.2 Helicopters

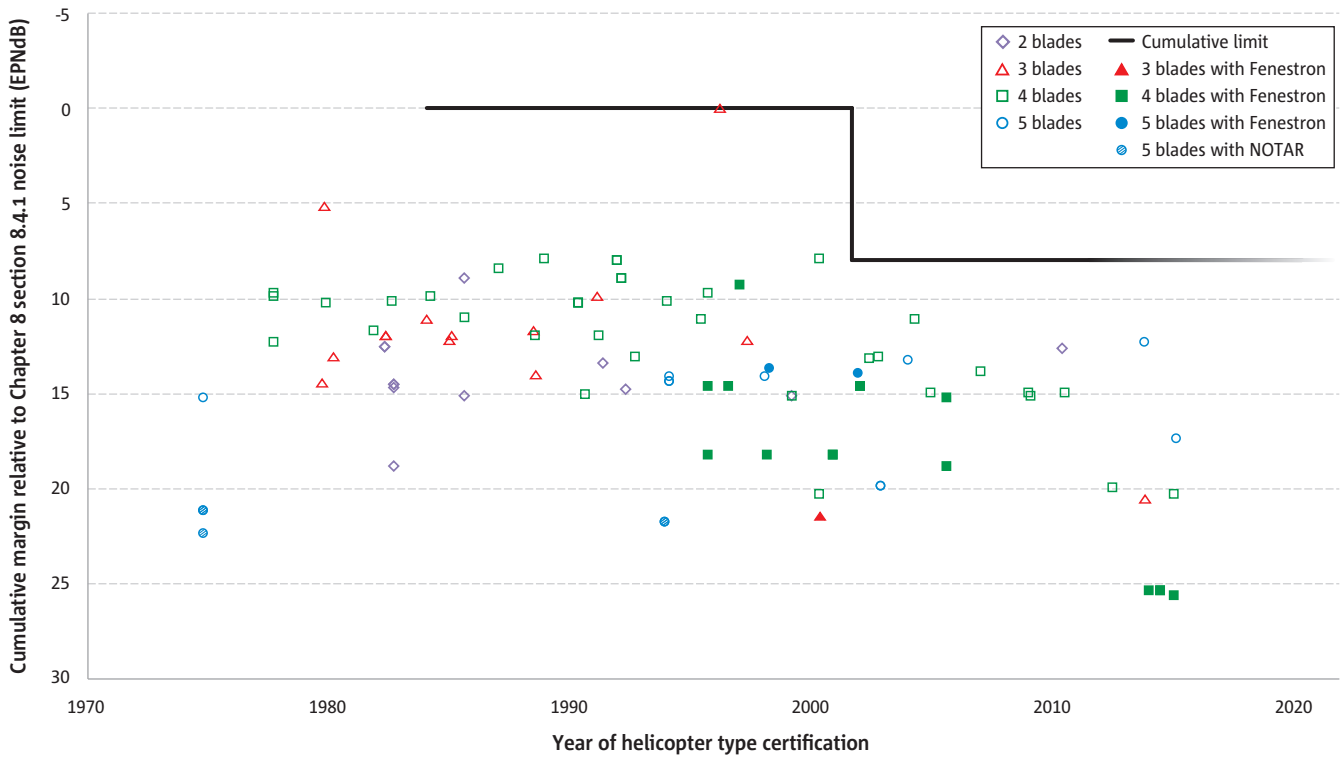
Helicopters are addressed in Chapter 8 of the ICAO noise certification requirements. In a similar way to jet and heavy propeller-driven aircraft, helicopter noise levels are evaluated in terms of EPNdB at three different measurement locations (approach, take-off and overflight) with a noise limit at each location. EASA

certified helicopter noise levels are plotted in Figure 2.4 as the cumulative margin relative to the original Chapter 8 limit which has been reduced over time. For each helicopter the number of rotor blades is identified in the figure and, where appropriate, the use of low noise tail rotor technology such as NOTAR (NO TAIL Rotor) and Fenestron.



Examples of Fenestron (top) and NOTAR (bottom) tail rotor technologies

Figure 2.4 Some improvement in helicopter noise performance has occurred over time, mainly via the use of low noise tail rotor technologies



2.2 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) and nitrogen oxides (NO_x). 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 2.5). 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 kN¹⁴ in the case of gaseous emissions.

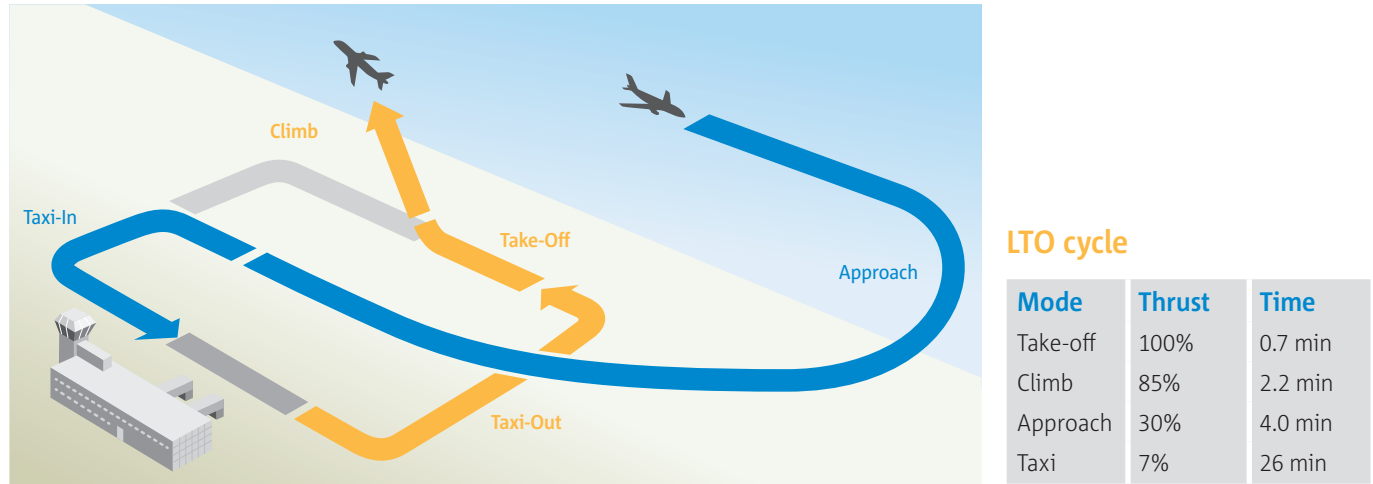
In order to improve fuel efficiency, engine pressures and temperatures are increased which can lead to higher NO_x emissions. As such, following the adoption of the original emissions

standards, more stringent NO_x limits have been periodically introduced in order to mitigate the potential trade-off with market-driven fuel burn improvements. The NO_x limits are referred to by the CAEP meeting number at which they were agreed (i.e. CAEP/2, CAEP/4, CAEP/6 and CAEP/8). The regulatory limits for smoke, HC and CO have not changed from their original value as they are considered to provide adequate environmental protection. These regulatory limits provide a design space for aircraft engine technology within which both NO_x emissions and fuel burn can be reduced.

An Aircraft Engine Emissions Databank (EEDB) is hosted by EASA on behalf of ICAO. Figure 2.6 provides an overview of all EASA certified NO_x emissions data for engine models in the Aircraft Engine Emissions Databank which are generally fitted to single aisle aircraft (e.g. A320, B737) or larger aircraft. The mass of NO_x emitted during the LTO cycle (D_p) is divided by the thrust of

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

Figure 2.5 Reference Landing and Take-Off (LTO) cycle



the engine (F_{oo}) and plotted against the engine overall pressure ratio¹⁵ for comparison against the regulatory limits. The regulatory value (Dp/F_{oo}) enables the comparison between small and big engines. Engines with a higher overall pressure ratio are typically utilised on larger aircraft with greater transport capability (e.g. payload and range). This benefit in transport capacity is recognised through a limited increase in the NO_x regulatory limit with higher overall pressure ratio. The NO_x technology goals for 2016 and 2026 were established by a group of independent experts during the CAEP/7 work programme (2004 to 2007). They are estimates of what the best ‘cutting edge’ technology could achieve, and provide an insight into potential future developments.

From 1 January 2013, all in-production engines must comply with the CAEP/6 standard. This

can be seen in Figure 2.6 with all current in-production engines being below the CAEP/6 regulatory limit. The figure also illustrates the continuous improvement achieved over time with newly certified engines achieving the largest margin to the limits. Some of the engines certified since 2008 are already close to mid-term and long-term technology goals.

Figure 2.7 illustrates the evolution of the average margin to the CAEP/6 NO_x limit for EASA certified in-production engine models. During the last five years the margin has increased by approximately 3% per year. It is noted however that the trend is influenced by which engines go out of production, and whether the new entries in the ICAO Aircraft Engine Emissions Databank represent new engines or derived versions of existing engines with smaller evolutionary improvements.

¹⁵ Ratio of total pressure at compressor exit compared to pressure at engine inlet.

Figure 2.6 Continuous improvement over time for engine NO_x emissions performance (engines > 89 kN)

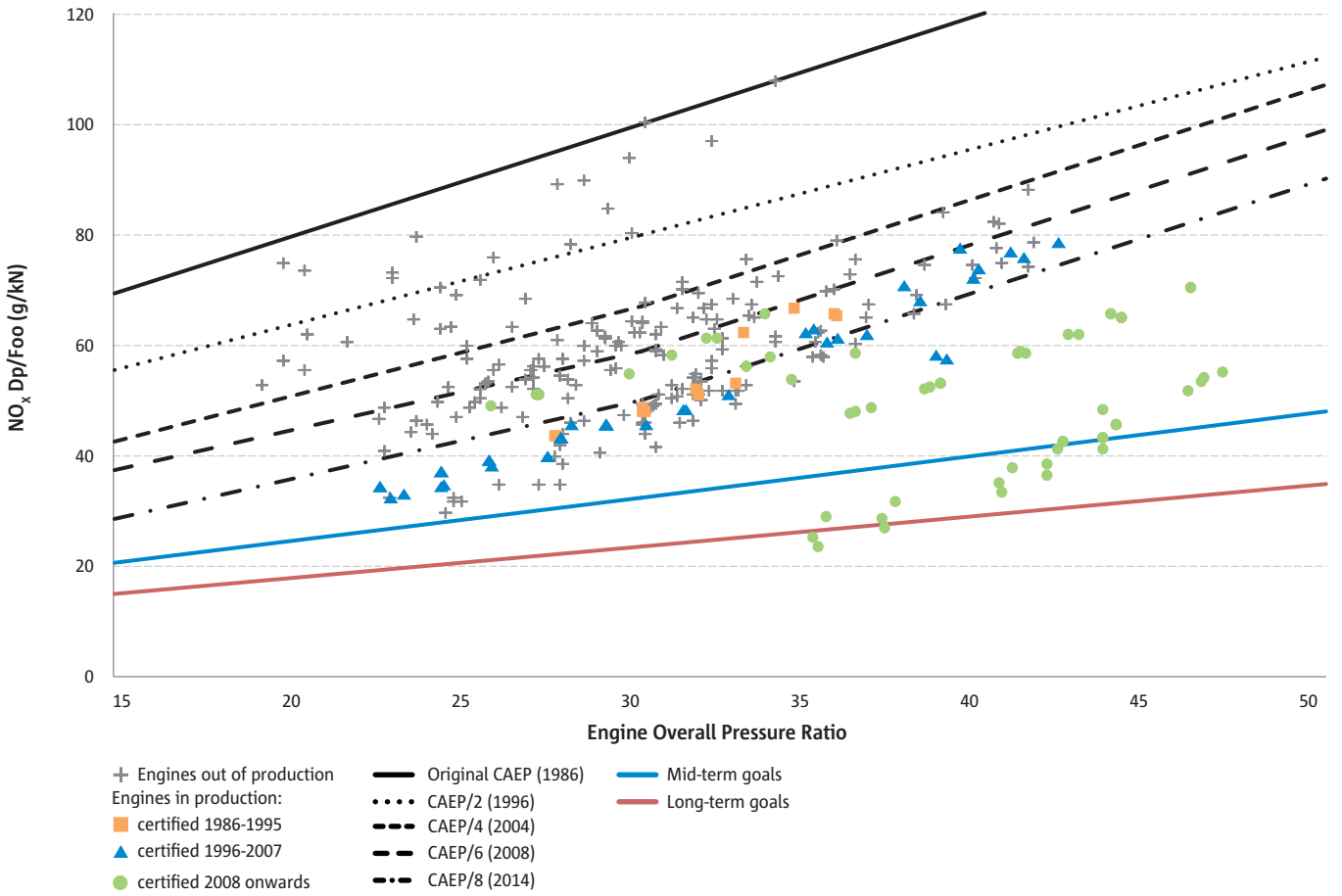
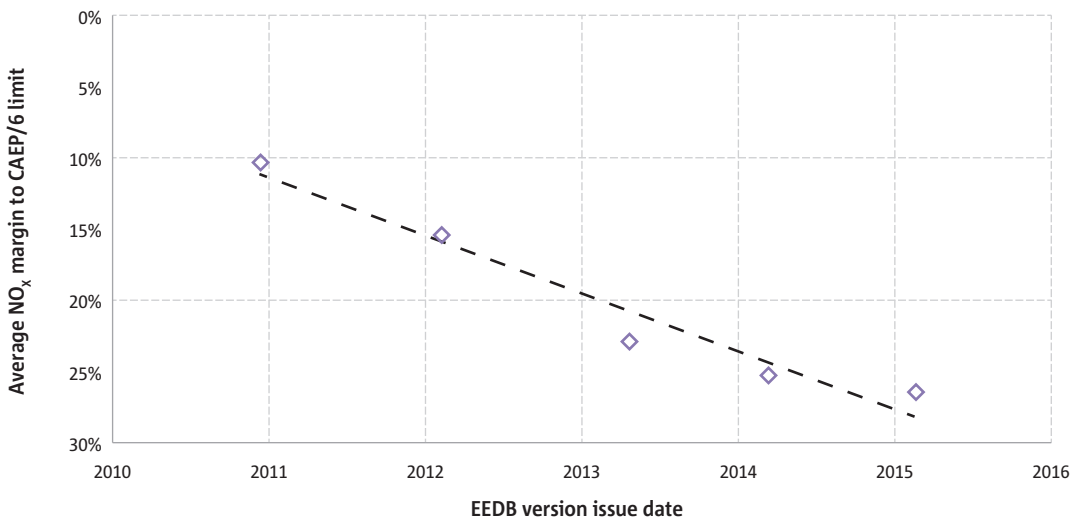


Figure 2.7 Improving average NO_x margin to CAEP/6 limit for in-production engines shown in successive versions of the EEDB



2.3 Future standards

EASA has played a leading role in the development of a new ICAO CO₂ certification standard to assess the fuel efficiency of aircraft and provided major input for the development of a new non-volatile PM standard for aircraft engines. These new standards are intended to address both climate change and local air quality issues, and will be discussed at the CAEP/10 meeting in 2016. If agreed, they are expected to be adopted into the European legislative framework.

2.4 Clean Sky Research Programme

The Clean Sky Joint Technology Initiative represents the principal European aviation technology and design research programme [34]. Clean Sky began in 2008 and is expected to run until 2017. It is a Public-Private Partnership with a budget of €1.6 billion jointly funded on a 50/50 basis by the European Commission and the aviation industry. The main objective of the programme is to contribute to the achievement of the Advisory Council for Aeronautical Research in Europe 2020 environmental goals for reduced aircraft emissions and noise, as well as the Flightpath 2050 European Vision for Aviation. Clean Sky aims to reduce the time to market for new and cleaner technology solutions tested on full scale demonstrators, and to also maintain the European aviation sector as a globally recognised centre of excellence. Clean Sky 2 has recently been launched, and will run from 2014 to 2024 with a budget of €4 billion.



STAKEHOLDER INPUT

AeroSpace and Defence Industries Association of Europe (ASD)

ASD's membership includes 15 major European aerospace and defence companies and 27 member associations covering 20 countries. In 2013, 777,000 people were employed by more than 3,000 aeronautics, space and defence companies generating a turnover of €197.3 billion.

The partnership between European Member States and ASD to address environmental challenges is highlighted hereafter through examples of research projects being taken forward under the EU Clean Sky research programme.

1. Counter-Rotating Open Rotor Engine (CROR)

Airbus, Rolls-Royce and Safran are undertaking research on this propulsion concept. The CROR may lead to a 30% reduction of CO₂ emissions compared to a 'Year 2000' reference aircraft, and produce noise levels similar to turbofan engines currently under development. The development of the CROR and its installation on the airframe is the most technologically complex project within Clean Sky. Several critical issues have been successfully addressed and aero-acoustic wind tunnel tests have shown encouraging results. A ground demonstration of a full CROR is anticipated at the end of 2015.

2. Laminar wing demonstrator (BLADE)

The BLADE flight test demonstrator is a new wing tip concept to be tested on an Airbus A340-300 aircraft. It provides an example of an integrated demonstrator, combining technology from various fields including aerodynamics, structures, control surfaces, coatings and test instrumentation (e.g. infrared camera to check for laminar flow). The manufacturing phase is well advanced following numerous wind tunnel tests, and the instrumentation has been tested on both ground and in-flight operations. The benefit is expected to be in the range of a 5% reduction in fuel consumption and CO₂ emissions.

3. Advanced Low Pressure System (ALPS)

The ALPS engine is intended to demonstrate the technological feasibility of carbon-titanium fan blades and composite engine casings which are expected to deliver a weight saving of around 700 kg on a twin-engine aircraft. This is equivalent to the weight of seven or eight passengers. The target is 1 to 3 dB reduction in noise. Early indications are that this is achievable.

4. Advanced Low Emissions Combustion System (ALECSys)

The ALECSys engine project is intended to demonstrate the lean burn whole engine system up to a Technology Readiness Level of TRL¹⁶. It is expected that the concept will be suitable for incorporation into civil aircraft engines in the 30,000 lbf to 100,000 lbf thrust class. The acquisition of lean burn combustion technology is crucial in order to comply with future CAEP emissions standards and the Advisory Council for Aeronautical Research in Europe's goals. The environmental target is focused on delivering NO_x emissions levels which are 60% below the CAEP/6 limits. Significant reductions in non-volatile PM are also expected. Testing is due to be completed by end of 2016.

5. Optimisation for low Environmental Noise impact Aircraft (OPENAIR)

Based on an airport impact assessment with a selection of the 15 technologies that had been demonstrated to Technology Readiness Level 4 or 5, an average noise reduction of 2.3 dB was achieved. These technologies included designs exploiting improved computational aero-acoustics and multi-disciplinary optimisation, new affordable sound absorbing materials and flow control techniques. Parallel studies on mechanical integration and manufacturing were also performed.

¹⁶ The Technology Readiness Level scale quantifies the state of a concept from idea (TRL1) to demonstration in a realistic environment (TRL5 or 6) to in-service on an aircraft (TRL9).



3. SUSTAINABLE ALTERNATIVE FUELS

While the uptake of sustainable alternative fuels in the aviation sector is still in its infancy, it is assumed that these fuels will play a large role in reducing aviation greenhouse gas emissions in the coming decades. The European Advanced Biofuels Flightpath provides a roadmap to achieve an annual production rate of two million tonnes of sustainably produced biofuel for civil aviation by 2020. European commercial flights have trialed sustainable alternative fuels. However, regular production of aviation alternative fuels is projected to be very limited in the next few years, and thus it is unlikely that the roadmap 2020 target will be achieved.

Facing increasing environmental and energy challenges, the aviation industry has engaged significant resources over the last decade to develop sustainable alternative fuels¹⁷ which can contribute to the agreed policy goals to diversify energy supply, support agriculture, and tackle climate change.

- Synthetic iso-paraffin fuels obtained from the conversion of sugars.

The two first fuels are approved for blending ratios up to 50% with conventional jet fuel, while synthetic iso-paraffin blending ratio is limited to 10%.

3.1 Alternative fuels for aviation

An international fuel specification committee has developed a standardised process [35] to check the suitability of sustainable alternative fuels with aviation's requirements, current systems and infrastructures. As a result, three jet fuel production pathways are currently approved for use in commercial aviation and have been included in a new alternative fuels standard [36]. These include:

- Fuels from hydroprocessing of vegetable oils and animals fats such as Hydroprocessed Esters and Fatty Acids / Hydrotreated Vegetable Oils (HEFA/HVO);
- Fischer-Tropsch fuels obtained from biomass (Biomass to Liquid-BTL); and

A larger quantity of biofuel could be made available to aviation in the short term if green diesel obtains approval for aviation. While it does not match aviation requirements, and needs further processing to produce equivalent jet fuel, it could potentially be used for aviation at low blending ratios of up to 10% with conventional jet fuel.

3.2 Emission reductions and benefits

Sustainable alternative fuels reduce aviation GHG emissions through savings which are achieved in the production phase of renewable, biological material (feedstock), and in the process of conversion into fuels. Emissions reductions are not achieved in the actual combustion phase. This is due to strict fuel specifications which require sustainable alternative aviation fuels to have 'drop-in'¹⁸

17 Sustainable alternative fuels lead to an overall GHG emissions reduction in comparison with traditional fossil based fuels. Coal to Liquid and Gas to Liquid are not considered to fall within this category.

18 A drop-in fuel is a substitute for conventional jet fuel which is fully compatible and interchangeable with conventional jet fuel.

characteristics with comparable behaviour to fossil fuel during the fuel combustion phase.

Potential emissions savings from using biofuels may be as large as 80%, but depend highly on the feedstock type and the production processes. For biofuels originating from agricultural crops, special attention must be paid to the potential emissions generated by the direct or indirect land use conversion induced by the cultivation of the crops¹⁹. From this point of view and regarding possible risks of competition with food production, alternative fuels produced from wastes are of special interest.

An additional benefit from the use of alternative fuels could be improved air quality. Depending on the type of production pathway, alternative fuels may contain no aromatics and sulphur, leading to a significant reduction of soot and sulphur oxides emissions when blended with conventional jet fuel.

3.3 Market for sustainable alternative fuels

In 2009 the European Commission initiated the SWAFEA study [37] to investigate the feasibility and impact of the use of alternative fuels in aviation to support future air transport policy discussions. The main recommendations covered various areas including economics, policy, sustainability, research and coordination. The output of this study fed into discussions with aircraft manufacturers, airline operators and European biofuel producers, and in 2011 resulted in the launch of the 'European Advanced Biofuels Flightpath'²⁰ [38]. This is an industry-wide initiative to accelerate the market uptake of aviation biofuels in Europe. It provides a roadmap to achieve an annual production rate of 2.06 million tonnes of oil equivalent (2.06 Mtoe / 600 million gallons) of sustainably produced biofuel for civil aviation in Europe by the year 2020²¹.

To support the emergence of sustainable aviation alternative fuels in Europe, aviation has also been included in the so-called Renewable Energy Directive [39], which defines a mandatory target of 10% renewable energy content in transportation fuels by 2020²². Aviation biofuels meeting the sustainability criteria of the Renewable Energy Directive are exempted from obligations under the EU ETS. Moreover, aviation fuels can contribute to the additional target set by the European Fuel Quality Directive [40] to cut the greenhouse gas intensity of transportation fossil fuels supplied in the EU by 6% in 2020 compared to a 2010 baseline.

Commercial facilities exist in Europe for hydroprocessing of vegetable oils and animal fats (HEFA/HVO), although these facilities are focused on diesel fuel production and are not specifically designed for jet fuel production. The potential use of green diesel would make existing production capacity available to aviation and lead to a biofuel with lower costs than HEFA/HVO, although use of green diesel in aviation would face competition with road transportation where conditions are more favorable to biofuels and incentives are already in place.

Production costs for sustainable alternative aviation fuels are expected to decrease once experience is accrued, the production volume increases and more producers enter the market. Sustained access to low-cost feedstocks is also considered necessary to become cost-competitive with conventional kerosene. In addition, capital investment may be a significant hurdle for the development of the sustainable aviation fuel industry infrastructure, which can be quite different depending on the chosen production pathway.

Due to the current price gap with conventional jet fuel, demand for sustainable alternative fuels has so far been limited to ad-hoc airline demonstration flights and pilot phases of sustainable biofuel supply chains by biofuel producers [41]. Consequently, to date, there

19 Indirect land conversion may occur due to the displacement of existing crops to produce biofuels.

20 Biofuels are alternative fuels produced from biomass (e.g. feedstock, vegetable oils and animal fats, waste).

21 In comparison, the US Farm to Fly initiatives aim at producing one billion gallons of sustainable jet fuel by 2018. Note the definition of sustainable biofuels is currently different in the EU and US regulatory frameworks.

22 To date, Indonesia is the only country to have introduced a biojet fuel mandate. This starts at 2% in 2016 and rises to 5% by 2025.

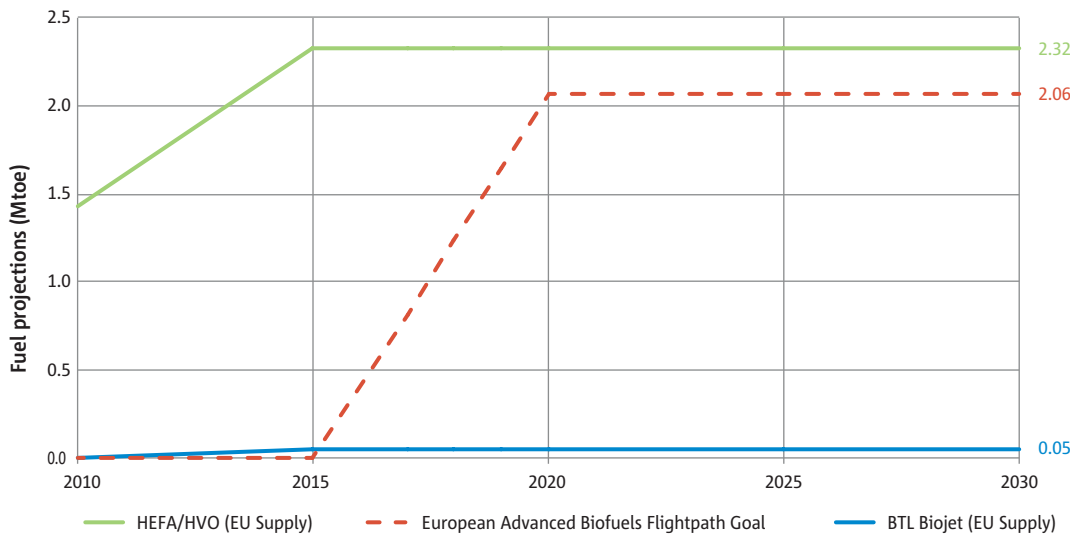
has been no regular production of aviation alternative fuels in Europe.

3.4 Future outlook

The proportion of biofuels in total fuel consumption by commercial aviation was 0.05% in 2009. Figure 3.1 shows the potential EU supply projections for various types of sustainable alternative fuels out to 2030 [42]. This study

concluded that the European Advanced Biofuels Flightpath goal of 2 million tonnes of sustainable alternative fuels in 2020 [43] could theoretically be met from the HEFA/HVO production at an EU level. However this is unlikely to be achieved due to the competition in demand for these alternative fuels from other transport sectors. The hesitation of the industry towards investing in dedicated production facilities for Biomass To Liquid fuel is clear from the limited projected supply of 0.05 million tonnes by 2020.

Figure 3.1 Projections for total EU supply of sustainable alternative fuels and production goal for the aviation sector



STAKEHOLDER INPUT

Alternative fuel case studies

In 2011, KLM was the first airline to use an alternative fuel based on used cooking oil for a commercial flight from Amsterdam to Paris. The BioPort Holland project and KLM Corporate Biofuel Programme aim to supply 1% of KLM's entire fleet with sustainable jet fuel in 2015-2016. Similarly, Lufthansa has been operating the domestic route from Frankfurt to Berlin using a 10% alternative fuels blend based on sugarcane, and the Frankfurt to Washington route using a 46.8% blended HEFA fuel based on jatropha, camelina and animal fats. Since 2013, Air France has been using a sugarcane based 10% blend alternative fuel on Toulouse to Paris (Orly Airport) routes. Iberia has also operated the Madrid to Barcelona route using a 25% HEFA (from camelina) alternative fuels blend.

The EU ITAKA [44] project (2013-2016) is also expected to support the development of a full value-chain to produce sustainable HEFA on a large scale based on camelina and used cooking oil. First demonstration flights were completed by KLM in 2014 with 200 tonnes of used cooking oil-based biofuel.



4. AIR TRAFFIC MANAGEMENT AND OPERATIONS

The European air traffic network handles an average of 27,000 flights and 2.27 million passengers per day. Europe is investing heavily in modernising the Air Traffic Management (ATM) system through the Single European Sky ATM Research (SESAR) programme which is the technological pillar contributing to the EU Single European Sky (SES) legislative framework. Much of what SESAR delivers will form the core of the Deployment Manager Programme, thereby contributing to achievement of the SES Performance Scheme performance targets and further enhancing global harmonisation, interoperability and efficiency. The SES high-level goals are: enable a three-fold increase in capacity which will also reduce delays both on the ground and in the air; improve safety by a factor of 10; reduce fuel consumption per flight by 10%; and provide ATM services to the airspace users at a cost of at least 50% less. Performance indicators show a moderate, but steady, reduction in distance flown and in excess CO₂ emissions. These improvements are attributable to improved organisation of European airspace and route designs. At airports, time-based indicators have recently been introduced. These aim to measure the efficiency of the approach and landing flight phase, and of the taxiing from the gate to the runway.

4.1 Single European Sky

Almost 6,000 individual aircraft operators provide commercial passenger and cargo services in Europe. Air traffic controllers, at over 60 en route Air Traffic Control centres and over 500 airport control towers work with pilots to ensure a high level of flight safety, efficiency and punctuality. The provision of air traffic services is the responsibility of every State under the ICAO Convention, and thus almost every State has its own Air Navigation Service Provider (ANSP). Through the Single European Sky²³ initiative [45], certain regulatory powers have been introduced

by the EU. Two key mechanisms were created that are critical to environmental performance: those of Performance Scheme [46] and Network Functions [47, 48] both of which build on capabilities developed by EUROCONTROL on behalf of Member States during the 1990s.

SES Performance Scheme

By setting binding EU and local targets, as well as performance monitoring and corrective actions, the SES Performance Scheme aims at driving performance improvements in European aviation. The EC designates

23 Single European Sky (SES) Member States include the EU28 plus Norway and Switzerland. All data in this section relates to SES States unless otherwise noted.

a Performance Review Body [49] in charge of assisting the EC in setting up and managing the performance scheme. The performance scheme currently considers the fields of safety, capacity, environment, cost-efficiency and their interdependencies. The scheme includes indicators for both the en route portion of flights within European airspace with EU-wide targets, and the operational Air Navigation Services (ANS) performance around airports with targets set at the local level. Performance targets have been set for two reference periods (2012-2014 and 2015-2019).

Network Functions

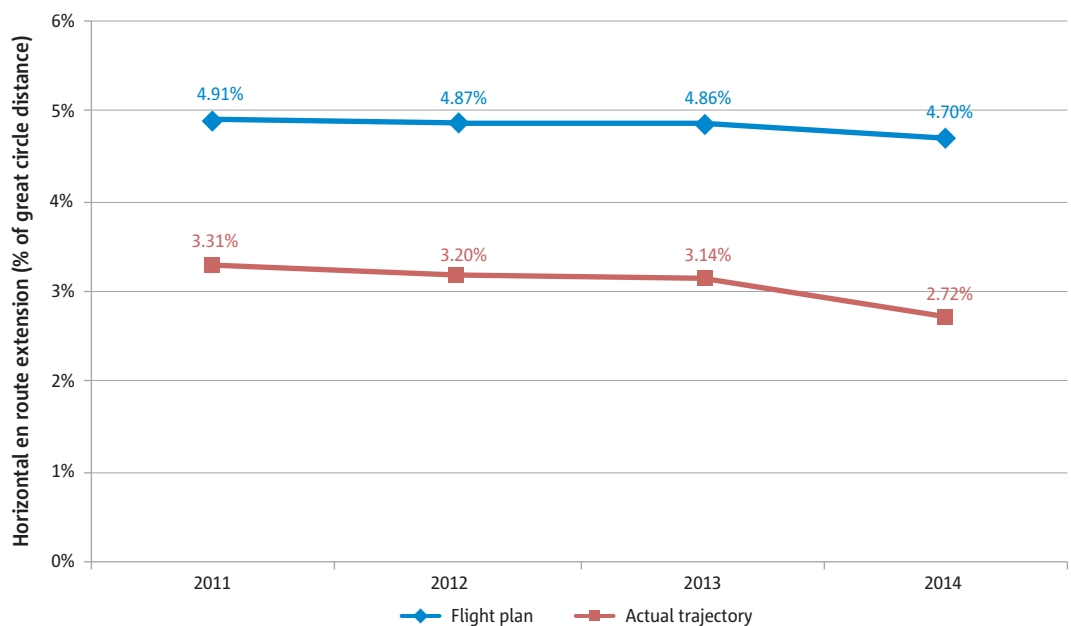
The objective of the network functions is to set up proper coordination between operational stakeholders and the Network Manager. The Network Manager is tasked to optimise the European aviation network and thereby contribute to the delivery of ATM performance targets, especially in the areas of capacity and cost-efficiency/environment. In order to meet this objective, the Network Manager has to manage imbalances between capacity and demand in air traffic so as to minimise their

impact on the overall European network. On a daily basis the Network Manager prevents congestion in the air through flow and capacity management which limits unnecessary fuel burn and emissions. The flight efficiency initiative, launched in 2013, offers operators the most efficient routes on each day of operation.

4.1.1 En route flight efficiency

Aircraft operators wish to fly preferred trajectories (horizontal route and vertical profile) which are influenced by schedule considerations, aircraft capabilities, weather, route charges, fuel burn and other factors. ATM is responsible for managing traffic flows and optimising the use of en route airspace in order to find a good balance between capacity and demand. This inevitably leads to some degree of inefficiency on the preferred trajectories. The environmental performance of ATM is therefore measured as the level of inefficiency in the system, i.e. the difference between the actual or planned trajectories and the corresponding portion of the great circle shortest distance. In en route airspace, the main flight efficiency factor is the horizontal additional distance.

Figure 4.1 Horizontal en route flight inefficiency for 2011 to 2014 (Source: PRR [50])²⁴



²⁴ 40 Member States of the EUROCONTROL area.

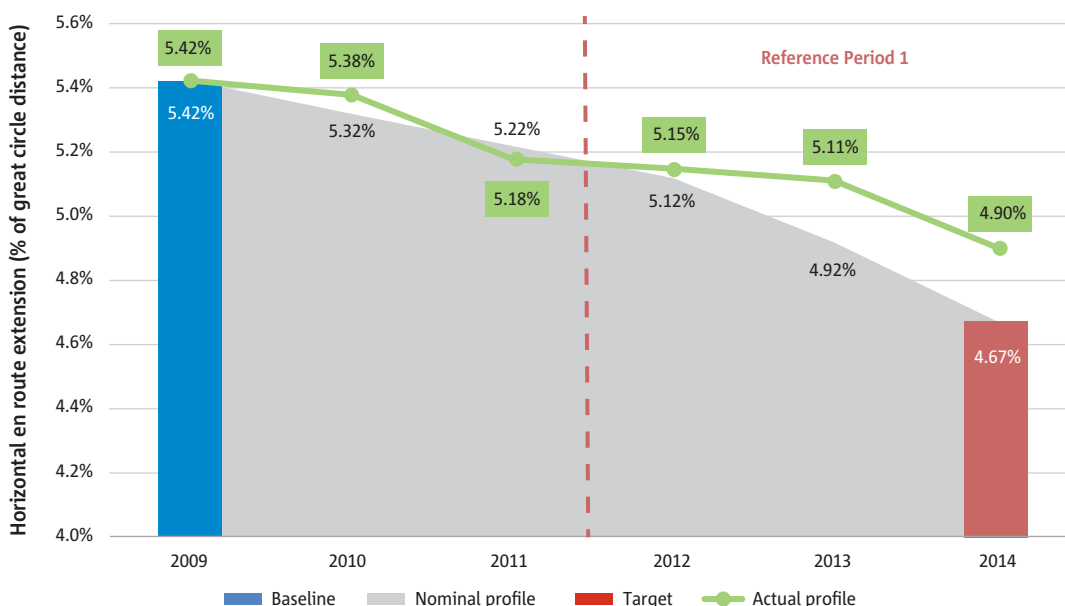
Figure 4.1 shows a moderate but steady improvement in the reduction of horizontal distance introduced in flight planning, with the inefficiency of flight plans gradually decreasing from 4.91% in 2011 to 4.70% in 2014. A slightly stronger trend was observed in the actual trajectory with a reduction from 3.31% to 2.72% in additional distance flown over the same period. The difference between the two indicators reflects the flexibility within the system on any given day. The figure shows that as a result of action by pilots and air traffic controllers, the horizontal distance originally planned can be reduced through operational initiatives.

These horizontal en route flight efficiency indicators form part of the SES Performance Scheme - from 2011 for the last filed flight plan and from 2015 for the actual trajectory - because: (1) ATM has a direct influence over them; (2) they can be accurately measured against the stable and known baseline of the

great circle distance; (3) they provide accurate values for trend analysis and application of target setting; (4) they are suitable as measures for environmental performance and (5) if needed, additional distance can be converted to an estimate of excess CO₂ emissions (see 4.1.3). Performance is measured against corresponding horizontal en route EU inefficiency targets that are binding for SES States. These targets have been set at 4.1% for the flight plan and 2.6% for actual trajectory by 2019 [50]. Performance indicators for the vertical profile component may be considered for the next reference period from 2020.

Figure 4.2 shows the achievements in reducing inefficiency of flight plans during the first reference period of the SES Performance Scheme (2012-2014). Despite the fact that the performance has gradually improved with respect to the original baseline, the actual performance in 2014 of 4.90% fell short of the target of 4.67%.

Figure 4.2 SES targets and achieved performance in horizontal en route flight inefficiency of the last filed flight plan (Source: PRB [52])



The goal in setting performance targets on flight efficiency is to reduce the additional distance flown per flight, thus reducing excess fuel consumption and CO₂ emissions attributable to ATM. In 2014, for example the total additional distance flown was 38.4 million kilometres which corresponds to approximately 127,000 tonnes of fuel, or 400,000 tonnes of CO₂, compared to the 2011 baseline²⁵.

4.1.2 Operational efficiency around airports

The airspace around airports can become very congested. To ensure the safe separation of climbing and descending aircraft, air traffic controllers use a combination of published standard approach and departure procedures and direct instructions to pilots known as 'vectoring'. Horizontal flight efficiency is therefore not measured in the airspace around an airport. Instead, a complementary measure for environmental performance has been developed, based on additional time flown, and is measured within a cylinder of airspace, centred on the airport with a radius of 40 nautical miles. This is the 'Arrival Sequencing and Metering Area (ASMA)' in which measurements are made of the time taken between aircraft entering the cylinder and their landing. Any additional time

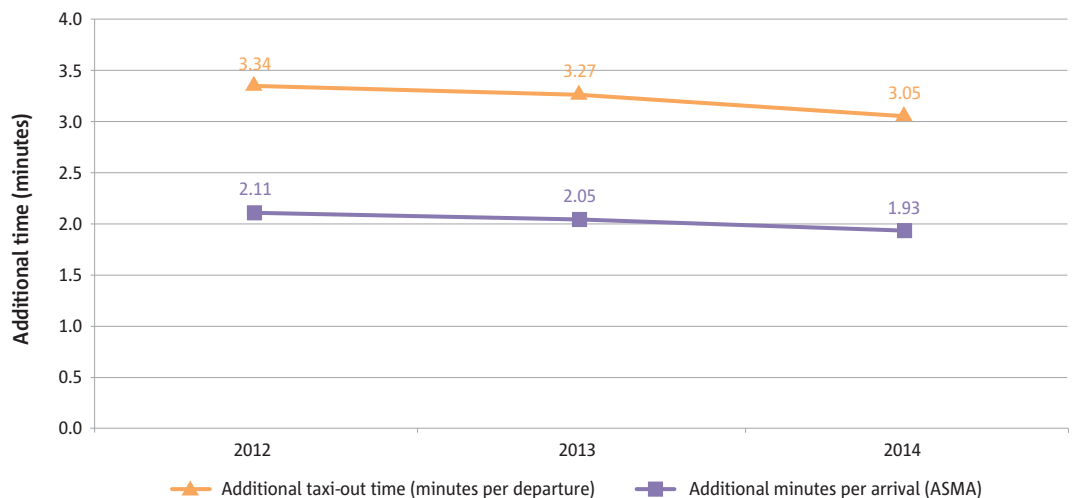
taken beyond the reference value is used as a measure of the level of inefficiency (holding and flight path extensions for sequencing purposes) of the inbound traffic flow during times when the airport is congested.

Likewise, in order to measure ANS performance of aircraft ground operations at airports, in particular queuing at the take-off runway, the 'additional taxi-out time' indicator is used to compare actual taxi times between the gate and take-off with the taxi-times during uncongested periods.

These two performance indicators monitor ANS-related inefficiencies in the arrival flow and ground departure flow at the airports in the scope of the SES Performance Scheme

On average, the additional time in the arrival sequencing and metering area has reduced from 2.11 minutes per arrival to 1.93 minutes between 2012 and 2014, whilst additional taxi-out time has reduced from 3.34 to 3.05 minutes (Figure 4.3). Although these numbers appear small, a reduction of 0.1 minute for 10 million flights could correspond to fuel savings of at least 10,000 tonnes and 30,000 tonnes CO₂ emissions.

Figure 4.3 Reduction in average ANS-related performance inefficiency on both the arrival flow and ground departure flow in Europe (Source: PRB [51])



²⁵ 40 Member States of the EUROCONTROL area.

4.1.3 Estimated excess CO₂ emissions due to overall network inefficiencies

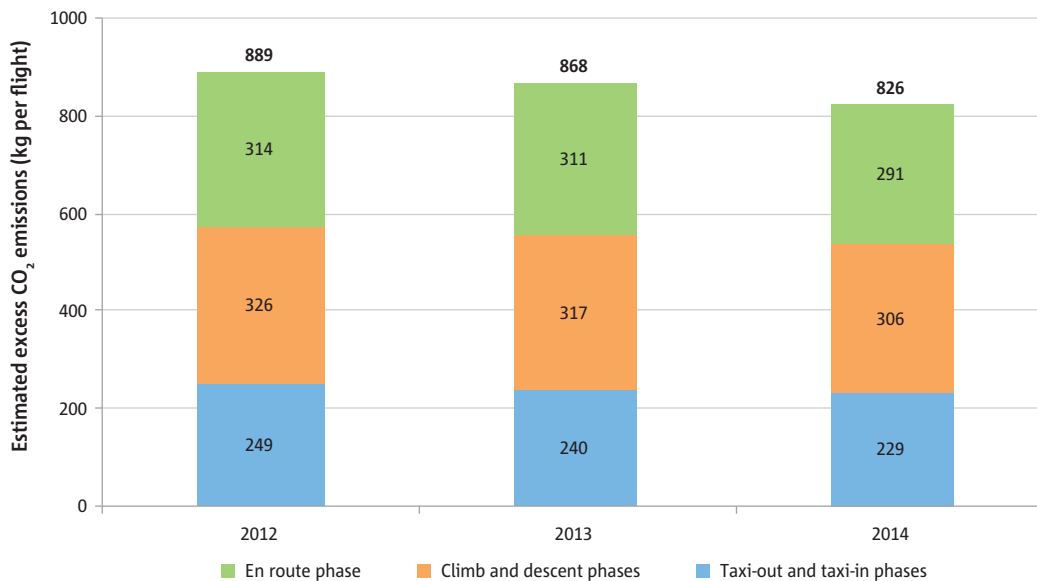
The excess CO₂ emissions of the network is measured by the inefficiency of the taxi-out, en route and arrival phases of flight as described in 4.1.1 and 4.1.2.

Figure 4.4 shows the estimated excess CO₂ emissions generated per flight that can be attributed to inefficiencies related to overall Air Navigation Services. These excess emissions have decreased by 7% since 2012, with the climb and descent phase decreasing by 6%, the taxi phase by 8% and the en route phase by 7%. It should be noted that the inefficiencies in

the individual flight phases are average excess emissions compared to theoretical optima. These theoretical optima are not achievable in reality at the air traffic system level due to safety or capacity limitations. Therefore the excess emissions indicated cannot be reduced to zero, as a certain level of excess fuel burn is necessary if a network system is to be run safely and efficiently.

Measurement of the taxi-in phase was undertaken for the first time in 2014. This measurement will serve as a baseline for assessing future trends, and may be considered for inclusion as an additional performance indicator in future reference periods.

Figure 4.4 Estimated excess CO₂ emissions per flight are decreasing in taxi, take-off, climb/descent and en route phases²⁶



²⁶ Average values for the EUROCONTROL area covering en route airspace plus the top 30 airports by aircraft movements. En route, climb and descent phase values include estimates of vertical flight inefficiency.

4.2 Improving ATM in the future: SESAR operational changes

In Europe, the SESAR project is expected to deliver much of the infrastructure and operational improvements that need be deployed to modernise ATM, in line with the European ATM Master Plan [53]. The Master Plan outlines the essential operational and technological changes that are foreseen in order to achieve the EU SES performance objectives. In doing so, it also ensures consistency with deployment of the Aviation System Block Upgrades as foreseen in the ICAO Global Air Navigation Plan. The implementation of performance improvements for global harmonisation will enable ATM systems

to work better together and thus improve interoperability. Following on from the SESAR Deployment Baseline²⁷, the SESAR Deployment Phase started in 2014 with a first set of ATM functionalities to be deployed in a timely and synchronised manner over Europe.

Recent work of ICAO has estimated the generic fuel savings that operational improvements could deliver (Table 4.1).

Figure 4.5 provides an overview of European airports where Continuous Descent Operations are available²⁸. Figure 4.6 illustrates the implementation status of some operational improvement solutions (AMAN, A-SMGCS, and A-CDM) together with an illustration of the availability of RNP AR APCH.

Table 4.1 Estimated fuel savings from selected operational improvements

Operational improvement	Estimation of benefit
Continuous Descent Operations (CDO)	60 kg fuel saving in descent
Arrival Manager (AMAN)	50 to 100 kg fuel saving per arrival during peak hours
Advanced Surface Movement Guidance and Control System (A-SMGCS)	5 to 24 kg fuel saving per taxi-out phase during busy periods, bad weather and at night
Required Navigation Performance Authorisation Required Approaches (RNP AR APCH)	300 to 500 kg fuel saving per missed approach / diversion due to improved access to runways
Airport Collaborative Decision Making (A-CDM)	12 to 36 kg fuel saving in the taxi phase per flight

²⁷ Operational and technical solutions that have successfully completed the Research & Development phase and have been implemented or are being implemented.

²⁸ Availability of continuous descent operation procedures varies per airport: it may range from 24 hours at smaller airports to during night time hours only at busier airports.

Figure 4.5 Airports within Europe where Continuous Descent Operations (CDO) were available in 2014

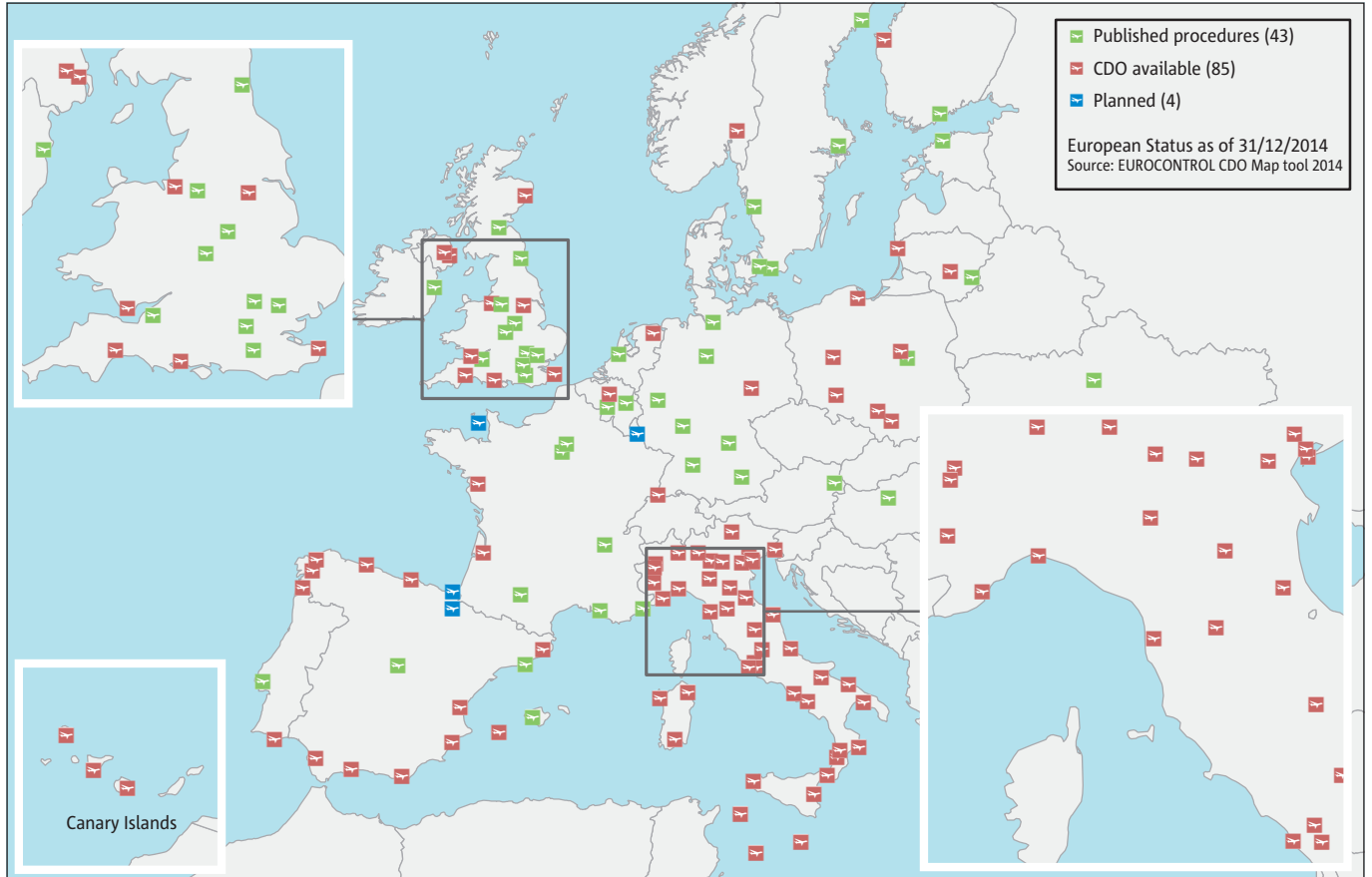
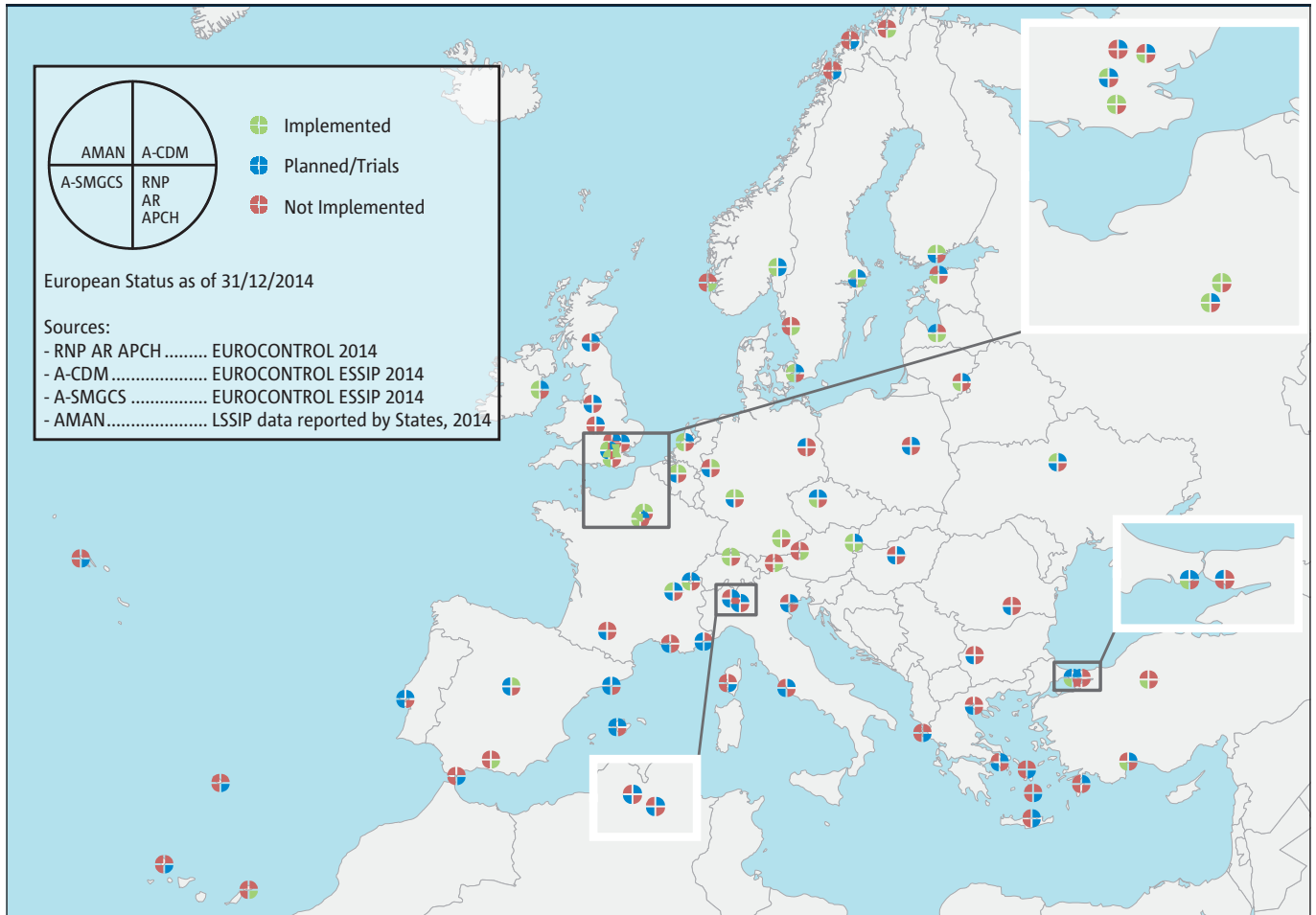


Figure 4.6 Airports which have implemented (2014) or plan to implement (2014-2018) selected operational improvements



Overall, it is expected that, between 2015 and 2018, the planned European deployment of 'Block 0' of the Aviation System Block Upgrades, facilitated through the SESAR Deployment Phase, could result in fuel savings of between 0.8 to 1.6 million tonnes per year, equivalent to 2.5-5.0 million tonnes of CO₂.

4.3 Free Route Airspace

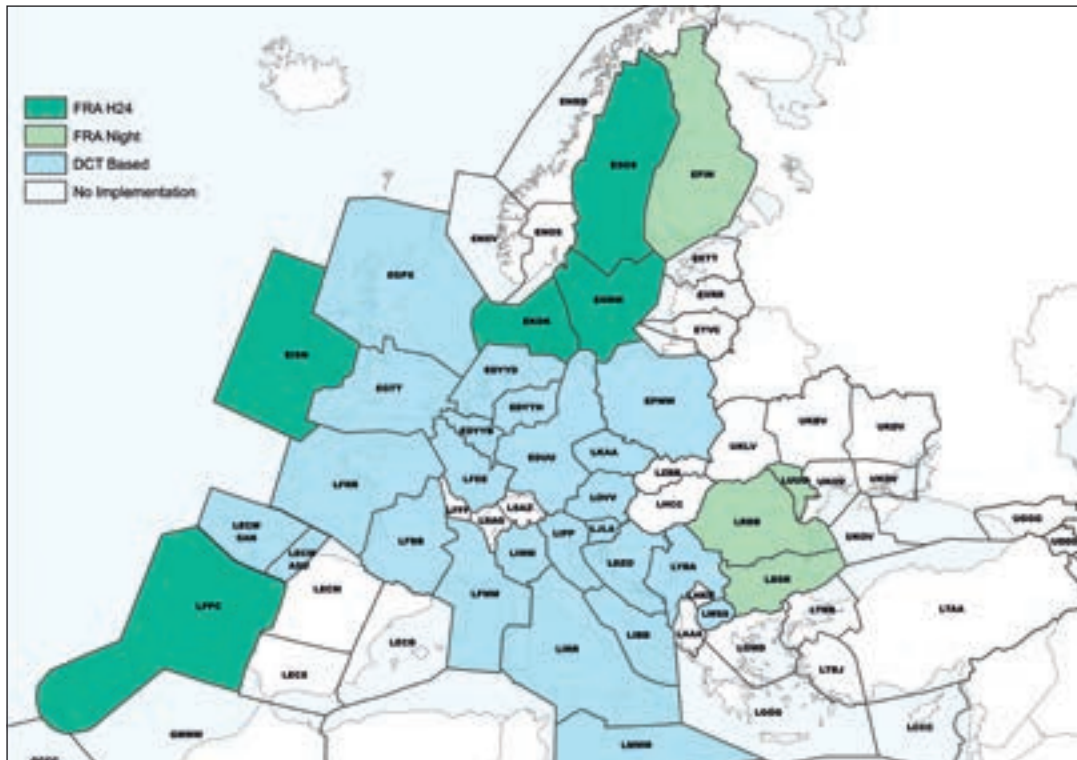
The development and implementation of Free Route Airspace (FRA) was initiated in 2008 to foster the implementation of shorter routes and more efficient use of the European airspace. Free Route Airspace is defined as that airspace within which users may freely plan a route between any defined entry and exit point, subject to airspace availability. Direct routing (DCT) is a precursor to

Free Route Airspace, where direct routing is only allowed between certain entry and exit point combinations.

Figure 4.7 shows the extent of Free Route Airspace and direct routing implementation in Europe as of 2014, including both free route airspace available at all times (24 hours) and that available only at night. The proportion of flight time flown in Free Route Airspace is 8.5% (70.6 million minutes) of the total duration of flights²⁹. The ultimate aim for the most cost-effective and fuel-efficient route structure is cross-border free route activities such as those currently found in the combined Denmark and Sweden airspace and the Maastricht Upper Area Control Centre (upper airspace of Belgium, Luxembourg, Netherlands, and North Western Germany).

29 28 EU Member States plus 4 EFTA Member States.

Figure 4.7 Free Route Airspace (24 hours or at night) and direct routing implementation in Europe in 2014 (Source: Network Manager)



Free Routing is considered to be the concept that will provide the greatest fuel saving in en route airspace. It is estimated that Free Route Airspace operations were taking place in more than 25% of the European area by the end of 2014³⁰. If Free Route Airspace operations were fully implemented across Europe, the distance saved could amount to approximately 46,300 km per day (16.9 million km per year), representing annual savings of 45,000 tonnes of fuel and 150,000 tonnes of CO₂.

4.4 Single European Sky ATM Research Programme

The Single European Sky ATM Research programme (SESAR) is the technological pillar of the EU Single European Sky framework which was launched with the aim of developing a seamless, pan-European ATM system that will contribute to making European aviation safer, performance-driven and environmentally sustainable [53].

Established in 2007, the SESAR Joint Undertaking is a public-private partnership which pools the knowledge and resources of the entire ATM community in order to define, research, develop and validate SESAR technological solutions. Founded by the EU and EUROCONTROL, the SESAR Joint Undertaking has 15 members who together with their partners and affiliate associations represent over 70 companies working in Europe and beyond. It also works closely with staff associations, regulators, airport operators, and the scientific community.

In 2014, the SESAR Deployment Manager, comprised of air navigation service providers, airlines and the SESAR-related Deployment Airport Operators Group, began to coordinate the implementation of the EU's Pilot Common Project [54], the first set of SESAR Solutions to be deployed in a synchronised and timely manner across Europe.

SESAR contributes to the SES targets by defining, developing, validating and deploying innovative technological and operational solutions for

managing air traffic in a more efficient manner. SESAR's contribution to the SES high-level goals set by the European Commission are continuously reviewed and kept up to date in the European ATM Master Plan [55].

Contributing to high performing aviation in Europe

SESAR is researching and developing greener solutions to improve ATM performance by reducing fuel burned per flight by up to 50% by 2035 which corresponds to up to 1.6 tonnes of CO₂ emissions per flight, split across operating environments.

The results are delivered through yearly releases, a process in which solutions undergo thorough pre-industrial development and integration testing within a given timeframe in order to establish their readiness for industrialisation and subsequent deployment. The process has resulted in 25 fully validated SESAR Solutions (until 2015), targeting the full range of ATM operational environments including airports. One such solution is the integration of pre-departure management within departure management at Paris Charles de Gaulle, resulting in a 10% reduction of taxi time, 4,000 tonnes of fuel savings annually and a 10% increase of Calculated Take-Off Time adherence. Another solution is Time-Based Separation at London Heathrow, allowing up to five more aircraft per hour to land in strong wind conditions and thus reduce holding times by up to 10 minutes.

Noise abatement is also an important part of SESAR's environmental work and, while not subject to quantitative targets, it is taken into consideration when developing solutions. While airport noise is essentially a local concern, it can represent an obstacle to the implementation of ATM improvements that offer other important airport performance gains, such as fuel efficiency. Each airport therefore needs to reduce the environmental impact per flight in accordance with local priorities and tradeoffs while contributing to the adopted SES Performance Scheme.

SESAR is also making a difference at airport level by developing solutions within the airport-collaborative decision-making framework to improve information sharing at airports, thereby improving efficiency and

predictability of flights. One such solution is the Airport Operations Centre, which brings together the main airport stakeholders to become a platform for stakeholder communication and coordination, based on shared knowledge. SESAR validations have shown how Airport Operations Centre can improve efficiency at both regional and large airports and, in 2014, such centres were opened at London Heathrow and Paris Charles de Gaulle airports.

SESAR Atlantic Interoperability Initiative to Reduce Emissions

In addition to its core activities, the SESAR Joint Undertaking co-finances projects where ATM stakeholders work collaboratively to perform integrated flight trials and demonstrations validating solutions for the reduction of CO₂ emissions for surface, terminal and oceanic operations to substantially accelerate the pace of change.

Since 2009, the SESAR Joint Undertaking has co-financed a total 33 'green' projects in collaboration with global partners, under the Atlantic Interoperability Initiative to Reduce Emissions, demonstrating solutions on commercial flights. Around 17 ANSPs, 9 airports, 26 airlines and 15 industrial partners from Europe, Canada, the United States, and Africa have been part of the initiative.

A total of 15,767 flight trials were conducted demonstrating savings ranging from 20 to 1,000 kg of fuel per flight (or 63 to 3,160 kg of CO₂), and improvements to day-to-day operations.

SESAR 2020

In 2014, the EU adopted legislation to extend the legal mandate of the SESAR Joint Undertaking until 31 December 2024. In addition, the amending regulation entrusted the Joint Undertaking with executing and delivering an extended research and innovation programme (SESAR 2020) to contribute towards achieving the SES and more particularly the European ATM Master Plan. This new phase of SESAR will continue to investigate solutions that will bring additional fuel and emissions savings, while also addressing other environmental aspects like noise impacts and local air quality.

STAKEHOLDER INPUT

Air Navigation Service Providers

National Air Navigation Service Providers (ANSPs) are working with industry partners and communities to reduce fuel burn, emissions and noise. In order to achieve these objectives, ANSPs have recently delivered or developed a number of specific projects, initiatives and collaborative forums with the aim of enhancing the operational performance of ATM, some of which are described below.

The NATS (UK ANSP) Flight Efficiency Partnership working group provides a forum for NATS and airlines to work together to develop and deliver short-term improvements to flight efficiency. It focuses on agreeing the shorter term improvements that can be made to vertical and lateral route profiles in and around the UK airspace, as well as exploring opportunities to work together to ensure the most effective flexible use of airspace. The working group has contributed to over 300 changes to the UK airspace as part of NATS' wider target to achieve an average 4% per flight length reduction by the end of 2014 and 10% by 2020.

AustroControl (Austrian ANSP) – together with Vienna Airport and Salzburg Airport – has established a formal consultation process to involve stakeholders in airspace and route planning. The Vienna Airport Dialogue Forum was founded in 2004 while the 'BBFS' (BürgerInnenbeirat Flughafen Salzburg - Citizens' Council Salzburg Airport) forum in Salzburg held its first assembly in 2013. Both bodies provide stakeholders (e.g. airspace/airport users, communities, political parties, civil initiatives) with the opportunity of participating in regular discussions about aviation noise.

The DSNA (French ANSP) has launched a nationwide working arrangement for Collaborative Environmental Management [56]. The aim is to establish and formalise a recognised communication framework to support core operational stakeholders in dealing with environmental challenges at and around airports, and to ensure that a robust and transparent dialogue can be developed so that environmental messages are correctly communicated.

ENAV's (Italian ANSP) Customer Care has promoted several initiatives in Italy to meet the needs of airspace users, mainly through regular meetings with airlines, aimed at increasing cooperation and sharing of operational suggestions. This has fine-tuned ENAV's Flight Efficiency Plan initiative which aims at ensuring greater accessibility of the airspace, delivering increased route availability, designing airspace portions and new operational procedures to enable a more efficient use of terminal areas and approaches by using Precision Area Navigation routes and Continuous Descent Operations.

NATS and NAV CANADA (Canadian ANSP) have jointly developed the 'Collaboration on Oceanic Airspace and System Tools' (COAST) programme to deliver advanced controller tools such as 'GoFli' that automate the detection of oceanic climb opportunities delivered by advanced data-linked messages between the ground and the aircraft.

NAV Portugal (Portuguese ANSP) and ENAIRE (Spanish ANSP) have been involved in the 'Dynamic Optimization of the Route In flight' (DORIS) project. This is focused on developing an in-flight dynamic route optimisation process without introducing a significant workload for either controllers or flight crew. The operational and technical enablers of this project were based on the ATM flexibility in the North Atlantic random route airspace (outside the organised track system), as well as the full exploitation of data link communications between the airline headquarters, the aircraft and the area control centres to support the route change in flight.

STAKEHOLDER INPUT

Aircraft Operators³¹

While airlines depend on aircraft and engine manufacturers for the most efficient aircraft, and on airports and ANSPs for infrastructural improvements, it is the operators' own responsibility to introduce more efficient operational procedures. Aircraft operators are also very engaged in the implementation of sustainable low-carbon fuels. Hereafter are some examples of various fields of improvements directly related to airline operations.

Development and deployment of sustainable biofuels

In contrast to the automotive transport, there are only limited possibilities for aviation to move away from liquid-based hydrocarbon fuels in the next few decades, despite emerging plans to develop technologies for battery-driven short-haul aircraft. Current sustainable alternative fuels, such as advanced biofuels, are therefore the only short-to-mid-term alternative to the current conventional jet fuel. The sector of alternative jet fuels has developed considerably since the first test flight in February 2008 by Virgin Atlantic.

Many European airlines have subsequently performed commercial passenger flights powered with biofuel blends. In September 2014, world leaders met at the United Nations Climate Summit in New York to discuss climate change. Finnair's flight from Helsinki to New York on the same day was operated using a biofuel mixture that was partly manufactured from used cooking oil. Finnair is also evaluating the possibility of establishing a biofuel hub at Helsinki Airport.

Operational innovations

Innovative environmentally friendly operational solutions are also being driven by airline operators. A towbar-less aircraft towing tug called 'TaxiBot' has been jointly developed by Lufthansa and Israel Aerospace Industries that allows taxiing from the gate to the departure position without using the main engines, thus offering significant fuel savings as well as noise and emissions reductions. Compared with electric drives installed in the landing gear, the TaxiBot does not increase the aircraft weight and is therefore particularly suited for long-haul aircraft. The TaxiBot is controlled from the cockpit, which allows the same reactivity to traffic or obstacles during the taxi process as for engine-powered taxiing. It received approval for airport use in November 2014, and has been in regular operation at Frankfurt Airport since February 2015.

Croatia Airlines aligned its potable water use with actual demand resulting in annual weight savings of about 40 tonnes of CO₂ per A319/A320. In addition, recent measures to modernise certain cabin reconfigurations have reduced the weight of a single aircraft by 200 kg, leading to annual savings of about 80 tonnes of CO₂ per aircraft.

In December 2014, Austrian Airlines and the Austrian rail services (ÖBB/Österreichische Bundesbahnen) started an intermodal cooperation project called 'AIRail' which links Linz Mainline Train Station and Vienna airport. Passengers with an Austrian Airlines ticket may alternatively use a train connection on this route, thereby saving Austrian Airlines around 800 tonnes of CO₂ a year. Up to 90% of the energy used for the train stems from hydro power and other renewable energy sources.

³¹ Association of European Airlines (AEA), European Express Association (EEA) and International Air Transport Association (IATA).

Improving safety and reducing effluents from de-icing and anti-icing

Whenever there is precipitation at freezing or near-freezing temperatures, airlines de-ice and anti-ice aircraft to ensure safe operations. De-icing removes any contaminants from the surfaces of the aircraft, and the anti-icing process covers these surfaces once again with a protective fluid that keeps the aircraft free of contaminants. During the most recent winter season (2014/2015), Finnair adopted the CheckTime decision-support system. This uses precision weather measurement equipment, and real-time environmental data, to provide dynamic information to the pilot in the cockpit on the state of the de-icing and anti-icing fluids on the aircraft. This helps determine how long aircraft surfaces are sufficiently protected against icing thereby widening safety margins, improving operational efficiency and reducing unnecessary chemical use.





5. AIRPORTS

In 2015, 92 European airports were participating in the Airport Carbon Accreditation programme, and 20 of these airports were carbon neutral. Around 80% of passenger traffic in Europe was handled via an airport with a certified environmental or quality management system. Significant aircraft noise levels around 45 major airports currently affect almost 2.5 million citizens in Europe, often leading to public protests and intense political pressure at local and national levels. A regulatory framework and airport initiatives have been put in place to deal with this issue. The involvement of all local stakeholders in these discussions on a balanced approach to aircraft noise management is recognised as a crucial factor in reducing the annoyance for people living near airports. By 2035, in the absence of continuing efforts, it is anticipated that some 20 major European airports will face significant congestion and related environmental impacts [21].

5.1 Balanced approach to aircraft noise management³²

The EU Environmental Noise Directive [5] and the associated Balanced Approach Regulation [7] aim at promoting the sustainable development of air transport through the reduction of aircraft noise pollution at airports. This legislation introduced the principle of a ‘balanced approach’ to aircraft noise management at airports, in line with ICAO guidance [57].

Within the balanced approach, airports are encouraged to initially assess the current noise situation via the identification of specific issues using a mix of modelling (computer simulations) and monitoring techniques (noise measuring equipment located around the airport). This

should then be used by airports to define a noise baseline, future objectives and an accompanying noise management action plan. This balanced approach consists of the following core elements:

1. **Reduction of noise at source** through the promotion and support of studies, research and technology programmes aiming at reducing noise at the source or by other means.
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).

32 See Chapter 1 (Overview of Aviation Sector) for airport noise performance indicators.

3. The practical application of **noise abatement operational procedures** [58], 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.

The involvement of all local stakeholders in the discussions on a balanced approach is an important factor in reducing aircraft noise and limiting the annoyance for people living near airports. While new European rules [7] require assessments of the impact of local restrictions

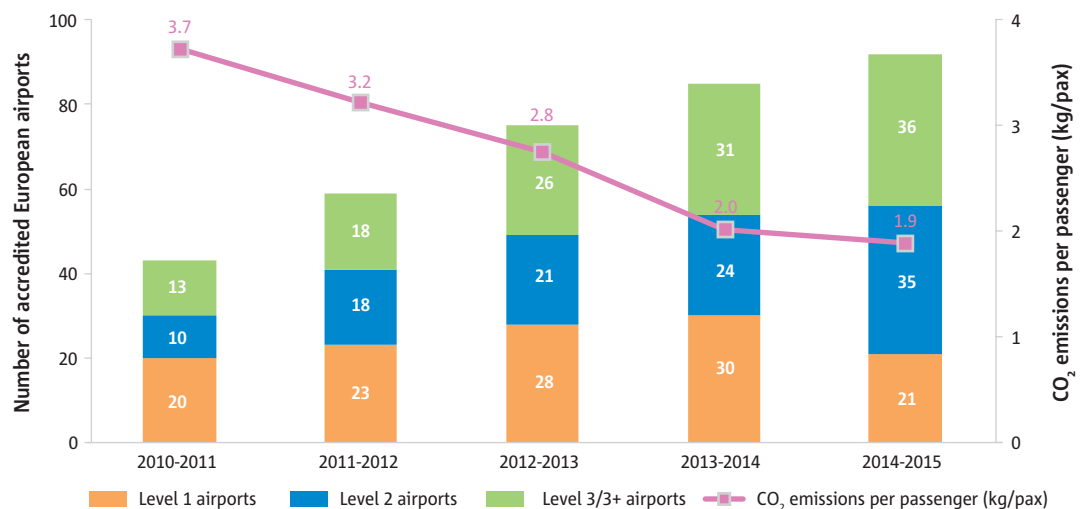
on the wider aviation network, it is important to note that the actual decisions related to a specific airport are taken by local decision makers.

5.2 Airport Carbon Accreditation

The Airport Carbon Accreditation programme [59] was launched by the Airports Council International Europe in 2009 and has now expanded globally. It provides a common framework and standard for carbon and energy management with the primary objective to encourage and enable airports to implement best practices, and gain recognition for subsequent achievements. All data submitted by airport companies via Airport Carbon Accreditation have to be externally and independently verified.

The programme is structured around four levels of certification (Level 1: Mapping,

Figure 5.1 Increasing number of accredited airports and reduction in CO₂ emissions per passenger



(Source: Airport Carbon Accreditation [59])

Level 2: Reduction, Level 3: Optimisation, and Level 3+: Neutrality) with increasing scope (emissions under airport control / emissions by other companies operating at the airport) and obligations for carbon emissions management. The number of European airports³³ which are participating in the programme has grown over the years (Figures 5.1):

- In the reporting period (2010-2011), 43 airports were accredited corresponding to 610 million passengers (43% of passengers in Europe). Total direct emissions which were under the full control of the airport were reported as 2.275 million tonnes of CO₂.
- In the latest reporting period (2014-2015), 92 airports were accredited corresponding to 1.105 billion passengers (64% of passengers in Europe). Total direct emissions of 2.089 million tonnes of CO₂ were reported.

The carbon performance of European airports at all levels of Airport Carbon Accreditation has improved, with emissions per passenger reducing from 3.7 kg CO₂ per passenger to 1.9 kg CO₂ per passenger. In the latest 2014-2015 period, a total reduction in direct emissions of 168 thousand tonnes of CO₂ (Figure 5.2) for all airports was reported, equivalent to 1,365 Paris - New York flights³⁴. The figure for indirect emissions reductions (aircraft, surface access, staff travel) at Level 3 and 3+ airports was 550 thousand tonnes of CO₂ (4,475 Paris - New York flights).

Typical CO₂ reduction actions taken by airports include optimised energy usage, replacement of conventional ground equipment by electric-powered equivalents, and use of more efficient lighting. Figure 5.3 shows a map of the airports accredited at the different levels within Europe.

Figure 5.2 Absolute reductions³⁵ in airport CO₂ emissions every year since 2010



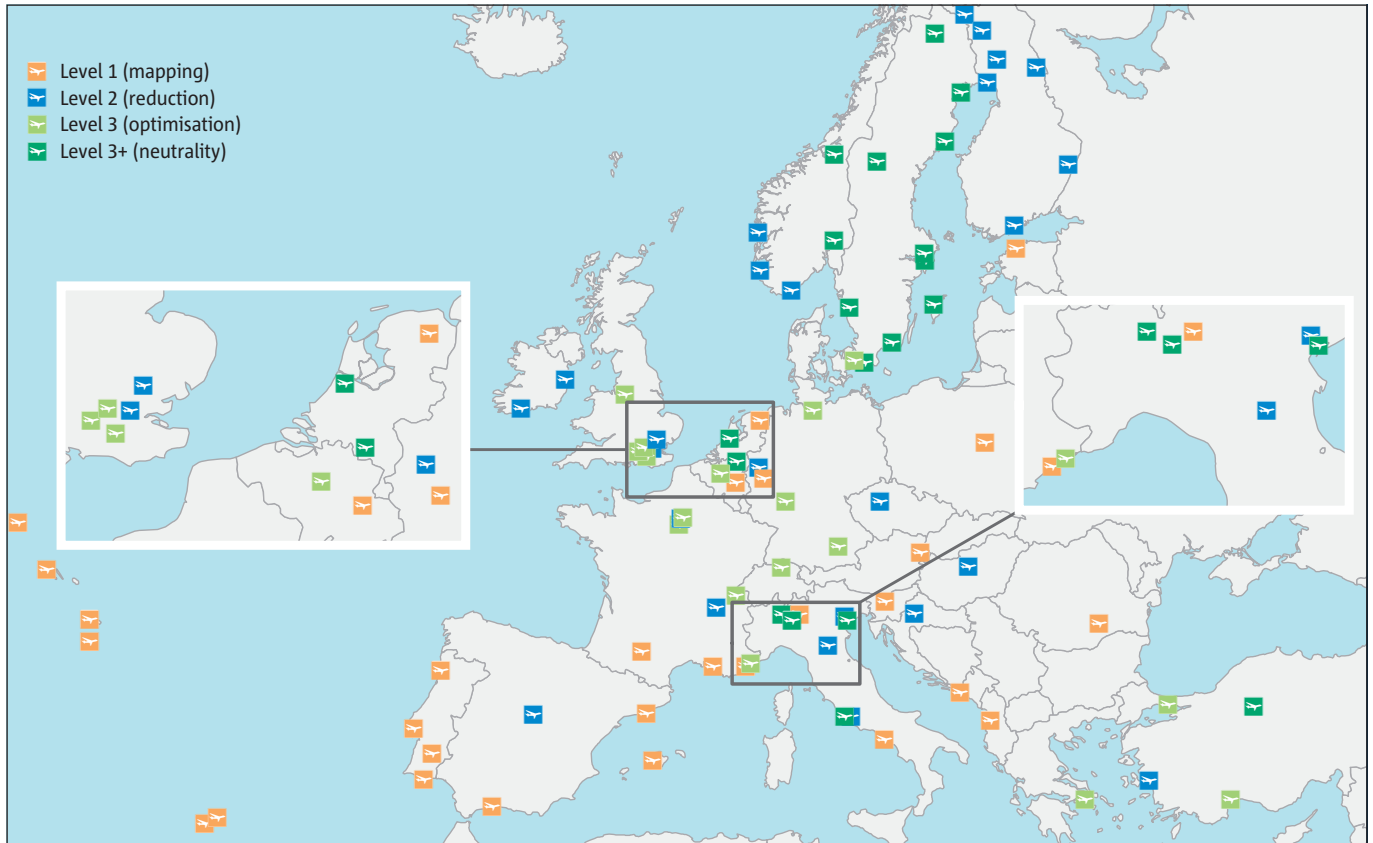
(Source: Airport Carbon Accreditation [59])

33 The figures presented on this page contain four Turkish airports (Istanbul Ataturk, Antalya, Ankara, Izmir) which are included in the European values provided in the Annual Reports.

34 Assuming one flight from Paris CDG to New York JFK emits approximately 123.1 tonnes of CO₂ (see ICAO Carbon Emissions Calculator for methodology and assumptions).

35 Reductions for Year 0 result from the comparison of the emissions reported for Year 0 against the arithmetic mean of emissions reported in Year 1, Year 2 and Year 3.

Figure 5.3 Map of accredited European airports (Source: Airport Carbon Accreditation [59])



5.3 Passenger access by public transport

Many of the indirect CO₂ emissions at airports originate from surface access transport (e.g. the road access to the airport). Developing 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 surrounding municipalities.

Publicly available data from a total of 51 European airports (corresponding to approximately 56% of European passengers) indicates that 43% of passengers gained access to these airports by public transport.³⁶

³⁶ This number was calculated by weighting each airport's figure by its number of passengers.

5.4 Environmental certification

There are several international standards available for organisations, including airports, to use in managing their environmental performance. These include:

- ISO 14001: Environmental Management Systems
- ISO 50001: Energy Management Systems
- EU EMAS: EU Eco-Management and Audit Scheme

Due to EU and national environmental management legislation, many more airports will comply with environmental certification requirements but have not been certified against the above standards. Many airports do however have ISO 9001 certified Quality Management Systems. In 2014, approximately 80% of passengers in Europe were handled via an airport certified against one of these environmental standards or ISO 9001.

STAKEHOLDER INPUT

London Airports Night Noise Quota Count System

Quota Count systems have been developed and implemented within Europe to help airports manage the impact from aircraft noise. The general principle involves a total noise budget which is allocated to an airport for use over a period of time. Aircraft are assigned a quota value and the schemes are designed to encourage the use of quieter aircraft by making noisier types use more of an allotted noise quota for each flight. This form of quota system is sometimes combined with a limit on the total number of flights.

Restrictions on night flights at Heathrow airport first came into effect in 1962 and were subsequently introduced at both Gatwick and Stansted airports. The underlying principle is to strike a balance between airlines wishing to operate at night, and the communities living around the airport who do not want their sleep disturbed by aircraft noise. Up until 1993, the maximum amount of noise that could be emitted by a night flight was based on supplementary data provided by aircraft manufacturers. However, it proved difficult to link this manufacturer data to the aircraft noise certification process, and thus the process lacked transparency and traceability.

A new Quota Count system was subsequently introduced that explicitly linked noise certification levels to noise exposure in the vicinity of an airport. This removed the need for manufacturers to supply supplemental data, and the use of ICAO noise certification data enabled the system to potentially be used more widely. A Quota Count, based on 3 dB bands, is assigned to all certified aircraft for which an application has been made to operate at night. Each airport then manages its quota locally, often in coordination with the slot coordination process. The 3 dB-wide bands, which are consistent with the doubling of noise energy principle, are simple, transparent and easy to administer.

The Quota Count system is typically reviewed every five years, and this involves extensive stakeholder consultation. It is considered to have worked well since it was introduced in 1993 and, despite various legal challenges, has remained largely unchanged with the notable exception of the introduction of a new lowest Quota Count band in 2006.

STAKEHOLDER INPUT

Airports Council International Europe (ACI EUROPE)

ACI EUROPE represents over 450 airports in 45 European countries. In 2013, its member airports handled over 90% of commercial air traffic in Europe, welcoming more than 1.7 billion passengers, 16.8 million tonnes of cargo and 20.8 million aircraft movements. This membership provides ACI EUROPE with insights into airports' environmental challenges, best practices and also allows the organisation to lead initiatives aimed at supporting its members in their day-to-day environmental management activities.

The principal sustainability issues that impact upon airports include local concerns such as noise, air quality, biodiversity and water management, but also, increasingly, more global environmental issues such as CO₂. However, European airports consider noise to be the number one environmental priority. Noise currently affects airports' ability to use their full operational capacity, as a number of airports are subject to operating restrictions, limiting the number of movements or the operating hours of the airport.

The noise issue illustrates the requirement for a high level of cooperation between various operational stakeholders (airport operator, airline and air navigation services provider). This has led ACI EUROPE to work together with EUROCONTROL in developing the Collaborative Environmental Management (CEM) specification in 2014 [56]. This provides the operational stakeholders with a check-list of actions to be taken in order to collaborate as efficiently and effectively as possible on environmental matters. A prerequisite to CEM is the definition of an environmental vision, which should guide operational stakeholders' activities and help them define priorities.

In a similar vein, cooperation is the principle underpinning airport operators' carbon management activities. This is reflected in the carbon management standard defined with Airport Carbon Accreditation.

Airports differ from one another by their size, the activities they operate and their geography. The numbers of companies that operate on the airport site, as well as their operating business models also have an influence on the actions that can be taken to manage their environmental impacts.

Initiatives implemented by airports include 'green taxiing', and wider use of electrical ground support equipment (vehicles). Airports are beginning to install electrical charging stations for ground support equipment and to reduce dependency on the use of an aircraft's on-board auxiliary power unit, normally powered by jet fuel.

STAKEHOLDER INPUT

Airport Regions Conference (ARC)

Regions, cities and municipalities have a key, often underestimated, role in the development of aviation in Europe by helping to manage the impact of aviation and integrating the development of the airport into the overall regional sustainable development. At many airports however, neighbouring cities and regions are not shareholders and therefore have a limited say in any future development plans.

As a result, many regions and cities of Europe have decided to act collectively in order to gather knowledge, and to identify actions that would help in finding solutions. ARC does not represent the specific interest of one industry, or a specific group of residents. Its members represent the democratically elected delegates of all residents of an airport region, who have to manage the pros and cons from the airport activities.

ARC supports the member regions in developing and implementing knowledge-based strategies through local solutions. It has funded an array of studies related to the main airport nuisances in order to gain a better understanding of such issues for its members.

One such study was on the relationship between airport infrastructures and CO₂ emissions. This identified that surface access is one of the few elements where local and regional authorities can have a direct impact, as they are often responsible for the provision of public transport. The situation varies significantly within Europe as some member regions have a high percentage (>50%) of public transport surface access, and a lower level of CO₂ emissions, whilst other still rely heavily on road access. ARC has also developed a model to support local and regional authorities in identifying the most effective action to reduce CO₂ emissions for specific local situations.

Case study: Implementation of a bus on demand system in the Barcelona-El Prat Airport area

Developing a better and more adapted public transport system has been a key challenge for the municipalities, counties and regions neighbouring airports. One common challenge is that it can often be easier to travel from the airport to the city centre, rather than from the airport to the immediate neighbourhood of the airport.

With support from the EU, the city of El Prat, Spain, decided to implement a 'bus on demand' in the area nearby Barcelona-El Prat airport in order to provide a sustainable public transport system. As the logistical area is very large, it was considered that a standard public transport system would generate substantial financial deficit and unnecessary pollution, and there would potentially be subsequent pressure to cut or reduce the services.

In comparison, the 'bus on demand' system has a button at each stop to request a transport service. When a user presses the button, this informs the system of the transport request. When there is a bus in the route detour zone, the system then informs the driver of the transport request with a message on the on-board touch screen. The driver confirms that the request has been received, and as soon as this confirmation has been received, the system sends the bus information to the bus stop to display the arrival time. Once the passenger is picked up, the bus stop automatically enters hibernation mode to save energy. With this 'bus on demand' service it is possible to re-design and optimise the routes of the buses to reduce costs, pollution, traffic and energy use by eliminating unnecessary bus travel.



▲	42.31	0.7%	594	6454
▼	10.90	0.1%	222	6458
▲	00.97	0.7%	594	6934
▼	65.45	0.3%	254	6560
▼	85.38	0.7%	248	6900
▲	45.58	0.1%	589	6990
▲	52.53	0.5%	264	6940
▲	75.90	0.6%	478	5990
▼	22.35	0.2%	245	6500
▲	54.35	0.6%	154	6000
▲	12.00	0.2%	254	6000

6. MARKET-BASED MEASURES

Market-based measures are part of the comprehensive approach needed to reduce aviation's emissions, as technological and operational measures alone are not considered sufficient to tackle the growing environmental challenges of the aviation sector. The EU has successfully implemented the European Emissions Trading System (EU ETS), which currently covers all intra-European flights. The EU ETS will contribute around 16 million tonnes of emission reductions annually or almost 65 million tonnes over the 2013-2016 period, achieved partly within the sector itself or in other sectors. More than 100 airports in Europe have also deployed noise and emissions charges schemes since the 1990s.

6.1 Trading schemes

Market-based measures such as trading schemes are designed to allow market sectors to continue to grow in a sustainable and cost-effective manner through the off-setting of some of the associated negative impacts. One example is the ETS which is

a cornerstone of the EU's policy to combat climate change and its key tool for reducing industrial greenhouse gas emissions cost-effectively. The ETS either incentivises CO₂ emission reductions within the sector, or through the purchase of emission reductions in other sectors of the economy where abatement costs can be lower.

EU Emissions Trading System (ETS)

In 2008, the EU decided to include aviation activities in the EU ETS [14]. These emissions now form part of the EU's internal 20% greenhouse gas (GHG) emission reduction target for 2020. On the basis of national GHG emission reports to the United Nations Framework Convention on Climate Change, domestic aviation from the EU Member States accounts for less than 0.5% of total EU GHG emissions³⁷, whereas international aviation represents 3%, a relative share which is increasing [60].

The initial scope of the EU ETS covered all flights arriving at, and departing from, airports in the European Economic Area which includes EU Member States, Norway, Iceland and 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 2016. This exclusion, first resulting from the 'stop the clock' decision [15], was made in order to facilitate negotiation of a global agreement on aviation emissions at the Assembly of the International Civil Aviation Organization (ICAO) in 2013. ICAO subsequently decided on a roadmap for the development of a global market-based mechanism to tackle aviation emissions, to be agreed in 2016 and implemented from 2020.

Given the developments within ICAO, the EU decided to continue with a reduced scope of aviation within the ETS during the period from 2013 to 2016 [16]. Only flights between airports located in the European Economic Area are presently included. Flights to and from outermost regions of the EU are covered only if they occur in the same outermost region.

37 Excluding emissions from the Land Use, Land Use Change and Forestry sector (LULUCF).

Emissions accounted for under the ETS

The original cap for aviation in the EU ETS is based on average historic aviation emissions between 2004 and 2006 (221.4 million tonnes of CO₂ for all participating countries). The cap for aviation activities set for the current trading period equals 95% of those historical aviation emissions. Whereas 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. From 2013 onwards, each aircraft operator is entitled to use international credits up to a maximum of 1.5% of its verified emissions during the period from 2013 to 2020, without prejudice to any residual entitlement from 2012 [14].

Around 1300 aircraft operators have reported data under the full scope EU ETS from 2010 to 2012. Under the current reduced ETS scope during 2013 and 2014 approximately 640 operators, including more than 100 non-European carriers, operated intra-European aviation activities. Over 2013-2016, with the inclusion of only intra-European flights in the EU ETS, the total amount of annual allowances to be issued will be around 39 million. Verified CO₂ emissions from ETS aviation activities between airports amounted to 54.9 million tonnes of CO₂ in 2014, an increase of 2.8% compared to the 53.4 million tonnes of CO₂ reported for 2013. Consequently, the EU ETS will contribute around 16 million tonnes of emission reductions annually, or almost 65 million tonnes over 2013-2016, partly within the sector (i.e. by airlines reducing their emissions to avoid paying for additional units) or in other sectors (by airlines purchasing units from other sectors, which would accordingly have to reduce their emissions). According to the preliminary data available, for all three years 2012-2014, verified emissions of aircraft operators have exceeded allowances available through free allocation or auctioning. Therefore, to date the aviation sector has used more emission allowances than they have received.

6.2 Airport charging schemes

Airport charges are levied by airports on the various users of their infrastructure. Noise and emission charges are generally part of the overall airport landing charges that airlines pay, and they aim to reduce or prevent noise and local air quality issues around airports. These schemes can be revenue neutral for the airport, or generate funds which are used to address the associated impact (e.g. noise insulation schemes, local air quality monitoring equipment).

One of the first noise charging schemes was introduced in 1980 at Zurich Airport [61]. Such schemes are now in place at more than 100 European airports, while emission charges are in place at 25 airports [62]. The schemes vary widely, notably with respect to the amount charged, which is generally based on the aircraft type (or its noise certification level), and the time of day. For example, noise charges are higher for landings taking place in the evening and at night.

In order to ensure these noise and emissions charging schemes are applied in a non-discriminatory and transparent manner to all carriers, the EU adopted further legislation [63] on airport charges in 2009. These transparency requirements notably cover the methodology for setting the charges, as well as the extracted revenue, and it establishes a consultation process involving both airports and airlines. Member States are also required to set up an independent authority to supervise the system and settle potential disputes between airlines and airports. The EU legislation builds on, and complements, the guidance provided by ECAC [64, 65] and ICAO [66].

STAKEHOLDER INPUT

Zurich Airport aircraft emission charges

Air quality levels in the Zurich airport region during the early 1990s exceeded national standards for nitrogen dioxide, ozone and particulate matter. At the same time, the airport saw the need to considerably expand its infrastructure in order to accommodate growing traffic. An environmental impact assessment confirmed a potential further deterioration of air quality due to increased emissions from aircraft, handling equipment, infrastructure and road access traffic. In order to obtain the permission to expand, and to comply with national clean air legislation, Zurich airport developed a mitigation plan that included all airport-related pollution sources.

The measure of choice for mitigating emissions from aircraft engines was an emission-based landing charge which would incentivise the use of the cleanest engines. This charge was introduced in 1997 and was based on the pollution efficiency of the engine (mass of NO_x and HC emitted during a standard landing and take-off cycle divided by the engine thrust rating). The charge itself ranges from 0 to 40% of the landing fee and is dependent on the class of aircraft. In order to obtain revenue neutrality for the airport, the overall landing fees were reduced at the same time by a flat 5%, thus creating a bonus class.

The charging scheme increased awareness of the air quality problems, and incentivised subsequent developments by the manufacturing industry to address NO_x and HC in addition to fuel efficiency and noise. Airlines also responded to the charging scheme by considering the choice of aircraft which they operated to Zurich. The airport initiative was recognised by both the public and regulatory authorities, and this enabled the further development of the airport infrastructure. Today, regional air pollution levels have improved significantly with only few exceedances at local hot spots on the airport apron and along main traffic roads.

Recognising the need for harmonisation, ECAC issued a recommendation in 2011 on aircraft emission charging schemes [65]. This is a strict polluter-pays approach (LTO emission mass) with no bonus class. Airports consequently standardised their charging schemes in line with this model, including Zurich, in 2010. Today, a range of airports in Europe have introduced this market-based measure as an incentive to reduce emissions from aircraft.



7. ADAPTING AVIATION TO A CHANGING CLIMATE

Climate change is a risk for the European aviation sector. Its impacts are likely to include more frequent and more adverse weather disruption as well as sea-level rise. The aviation sector needs to prepare for and develop resilience to these potential future impacts. Adaptation actions have been initiated at European, national and organisational levels.

7.1 Impacts of a changing climate on European aviation

There is broad political and scientific agreement on the main types of future impacts from climate change which Europe will experience [8, 67, 70]. The specific impacts for aviation will vary according to the different European geographical climate zones (Figure 7.1). However, in general, the expected impacts are:

- **More frequent heavy rain** in areas such as Northern Europe which may reduce the number of flights taking off and landing at an airport. This can lead to delays and cancellation of flights.
- **Higher air temperatures** that affect the general performance of an aircraft such as rate of climb. There may also be heat damage to airport surface areas such as runways and taxiways if sufficiently resilient materials are not used.
- **Changes in snow cover** throughout Europe could either reduce snow-related delays and cancellations, or lead to heavy snow events in areas previously unaccustomed to such weather. Snow in locations where it is not usually experienced has the biggest impact on airport operations due to insufficient snow clearing and de-icing equipment being available.

- **Europe's strongest storms** are expected to become larger, more frequent and more powerful. This can impact flight regularity and punctuality whilst also having implications for flying the most efficient routes.
- **Changing wind direction** can lead to an increase in runway crosswinds. Any subsequent changes which are required in airport operational procedures may have a negative environmental impact, with capacities potentially reduced at airports with no crosswind runway.
- **Long term sea-level rise** will threaten coastal airports. At some locations, ground transport connections to the airport may also be at risk. In the shorter timescale, more frequent and more intense storm surges are expected in several areas, reducing capacity and increasing delay.

Continued changes to temperature, precipitation (rain and snow), and storm patterns are all expected during the next decade. This will lead to more frequent incidents of turbulence which is the leading cause of weather-related injuries on planes, and costs airlines millions of euros every year. The impacts of sea level rise are more gradual and are not expected to become significant until later this century.

Figure 7.1 Impacts for European aviation by climate zone



7.2 Adaptation action in Europe

Europe and other parts of the world will need to take adaptation measures to deal with the unavoidable impacts of climate change and their economic, environmental and social costs. Pre-emptive action is likely to be cost-effective in comparison to addressing impacts as they occur in the future [67]. In Europe, action to adapt aviation to a changing climate is already being taken at European, national, and organisational levels.

The EU Strategy on Adaptation to Climate Change identifies the risks of climate change in relation to aviation infrastructure. It also

sets out a framework and mechanisms for responding to current and future climate impacts on infrastructure. More specifically, several overviews of the adaptation challenges facing the European aviation sector have recently been developed [68, 70, 71, 72]. The European Climate Adaptation online platform [69] provides information and guidance on adapting to the impacts of climate change, with a series of aviation case studies presently being developed.

Member States are also now starting to include aviation in their National Adaptation Plans, with some launching specific aviation adaptation

programmes or including aviation as part of wider transport adaptation programmes. Furthermore, a number of airports and ANSPs are also now carrying out climate change risk assessments and developing their own adaptation plans.

STAKEHOLDER INPUT

Adaptation case studies

London Heathrow: Preparing for changing winds and temperatures

As a result of future climate change patterns, the UK is expected to experience more extreme summer and winter temperatures, as well as changing wind speeds and direction, which can disrupt air traffic flow. One way Heathrow is mitigating the impact of changes to wind, a key issue at the airport, is through the implementation of time-based separation procedures instead of distance-based separation.

Heathrow's climate change risk assessment also examined how more extreme temperatures might affect the airport pavements. The risk is considered low in the near to medium term. However, in 50 years or more, there may be more significant temperature increases. Therefore, Heathrow revisits its adaptation response plan regularly to ensure that it is up to date and that its engineering strategy is adequately responding to changing risks.

Avinor: Preparing for more water at Norwegian airports

Most of Avinor's (Norwegian airport operator and ANSP) airports are scattered along the rugged Norwegian coastline, with several having runways less than 4 metres above sea level. Avinor began considering climate adaptation in 2001. Following new legislation in 2006, a procedure was developed for defining the dimensioning criteria for runway safety areas close to the sea, as well as a set of guidelines for low-lying coastal runways and strengthened requirements for potential new runways, which now have to be established at least 7 metres above sea level.

A comprehensive risk assessment of all Avinor airports has now been undertaken. In general, more extreme weather events, storms and storm surges are expected. Heavier and more frequent precipitation will challenge drainage systems. During the planning phase of the terminal expansion at Oslo Airport and the related work on the apron, it was revealed that the new drainage systems required 50% additional capacity compared with the original drainage systems from the 1990s.

Avinor's experience is that adaptation investments in planned and/or ongoing projects can have both a positive impact on airport operations and save on future resources.



APPENDICES

APPENDIX A: LIST OF RESOURCES

Introduction

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APPENDIX B: ACRONYMS AND UNITS

ANS	Air Navigation Services
ANSP	Air Navigation Service Provider
ASBU	Aviation System Block Upgrades
ATM	Air Traffic Management
CAEP	Committee on Aviation Environmental Protection
CO / CO ₂	Carbon monoxide / dioxide
dB	decibel
EASA	European Aviation Safety Agency
EC	European Commission
ECAC	European Civil Aviation Conference
EEA	European Environment Agency
EFTA	European Free Trade Association
END	EU Environmental Noise Directive 2002/49/EC
EPNdB	Effective Perceived Noise decibel
ETS	EU Emissions Trading System
EU	European Union
EU28	28 Member States of the European Union
ft	feet
GHG	Greenhouse gas
HC	Hydrocarbons
HEFA	Hydroprocessed esters and fatty acid
HVO	Hydrotreated vegetable oil
ICAO	International Civil Aviation Organization
kN	kilonewton
lbf	pound (force)
L _{den} / L _{night}	Day-evening-night / Night-time sound pressure level
LTO	Landing and Take-Off
m	metre
Mt	megatonne, million tonnes
Mtoe	million tonnes of oil equivalent
NO _x	Nitrogen oxides
PM	Particulate matter
SES	Single European Sky
SESAR	Single European Sky ATM Research
t	tonne
WHO	World Health Organization

APPENDIX C: DATA SOURCES, MODELS AND ASSUMPTIONS FOR THE SECTOR OVERVIEW

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). 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.

Data sources

PRISME³⁸

Historical 2005-2014 flight operations were extracted from the EUROCONTROL database of filed flight plans called PRISME. PRISME covers all Instrument Flight Rules flights in Europe, including some military transport flights and general aviation. Flight data is 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).

Eurostat³⁹

European States collect statistics on air transport from their airports and airlines and provide these to Eurostat, which makes them publicly available, 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, these data are used to indicate trends in load factors, but are not sufficient to derive total available seat-

kilometres. 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.

STATFOR⁴⁰

The EUROCONTROL STATFOR 20-year forecast that was published in 2013 provided the traffic volumes from 2015 to 2035 used in this report, with minor variations due to the use of the Aircraft Assignment Tool. This report focuses on three of the four forecast scenarios: Scenario C – Regulated Growth is the most likely or ‘base’; Scenario A – Global Growth gives the ‘high’; and Scenario D – Fragmenting World gives the ‘low’. The forecast was prepared as part of the Challenges of Growth 2013⁴¹ study. 108 airports provided future capacity plans to this study, and the forecast traffic respects the capacity constraints implied by these plans; as a sensitivity test, a forecast with no airport capacity constraints was also evaluated.

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

38 www.eurocontrol.int/services/prisme-fleet

39 ec.europa.eu/eurostat/data/database

40 www.eurocontrol.int/statfor

41 www.eurocontrol.int/articles/challenges-growth

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 hosted and maintained by EUROCONTROL on behalf of ICAO. It provides the noise and performance characteristics of a wide range of civil aircraft types, which are required to compute noise contours around civil airports using the calculation method described in European Directive 2002/49/EC relating to assessment and management of environmental noise which is equivalent to ECAC Doc 29 and ICAO Doc 9911 guidance documents. ANP datasets are supplied by aircraft manufacturers for specific airframe-engine types, in accordance with a specific ANP Data Request Form developed and maintained within the ICAO and European organisations.

EASA Approved Noise Levels⁴²

EASA maintains a database of all aircraft noise certification levels which the Agency has approved. The database provides certified noise levels for over 27,000 aircraft variants, including jet, heavy and light propeller aircraft as well as helicopters. In this report, the certified noise levels are used to assess noise energy, as well as to attribute an ANP airframe-engine type to each aircraft type in the fleet using the ECAC Doc 29 recommended substitution method.

ICAO Aircraft Engine Emissions Databank (EEDB)⁴³

The ICAO Aircraft Engine Emissions Databank (EEDB) hosted by EASA contains Landing and Take-Off (LTO) emission indices for NO_x, HC, CO as well as smoke number for over 500 jet engine types. The EEDB emission indices are used by the IMPACT model to compute NO_x, HC, CO and PM.

FOI Turboprop Emissions Database⁴⁴

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 Database⁴⁵

EUROCONTROL's Central Office for Delay Analysis (CODA) collects flight-by-flight data from around 110 airlines and 120 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 [46, 49]. CODA publishes aggregated performance statistics, such as on punctuality and all-causes delays from these data. The detailed actual taxi times from this source were used to assess taxi fuel burn and emissions.

Population Data⁴⁶

The population database developed and maintained by the European Environment Agency (EEA) was used to estimate population within the STAPES airport noise contours.

For Switzerland, the EEA population database was complemented with census data provided by the Swiss Federal Office of Civil Aviation (FOCA).

42 easa.europa.eu/document-library/noise-type-certificates-approved-noise-levels

43 easa.europa.eu/document-library/icao-aircraft-engine-emissions-databank

44 www.foi.se/en/Our-Knowledge/Aeronautics/FOIs-Confidential-database-for-Turboprop-Engine-Emissions/

45 www.eurocontrol.int/coda

46 www.eea.europa.eu/data-and-maps/data/population-density-disaggregated-with-corine-land-cover-2000-2

Models and methods

IMPACT

IMPACT is a web-based environmental modelling system developed by EUROCONTROL in the context of the SESAR programme. 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. CO₂ is derived from fuel burn assuming 3.16 kg of CO₂ are emitted per kg of fuel burn. NO_x, HC, CO and PM emissions are computed using the LTO emission indices in the ICAO EEDB 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) method⁴⁷. Both BFFM2 and FOA3.0 methods are detailed in the ICAO Airport Air Quality Manual (Doc 9889).

System for Airport Noise Exposure Studies (STAPES)

STAPES is a multi-airport noise model jointly developed by the EC, EASA and EUROCONTROL. It consists of software compliant with the European 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 their usage (i.e. statistical data on the distribution of aircraft movements over the runways and routes). Currently 45 European airports within EU28 and EFTA are modelled in STAPES, and this is 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 EC, EASA and EUROCONTROL. The tool 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. For this issue of the report, the AAT was used for scheduled and charter passenger flights (>85% of flights); other segments were modelled with a simpler scaling process. Forecasting of all-cargo (<4% of flights) and business aviation (<8% of flights) operations in AAT is planned for a later issue. The AAT output operations are processed through the IMPACT and STAPES models to assess fuel burn, emissions and noise in 2025, 2030 and 2035. EASA and EUROCONTROL experts undertook specific enhancements of the AAT to meet the needs of this report, with EUROCONTROL ensuring their implementation within the STATFOR processing chain.

Assumptions

Fuel burn, emissions and noise assessment

Full-flight emissions include all flights departing from EU28 or EFTA, while emissions below 3,000 feet 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 2014. Future taxi times are assumed to be equal to the 2014 taxi times. Helicopter operations are excluded from the assessment.

For the STAPES noise assessments, the number of airports, together with their respective runway and route layout, are 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 are applied. For historical noise, the day/evening/night flight distribution is based on actual local departure and landing times assuming the following definition 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 is assumed to be unchanged compared to 2014. Population density around

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

airports is also assumed to be constant throughout the analysis period. The mapping of the fleet to the ANP aircraft follows the ECAC Doc 29 recommended substitution method.

In addition to the noise contours at the 45 STAPES airports, noise from aircraft operations in the entire EU28 and EFTA area is estimated using noise energy, computed with the following formula:

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

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 type⁴⁸.

Future fleet technology improvements

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 2015 onwards following two technology improvement rates, one 'low' and one 'advanced'. The definition of these improvement rates were derived from the reports on analyses performed by groups of Independent Experts for the ICAO CAEP.

For fuel burn (CO_2), the low and advanced improvement rates respectively assume a 0.57% and 1.16% per annum improvement⁴⁹. For NO_x , the low and advanced improvement rates respectively assume a 50% and 100% achievement of the CAEP/7 NO_x Goals by 2026⁵⁰.

For noise, the low and advanced improvement rates respectively assume a 0.1 EPNdB and 0.3 EPNdB per annum reduction in aircraft noise levels at each certification point.

No technology improvement is applied when estimating future HC, CO and PM emissions. In addition, the technology improvement assumptions do not take into account potential future counter-rotating open rotor powered aircraft.

Future ATM improvements

The existing ATM system efficiency is assumed to remain constant after 2014 despite future increases in overall air traffic. As a first approximation, fuel burn and emission gains can be directly deducted from the anticipated 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).

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

49 ICAO Environmental Report 2010 (p. 33).

50 ICAO Environmental Report 2010 (p. 29). The 'low' NO_x improvement rate in this report corresponds to the 'moderate' NO_x improvement rate in the ICAO Environmental Report. Both low and advanced improvement rates assume a continued technology improvement until 2035.

