EUROCONTROL Aviation Long-Term Outlook: Flights and CO_2 emissions forecast 2024 – 2050

CONSORTIUM COORDINATOR sesar DEPLOYMENT MANAGER

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Foreword by the Director General of EUROCONTROL

EUROCONTROL's Aviation Long-Term Outlook to 2050 foresees that over the next 25 years, there will be an increase in the number of flights across Europe of between 1% and 2.4% per year, depending on the scenario. Since the end of the COVID-19 pandemic, which caused a significant short-term drop in traffic, air travel has seen a continued recovery, with a return to pre-pandemic levels expected by 2025. After this, flight numbers are set to continue rising, and by 2050, the number of flights in Europe is likely to increase by over 50% compared to 2023. The number of airports operating near their capacity will rise, combining with the increase in overall traffic to place greater pressures on the entire network.

Simultaneously, in line with the EU Green Deal and ICAO's long-term aspirational goals, the aviation sector is committed to achieving net-zero carbon emissions by 2050.

Achieving net-zero remains an ambitious goal. The aviation industry will greatly rely on appropriate financial incentives and a solid regulatory framework. The main factors identified in this Outlook all have their challenges: as far as ***fleet and technology improvements*** are concerned, the pace of fleet renewal with more fuel-efficient aircraft will be key, as well as the development and effective use of electric and hydrogen-powered aircraft. ***Operations and infrastructure*** also have a role to play: this includes innovation at airports and ATM infrastructures through SESAR solutions as well as improved efficiencies in coordination between all operational stakeholders. ***Sustainable aviation fuels (SAF)*** is another promising solution. Here, the scaling up of production to meet demand and price of SAFs will be critical, as SAF are costly and their availability is currently limited. Finally, the challenges that cannot be handled by the above in order to reach net-zero will have to be tackled with ***out-of-sector measures***, such as market-based measures, carbon offsetting and capture, the integrity and effectiveness of which will be critical to ensuring that they genuinely reduce emissions.

The aviation industry as a whole is facing a considerable challenge over the coming years to manage the growth in traffic while striving to reduce our carbon footprint. This report is a major input for the European Aviation Environmental Report 2025 and the common section of the ECAC/EU European States' Action Plans 2024, both demonstrating European commitment to sustainable aviation at ICAO level. It aims to provide a clear overview of these challenges and in this way make a positive contribution to identifying and implementing shared solutions on European level.

Raúl Medina

December 2024

Executive summary

This Aviation Long-Term Outlook to 2050 is EUROCONTROL's 9th long-term flight forecast. This is the second edition providing a pan-European view of both flights and CO_2 emissions forecasts, looking out to the European net-zero target horizon of 2050.

The EUROCONTROL Aviation Long-Term Outlook to 2050 is also an essential feeder into, on the one hand, the European Aviation Environmental Report (to be released in 2025), produced in collaboration with the European Commission (EC), the European Environmental Agency (EEA) and the European Aviation Safety Agency (EASA), and, on the other hand, the common section of the State Action Plans to support an effective and harmonised submission from all 44 ECAC Member States ahead of the 42nd Session of the ICAO Assembly (September 2025).

In the most likely scenario, there will be 15.4 million flights in Europe (ECAC) in 2050, representing an increase of 52% compared to 2023, with an average growth rate of +1.6% per year. High and low scenarios results (18 million flights and 12.2 million flights by 2050) are also presented. Flight growth in Europe will be 14 years behind compared to flight growth in the long-term forecast published prior to the COVID-19 pandemic (see Ref. iv). Despite the current slowdown we still forecast significant growth, and we still expect it to be challenging. In particular, demand will exceed the capacity of key airports resulting in a 'capacity gap' of 1.1 million flights (base scenario).

ECAC	IFR Movements						
	2023		2050			Total growth 2050/2023	Avg. Annual Growth Rate 2024-2050
	Total (million)	Avg. daily (thousands)	Total (million)	Avg. daily (thousands)	Extra flights/day (thousands)		
High	10.1	27.8	18.0	49.4	5.9	+78%	+2.2%
Base			15.4	42.1	0.9	+52%	+1.6%
Low			12.2	33.5	0.9	+20%	+0.7%

We forecast that a small minority of flights (those exceeding 4,000 km) will continue to account for approximately half of CO_2 emissions. In all scenarios, the share of long-haul flights is expected to increase by 2050. Sustainable aviation fuels (SAF) will be crucial in reducing emissions from these long-haul flights.

For shorter distances, various options are available, including new technologies such as electric and hydrogen-powered "revolutionary" aircraft, or alternatives like trains when infrastructure permits.

The scenarios presented in EUROCONTROL's Long-Term Aviation Outlook to 2050 show that if the aviation industry is stronger, it will be in a better position to invest in more efficient technologies. CO_2 improvements by 2050 from "revolutionary" aircraft changes remain modest (less than 2% in 2050). Therefore, industry and regulators will need to find ways to boost investment to improve on this. Thanks to the aircraft retirement and replacement process, most of the fleet will be renewed by latest generation ("evolutionary") aircraft, quieter and more fuel efficient than their predecessors.

The reduction of the CO_2 emissions will also be achieved owing to measures for reducing the ATM environmental footprint of airports and aircraft operations, as detailed in the SESAR project. This will require the deployment of innovative solutions as defined in the European ATM Master Plan.

No single solution will enable aviation to achieve net-zero, but in all the scenarios presented here, it is the scaling up of production, the distribution and the use of SAF that will make a major contribution in the long term, with operational improvements having a more immediate positive impact.

As other studies have indicated, the final step towards achieving net-zero CO_2 emissions involves carbon offsetting and removal.

In order to achieve the most sustainable outcomes, the aviation industry will need to work with governments to ensure that the right investments and suitable regulations are being made, within aviation and beyond.

1 Setting the scene

EUROCONTROL has produced nine long-term forecasts since 2004. EUROCONTROL's Long-Term Aviation Outlook to 2050 is the second of a series presenting both long term flights and CO_2 emissions forecasts and looking out to the European net-zero target horizon of 2050.

Aviation policy is increasingly focused on the sustainability challenges, and a set of targets have been adopted to mitigate CO_2 emissions from air transport. This forecast provides an impartial view of future flight and CO_2 emissions in Europe, offering key input for discussions between States and aviation stakeholders. This report aims to support these discussions.

This forecast updates the previous EUROCONTROL Aviation Outlook 2050 (see Ref. i), published in April 2022.

2024 is coming to an end, and although the COVID-19 pandemic is now behind us, geopolitical tensions are having a significant impact on the aviation sector, disrupting the flow of goods and services across borders as well as the availability of the European aviation network.

The impact of the COVID-19[1] pandemic is felt in the actual traffic to date and in our forecast. In 2024, the current number of flights is still measured against the pre-COVID-19 period: actual traffic in Europe (ECAC) is averaging 96% of the levels seen in 2019. This recovery rate does not reflect local disparities, and most of the States located in the south of Europe have already recovered to 2019 levels. It is important to note that the number of passengers, at European level, has already recovered (101.2%, ACI, see Ref. ii).

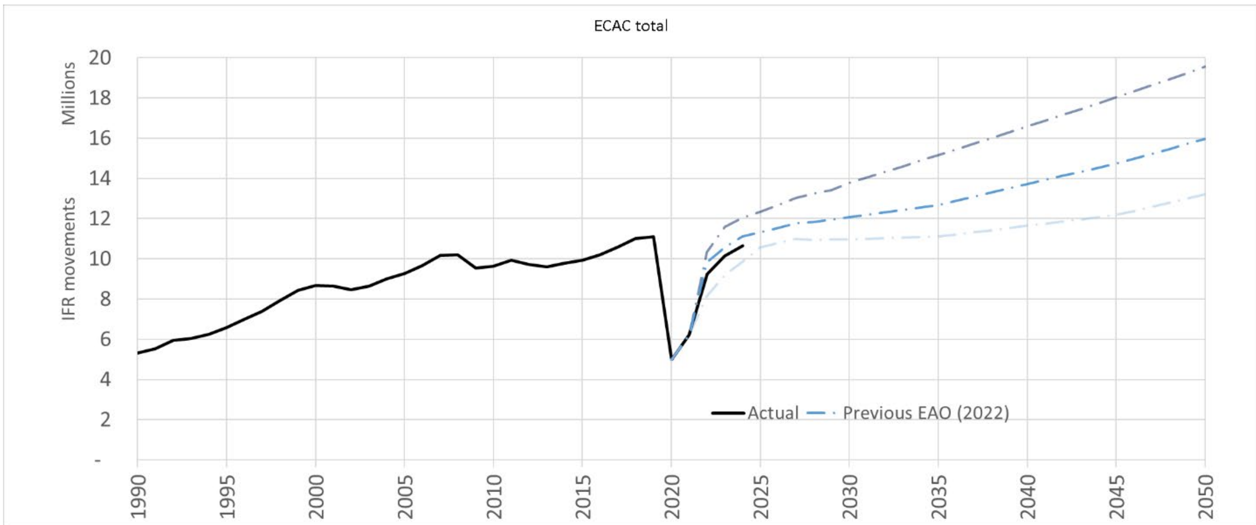
The COVID-19 pandemic has left a mark in many ways: airlines' behaviours have changed (more flexibility with their fleet, more "cancellations"), and travellers' behaviours have changed too (more remote work, higher environmental awareness). The supply chain in the aviation industry has become more vulnerable (challenges from aircraft manufacturing to routine maintenance), and aircraft operators have also been forced to review their strategies (accelerated fleet renewal, diversification of suppliers, investment in advanced technology). Technological innovation and strategic adaptations have been considered, particularly in the context of future aircraft programmes.

As noted above, besides the COVID-19 pandemic, geopolitical tensions have had an impact. Russia's full-scale aggression against Ukraine (initiated in February 2022) is ongoing, and additional geopolitical events have arisen in the Middle East. Economic sanctions and airspace closures have significantly affected the aviation supply chain and air routes. Additional factors have led to structural shifts, where some European airlines have been forced to change their business models (e.g. reduction in the number of long-haul frequencies to China).

This forecast uses 2023 actual traffic as the baseline year. The figures for the seven years that follow (2024-2030) were derived from EUROCONTROL's seven-year forecast (see Ref. iii). Unlike the COVID-19 pandemic, conflicts are ongoing, and it remains difficult to fully assess their impact. It is impossible to predict when the airspaces that are currently closed will be fully reopened. This should not be interpreted as a prediction on the part of EUROCONTROL of how these restrictions may evolve in future. Compared to the EUROCONTROL Aviation Outlook (see Ref. i) published in 2022, current traffic has developed in line with the base scenario, although slightly more slowly. The effects of Russia's full-scale invasion of Ukraine and the recovery from the COVID-19 pandemic have affected the speed of recovery to 2019 levels.

[1] According to the World Health Organization (WHO), the COVID-19 pandemic started in December 2019 and ended in May 2023. The virus had a dramatic impact on the world population during this period, and sanitary measures, including travel restrictions and lockdowns, had an impact on the economy and aviation.

Figure 1. Flight numbers recovered slightly more slowly than in the most likely scenario from the 2022 long-term forecast (see Ref. i)



If it is difficult to anticipate geopolitical developments and their future impact on aviation, there is an area for which the roadmap is clearer, driven by developments in European legislation. In October 2023, the Revised Renewable Energy Directive and the ReFuelEU[2] Aviation Regulation were adopted, completing the "Fit for 55" legislative package[3] setting out the obligation for aviation fuel suppliers to ensure that all fuel made available to aircraft operators at EU27 and EFTA[4] airports contain a minimum share of sustainable aviation fuel (SAF) from 2025 and, from 2030, a minimum share of synthetic fuels, with both shares increasing progressively until 2050 (for more details, see Section 4.4).

It should be noted that, although the ReFuelEU Aviation Regulation applies to EU/EEA States only, this forecast considers a wider scope: ECAC. Hence, this study explores an optimistic approach where the above-mentioned targets would be followed by all ECAC Member States, including non-EU Member States.

1.1 Three scenarios for the future

As in the previous edition (see Ref. i), this EUROCONTROL Long-Term Aviation Outlook uses scenarios, with different assumptions about the future and the possible speed, intensity and success of developments in technology and policy. These scenarios provide a structured approach to uncertainty, each with qualitatively different outcomes, but aiming to cover a wider range of possible future outcomes. The range of scenarios guides users to anticipate the implications of future events, helping them prepare for change and uncertainty (see Annex 0). The effects of Russia's full-scale invasion of Ukraine, initiated in 2022, highlight the need to consider a number of aspects related to oil prices and the economic cycle. On the other hand, several significant past events have proven to have a relatively short- to medium-term impact, emphasising the limited relevance of such events to a long-term forecast.

[2] Regulation (EU) 2023/2045, adopted on 31 October 2023, and Regulation (EU) 2024/795 of the European Parliament and of the Council of 29 February 2024 establishing the Strategic Technologies for Europe Platform (STEP), and amending Directive 2003/87/EC.
[3] "Fit for 55" refers to the EU's target of reducing net greenhouse gas emissions by at least 55% by 2030.
[4] EU27+EFTA refers to the 27 Member States of the European Union and the four States that are members of the European Free Trade Association (EFTA): Iceland, Liechtenstein, Norway and Switzerland.

These are the three scenarios:

High scenario**:** this high-growth scenario in flight terms is characterised by strong economic growth in a globalised world, with intense investment in technology supporting sustainable aviation growth.

Base scenario**:** This 'most likely' scenario is characterised by moderate economic growth, with regulation reflecting environmental, social and economic concerns to address aviation sustainability. This scenario follows current trends and what are seen as the most likely trends in the future.

Low scenario**:** This low-growth scenario in flight terms is characterised by slower economic growth, higher fuel, SAF and carbon prices, more limited investment in new technologies (or investments made later than in the other scenarios). Air travel actors must adapt to environmental and potential trade constraints, taking a more "inward" perspective. European travellers are likely to travel and consume more locally. This scenario encompasses assumptions where travel prices would be particularly high, and a severe economic downturn might happen over the horizon.

1.2 How have the assumptions changed?

The main features of our three scenarios remain stable compared to the previous publication (see Ref. i). However, this forecast is now based on a more recent medium-term flight forecast (2024-2030).

The following input parameters have been updated in all three scenarios:

- The **baseline year** (2023) and the **main seven-year forecast** (2024-2030).
- While high-speed train lines are expected to be built (greater number of night trains or high-speed trains) and are likely to play a key role in developing air-rail multimodality, several construction projects have been withdrawn since the previous publication.
- The assumptions related to the **impact of oil prices** on ticket prices have been reviewed, including updated forecasts of **oil prices**, **SAF prices**, **carbon allowances** as well as **SAF shares**. The latter are in line with the adopted ReFuelEU Aviation Regulation (extended to all ECAC States).
- The assumptions related to **future fleet**, including "evolutionary" (new generation aircraft using fuel-type propulsion) and "revolutionary" (new generation aircraft using hydrogen or an electric type of propulsion) aircraft deliveries for each market segment (i.e. the business aviation, all-cargo and passenger segments) have been reworked.
- Finally, the expected **maximum capacity levels** at major airports have been updated too, covering a larger set of airports, based on reviewed data from the EUROCONTROL Airport Corner[5] repository.

The changed inputs have been summarised in Figure 2, while the other inputs remained unchanged (see Annex 0).

[5] https://www.eurocontrol.int/tool/airport-corner

Figure 2. Summary of the input changes from the 2022 long-term forecast (see Ref. i) (*base scenario* only)

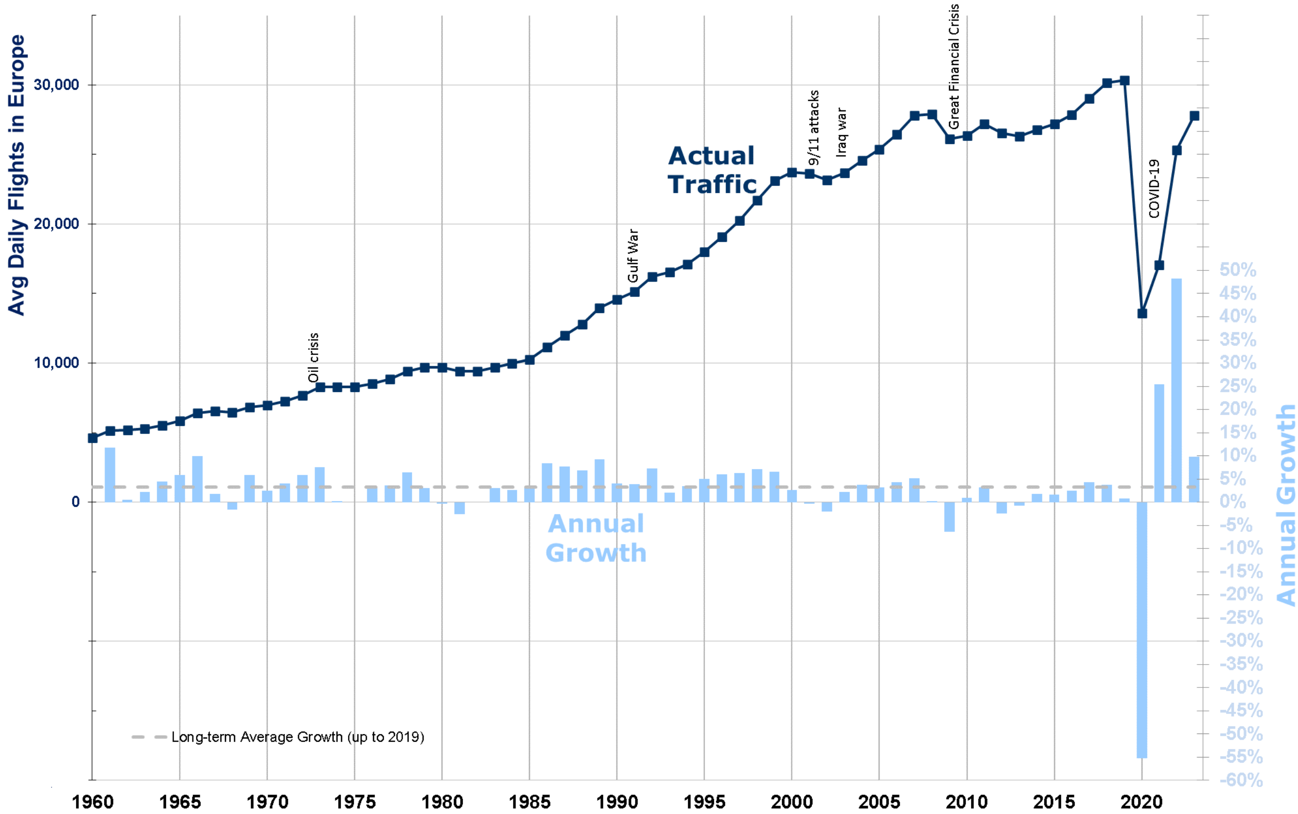
	Previous EUROCONTROL Aviation Outlook (April 2022)	*Current EUROCONTROL Long-Term Aviation Outlook*
	Base	**Base**
Baseline year	*2021*	**2023**
EUROCONTROL 7-year forecast	*7-year forecast 2022-2027 (October 2021)*	7-year flight forecast 2024-2030 (February 2024)
Passenger		
High-speed train (HST) and night connections (NIT) (new & improved connections)	*56 HST between city-pairs, implementation slightly behind plans (+2yr). 29 NIGHT links between city-pairs,*	32 HST between city-pairs, implementation slightly behind plans (+2yr). 29 NIGHT links between city-pairs, implementation as
Economic conditions		
EU Enlargement	*+6 States, as planned*	+7 States, as planned
Price of travel (2025/2050)		
Price of CO_2 allowances (€/t)	*Moderate (68€/120€)*	Moderate (80€/369€)
Price of conventional fuel (€/t)	*Moderate (539€/866€)*	Moderate (715€/819€)
Price of Sustainable Aviation Fuel (€/t)	*Moderate (1.162€/1.155€)*	Moderate (1.897€/1.720€)
Market Structure		
Growth and replacement	*Assumptions based on EUROCONTROL analysis, CIRIUM fleet forecast and Clean Aviation Joint Undertaking review (2024).*	Assumptions based on EUROCONTROL analysis and CIRIUM fleet forecast (2020-2021).
(new) pax evolutionary a/c	*2 TP, 3 RJ, 4 SA, 5 TA*	3 TP, 2 RJ, 12 NB, 9 WB
(new) pax **revolutionary** a/c	*3 TP electric 9/29/35 seats, 1 RJ electric 100 seats, 1 NB Hybrid-electric 200 seats , 1 NB Hydrogen 140 seats*	3 TP Hybrid-electric 9/19/35 seats, 2 TP Hydrogen 40/90 seats, 1 NB Hydrogen 125 seats
Entry into service	*2030/2033/2035, 2040, 2037, 2040*	2030/2035/2044, 2038/2040, 2045
Availability of SAF		
Fuel mix	*ahead of "fit for 55 proposal" (Nov. 2021)* *10% SAF - 90% Jet by 2030* *49% SAF - 51% Jet by 2040* *88% SAF - 12% Jet by 2050*	inline with "fit for 55" (Oct. 2023) 6% SAF - 94% CAF by 2030 34% SAF - 66% CAF by 2040 70% SAF - 30% CAF by 2050
AP Capacities		
Number of airports in the sample	*92*	95

1.3 Flight growth trends to date

The COVID-19 pandemic put a halt to the growth seen in previous decades. Although the days of lockdown are now behind us, the pandemic has left a strong mark on the industry. There are still significant challenges with regard to growth in the post-pandemic period, spanning from production delays in the aircraft manufacturing industry, to airport and airline staff shortages. Even if these may be short-lived, other trends may be here to stay; domestic traffic is in decline and changes can be seen in the area of business travel, with business travellers shifting to digital meeting alternatives. By 2023, traffic had not recovered to pre-pandemic levels and, in some European states, a return to these levels does not appear to be imminent.

Since the end of the pandemic, two major conflicts have arisen within the boundaries of the network: Russia's war of aggression against Ukraine, and the geopolitical events in the Middle East.

Figure 3. Annual flight growth rates in Europe settling down over the last decade, before the COVID-19 pandemic hit



Flights in Europe recorded a rapid expansion over the 20-year period from 1988 to 2007 (traffic doubled from around 5 million to 10 million flights per year), thanks to the expansion of the Single Market and related trade, the development of low-cost carriers and overall economic expansion. Growth in flights averaged 4% per year.

The following decade was notably marked by a double-dip recession, as a severe worldwide economic crisis, which started in 2007-2008 in the United States, ultimately contributed to the Eurozone crisis (2009-2012), leading to a multi-year debt crisis until 2013. Traffic levels in Europe (ECAC) did not recover to 2007 levels (10 million flights) before 2016.

Between 2016 and 2019, the average growth rate per year reached 2.8% with low-cost carriers' growth leading the way (+7.9% per year). In 2019, the European economy experienced more restrained growth due to trade tensions and the slowdown in emerging markets, rising geopolitical tensions, persistent weakness in the manufacturing sector as well as the uncertainty surrounding the banking sector and Brexit.

Although a record was reached, with 11.1 million flights controlled in European skies, growth in 2019 was weak (at 0.4%) due to a deteriorating situation in major European economies, trade tensions, a slowdown in emerging markets, Brexit, and events such as the grounding of Boeing 737 MAX aircraft.

The COVID-19 pandemic, which started at the end of 2019, was the most severe global pandemic in a century. Restrictions were imposed on human mobility to prevent the highly contagious virus from spreading, with all economic sectors being impacted on global scale. The aviation industry was majorly affected. The number of IFR movements in 2020 dropped by 55% compared to 2019. Health measures and vaccination campaigns led to an easing of travel restrictions during the following years, and the industry was able to resume growth.

Despite this, there were disparities both within Europe and on global level. As a result, the recovery was slow and did not happen at the same pace in the different regions. By 2023, the number of flights in Europe had reached 92% of the levels seen in 2019 (10.1 million flights).

Recent years have seen two major conflicts impacting aviation in Europe: Russia's full-scale invasion of Ukraine, initiated in February 2022, and the geopolitical events in the Middle East, which started in October 2023.

The risks associated with the war in Ukraine and the damage caused to aviation infrastructure have led to a halt in commercial operations in Ukraine and, to a lesser extent, in Moldova. The EU has imposed sanctions[6] on Russia, with an impact on some air traffic flows (e.g. European carriers struggle to remain competitive on routes from/to Asia). Most of the airspace and routes in this region remain closed at the time of writing, affecting important traffic flows, especially the South-East European flows.

Both Russia's full-scale invasion of Ukraine and the geopolitical events in the Middle East are affecting global trade relations, leading to an unstable economic situation, especially in Europe. It is impossible to predict when the restricted airspaces will be fully reopened. This forecast has therefore been prepared using the routing patterns observed in 2023 as a baseline (these routes are consistently used over our long-term horizon). This should not be interpreted as a prediction on the part of EUROCONTROL of how these restrictions may evolve. For more details about the actual situation for European aviation in 2023, please consult the EUROCONTROL Aviation Overview 2023.

2 Flight forecast to 2050

According to the most likely forecast, there will be 15.4 million flights in Europe[7] in 2050, i.e. 52% more than in 2023 (and 39% more than in 2019). This is an average growth rate of 1.6% per year between 2024 and 2050 (see Figure 4). The evolution towards a full recovery to pre-pandemic traffic levels (expected in 2025), industry-wide decarbonisation efforts and constraints on the main airports of the network will be the major elements influencing traffic growth over the next 20 to 30 years.

2.1 Overall results

In the *base scenario*, traffic is expected to reach 15.4 million flights in Europe by 2050 (see Figure 4). Growth will average 2.5% over the 2024-2030 period, a relatively strong figure owing to the rebound from the COVID-19 pandemic. The first part of the horizon is expected to see sustained growth rates for flights compared to the 2010-2019 period (1.6%). A return to steady growth is expected to happen after 2025, when the 11.1 million flight mark recorded in 2019 will be reached again. Nevertheless, it will still be a challenging period for the industry, marked by a transition to post-pandemic trends, the war in Ukraine, and geopolitical events in the Middle East. More moderate growth of 1.4% is expected in the 2030-2040 period, with Europe reaching just under 14 million flights in 2040. The aviation markets are expected to become more mature, with a slight

[6] EU restrictive measures in view of Russia's full-scale invasion of Ukraine (sectoral restrictive measures): it is prohibited for any aircraft operated by Russian air carriers or for any non-Russian-registered aircraft which is owned or chartered, or otherwise controlled by any Russian person or entity, to take off from, land in or overfly the territory of the Union. The prohibition also applies to any other aircraft which is used for a non-scheduled flight and with regard to which a Russian person or entity is in a position to effectively determine the place or time of its take-off or landing.

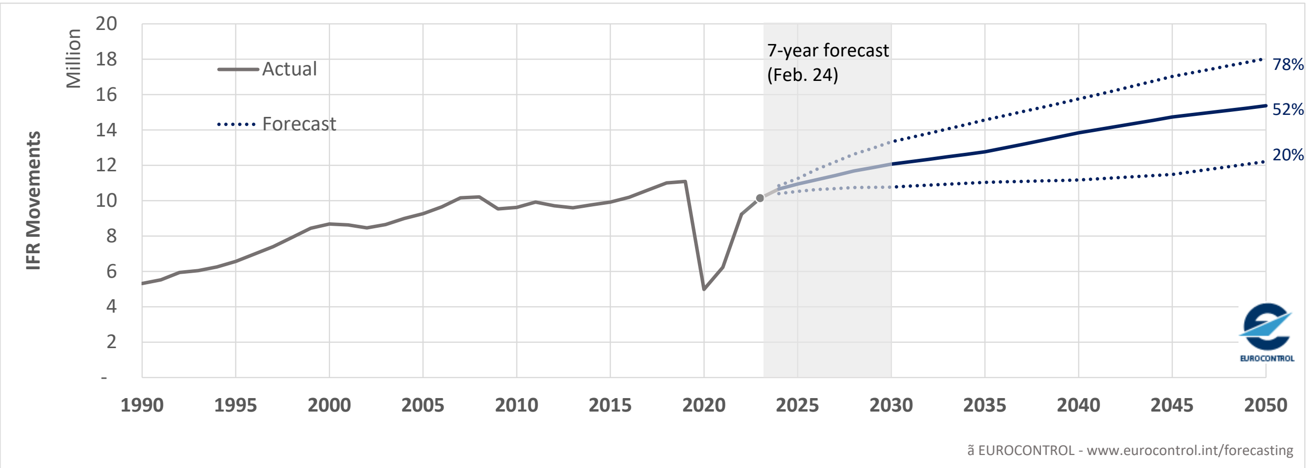
[7] Europe here designates the ECAC region, covering the zone between Iceland and Azerbaijan.

deceleration in economic growth, although people are still expected to want to fly in increasing numbers. In this scenario, Europe remains a significant hub at the crossroads of the world's regions. Exchanges within Europe and between Europe and the rest of the world continue to be stimulated by trade, tourism and business, albeit with greater sustainability concerns.

In this scenario, a staggered blending mandate and availability of SAF progressively expands from 2025 onwards. Sustainable technology is embraced by the industry, and this decade will see the first revolutionary aircraft arriving in commercial fleets. A significant impact on CO_2 reductions is expected to happen from 2030 (see Section 3).

Growth in terms of flights in Europe is expected to be at 1.1% at the end of the forecast (average annual growth rate for 2040-2050), slightly slower than in the previous decade. This lower rate in the *base scenario* is influenced by capacity constraints affecting airports in different States.

Figure 4. Flight forecast for Europe, with total growth between 2024 and 2050

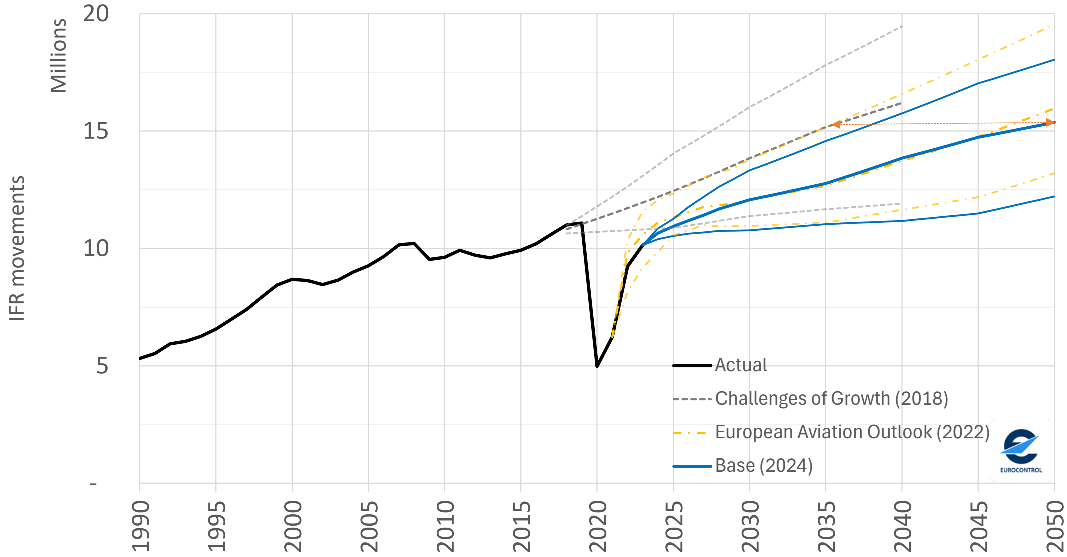


ECAC	IFR Movements										
	2019		2023		2050			Total growth 2050/2023	AAGR 2024-2050	Total growth 2050/2019	AAGR 2020-2050
	Total (million)	Avg. daily (thousands)	Total (million)	Avg. daily (thousands)	Total (million)	Avg. daily (thousands)	Extra flights/day (thousands)				
High					18.0	49.4	5.9	+78%	+2.2%	+63%	+1.6%
Base	11.1	30.4	10.1	27.8	15.4	42.1	0.9	+52%	+1.6%	+39%	+1.1%
Low					12.2	33.5	0.9	+20%	+0.7%	+10%	+0.3%

In the *low scenario*, some factors are hindering traffic growth: the prices of conventional fuel, SAF and CO_2 allowances are high, making the price of travel higher. In addition, economic development is slower and flight demand is weaker, meaning that the industry is less able to invest in fleet renewal. Only a limited number of revolutionary fleet projects can be developed, occurring at a later stage compared to other scenarios. Flight growth develops more slowly in this scenario, with 12.2 million flights by 2050, 20% more than in 2023 – an average growth of 0.7% per year. In this context, the number of flights is only expected to get back to pre-COVID levels by 2037 (0.6% growth on average over the first 15 years).

In the *high scenario*, high flight growth comes from sustained economic growth, a high propensity to fly, and relatively lower SAF and conventional fuel prices. A wide range of new fleet projects are implemented between 2030 and 2050 (electric, hybrid-electric, hydrogen). This scenario sees 18 million flights in 2050 in Europe, 78% more than in 2023. In this case, traffic will grow at 4% on average until 2030, with a fast recovery to pre-COVID levels, due to happen in 2025. In this scenario, the following decades see more modest growth (1.8% on average during the 2030-2040 period, and 1.4% during the 2040-2050 period). This decelerating trend can be explained by multiple factors, including market maturity, larger aircraft, and capacity constraints at airports.

Figure 5. Flight forecasts for Europe – current (2024) and previous (April 2022 and June 2018) forecasts



Comparing this Outlook with EUROCONTROL's previous forecast (see Ref. i) published in April 2022 (Figure 5), the Outlook was reviewed downwards and it is now slightly lower in all scenarios. This is especially visible in the first years of the forecast. In the previous edition, there was still a lot of uncertainty surrounding the post-COVID recovery and the extent of the impact of Russia's war of aggression against Ukraine. Despite this, the current version is well aligned with the previous EUROCONTROL Aviation Outlook forecast during most of the horizon in the *base scenario*. Hence, over the 2030-2045 period, both forecasts are very similar for the most likely scenario. In our previous forecasts, traffic was expected to reach 15.4 million flights by 2048. This was driven by the reviewed assumptions on fuel prices and capacities at the main airports.

Comparing this Outlook with the EUROCONTROL forecast (see Ref. iv) published in June 2018 (Figure 5), the COVID-19 pandemic has led to a fourteen-year hiatus in traffic growth, meaning that the 15.4 million flights previously expected by 2036 in the base scenario is now forecast for 2050 (ECAC figures).

2.2 Details within Europe

Growth will not be uniform across Europe. States in North-East and South-East Europe will grow faster than those in the west, a trend observed in all the forecast scenarios. In the *base scenario*, growth will range from 1% on average per year in the Netherlands and the Canary Islands, to above 3% per year in the Caucasus States of Armenia, Azerbaijan and Georgia.

In general, the most rapid growth will occur in the States along the eastern border of Europe, with annual growth rates above 2%. This reflects a higher potential for traffic growth in these regions, most notably in Türkiye. Figure 6 shows that this State is expected to see a traffic increase of 2.6% per year, with an additional 4,420 flights a day by 2050 and almost double the amount of traffic (+98%).

Figure 6. Average annual flight growth rates in the *base scenario* (2024-2050)

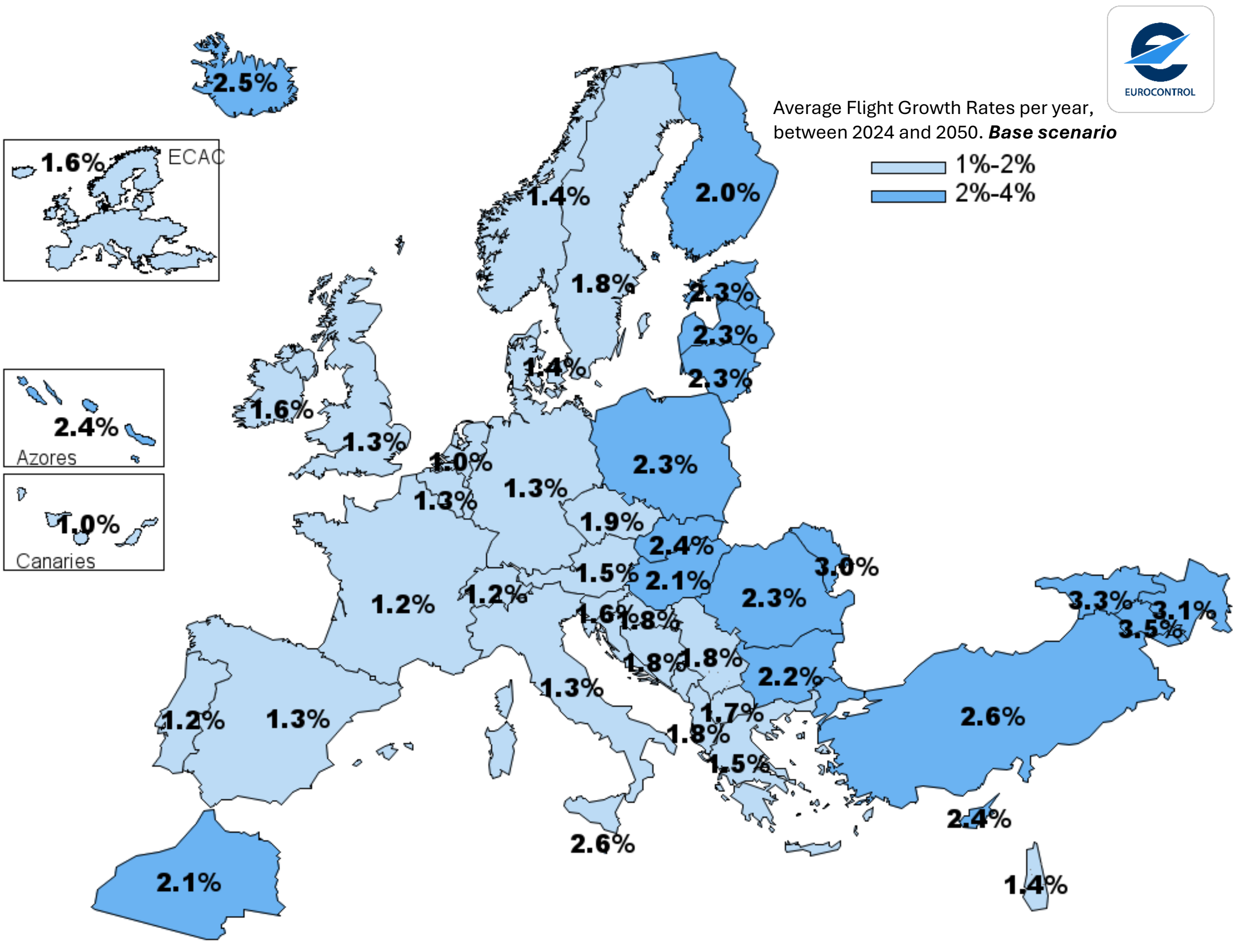
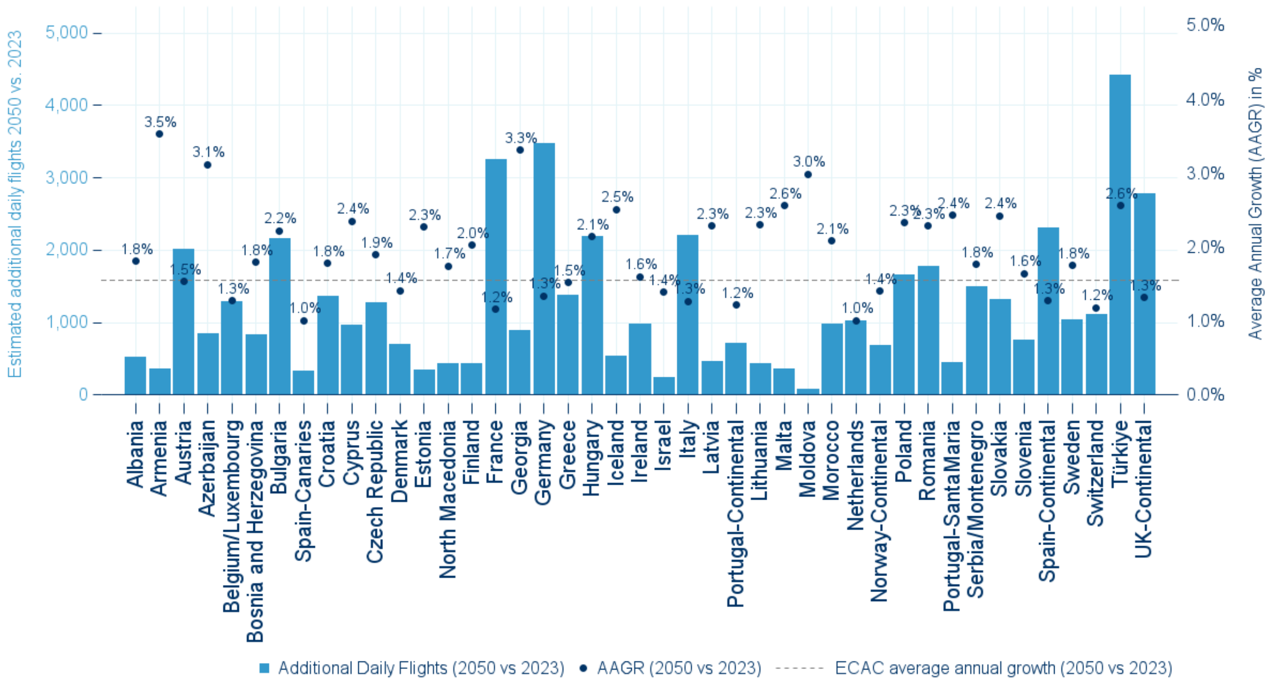


Figure 7. Average annual growth rate in 2050 and additional flights per day, *base scenario*



Türkiye will become the 4th busiest State in Europe in 2050, ahead of Spain and Italy, which will grow at half the rate (1.3% average per year) with 2,300 and 2,200 additional flights respectively. France and Germany will remain the busiest States, will record moderate growth and see 3,200 and 3,500 additional flights per day respectively, followed by the United Kingdom, which is expected to add 2,700 flights to the network by 2050.

2.3 Airport capacity constraints

A key feature of EUROCONTROL forecasts is the fact that airport capacity constraints are considered. In practice, the total number of flights is capped by the future declared capacity, even if the expected growth generates demand for more flights. The main reason the threshold is met in more countries is often because more growth is expected or capacity is revised downwards.

As shown in Figure 8, it is expected that in 2050, 7% of the demand in the *base scenario* (i.e. 1.1 million flights) won't be met because of movement limitations due to airport constraints. This number reaches 14% (3 million flights) when the *high scenario* is considered. In the *low scenario*, there is little to no unaccommodated demand. These numbers are slightly higher than forecast in the previous EUROCONTROL Aviation Outlook (see Ref. i). The previous long-term forecast was published in the middle of the COVID-19 crisis, which itself significantly delayed air traffic growth, thereby reducing the forecast unaccommodated demand for a given year.

Figure 8. Demand exceeds capacity by more than a million flights in 2050 across the network in the *base scenario*, climbing to 3 million (14%) in the *high scenario*

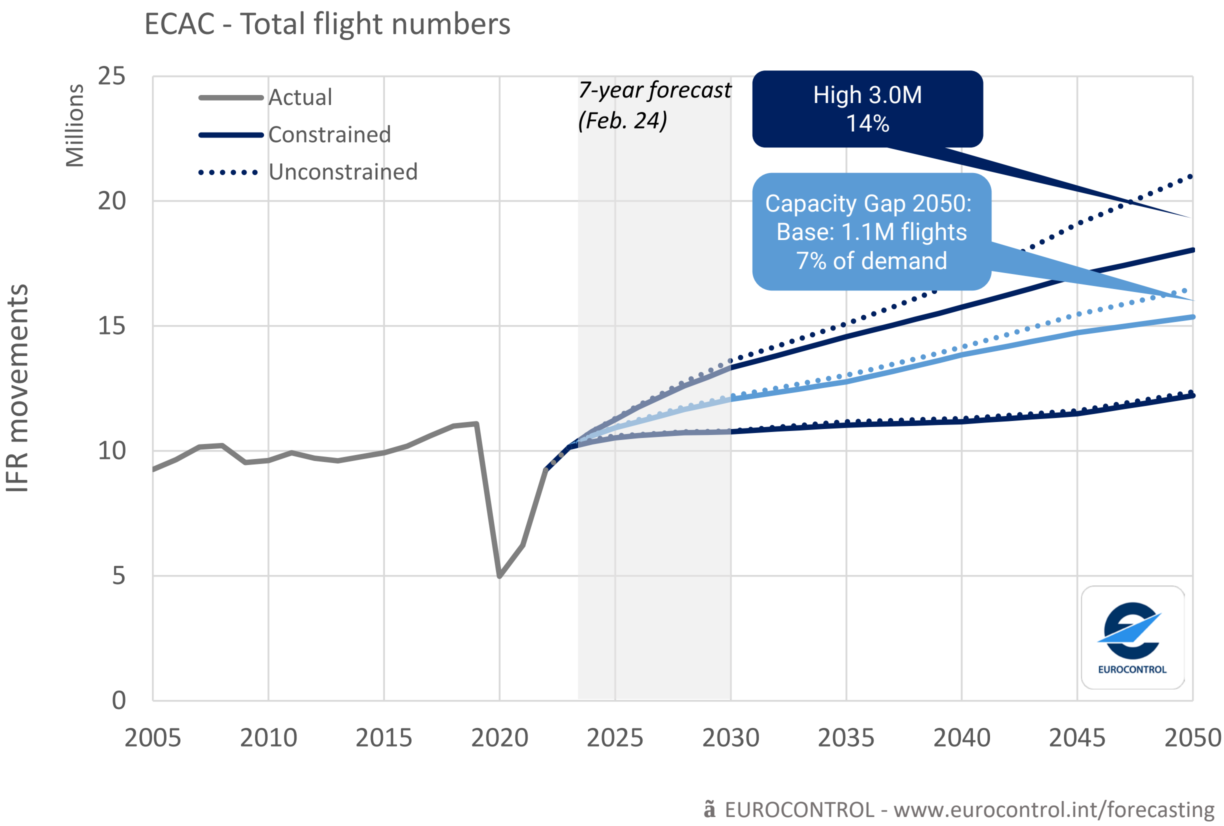
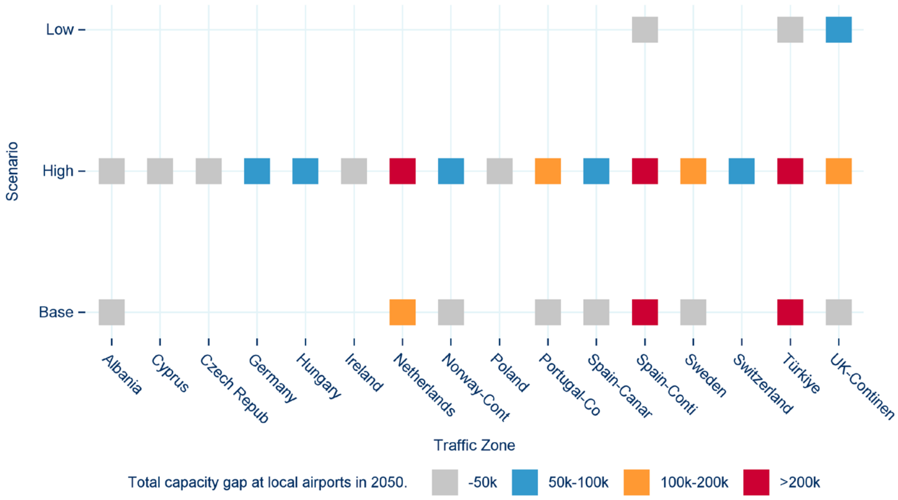


Figure 9 summarises where there is more demand for flights than there is capacity in 2050. In the most likely scenario, airports in Albania, Norway, Portugal, Spain (Canary Islands), Sweden and the United Kingdom will each see less than 50,000 flights unaccommodated. In this scenario, airports in the Netherlands should see between 100,000 and 200,000 unaccommodated flights. Airports in (continental) Spain and Türkiye are expected to see a gap of more than 200,000 flights in the same scenario. There are also slightly greater challenges in terms of coverage. The number of flights in nine different States is expected to be limited by airport capacity in the most likely scenario, compared to a set of six countries in the previous forecast (see Ref. i).

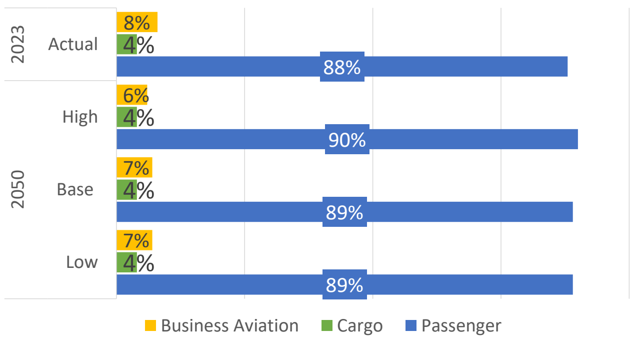
Figure 9. In the most likely *base scenario*, there is a capacity gap at airports in nine countries, up from six in the previous edition.



2.4 Market segments

The distribution of flights amongst the three main market segments (passenger, business aviation and full cargo) is expected to remain relatively stable across the horizon. In the *base scenario*, passenger flights are forecast to account for 89% of flights in 2050 (vs 88% in 2023), while business aviation flights are expected to account for 4% in 2050 (as in 2023) and all-cargo flights are expected to account for 7% in 2050 (vs 8% in 2023).

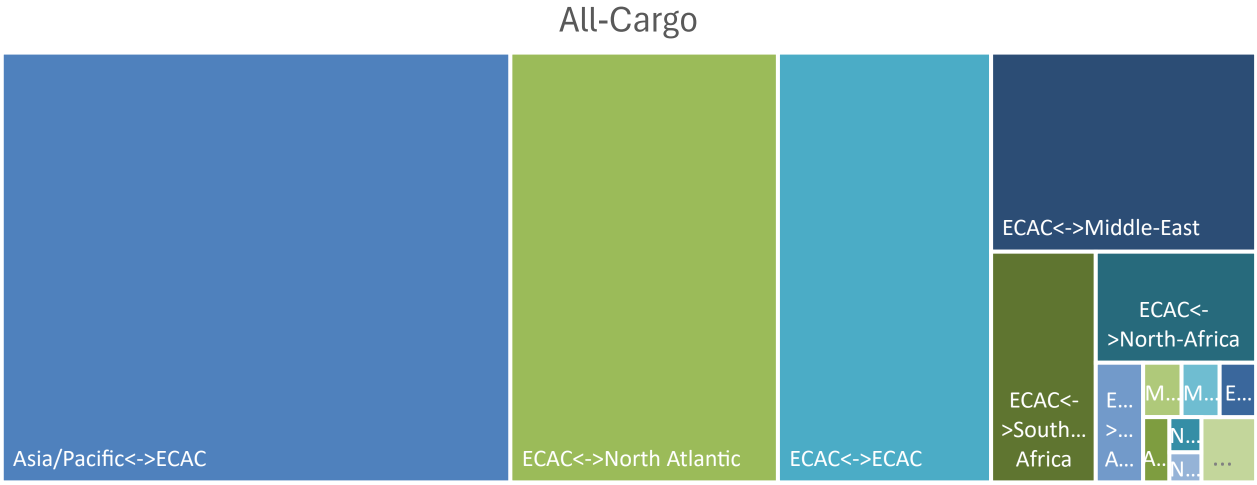
Figure 10. Share of market segments and average annual growth rates for the market segments



Average annual growth rate 2024 - 2050 (%)			
IFR flights	Passenger	Business Aviation	All-cargo
High	2.2%	1.4%	2.2%
Base	1.4%	0.9%	1.7%
Low	0.4%	0.2%	0.6%

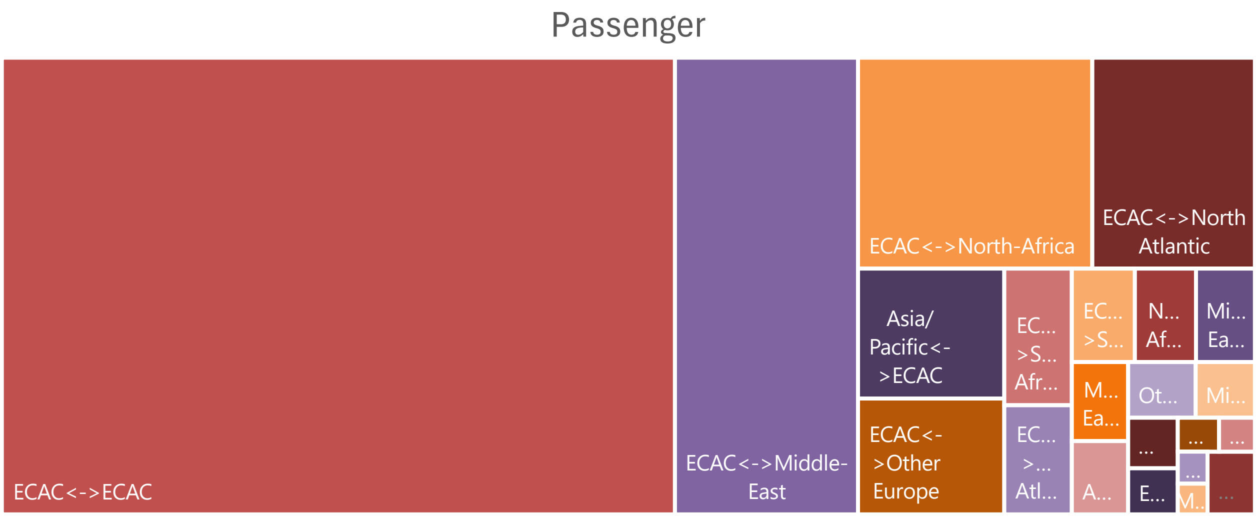
All-cargo flights, although accounting for the smallest share of flights in 2050, will see the most dynamic increase (1.7%) in growth rates (*base scenario*). This segment will benefit from the strong economic growth in the Asia/Pacific, North-Atlantic and Middle East regions (Figure 11).

Figure 11. Flows adding the most flights in the all-cargo segment (*base scenario*)



Passenger flights will grow by 1.4% per year in the *base scenario* (Figure 10), slightly expanding from 88% to 89% of flights between 2023 and 2050. In this segment, the most important flows between 2030 and 2050 will be domestic ECAC, ECAC ↔ Middle East and ECAC ↔ North Africa (Figure 12). The passenger segment is further discussed in the next section.

Figure 12. Flows adding the most flights in the passenger segment (*base scenario*)



Business aviation is expected to grow at an average rate of 0.9% per year between 2024 and 2050 in the *most likely scenario*. Similarly to the passenger segment, the flows recording the highest number of additional movements between 2030 and 2050 will be the intra-European flow, followed by ECAC↔ Middle East and ECAC ↔ North-Africa.

2.5 Passenger forecast

The passenger market segment accounts by far for the greatest share of flights. In 2023, while passenger flights increased by 10.6% in Europe (see Ref. v), the number of passengers at European airports (see Ref. v) grew by 17.9% (compared to 2022). The amplified magnitude of the passenger rates compared to flight rates is due to both larger aircraft and increased load factors.

An estimated number of passengers on board was determined based on Eurostat data at airport pair level, together with an analysis of the Eurostat flows and data from EUROCONTROL. In 2023, the number of passengers in the ECAC area is estimated at 1.19 billion in our statistics.

By 2050, the number of passengers in the ECAC area is expected to reach 1.81 billion in the *base scenario*, corresponding to an average growth rate of 1.6% per year between 2024 and 2050.

In the *high scenario*, the number of passengers in the ECAC area is expected to grow to 2.1 billion in 2050, corresponding to an average annual growth rate of 2.1% between 2024 and 2050.

In the *low scenario*, the number of passengers in the ECAC area is expected to grow by 0.5% per year on average only, from 1.2 billion passengers in 2023 to 1.4 billion passengers in 2050.

2.6 Impact of high-speed trains and night trains

High-speed train (HST) travel times have been updated for this forecast, as future projects will have an impact on air travel demand (see Ref. vi). A review of the current status of future projects has been carried out; the principal source being specialised websites for rail industry professionals (UIC) and dedicated HST project websites (e.g. railbaltica.org).

Given the length of the forecast horizon and the growing environmental concerns that are driving a shift from air travel to alternative modes of transport, an optimistic approach has been taken, with a number of projects covering 32 city pairs in the *high* and *base scenarios* and 26 city pairs in the remaining scenario. The previous forecast had considered 56 city pairs, but a number of projects have been postponed, adjourned or abandoned since 2021 (e.g. in the United Kingdom, the Northern leg of HS2 has been abandoned, and in Sweden, the government is now prioritising better roads and more charging points for electric vehicles over investment in high-speed rail). However, some links have been added (e.g. new links in Morocco and links between Poland and Central Europe).

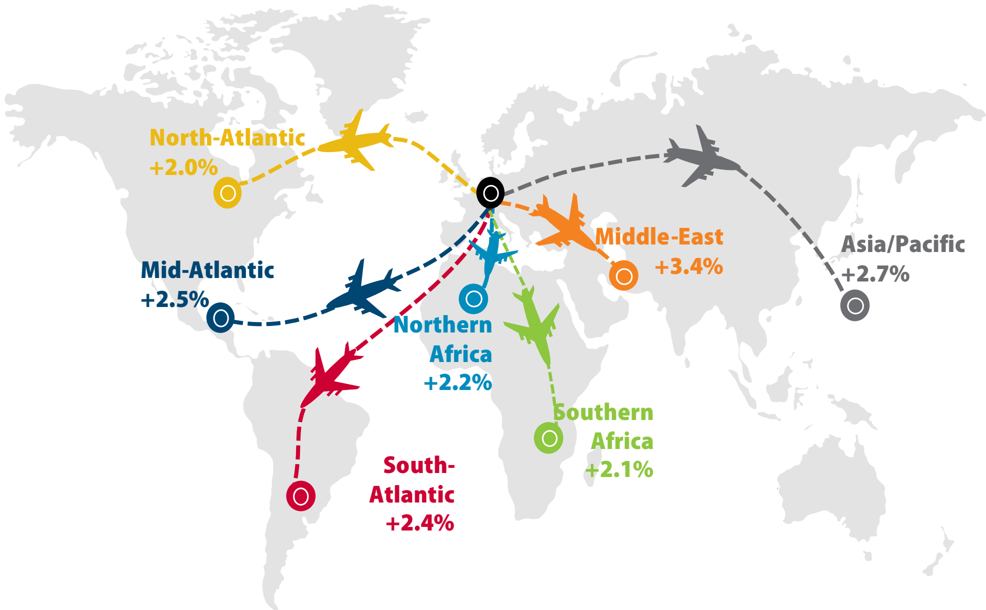
If the benefits of travel time can play an obvious part in the case of high-speed trains, slower train links have also been considered, as they could gain market share in the longer term. The focus is on night trains, which can easily operate on the existing track network. Based on information found on other dedicated websites (e.g. interrail.eu), 29 city pairs were identified as plausible candidates. A constant impact has been assumed for every line in terms of passengers: 10% of the market share from air to rail in the *high scenario*, 6% in the *base scenario* and no impact in the *low scenario* (as limited investments are made in the latter scenario).

Even if the train networks are cross-border networks, the States with more projects in the pipeline are likely to see a stronger reduction in departures by 2050, such as Sweden (-7.1% in the most likely scenario), the Czech Republic (-4.0%), Morocco (-3.5%), Slovakia (-3.0%), Austria (-2.4%), Hungary (-1.3%) and Poland (-1.1%). At ECAC level, high-speed trains and night trains are expected to lead to a drop in demand by 0.4% in the *base scenario* and the *high scenario*, and by 0.3% in the *low scenario*.

2.7 ECAC and other regions

Considering all IFR flights, Figure 13 shows that the Middle East and Asia/Pacific regions will be the most dynamic partners by 2050: the average annual growth rate for flights departing the ECAC area to these regions is likely to be 3.4% for the Middle East and 2.7% for the Asia/Pacific region per year in the *base scenario*.

Figure 13. Average annual flight growth rates from Europe (ECAC) to World regions (2024-2050) *base scenario*



More mature markets will record moderate growth: for example, the North Atlantic is expected to grow at an average rate of 2.0% per year on average.

Arrivals and departures in the Middle East will become the busiest external flow by 2050, taking the position of the North Atlantic in all three scenarios. In the *high scenario*, traffic to/from that region is set to exceed one million flights. In the case of Middle Eastern flows, the United Arab Emirates and Saudi Arabia will be the main traffic generators by 2050, with annual growth of 3.6% and 3.8% over the 2024-2050 period in the most likely scenario.

The Asia/Pacific region is likely to remain the third extra-European partner with Europe by 2050 (in all scenarios). China, Kazakhstan and India will be the countries adding more flights on the Europe ↔ Asia/Pacific flows with annual growth of 2.8%, 3.6% and 2.4% respectively over the forecast horizon in the *base scenario*.

3 CO_2 emissions forecast to 2050

Our three scenarios include assumptions about how aviation rises to sustainability challenges: through improvements to existing aircraft and engines, as well as radical changes in aircraft design and propulsion. A large-scale switch to sustainable aviation fuels (SAF) is also expected to be consistent with the mandates of the RefuelEU Aviation Regulation (see Section 4.4).

These assumptions affect the price of flying, and hence demand. This has already been taken into account in the flight forecast just described (see Section 1.2). In addition, the assumptions also allow us to estimate the net CO_2 emissions from those flights.

These radical changes are tuned to model the specificities of the scenarios. For example, in the *high scenario*, investment both within and outside the aviation sector pays off, with SAF more widely available and cheaper, and new aircraft types available sooner. In the *low scenario*, weaker aviation growth means that airlines and manufacturers are less able to invest in overhauling the existing fleet, and the SAF mandates are delayed by five years.

These assumptions are completed by the expected airport and ATM infrastructure as well as airline operations improvements, in line with the ATM Master Plan, and future out-of-sector measures, such as carbon offsetting and carbon capture. Therefore, we focus here on how these different assumptions enable reductions in CO_2 emissions in order to meet the net-zero carbon emission objectives.

3.1 Key factors contributing to the reduction in CO_2 emissions

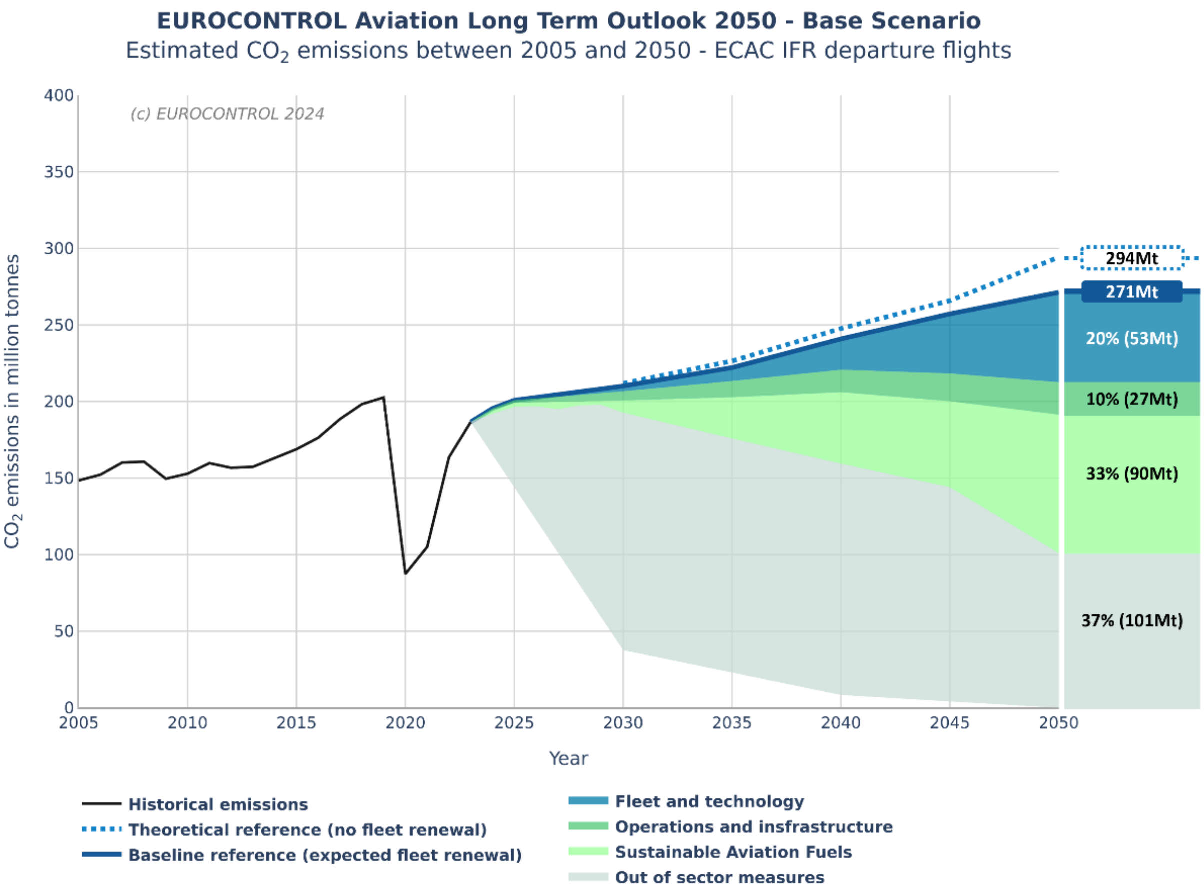
To calculate such CO_2 amounts and savings, this forecast models the following references, improvements and sustainability factors. The corresponding CO_2 emissions estimates (*base scenario*, for all ECAC departures) are presented when broken down per factor:

- **Theoretical reference (no fleet renewal)**—estimated at 294 million tonnes of CO_2 (2050)
    - *Indicative CO_2 forecast with a constant fuel efficiency level from 2023*
- **Baseline reference (expected fleet renewal)**—estimated at 271 million tonnes of CO_2 (2050)
    - *Forecast fleet renewal modelling with the aircraft types certified in 2023* ***(used as a reference for estimating the contribution of each factor towards achieving net-zero CO_2 emissions)***
- **Fleet and technology Improvements**---estimated at 218 million tonnes of CO_2 (2050)
    - *Anticipated fleet renewal with future evolutionary (new generation aircraft based on fuel-type propulsion) and revolutionary (new generation aircraft based on hydrogen or electric-type of propulsion) aircraft, including ICAO CAEP advanced fuel efficiency/CO_2 improvements (1.16% per annum); varies per scenario based on different entry into service years*
- **Operations and Infrastructure**---estimated at 191 million tonnes of CO_2 (2050)
    - *Not varied by scenario: SESAR, ATM, airports and related aircraft operations improvements*
- **Sustainable aviation fuels**---estimated at 101 million tonnes of CO_2 (2050)
    - *ReFuelEU mandates applied to all ECAC States, with a 70% decarbonisation factor for eSAF and 65% for bio-SAF*
- **Out-of-sector measures**---expected to annihilate the remaining CO_2 emissions
    - *Not varied by scenario: EU "Fit for 55" objectives with carbon capture, offsetting, market-based measures*

3.2 Pathway to net-zero

Figure 14 shows the CO_2 forecast in the *base scenario* for departing flights, estimated for the entire range of ground and airborne trajectories. It points out the estimated CO_2 emissions forecast trends from 2005 (with an estimated amount of 148 million tonnes of CO_2 emitted) showing the potential and expected savings with a set of dedicated indicators.

Figure 14. By 2050, CO_2 emissions, net of SAF, fleet and operational improvements, are reduced by about 63% compared to the baseline reference in the *base scenario*



271 million tonnes in CO_2 emission reductions would be needed in order to reach net-zero by 2050. A major factor for these savings is expected to be obtained by the use of SAF (33% savings in 2050), if the ReFuelEU mandates are met in good times. New aircraft types come into service and deliver CO_2 savings too, with electric propulsion over some distances, and hydrogen over slightly longer distances (CO_2 reduction of 20% or 53 million tonnes in 2050), but such aircraft types are still relatively new and not a dominant part of the fleet in 2050 (see Section 4).

Nevertheless, in the context of the ECAC Member States' air traffic, technical, operational and SAF-based savings alone will not be enough to meet the objectives in the "Fit for 55" legislative package. Out-of-sector measures will need to be taken in order to achieve a supplementary reduction in net CO_2 emissions from 92% in 2030 (193 million tonnes) to 75% in 2040 (160 million tonnes) and finally 37% (101 million tonnes) in 2050, compared to the baseline reference.

The CO_2 emissions timeline graphics for the *low* and *high scenarios* are displayed in Annex C.

Figure 15 below summarises the results for the three scenarios. It shows the relative share of each key decarbonisation factor identified for aviation as well as the relative stability of the share of "fleet and technology" across the three scenarios. It also shows the importance of SAF, which is a main contributing factor to reaching net-zero CO_2 emissions. In all our scenarios, out-of-sector measures will still be needed in 2050 to fully decarbonise aviation with levels comprised between 101 million tonnes (*base scenario*) and 118 million tonnes (*high scenario*).

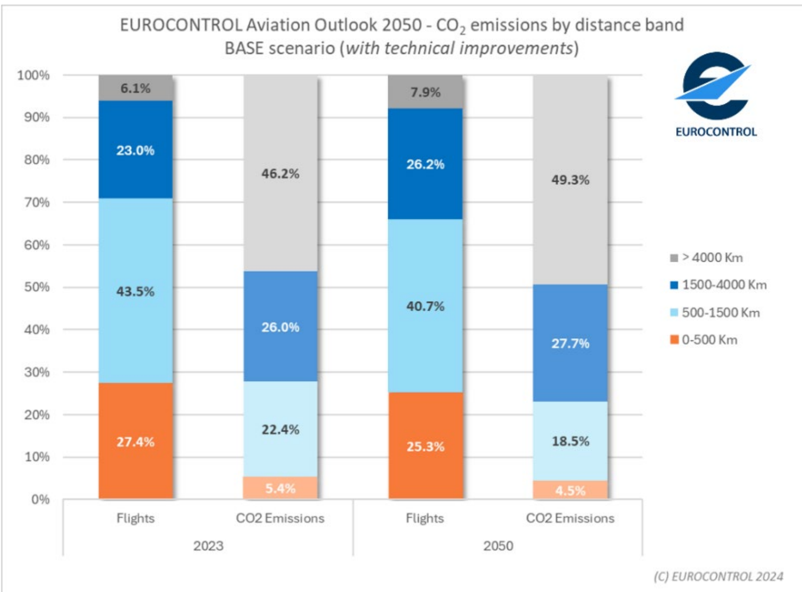
Figure 15. Summary of net-zero CO_2 results for each scenario

Net-zero CO_2 can be achieved by 2050 via the following:	*Low scenario* 193Mt	*Base scenario* 271Mt	*High scenario* 328Mt
Fleet and technology	**17%**	**20%**	**22%**
Operations and infrastructure	**10%**	**10%**	**10%**
Sustainable aviation fuels (SAF)	**21%**	**33%**	**32%**
Out of sector measures (carbon capture, offsetting, market-based measures)	**52%**	**37%**	**36%**

We have reported in a data snapshot (see Ref. vii) how a small proportion of flights (those over 4,000km) account for around half of CO_2 emissions (Figure 16). In all three scenarios, we forecast that the share of long-haul flights will increase by 2050. Over this time horizon, it will remain difficult to substitute for long-haul flying, so the CO_2 efficiency of SAF will be key (see Ref. viii).

Over shorter distances, there are substitutes; we discuss high-speed rail and night trains, for example, in Section 2. Even with substitute travel modes, the *low scenario* forecasts an increasing share of very short-haul flights (less than 500km) driven, in part, by the arrival of electric aircraft with fewer seats, hence increasing frequencies, but not increasing the share of CO_2.

Figure 16. Long-haul continues to be the source of the majority of CO_2 emissions – timeline in *all scenarios* (*base scenario presented*)



3.3 Fuel and CO_2 efficiency results

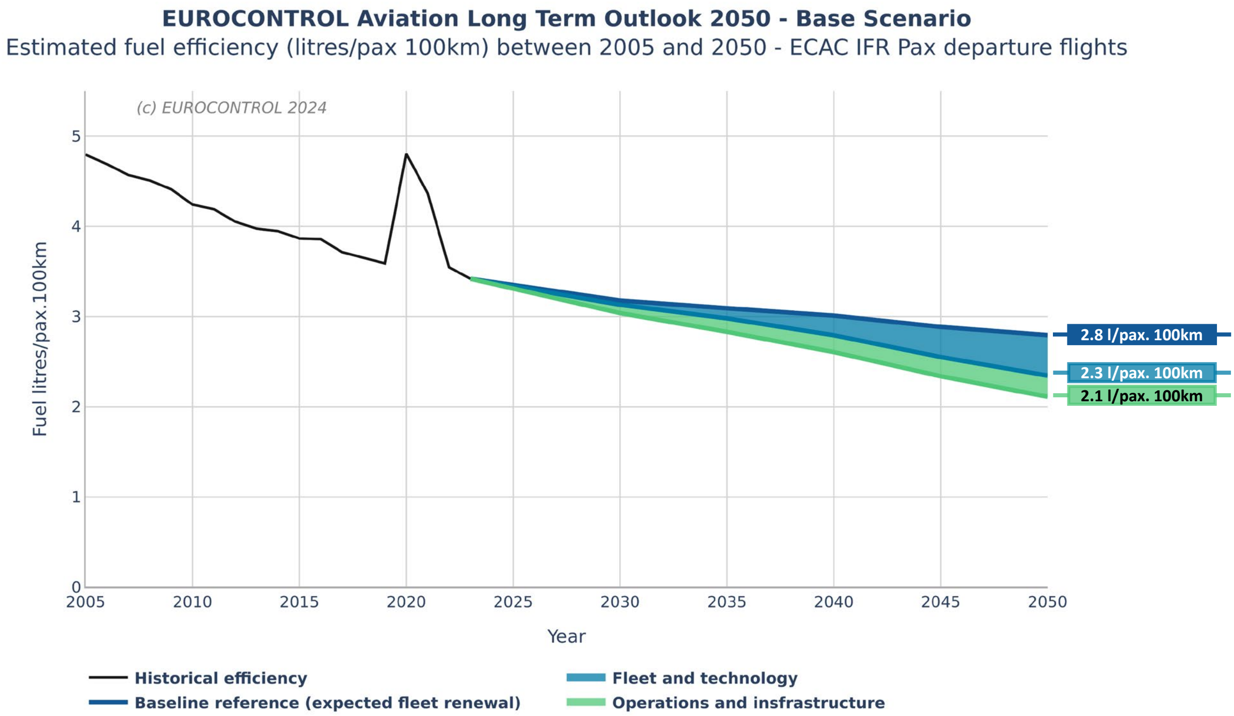
Figure 17 shows fuel and CO_2 efficiency trends for ECAC passenger flights from 2005 to 2050, for the *base scenario*. The fuel and CO_2 efficiencies correspond to the overall ratio of emitted fuel and CO_2 by revenue passenger kilometre. These indicators highlight the impact of the improvements on fuel consumption translated into negative rates for a reduced consumption and therefore better (fuel and CO_2) efficiency. The CO_2 efficiency trend would follow an average annual improvement of 1.8% and decrease from 121g in 2005 to 53g in 2050. The impact of mixed fleet and technology as well as operations and infrastructure improvements in fuel and CO_2 efficiency since 2005 is expected to deliver a similar annual rate between 2024 and 2050 (1.8%).

As a result, the corresponding fuel efficiency would improve from 4.8 litres per passenger/100km in 2005 down to 2.1 litres per passenger/100 km in 2050.

Figure 17. In the *base scenario*, the average annual fuel and CO_2 efficiency growth rate raises by 1.8% between 2005 and 2050.

<table>
<tr><th>Base scenario</th><th rowspan="2">Indicator</th><th rowspan="2">2005</th><th rowspan="2">2023</th><th rowspan="2">2050</th><th colspan="2">Total change</th><th colspan="2">Average Annual Change Rate</th></tr>
<tr><th>Fuel and CO_2 efficiency trend</th><th>2050/2005</th><th>2050/2023</th><th>2006-2050</th><th>2024-2050</th></tr>
<tr><td>Baseline reference</td><td rowspan="3">CO_2 g per pax km</td><td rowspan="3">121</td><td rowspan="3">86</td><td>76</td><td>-37.0%</td><td>-11.6%</td><td>-1.0%</td><td>-0.5%</td></tr>
<tr><td>Baseline reference with fleet and technology improvements</td><td>59</td><td>-51.1%</td><td>-31.4%</td><td>-1.6%</td><td>-1.4%</td></tr>
<tr><td rowspan="2">Baseline reference with fleet and technology and operations and infrastructure improvements</td><td>53</td><td rowspan="2">-56.0%</td><td rowspan="2">-38.3%</td><td rowspan="2">-1.8%</td><td rowspan="2">-1.8%</td></tr>
<tr><td>Fuel litres per pax /100 km</td><td>4.8</td><td>3.4</td><td>2.1</td></tr>
</table>

Figure 18. In the *base scenario*, the fuel efficiency is likely to decrease down to 2.1 litres per pax/100 km by 2050 with technical, infrastructure and operational improvements.



4 Key factors for a shift towards sustainability by 2050

A variety of approaches to reducing the emissions impacts of aviation have been identified, ranging from new fuel sources (biofuels or power-to-liquid fuels, collectively referred to as sustainable aviation fuels or SAF; hydrogen in fuel cells or directly combusted; electric; or hybrid-electric) as well as operational measures and policy measures. For short-haul flights, 9- and 19-seat electric aircraft will start paving the way for sustainable aviation in the 2025-2030 timeframe, while new propulsion technology, hybrid-electric or hydrogen could serve slightly longer segments of air travel in the *base scenario* by 2040. These fleet and fuel-related improvements are discussed further in this section.

Over the next ten years, aviation expects to unlock the potential of unmanned aircraft systems (drones operating as IFR) and supersonic aircraft. However, these future projects have not been included in this forecast.

4.1 Fleet and technology development

The development and deployment of new and more efficient aircraft are key to reducing the aviation industry's CO_2 emissions. The successful roll-out of these more efficient aircraft is conditioned on six elements:

1. The successful development of the necessary technologies to equip revolutionary new types of aircraft (high-energy density batteries, efficient storage of H_2, new engines, new design),

2. A certification process for the new types of technologies likely to be deployed for new types of aircraft (H_2, hybrid-electric, full electric),

3. The deployment of an efficient, cost-effective and sustainable production process for SAF and H_2, and access to sufficient renewable energy to allow hybrid-electric and electric aircraft charging,

4. An efficient aircraft production process supported by a sustainable supply chain,

5. The planning and construction of the required infrastructure to operate H_2, hybrid-electric and electric-powered aircraft. The electric grid infrastructure will also need to undergo specific work at different airports to allow the smooth deployment of electric and hybrid-electric aircraft,

6. Joint support from European, national and local authorities to support and incentivise the deployment of more CO_2 efficient aircraft is key to ensure vital support from the financial sector (for aircraft manufacturers, airports and airlines).

We consider that a proactive fleet renewal effort is key to achieve a significant CO_2 emissions reduction.

We assume that between 2025 and 2050, in the *high scenario*, 32 types of aircraft will be rolled out (evolutionary and revolutionary aircraft). We have based this on the review of the different aircraft projects currently in progress, the analysis of the progress made in the area of technology, and their availability. We also benefited from the insights of various stakeholders in the aircraft manufacturing industry. These assumptions are presented below.

4.2 Evolutionary and revolutionary aircraft types

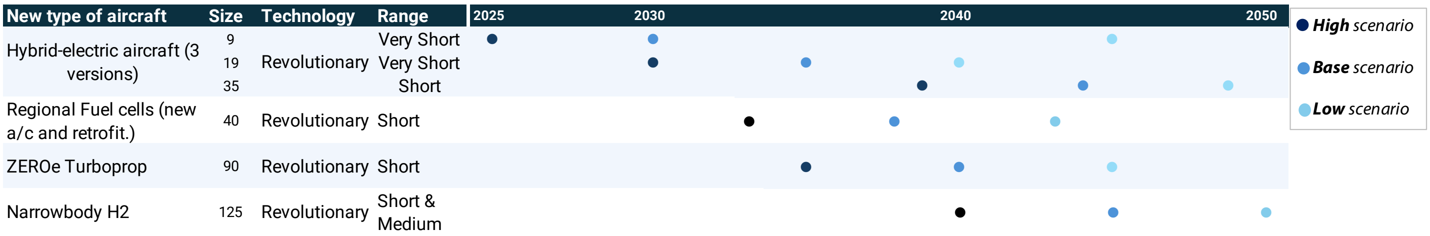
4.2.1 Passengers

Figure 19 and Figure 20 present the new projects considered in the forecast that will come on top of the conventional fleet and aircraft programmes currently available in the passenger market.

We first expect that sixteen types of aircraft will take off in the next ten years. These aircraft are divided into two categories, the *revolutionary* types of new aircraft (Figure 19) and the *evolutionary* ones (Figure 20). In the *high scenario*, the first revolutionary aircraft to be rolled out are a nine-seater electric aircraft in 2025 followed by a nineteen-seater version shortly before 2030 and a 30- to 40-seater hybrid-electric aircraft in 2030. An H_2 powered turboprop may enter into service between 2035 and 2045 (depending on the scenarios), introducing new types of aircraft to the fleet.

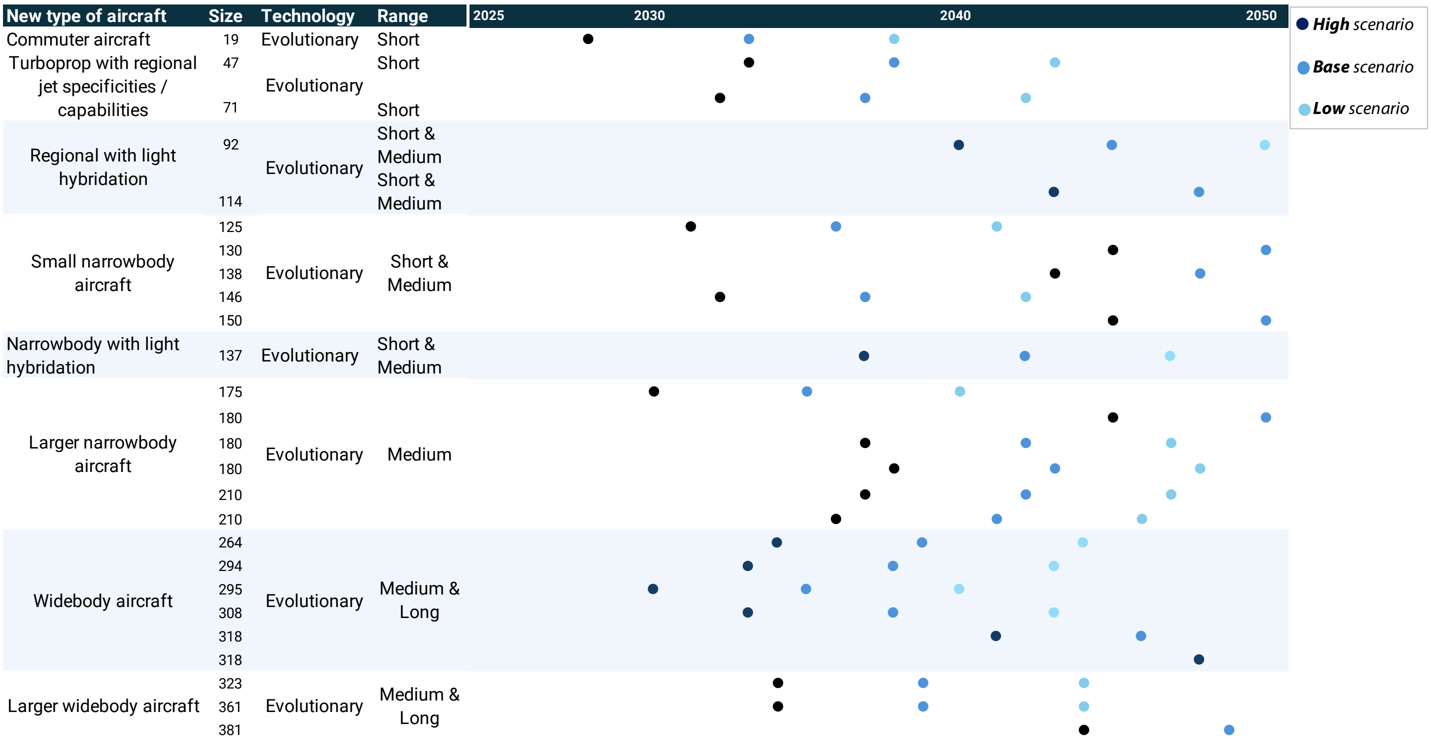
We expect six *revolutionary aircraft types* with hybrid-electric, electric or H_2 propulsion systems with an estimated CO_2 emissions reduction of 50 to 100% if electricity and hydrogen are sustainably produced (not taking account of the SAF impact at this level).

Figure 19. New revolutionary types of aircraft –passenger segment – entry into service year timeline per scenario.



We similarly expect 26 new types of aircraft based on the evolution of existing aircraft with a CO_2 emissions reduction potential ranging from 3 to 20%.

Figure 20. New evolutionary types of aircraft – passenger segment– entry into service year timeline per scenario.



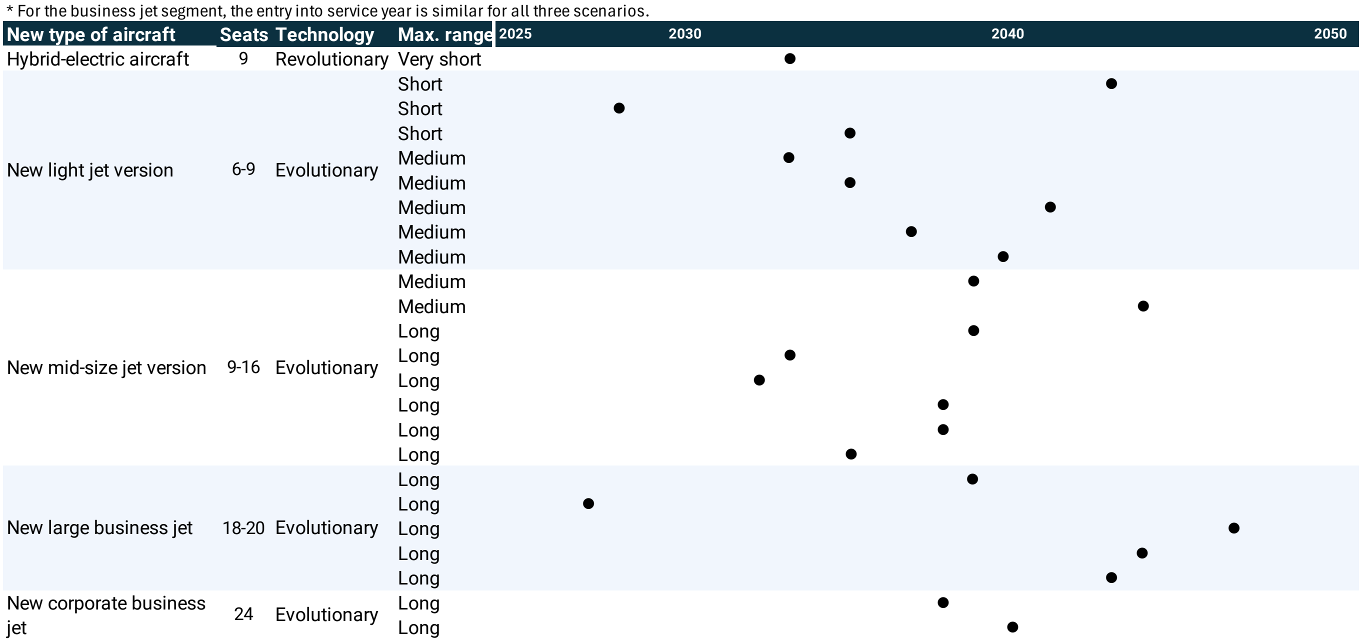
4.2.2 Business aviation

Figure 21 presents the new projects considered in the forecast that will come on top of the aircraft programmes currently available in the business aviation market.

We expect 24 new aircraft that can be operated as business jets. 23 are an evolution of existing aircraft from very light business jets to very large ones. One aircraft type is a revolutionary aircraft type with hybrid-electric propulsion (also deployed in the passengers' segment). The business jet decarbonisation strategy is currently focusing on SAF deployment and aircraft technology improvements[8]. The Business Aviation Commitment on Climate Change; as presented in the European Business Aviation Association (EBAA) *Flying into the future* booklet published in October 2024; is committed to achieving net-zero emissions by 2050 and continuing to improve fuel efficiency by 2% per year from 2020 to 2030. Four pathways, similar to the ones listed for aviation in general in Section 4, are expected to achieve these objectives. The forecast deployment of an important number of more efficient aircraft in the years to come is instrumental to achieving these goals.

Figure 21. New types of aircraft – business aviation segment – entry into service year timeline.

* For the business jet segment, the entry into service year is similar for all three scenarios.



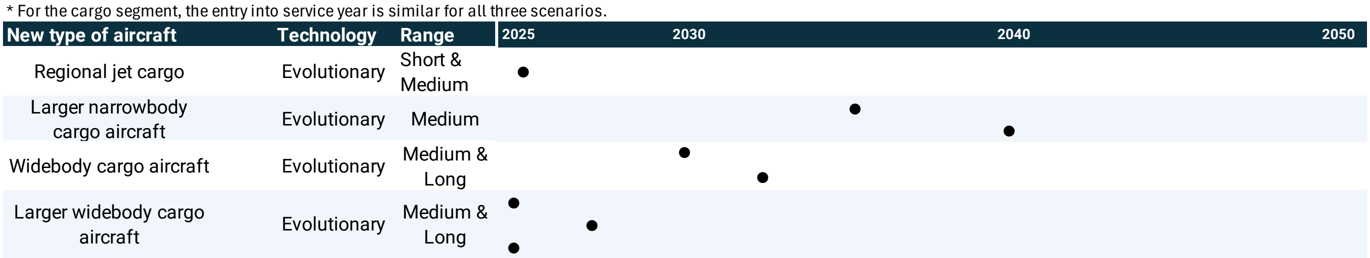
4.2.3 All-cargo

Figure 22 presents the new projects considered in the forecast that will come on top of the aircraft programmes currently available on the freighter market.

In the all-cargo segment, we expect eight new aircraft types. Here, we consider the conversion of passenger aircraft to freighter aircraft and a new-built freighter aircraft. These aircraft are all-cargo versions of existing or announced commercial aircraft.

Figure 22. New types of aircraft – all-cargo segment – entry into service year – timeline.

* For the cargo segment, the entry into service year is similar for all three scenarios.



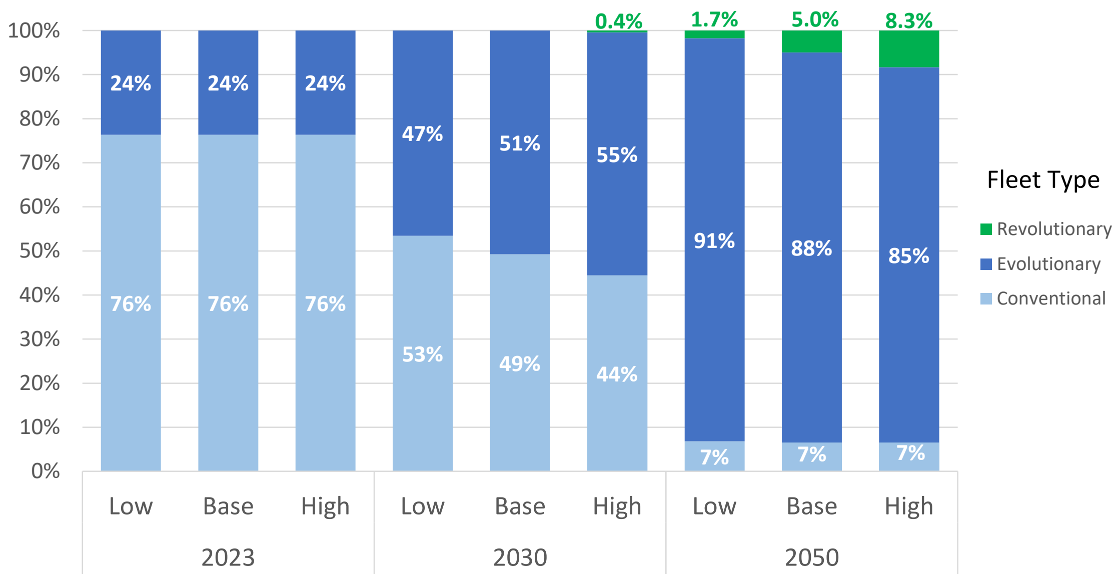
8 See in particular https://www.ebaa.org/industry-updates/the-paths-to-net-zero-strategies-for-reducing-carbon-emissions/ and https://bizav.ebaa.org/

4.2.4 Future fleet

Using the fleet and operations forecasting model (Aircraft Assignment Tool – AAT), the expected passenger/business aviation/all-cargo flight demand forecast is converted 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.

Figure 23 illustrates the expected share of passenger flights per "type" of aircraft. If the flights operated in Europe already integrate approx. 25% of new generation (cleaner) aircraft (e.g. NEO, MAX), there will be a clear transition to a balanced share of conventional and new generation aircraft by 2030. Then, with the retirement of less efficient aircraft and the deliveries of both evolutionary and revolutionary aircraft by 2050 (see Figure 19 and Figure 20), flights will be predominantly operated by new generation (evolutionary) aircraft. The share of flights operated by revolutionary aircraft types will remain marginal (5% in the *base scenario*).

Figure 23. Forecast mix of aircraft in future years, based on the actual and expected number of flights.



4.3 Operations and infrastructure improvements

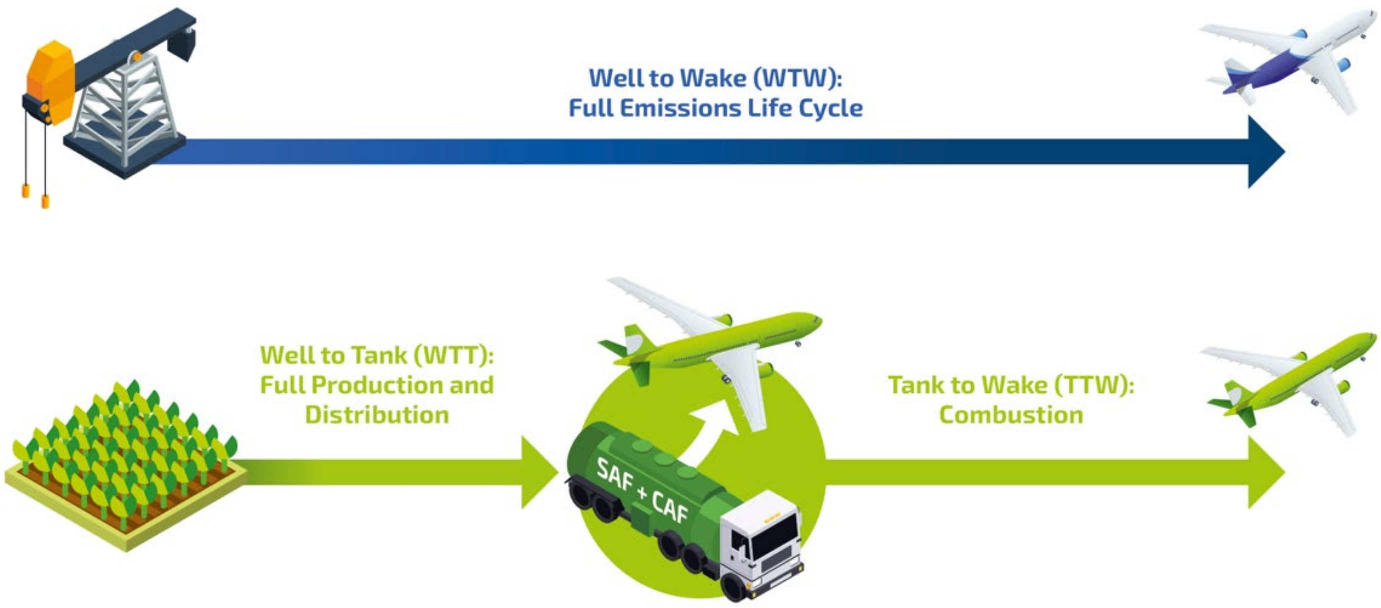
Operations and infrastructure improvements cover air traffic management (ATM), airports and aircraft operations. In the short to medium term, operational measures improving aircraft fuel efficiency will be key and can be considered "low hanging fruit" on the way towards net-zero carbon emissions. They include optimising flight efficiency (e.g. flying more fuel-efficient trajectories), introducing specific operational measures to reduce fuel burn (e.g. reduce holding and taxi times), energy efficiency standards (but with a limited range) and minimising fuel burn in aircraft operations in all phases of flight (e.g. through better aircraft weight management and optimising fuel management practices). In the medium term, input from SESAR 3 (2021–2031) and the Digital European Sky will help to deliver these benefits. While ATM primarily impacts the "tank to wake" phase of aviation fuel usage, it's important to recognise that any sustainable or conventional aviation fuel (SAF or CAF) saved during this phase reduces the need for production, thereby benefiting the "well to tank" segment as well. Therefore, ATM's energy efficiency efforts have a broader indirect impact that extends beyond the direct advantages in the "tank to wake" segment.

4.4 Sustainable Aviation Fuels

Sustainable aviation fuels (SAF) are one of the most promising pathways to aviation decarbonisation. Unlike other pathways, SAF, being a 'drop-in' type of fuel, can be used without changes to aircraft and airport infrastructure and can be at the leading edge of how we travel for all distances (short to long-haul). Today's aircraft are 50% SAF-certified, and will be 100% SAF-certified by 2030, according to manufacturers.

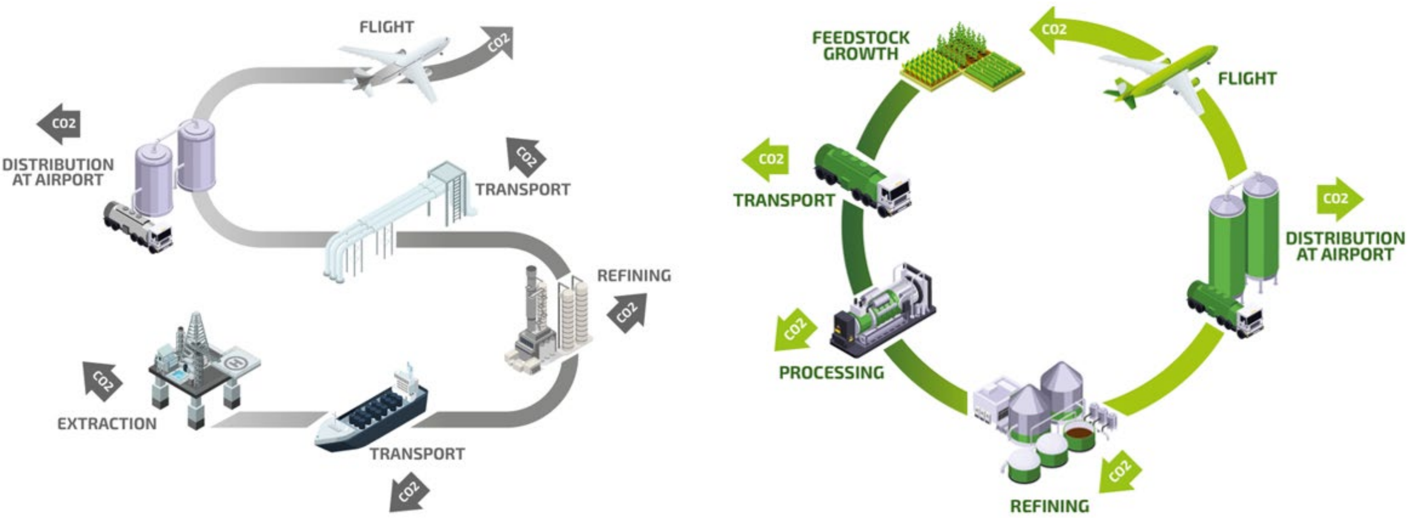
As shown on Figure 24, the lifecycle of fuel emissions is usually assessed in two stages: "well to tank" (covering production to delivery) and "tank to wake" (covering combustion). The complete lifecycle, encompassing both stages, is known as "well to wake".

Figure 24. Lifecycle of fuel emissions



Electric and hydrogen systems have the potential to be 'true zero' carbon solutions during combustion. However, their production ("well to tank") would require energy, therefore resulting in CO_2 emissions. During combustion ("tank to wake"), both CAF and SAF release the same amount of CO_2, which is 3.16 kg of CO_2 per kg of fuel burned. The key difference is that some of the CO_2 emitted during SAF combustion is previously captured from the atmosphere, either by plants or through direct air capture, and then converted into fuel during the production process ("well to tank" (see Figure 25).

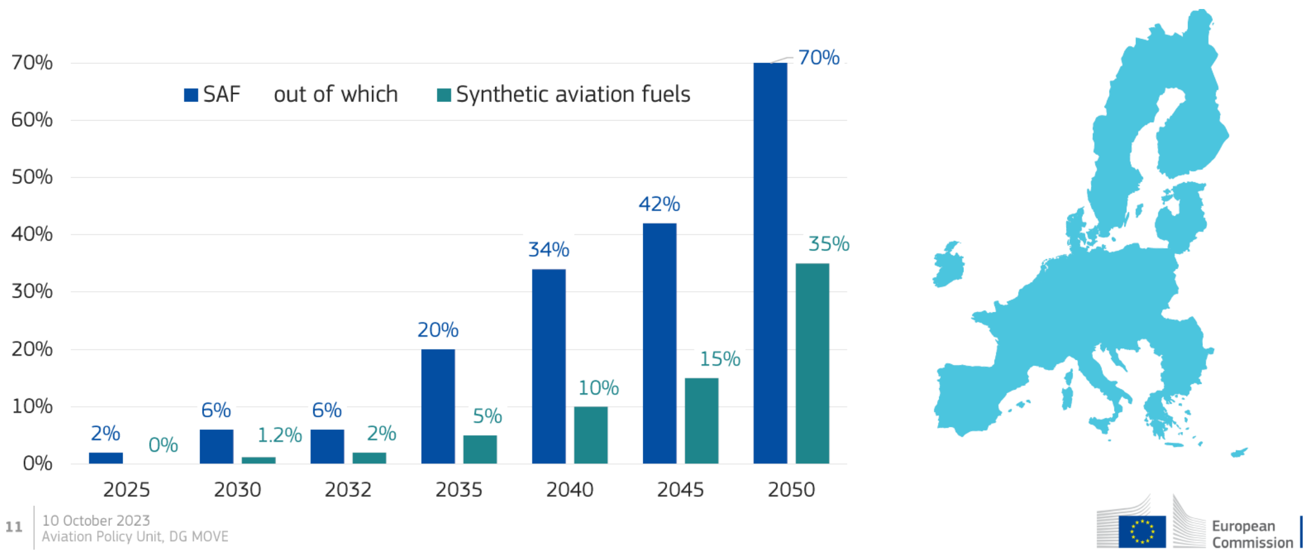
Figure 25. Carbon lifecycle diagram for conventional aviation fuel (left) and sustainable aviation fuel (right)



Considering the minimum greenhouse gas (GHG) reduction thresholds set by the Renewable Energy Directive (2018/2001/EU), bio-SAF must achieve a 50% to 65% reduction in GHG emissions over its entire lifecycle (well to wake), depending on the plant's operation start date. For synthetic SAF, the required GHG reduction is 70% throughout its entire lifecycle, compared to the current lifecycle emissions of conventional aviation fuels (CAF). A value of 70% for e-SAF and a 65% bio-SAF reduction compared to fossil-based aviation fuel were used in our parameters.

The faster that production and use are scaled up, the faster aviation will be able to decarbonise. In this context, the “Fit for 55” climate package, integrating the ReFuelEU Aviation Regulation, is an instrumental booster for the uptake of SAF. This outlook considers that the EC’s mandates, i.e. a blending obligation commencing from 2025 at 2% SAF, gradually increasing to 70% in 2050 and including a sub-obligation for synthetic aviation fuels starting in 2030 with 6% and progressively reaching 35% of fuels in 2050, will apply to the *base* and *high scenario*. Finally, the *low scenario* considers a five-year delay in the mandate execution commencing from 2% in 2030 and reaching 42% in 2050 (see Figure 26).

Figure 26. Binding shares of SAF (source: European Commission, Aviation Unit Policy, DG MOVE)



SAF costs considerably more to produce than fossil jet fuel. Due to high price pressure, a currently low demand for SAF and, although the blending mandates provide guarantees that there should be a market, there is a great deal of uncertainty surrounding SAF costs and availability. Uncertainty in terms of costs has been quantified by the use of ranges of cost for the different technology pathways considering the cost of feedstock and availability, capital investments and costs driven by the cost of green hydrogen production as well as carbon capture.

4.5 Out-of-sector measures

Out-of- sector measures ensure or incentivise the reduction of aviation emissions, either directly or indirectly. They are complementary, in that they cover the gap in areas where the targets cannot be met with other measures (such as fleet and technology and SAF measures). Market-based measures allow, or require, aircraft operators to balance some of their CO_2 emissions by paying for CO_2 savings elsewhere.

Here we describe two major measures from the latest EU legislative package known as "Fit for 55" (see Ref. ix): the EU Emissions Trading System (EU ETS) and the ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

EU Emissions Trading System (EU ETS)

The EU ETS applies to domestic and international flights operating within the European Economic Area[9] (EEA). The revision of the EU ETS Directive defines the ETS and CORSIA implementation mechanisms under the umbrella of the EU Green Deal reduction in greenhouse gas emissions by 2030. The EU ETS sets a cap on emissions from aircraft operators flying within the EEA and departing to Switzerland and the United Kingdom. The aviation cap is calculated bottom-up: allowances allocated for free represent 82% of the aviation cap, 3% of the aviation cap is set aside for the special reserve of new entrants and 15% of the aviation cap is auctioned. The cap is reduced annually in line with the EU's climate target. From 2021, the revised Directive applies a linear reduction factor to the aviation cap from 2.2% to 4.3% for the period from 2024 to 2027, and 4.4% from 2028, and defines a reduction of the free allocation to aircraft operators by 25% in 2024 and by 50% 2025, moving to full auctioning for the sector by 2026.

With regard to ETS-financed support for uplifting eligible alternative aviation fuels, 20 million ETS allowances (EUR 1.6 billion at an allowance price of EUR 80) have been reserved to cover some, or all, of the price gap between conventional fossil fuels and eligible alternative aviation fuels uplifted from January 2024.

Levels of support can go up to 100% of the price difference for eligible fuel uplifted at small islands, small airports, and outermost regions. For uplift at other airports, renewable fuels of non-biological origin will receive a level of support of 95%, while it will be 70% for advanced biofuels and 50% for other fuels of non-fossil origin included in the scope of ReFuelEU Aviation. Only fuels used on flights covered by an ETS compliance obligation will be supported.

Eligible SAF under ETS are considered "zero-rated" fuel and are therefore exempt from ETS allowances. The 2023 revision of the EU ETS aviation rules extended the restriction of the EU ETS geographical scope until the start of 2027. After this date, departing flights from the EEA to States not implementing ICAO's CORSIA scheme would be included in the EU ETS. This is an incentive for third countries to apply the CORSIA scheme.

[9] The EEA includes EU27 countries and Iceland, Liechtenstein and Norway.

CORSIA

ICAO's CORSIA scheme aims to stabilise CO_2 emissions at 2019 levels. It applies from 2019 until 2035, with reporting-only in 2019 and 2020, and from 2021 offsetting of emissions above the baseline (a new CORSIA baseline from 2024 onward was defined at 85% of the CO_2 emissions level in 2019). It covers international civil aviation emissions between ICAO Member States (excluding domestic flights). The revised EU ETS Directive exempts EEA airlines from CORSIA offsetting requirements where ETS applies.

In the forecast, we model estimates of the carbon allowances' costs (Section 4.5) together with SAF prices (Section 4.4) and jet fuel prices to get estimates of the future total impact of fuel-related prices.

In October 2022, during the 41st ICAO Assembly, ICAO Member States adopted a collective long-term global aspirational goal (LTAG) of net-zero carbon emissions by 2050.

Annexes

A. Input assumptions

To structure the uncertainty surrounding the possible outlook in the long term, some scenarios have been defined, with qualitatively different representations of the many possible futures. Each scenario follows a specific path of events and developments that then drives the flight forecast.

These scenarios are characterised by specific assumptions expressed in the figures. The scenarios have been inherited from the previous EUROCONTROL Aviation Outlook (see Ref. i) and are reproduced in Figure 28.

The changes in assumptions from the previous edition are highlighted in orange (the remaining assumptions were left unchanged from the previous publication). The following information should be noted in particular:

- There are now fewer high-speed train connections: for example, there have been plan cancellations between 2022 and 2024 (and a few additional plans too). There are now 32 high-speed train line projects (vs 56 projects in 2022). In particular, the following projects were removed: the Stockholm-Kalmar project, and various projects in the United Kingdom. Night train assumptions have been kept unchanged.

- The impact of the price of (conventional and sustainable) fuel and CO_2 allowances on ticket prices have been reworked compared to the previous edition:

    - Conventional jet fuel prices (expressed in EUR/tonne) are based on the different scenarios of the International Energy Outlook 2023 (U.S. Energy Information Administration, EIA);

    - Sustainable aviation fuel prices are derived from different documents published by Ricardo, *la Fédération Nationale de l'Aviation et de ses Métiers* (FNAM), the French Senate, and McKinsey;

    - CO_2 emission allowances are derived from a range of forecast studies from S&P, PWC, EnerData, and Bloomberg.

  The future SAF and CO_2 allowances prices are higher than in the previous edition.

- The future fleet forecast has been fully reviewed compared to the previous edition (see Ref. i). This input is based on a CIRIUM fleet forecast together with the Clean Aviation Joint Undertaking based on Clean Sky 2 new aircraft concepts and EUROCONTROL assumptions.

- The airport capacity dataset has been updated based on the latest data from the EUROCONTROL Airport Corner[5]. Out of the 92 airports considered in the previous edition (see Ref. i), 4 airports have been removed (no more data) and 7 airports have been added. Some of the airports' capacity has been revised downwards after the COVID-19 pandemic or owing to environmental reasons (noise). Overall, and when compared with the previous forecast, 51 airports have seen their maximum capacity revised downwards, 11 have seen an increase and 36 remained unchanged. One airport has a mix of decreased and increased limits over the horizon.

Figure 27. Airports having a maximum capacity value

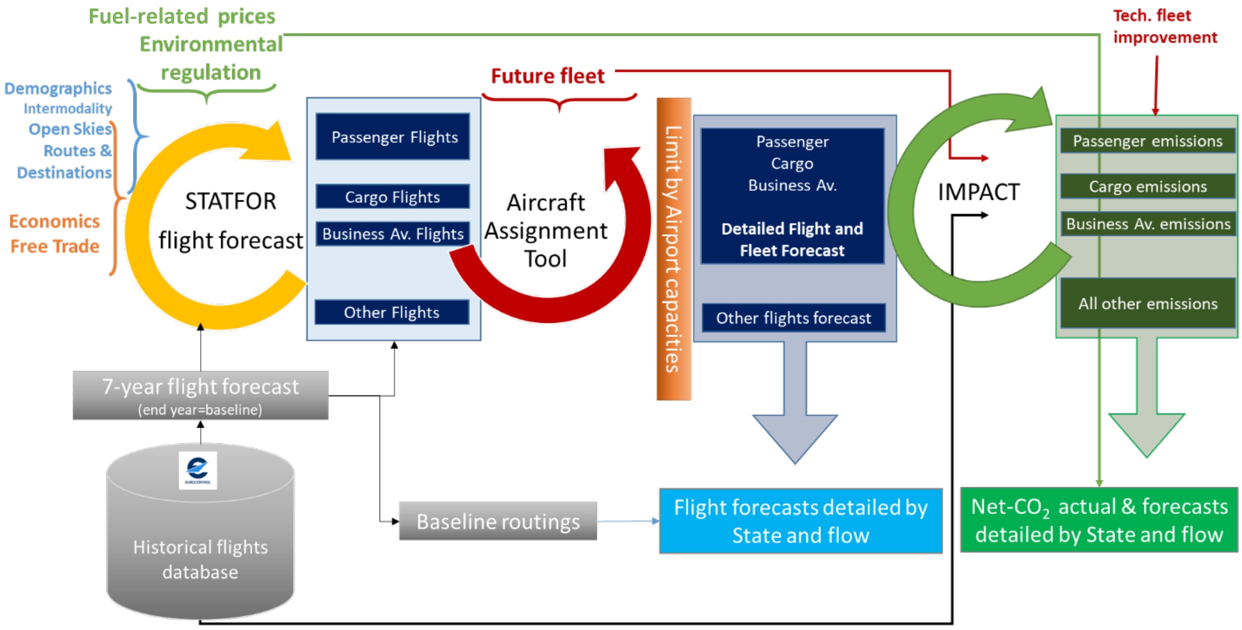
Figure 28. Summary of the input assumptions per scenario

Scenario	High	Base	Low
7-year flight forecast 2024-2030 (baseline)	High ↗	Base →	Low ↘
Passenger			
Demographics (Population)	Aging UN Medium-fertility variant	Aging UN Medium-fertility variant	Aging UN Zero-migration variant
Routes and Destinations (summary)	Less short-haul (due to HST and NIGHT trains) but non drop-in fuel short-haul a/c (H2, electric)(on-time)	Maintained short-haul (HST delayed 2 years and lower impact of NIGHT trains), non drop-in fuel short-haul a/c (behind schedule).	More short-haul (HST delayed 5 years, no NIGHT trains), non drop-in fuel short-haul a/c but supply is insufficient (batteries, …) and becomes a limiting factor ("late")
Touristic flows	Long-haul ↗	No Change →	Long-haul ↘ (price is high) except N.Atlantic
High-speed train (HST) and night connections (NIT) (new & improved connections)	32 HST between city-pairs, *implementation as planned.* 29 NIGHT links between city-pairs, *implementation as planned (or shortest*	31 HST between city-pairs, *implementation slightly behind plans (+2yr)* . 29 NIGHT links between city-pairs, *implementation as planned.*	26 HST city-pairs *implementation behind plans (+5yr)* . No NIGHT links.
Economic conditions			
GDP growth	Stronger ↗	Moderate → (baseline OE)	Weaker ↘↘
Free Trade	Global	Global	No additional benefits
Price of travel (2025/2050)			
Price of CO_2 allowances (€/t)	Moderate (80€/369€)	Moderate (80€/369€)	Moderate (80€/369€)
Price of conventional fuel (€/t)	Low (720€/834€)	Moderate (715€/819€)	High (1.408€/1.554€)
Price of Sustainable Aviation Fuel (€/t)	Moderate (1.897€/1.720€)	Moderate (1.897€/1.720€)	High (2.537€/2.406€)
(airline) operating cost	Decreasing ↘↘	Decreasing ↘	Increasing ↗
Structure Network			
Long Haul, Medium Haul, Short Haul	Hubs: Europe (major hubs)↘, Türkiye↗ Middle-East ↗↗ Point-to-Point: N. Atlantic ↘	Hubs: Middle-East ↗↗ Europe&Türkiye ↗ Point-to-Point: N. Atlantic ↗, European secondary airports ↗ N. Atlantic (major European hubs) ↘	No change →
Market Structure			
Growth and replacement	Assumptions based on EUROCONTROL analysis, CIRIUM fleet forecast and Clean Aviation Joint Undertaking for Passenger/Cargo/Business Aviation market segments.		
(new) Passenger evolutionary a/c	3 Turboprop, 2 Regional Jets, 12 Narrowbodies, 9 Widebodies		
(new) Passenger **revolutionary** a/c	3 Turboprop Hybrid-electric 9/19/35 seats + (2 Turboprop + 1 Narrowbody) Hydrogen		
Entry into service	As announced (earliest)	5 years later	10 years later
(new) Cargo evolutionary a/c	4 new-built (A330 neo, B787, A350, B77X) + 6 P2F conversions (B787, A320 Neo, B737 Max, E190/E195, B777)		
Entry into service	As announced	As announced	As announced
(new) BusinessJet evolutionary a/c	23 new-built a/c, evolutions of existing programmes, with expected gains in performance and efficiency.		
(new) BusinessJet **revolutionary** a/c	1 Turboprop Hybrid-electric 9 seats		
Entry into service	As announced	As announced	As announced
Retirement	Retirement curves varied by market segment classes, derived from historical trends over the past 50 years.		
Availability of SAF			
Fuel mix	inline with "fit for 55" 2% SAF - 98% CAF by 2025 6% SAF* - 94% CAF by 2030 34% SAF* - 66% CAF by 2040 70% SAF* - 30% CAF by 2050 *includes synthetic SAF.	inline with "fit for 55" 2% SAF* - 98% CAF by 2025 6% SAF* - 94% CAF by 2030 34% SAF* - 66% CAF by 2040 70% SAF* - 30% CAF by 2050 *includes synthetic SAF.	5 years behind "fit for 55" 2% SAF- 98% CAF by 2030 20% SAF* - 80% CAF by 2040 42% SAF* - 58% CAF by 2050 *includes synthetic SAF.

B. Methodology

The EUROCONTROL Long-Term Aviation Outlook uses a method relying on a model of economic and industry developments to grow airport-pair demand from the seven-year flight forecast for the 2024-2030 (see Ref. iii) period further into the future. An aircraft fleet forecast, in line with the initial flight forecast, is modelled for the main market segments using the Aircraft Assignment Tool (AAT). A final flight forecast is then derived, adjusted to take account of the effects of future airport capacity constraints. The flight forecast is then used by the IMPACT environmental modelling tool to forecast fuel burn and CO_2 emissions (Figure 29).

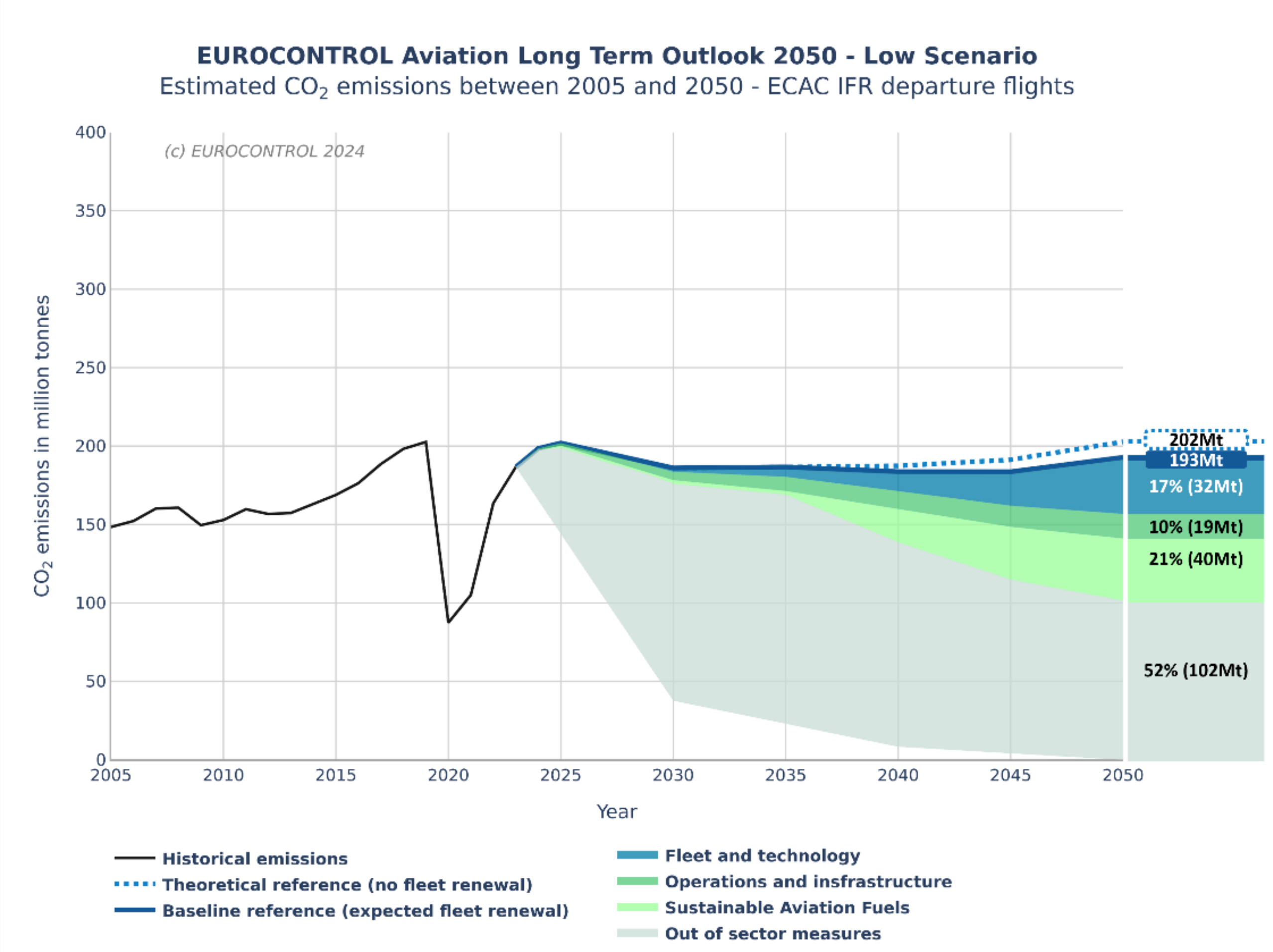
Figure 29. The long-term flight forecast feeds the fleet forecasting tool (AAT), which is handed over to the emission modelling tool (IMPACT)



AAT is a fleet and operations forecasting model jointly developed by the European Commission, EASA and EUROCONTROL. AAT converts a passenger and flight demand forecast into detailed operations by aircraft type and airport pair for a given future year and scenario, taking into account aircraft retirement and the introduction of new aircraft into the fleet. As shown in Figure 29, it is an integral part of the STATFOR long-term forecast methodology.

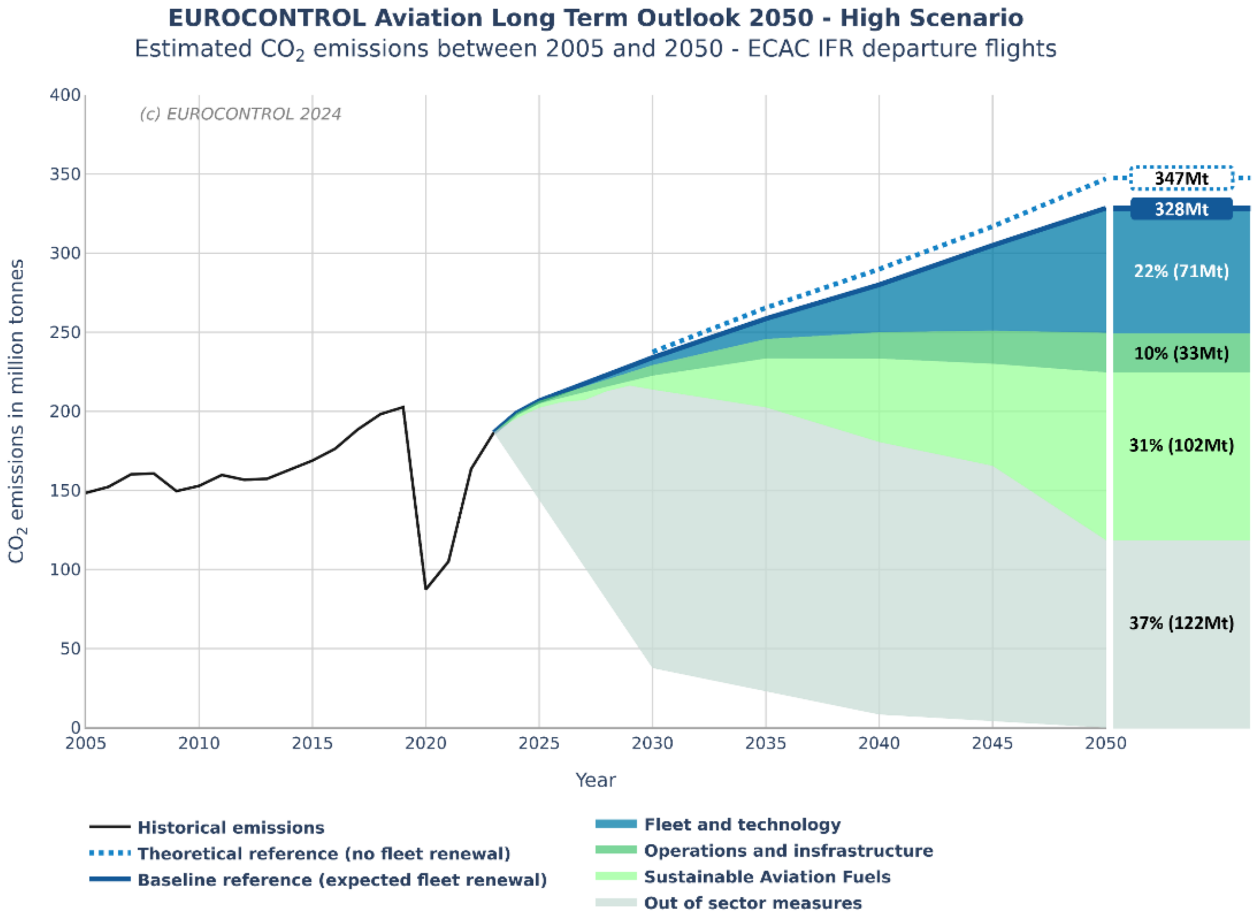
C. CO_2 emissions for the *low* and *high scenarios*

Figure 30. CO_2 emissions timeline for the *low scenario*



The *low scenario* has the fewest flights in 2050. Net CO_2 is reduced, around 32% lower than in 2005, down to 102 million tonnes in 2050. Less SAF is available (21% or 40 million tonnes in savings), and it is more expensive due to demand from other sectors. Higher ticket prices have reduced demand and there is less scope for radical re-shaping of the fleet (17% or 32 million tonnes in savings).

Figure 31. CO_2 emissions timeline for the *high scenario*



The *high scenario* has more than twice as many flights in 2050 than in 2005, but net CO_2 is significantly reduced by around 20% compared to 2005 volumes (119 million tonnes of net CO_2 emitted in 2050). In addition to widespread use of SAF (32% or 106 million tonnes in savings), this scenario sees wider and earlier adoption of new aircraft types (up to 71 million tonnes in savings in 2050 compared to the use of the 2023 fleet), although even then, by 2050, the changes to the fleet are only partly revolutionary and partly evolutionary.

i EUROCONTROL Aviation Outlook 2050, EUROCONTROL, April 2022 (link, accessed on 08/11/2024).
ii Airport Traffic Report, September & Q3 2024, ACI Europe, October 2024 (link accessed on 11/11/2024).
iii EUROCONTROL Seven-Year Forecast 2024-2030, Spring 2024 Update, EUROCONTROL, February 2024 (link accessed on 11/11/2024).
iv European Aviation in 2040, Challenges of Growth, EUROCONTROL, June 2018 (link accessed on 15/11/2024).
v Airport Traffic Report ACI Europe December 2023, Q4 2023 Full Year 2023, ACI, February 2024 (link to press release accessed on 13/11/2024).
vi EUROCONTROL Think Paper #11 – Plane and train: getting the balance right, EUROCONTROL, 2021 (link accessed 11/11/2024).
vii EUROCONTROL Data Snapshot #4 on CO_2 emissions by flight distance, EUROCONTROL, February 2021 (link accessed on 13/11/2024).
viii Decarbonising long-haul flights by 2050: Is there a pathway through sustainable aviation fuel use, fleet renewal and green energy upscaling? EUROCONTROL, October 2024 (link accessed on 13/11/2024).
ix Regulation (EU) 2023/2405 of the European Parliament and of the Council of 18 October 2023 on ensuring a level playing field for sustainable air transport (link accessed on 13/11/2024).

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