BRIEFING - JUNE 2025

The aviation industry and the stall in aircraft innovation

Between broken promises and big opportunities

Summary

Decarbonising aviation requires a sector-wide approach – from measures to address the industry's continuing growth, to ensuring that truly sustainable aviation fuels (SAFs) are prioritised. **Aircraft technology** also has a key role to play, but the onus so far has been on airlines and energy providers, with plane manufacturers largely left off the hook.

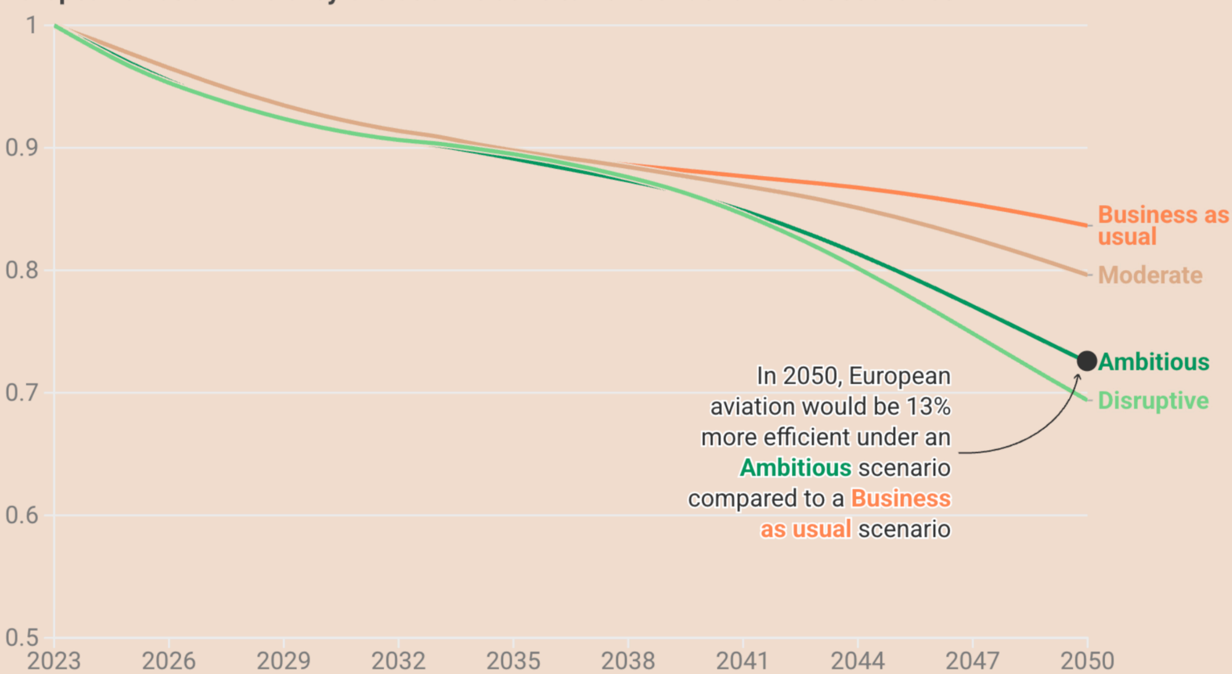
While manufacturers have been quick to highlight their contribution to aviation's green transition – producing more efficient aircraft – the majority of these new models are re-engined versions of existing planes. The most innovative projects from the world's leading aircraft original equipment manufacturers (OEMs), Airbus and Boeing, are either delayed or paused.

This suggests a clear decline in aircraft technology innovation over the past decade. It appears that this trend is set to continue, with no new aircraft models expected from Airbus or Boeing in the next ten years either. At a time when we need aviation to significantly increase its efficiency and reduce its energy use and emissions, these delays in innovative aircraft technologies are hampering the industry's green transition.

New, innovative planes can make European aviation more efficient by 2050 and beyond

However, efficiency improvements expected to stall in the next decade due to lack of new planes in coming years

European aviation efficiency evolution relative to 2023 under different scenarios



Source: T&E, Boeing Cascade, PH Shift

The root causes are clear: a lack of market competition, and no effective policies pushing manufacturers to innovate. For aircraft technology to have the chance to make a dent in emissions and energy consumption by 2050, this briefing highlights the need for strong policies to **spark the truly radical innovations that the aviation sector needs**.

Our modelling suggests that **European aviation could be up to 13% more efficient by 2050** in an ambitious yet achievable innovation scenario – saving enough renewable electricity to power 27 million heat pumps. This scenario assumes that cleaner, more advanced technology, including zero-emission aircraft, will be developed and widely used, following expert forecasts. If manufacturers went even further, efficiency gains could increase to 17%. This shows that aircraft technology can provide a significant contribution towards meeting the EU's aviation climate goals in 2050 and beyond.

To unlock aircraft technology's full decarbonisation potential, **T&E makes the following recommendations:**

- Strengthen the "polluter pays" principle, including an extension of the EU Emissions Trading System (ETS) to cover all flights departing Europe, and jet fuel taxation through the Energy Taxation Directive (ETD), to bridge the price gap between current polluting aircraft and future green technologies.
- Set and implement robust aircraft CO_2 standards, either at international or European level, to incentivise the production and design of new, more efficient aircraft models.
- Maintain and diversify EU support to aircraft research and development, including instruments for innovative companies developing disruptive technologies, such as zero-emission aircraft and infrastructure, to help them enter the market.
- Update relevant EU aviation legislation, including airport legislation and public service obligation (PSO) routes under the Air Services Regulation, to favour the use of latest generation and zero-emission aircraft.

1. The role of aircraft efficiency in aviation's green transition

Aviation is one of the most emission-intensive modes of transport, and an industry that is projected to keep on growing significantly. Decarbonising this sector requires attention from all angles – from measures to address the industry's unsustainable growth, to ensuring that the right kinds of sustainable aviation fuels (SAFs) are prioritised across legislation and financing mechanisms. Within this context, aircraft technology also has an essential role to play in reducing the emissions and energy use from the sector.

Over the past decades, new aircraft designs have resulted in greater efficiency, helping to reduce fuel consumption and carbon emissions per passenger – albeit driven by commercial pressure to deliver planes that are cheaper to operate, rather than by environmental concerns.

These gains, however, have been increasingly marginal and largely outpaced by growth in air traffic, with aviation emissions increasing faster than any other transport sector in Europe since 1990. After the COVID setback, recent T&E analysis showed that air traffic and emissions have almost bounced back to 2019 levels, with flights within Europe even exceeding these in 2024.

Looking ahead, new technologies could help bring about greater efficiency gains. On the one hand, improvements in aerodynamics and propulsion systems, and weight reductions, can increase the tank to wing (TTW) efficiency, reducing the energy consumption of the aircraft. On the other hand, zero-emission (ZE) propulsive technologies can make direct use of electricity and hydrogen, increasing the well to tank (WTT) efficiency, and lowering the amount of renewable electricity and other energy sources required to decarbonise aviation. This briefing shows that in both TTW and WTT efficiency, radical disruption - rather than small-step changes - will be needed to make a dent in the emissions reduction of the sector.

The above-mentioned technologies will play an essential role in meeting aviation's climate goals, especially under the EU's SAF mandate, ReFuelEU, which sets blend targets that the sector will need to meet up to 2050. Since the supply of truly sustainable feedstocks for bio-based SAF is limited, lower energy demand from aviation will minimise the risk of unsustainable SAFs flooding the market, which can increase aviation emissions. E-fuels from renewable hydrogen and captured CO_2, on the other hand, are green and scalable, but energy-intensive. Working to reduce aircraft fuel consumption altogether could help meet the synthetic fuels sub-target under ReFuelEU and the sector's wider decarbonisation goals.

1.1 Commercial aircraft innovation is on the decline

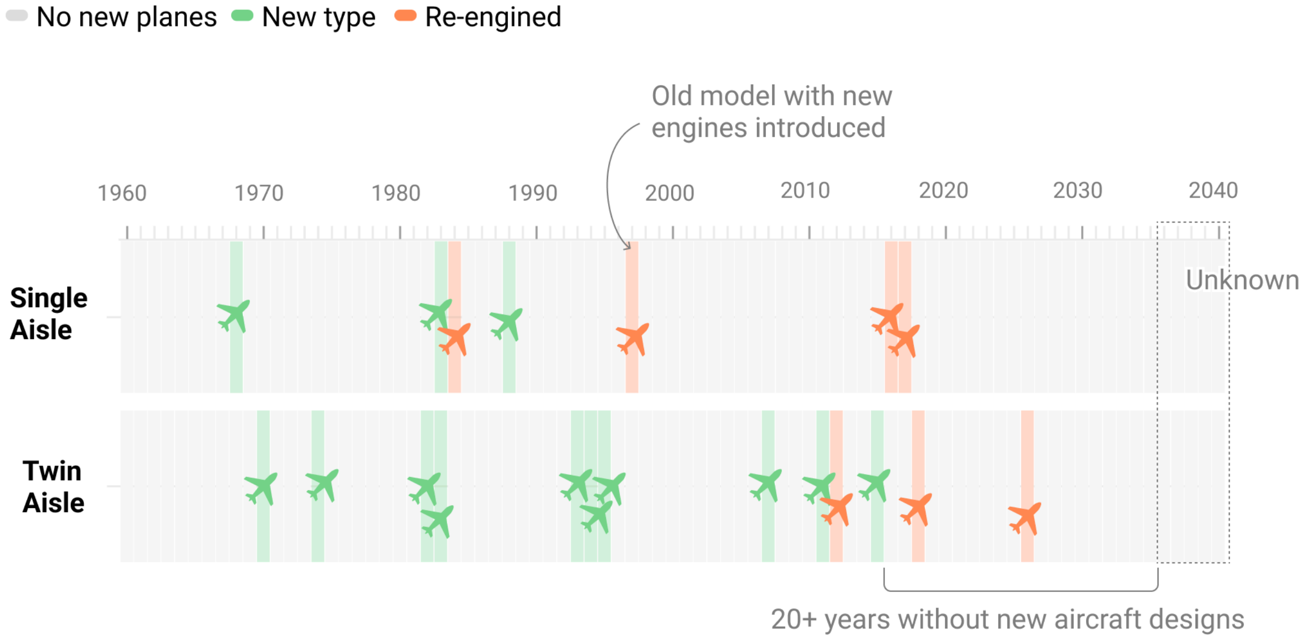
Over the past ten years, we have seen far fewer new aircraft models entering the market. This trend appears to be set to continue, especially on the narrowbody and widebody markets, which are dominated by the two global giants: Airbus and Boeing. The last time either of these companies – whose aircraft will be responsible for an estimated 95% of the existing in-service fleet's CO_2 emissions — introduced a new, clean sheet design aircraft to the market was in 2015. Since then, their efforts have gone into re-engining existing airframes, such as Airbus' A320neo and A330neo, and Boeing's 737MAX and 777X.

While there has been talk of new, far more innovative technology – such as Airbus' ZEROe programme and its hydrogen aircraft, and Boeing's Transonic Truss-Braced Wing concept – these have yet to see the light of day, having either been delayed or paused. With no new aircraft designs in sight from the European or US manufacturers, the decline in commercial aircraft innovation appears set to continue for at least another decade.

Rather than bringing new models to market, aircraft manufacturers have focused on fitting new engines into existing models. These re-engined planes are based on existing airframes, some dating back to the 1980s – in the case of Airbus' A320 family – and to the 1960s when it comes to the Boeing 737 family. Although these re-engined planes are more efficient than the models they replaced, they have lower efficiency gains than what would be achieved through a new, clean sheet design using the latest advancements in aerodynamics and new materials.

Fewer new aircraft models are entering the market

An unprecedented 20+ year period without new aircraft designs from Airbus and Boeing is expected



Source: Airbus, Boeing, industry information

2. The aviation ecosystem does not foster innovation

While a myriad of factors can explain the current stagnation in aircraft technology innovation, two stand out as key drivers: **market dynamics** and **the absence of effective policies.**

2.1 Aircraft manufacturing is dominated by a duopoly

The world's two biggest aircraft manufacturers, Boeing and Airbus, dominate the aircraft design and manufacturing market.

Short haul aircraft (between 100 and 200 passengers, less than 6,000 km) are largely provided by the Airbus A320 and the Boeing 737 families. Other companies, such as Embraer and COMAC, currently capture less than 5% of the market, but COMAC is projected to grow its share. When it comes to the long haul market (200+ passengers, 6,000+ km), Airbus and Boeing are the sole providers, with the Airbus A330 and A350 families, and the Boeing 777 and 787.

While there is a clear duopoly at play, Boeing appears to be in the midst of financial turbulence. The US giant recently experienced safety and labour issues which have resulted in it reporting losses between 2019 and 2024. This has limited Boeing's capacity to innovate, with research and development (R&D[1]) expenditures taking a hit, especially in the years 2020 and 2021. Despite this, the company's backlog reached more than $520 billion (€455 billion) in 2024, including $435 billion (€381 billion) from more than 5,600 orders for commercial planes.

Boeing's financial woes, combined with its product portfolio, mean Airbus has comfortably stepped into the role of the leader of the commercial aircraft market. However, when analysing Airbus' financial results, it appears that it is not using its privileged market position to boost innovation – according to its annual reporting, Airbus R&D expenditure has flatlined in the last decade to around €3 billion and 5% in revenues. On the other hand, its dividend payouts soared during the same period, increasing from €500 million in 2012 to €2.38 billion in 2024, and profit margins close to 10% in recent years. 2024 also saw a substantial 12.5% increase in the company's backlog from 2023, totalling €628 billion, with commercial aircraft representing €558 billion - 89% of the total - with more than 8,600 orders.

This lack of competition in the aircraft market disincentivises the creation of new, disruptive aircraft, favouring instead the development of incremental improvements in existing models.

2.2 No effective policy to drive aircraft innovation

Policy measures to date have not been enough to incentivise aircraft manufacturers to deploy cleaner and more cutting-edge technology.

Poor application of the **"polluter pays" principle** for aviation still makes it relatively inexpensive to operate a plane using cheap, highly polluting fossil jet fuel. Prior T&E analysis has shown that a more effective application of relevant policies, such as carbon pricing and jet fuel taxation, would reduce the price gap between technologies such as hydrogen aircraft, and old, fossil-powered planes. This would accelerate the transition towards cleaner aircraft.

Similarly, aircraft **CO_2 standards** are widely regarded as a policy lever to help drive the design and uptake of more efficient aircraft. However, the existing standards, recommended in 2016 by the International Civil Aviation Organization (ICAO), fell behind the newest developments in aircraft technology at the time, as recognised by aviation regulators, and are comfortably met by current planes, not driving further innovation in aircraft design or production.

ICAO's Committee for Aviation Environmental Protection (CAEP) recently recommended that these standards be updated. However, while they are more stringent, these new standards still fall well short of pushing manufacturers to innovate faster. For instance, the Boeing 737 MAX 8, a plane designed in the 1960s and upgraded with a 2010s engine, may still comply with the in-production standard applicable from 2035 onwards[2].

[1] R&D figures for Airbus and Boeing are company-wide, including commercial aviation and other divisions.
[2] Based on preliminary analysis by the ICCT.

These weak CO_2 standards have also led to lax criteria for green investments in the **EU Taxonomy**. As most of the planes currently on the market, including the majority of the Airbus aircraft portfolio, meet the existing CO_2 criterion for transitional activities, neither investors nor manufacturers have a strong incentive to accelerate the shift to more efficient aircraft designs.

Lastly, there are currently no policies to support or mandate the use of disruptive technologies, particularly zero-emission (ZE) aircraft. Policies that ban fossil fuel use on some routes, or provide preferential access to airports, would help build early markets for ZE planes and other green tech, to prove their commercial viability ahead of their wider adoption.

European research funding for aviation is not backed by policy

Programmes like Clean Aviation, a €4 billion public private partnership partly funded by the European Commission under Horizon Europe, play a central role in supporting the European aviation industry in its quest for aircraft innovation.

However, due to the lack of policies and market pressure, new aircraft designs, such as Airbus' hydrogen plane – which has received hundreds of millions of euros from the European Commission and the French government – keep being delayed.

To make Clean Aviation and other research programmes as effective as possible, the EU must ensure that R&D investments are accompanied by a policy framework to support the commercial development and uptake of cleaner, more efficient aircraft, and diversify investments to also support new companies aiming to enter the market.

3. True innovation is possible in aviation

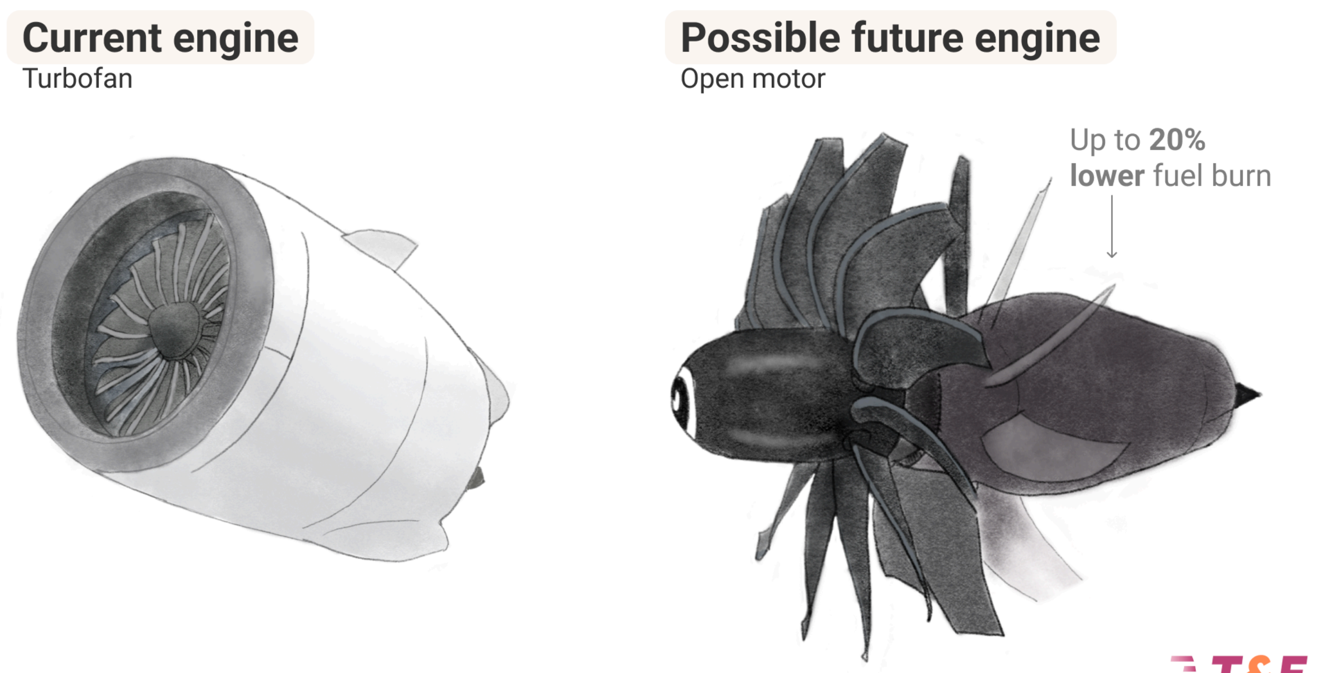
While emissions and energy use from aviation continue to increase, and the main aircraft manufacturers insist on squeezing ever-smaller gains from existing aircraft models, an array of new technologies to improve aerodynamics and propulsion systems, and to reduce weight, could support the aviation sector's green transition.

3.1 Rethinking designs and ways of flying to reduce energy use

Improving propulsion efficiency and aerodynamic performance, and reducing weight, are key levers to reduce aircraft energy use. ICAO's Committee on Aviation Environmental Protection (CAEP) commissioned an independent review of existing and future aircraft technologies, and their potential to increase efficiency. The main conclusions are outlined below.

Innovative engine configurations, such as open rotors (where fan blades are not surrounded by a casing), could improve fuel efficiency by up to 20% in the coming years, compared to the most recent generation of turbofans.

New engine architectures to improve flight efficiency



Source: CFM

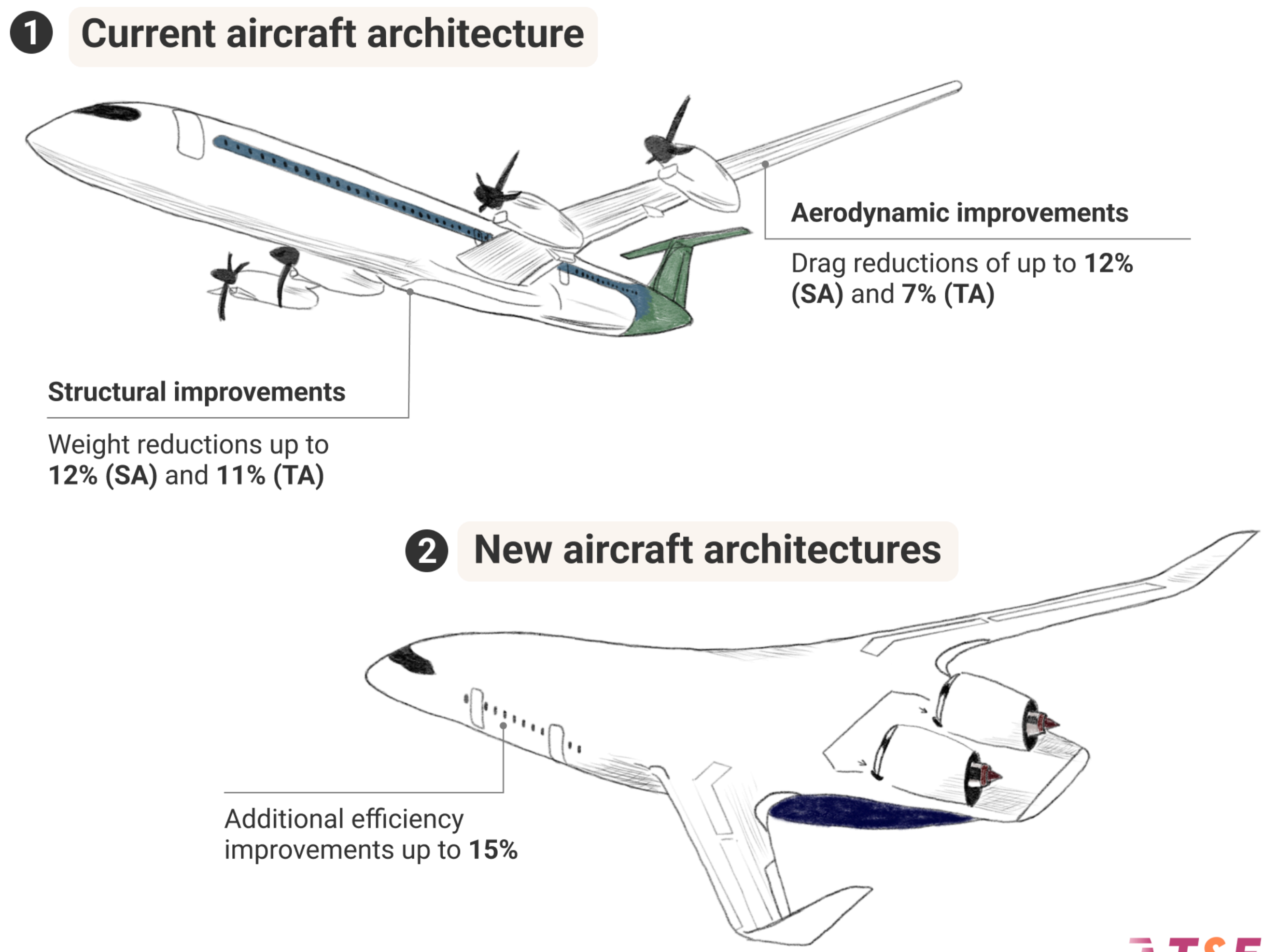
On the airframe side, a number of promising pathways could significantly reduce energy consumption by the mid 2030s, including the use of smoother surfaces to reduce drag, or advanced design and manufacturing for structures to reduce weight.

In addition to these technologies, **disruptive aircraft architectures**, which break away from the classic tube and wing configuration, have great potential for significant aerodynamics and structural improvements, reducing fuel burn per passenger kilometer by a further 5 to 15%. These novel designs include the blended wing body, where the aircraft's fuselage also contributes to lift generation, and the truss-braced wing concept, with thinner, more efficient wings supported by structural reinforcements.

Lastly, **changes to the performance requirements of new planes** could unlock significant improvements in efficiency. Designing new aircraft to fly 15% slower could reduce fuel burn by up to 7%, while only increasing flight time on a transatlantic flight by about 50 minutes. Introducing new aircraft variants optimised for different ranges could also reduce fuel burn by up to 7%. This would allow more planes to fly closer to their ideal design ranges. This is not the case today, where fleet harmonisation has led to a "one size fits all" approach, with the same aircraft model sometimes covering an airline's entire network, ranging from routes under 200 km to more than 4,700 km. These changes could impact the way flight networks are currently designed, but are technically viable, would bring efficiency gains and need further development.

Potential of future technologies to improve flight efficiency

Estimated improvements on Single Aisle (SA) and Twin Aisle (TA) aircraft by 2037



Source: ICAO CAEP, DLR, Jet Zero

3.2 Zero-emission technologies: a more efficient decarbonisation pathway

The traditional propulsion systems of commercial planes consist of jet fuel-powered turbines. A crucial decarbonisation lever is the production of sustainable aviation fuel (SAF), which can be used in these propulsion systems. However, scaling up SAF faces a number of challenges, due to the limited availability of truly sustainable feedstocks for bio-based SAFs, and the high energy needs of synthetic kerosene.

In this context, the use of electric, hydrogen or hybrid propulsion systems may present opportunities to decarbonise flying much more efficiently.

As in road transport, electrification is an efficient pathway to power an aircraft. The direct use of green electricity removes the losses due to conversion into hydrogen or e-fuels. Moreover, the propulsive efficiency of electric engines is higher than gas turbines.

Companies such as Vaeridion or Elysian Aircraft are exploring this solution. However, battery weight limits these aircraft to ranges up to 800 km. For that reason, hybrid concepts, which combine the use of electric propulsion and jet fuel- or hydrogen-powered gas turbines, are being developed by companies like Aura Aéro or Heart Aerospace, to extend the range up to 1,600 km. These ranges are expected for the first generation of aircraft, targeted to enter into service in the late 2020s or early 2030s. Advancements in battery technology should extend the range of these electric and hybrid electric aircraft.

The direct use of hydrogen also presents advantages compared to the use of e-kerosene (which uses hydrogen indirectly as a key component of the fuel), notably higher production efficiency and it does not require carbon. Hydrogen also contains more energy per unit of weight than jet fuel, helping reduce aircraft weight.

Nonetheless, hydrogen has less energy per unit of volume than jet fuel, and may need to be accommodated in the cabin, losing space for passengers and cargo. Challenges such as distribution, liquefaction and refuelling infrastructure, and on-aircraft storage systems, must also be overcome to make hydrogen flying a reality.

All in all, hydrogen is an efficient technology to decarbonise aviation. Despite the delay of Airbus' hydrogen aircraft, other companies are still betting strongly on this technology. Zero Avia has already flown a hydrogen aircraft prototype, and intends to enter commercial operation before the end of this decade. Beyond Aero or Fokker Next Gen are among other companies currently designing hydrogen aircraft.

4. A stretch in innovation could help reach climate goals

This section analyses the potential efficiency gains of the sector if aircraft manufacturers stepped up their game and introduced more radical technologies into planes (both tank-to-wing and wing-to-tank efficiencies). Our analysis estimates the emissions and energy consumption of all flights departing Europe under different scenarios of aircraft efficiency evolution, to quantify the benefits of stepping up innovation in aircraft design.

The reference scenario, labelled as business as usual (BAU), features a continuation of current industry trends, with entry into service of new single-aisle (SA) and a re-engined twin-aisle (TA) in 2040 and 2045, respectively. The ambitious scenario assumes the development and uptake of new, more efficient models, including zero-emission aircraft, between 2030 and 2040, in line with independent expert reviews performed by the ICAO CAEP and ICCT. A moderate scenario, based on industry announcements, and a disruptive scenario, which assumes efficiency gains slightly above the more optimistic projections from the ICAO and ICCT, are also modelled.

Our analysis uses air traffic growth projections from Airbus and Boeing market forecasts, and assumes a future blend of fossil jet fuel, synthetic fuels and SAF as per the ReFuelEU mandate.

More information on the scenarios, methodology and assumptions can be found in the annex.

4.1 Aviation efficiency will stall, but greater ambition now could make a difference by 2050

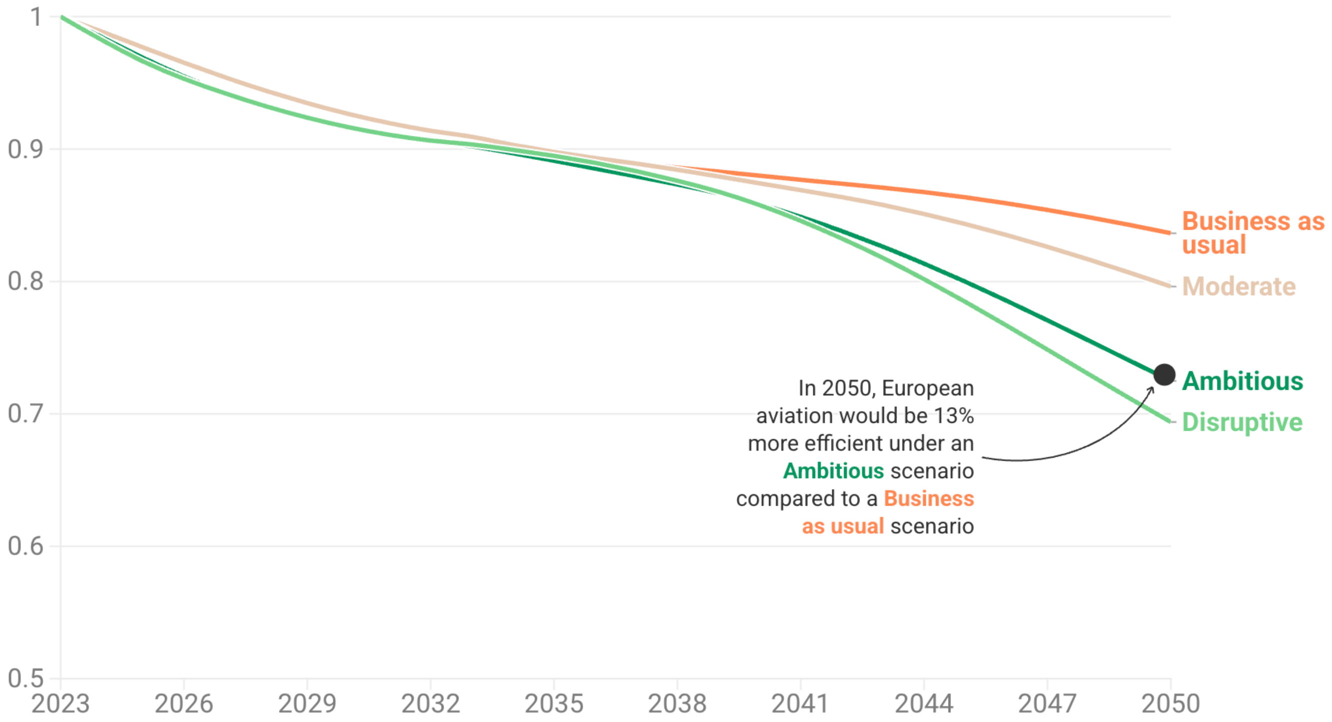
Our modelling suggests that European aviation could be **13% more efficient** in the ambitious scenario compared to the BAU reference scenario by the year 2050. The efficiency gains could increase to 17% for the disruptive scenario, while the moderate scenario would yield a 5% gain.

However, the evolution in aircraft efficiency across all four cases appears to be very similar across all scenarios until the mid 2030s. This can be explained by the lack of new aircraft designs expected to enter into service in the coming years, resulting in a stall in the efficiency improvement of the European fleet, which is very much locked in at this point. Decisive action to bring radical innovations to the market as quickly as possible is therefore crucial to ensure that improved aircraft technology can make a dent in emissions and energy consumption by 2050.

New, innovative planes can make European aviation more efficient by 2050 and beyond

However, efficiency improvements expected to stall in the next decade due to lack of new planes in coming years

European aviation efficiency evolution relative to 2023 under different scenarios



Source: T&E, Boeing Cascade, PH Shift

4.2 Cumulative emissions could be reduced by 123 Mt CO_2 by 2050

Under the ambitious scenario, efficiency improvements brought about by newer technologies are expected to have a significant positive impact in terms of reduced emissions and decreased energy use by 2050. The 13% efficiency gain on the BAU reference scenario translates into:

- A reduction of 123 million tonnes (Mt) of CO_2 emissions between 2025 and 2050, equivalent to the yearly emissions of 62 million diesel and petrol cars;
- 101 terawatt-hour (TWh) of renewable electricity saved per year to produce synthetic fuels, enough to power more than 27 million heat pumps for a year;
- A reduction of 1850 km^2 in the surface required for renewable electricity generation for synthetic fuels – the area of Madrid and Rome combined.

These results suggest that aircraft technology has significant potential to help reach aviation's climate goals, highlighting the importance of enabling policies that complement pricing mechanisms and SAF use.

13% efficiency increase reduces emissions and energy consumption by 2050

Cumulative emissions savings

123 Mt CO_2

Equivalent to yearly emissions of 63 million petrol and diesel cars

Reduction of electricity demand

101 TWh

Enough to power 27 million heat pumps

Less area for renewable energy

1,850 Km^2

Equivalent to the area of Madrid and Rome combined

Source: T&E

5. Conclusions and recommendations

Aircraft technology will play a pivotal role in helping to meet Europe's climate goals for aviation. More efficient aircraft technologies will both reduce CO_2 emissions, and minimise energy use, both of which are needed to reach the sustainable aviation fuel targets set under ReFuelEU.

However, current market dynamics, and a lack of effective policies, have removed any incentives for meaningful innovation in aircraft technology, with no new new aircraft expected from either Airbus or Boeing in a 20 year span, resulting in a stall in fleet efficiency.

To revert the decline in aircraft technology innovation and help meet the sector's climate goals, T&E recommends the following:

1 Remove unfair fossil fuel subsidies

To reduce the price gap between clean technologies, including zero-emission and more efficient aircraft, and old, fossil-powered planes, and to generate revenues to fund research, the pricing of air tickets needs to address the "true cost" of aviation's impact on our climate, in particular through the following measures:

- **Inclusion of a fossil kerosene tax in the EU Energy Taxation Directive (ETD), or equivalent measures at member state level:** the revision of this legislation – which was put forward back in 2021 – has still not eradicated the generous tax exemption aviation benefits from for the use of fossil jet fuel, despite citizens and businesses having to pay taxes for the fuel they use for their cars, homes and company buildings. This urgently needs to be fixed. Member states should approve a fuel tax for all flights departing from the EU. If this is not approved at the EU-level, member states should step in and compensate for that gap by applying similar levels of taxes for flights departing from their territory.
- **Extension of the scope of the EU Emissions Trading System (ETS) for aviation to cover all departing flights:** as much as 70% of CO_2 emissions from European aviation remained unpriced in 2024, and nearly half will still be exempt from paying under the current scheme. In contrast, the cement, chemicals and power sectors are obligated to pay for their fair share. To ensure airlines pay for the true cost of their emissions, T&E recommends that the EU ETS be extended to include all departing flights as part of the upcoming review of the legislation. This would significantly increase revenues for EU funding instruments such as the Innovation Fund, which is already supporting the development of disruptive aircraft technologies.

2 Set robust CO_2 standards to drive the design and production of more efficient aircraft

Current and future ICAO CO_2 standards for commercial aircraft may be met by most of the current aircraft fleet. Although they are expected to be updated soon, the planned changes are not expected to significantly increase the stringency, especially for in production aircraft.

For that reason, we recommend:

- **The adoption of new, ambitious CO_2 standards for new types and in-production aircraft**, to drive the design and production of more fuel efficient aircraft. They should ideally be adopted at international level but, in the absence of ambitious action from the ICAO, the EU should consider setting its own standards or similar measures, such as incentivisation of fleet replacement.
- **Stronger CO_2 criteria for aircraft manufacturing in the EU taxonomy** for transitional activities, to guide investors towards truly disruptive and zero-emission planes.

3 Maintain support of research and development of aircraft technology, and accompany new market entrants

To secure a strong aviation industry in Europe that leads the green transition of the sector, we recommend:

- **Maintaining the Clean Aviation Joint Undertaking programme in the next MFF**, diversifying the recipients of funds to include smaller, disruptive players, to strengthen European leadership in the aircraft industry.

- **Ramping up support to new entrants in the aircraft market** through proven instruments such as the European Innovation Council, the Innovation Fund or the European Investment Bank, to increase the success of new companies and foster healthy competition.

4 Update EU's aviation legislation to favour zero emissions and other green aircraft technologies

To complement the aforementioned measures, we also recommend a comprehensive review of relevant EU aviation legislation to favour more efficient and zero-emission aircraft, including:

- **Update the Airport Charges Directive and the Slots Regulation**, in particular modulating charges based on emissions, and prioritising slot access to zero-emission and more efficient planes, to benefit new, cleaner aircraft.

- **Strengthen the Air Services Regulation** to allow member states to require the use of the latest, cleanest aircraft technologies, on PSO or other routes - including the possibility of banning use of fossil fuel -, to provide a market for the early adoption of zero-emission and ultra-efficient planes.
- **Include renewable electricity for aircraft as an energy carrier to comply with the synthetic fuels sub-targets in ReFuelEU**, to incentivise the use of electric propulsion.
- **Amend existing legislation, or create new legislation, to require private flyers to use the latest, cleanest technology**, to ensure the wealthiest segment of the market supports the green transition of the sector.

Further information

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Annex

1. Fleet modelling and scenario definition

Our analysis estimates the emissions and energy consumption of all flights departing Europe under different scenarios of aircraft efficiency evolution. This section outlines the main parameters and assumptions of the model.

1.1 Fleet modelling

The model used estimates concerning the evolution of the European aviation aircraft fleet, based on several assumptions and inputs. The model is based on Boeing's Cascade, an open tool that allows simulations of future decarbonisation scenarios.

1.2 Parameters of the model

The main input parameters for the model are:

- Market segments: we assume three different segments
    - Regional aircraft, with ranges up to 1800 nautical miles (nm)
    - Single aisle, up to 4200 nm
    - Twin aisle, up to 9200 nm
- Characteristics of new aircraft designs: for each segment, the model can simulate the impact on efficiency of the introduction of new aircraft designs, defined by
    - Year of entry into service (EIS)
    - Efficiency gains compared to latest generation aircraft
        - ATR 72 for regional aircraft
        - A320neo for single aisle aircraft
        - A350 for twin aisle aircraft
- The age after which planes are retired from service and replaced by new ones

1.3 Scenario assumptions

The analysis simulates four different scenarios, based on possible trends from the industry and experts review of existing and future aircraft technology. The main assumptions for each of the four scenarios are gathered below.

1.3.1 Business as usual (BAU) scenario

The business as usual scenario is modelled to follow the current trend of incremental technology improvements in the coming decades. For each market segment, we assume the following:

- Regional jet: EIS of a re-engined aircraft by 2037, with an efficiency increase of 15% - slightly below industry announcements[3]
- Single aisle: EIS of a new aircraft by 2040, with an efficiency increase of 20% - in the lower bound of recent industry announcements[4]
- Twin aisle: EIS of a re-engined aircraft by 2045, with an efficiency increase of 15%
- Fleet renewal age of 25 years

All aircraft referred to above are jet fuel-powered. No fully electric or hydrogen aircraft in any of the segments is assumed in this scenario.

1.3.2 Moderate scenario

The moderate scenario assumes that recent industry announcements for the next decade will be fulfilled. For each market segment, we assume the following:

- Regional jet: EIS of a re-engined aircraft by 2035, with an efficiency increase of 20% - as per industry announcements
- Single aisle: EIS of a new aircraft by 2038, with an efficiency increase of 30% - in the upper bound of recent industry announcements
- Twin aisle: EIS of a re-engined aircraft by 2043, with an efficiency increase of 20%
- Fleet renewal age of 25 years

All aircraft referred to above are jet fuel-powered. No fully electric or hydrogen aircraft in any of the segments is assumed in this scenario.

1.3.3 Ambitious scenario

The ambitious scenario is modelled assuming the wide adoption of the propulsive and aerodynamic improvements, and weight reduction technologies, described in ICAO CAEP's independent expert review. For each market segment, we assume the following:

- Regional jet: EIS of different aircraft
    - A new jet fuel-powered aircraft by 2030, with an efficiency increase of 25%

[3] ATR has planned the launch of the ATR EVO, a hybrid-electric regional aircraft expected to deliver efficiency gains of 20% versus current generation of aircraft. The expected entry into service was recently delayed from 2030 to "around 2035"
[4] Airbus recently announced the intention to launch of a new single aisle aircraft, with an expected fuel efficiency gain between 20% and 30%, to enter into service by the second half of the 2030s

    - A hydrogen aircraft by 2030, with an efficiency increase of 20%[5]
    - A new electric aircraft by 2030, with an efficiency increase of 20%[6]
- Single aisle: EIS of different aircraft
    - A new jet-fuel powered aircraft by 2035, with an efficiency increase of 35%
    - A hydrogen aircraft by 2040, with a 25% efficiency increase
- Twin aisle: EIS of a new jet fuel-powered aircraft design by 2040, with an efficiency increase of 25%
- Fleet renewal age of 20 years, spurred by policies that incentivise the use of more efficient planes

1.3.4 Disruptive scenario

The ambitious scenario is modelled assuming the wide adoption of the propulsive and aerodynamic improvements, and weight reduction technologies, described in ICAO CAEP's independent expert review, plus the application of disruptive architectures and new performance requirements, such as optimised ranges and/or reduced speeds. For each market segment, we assume the following:

- Regional jet: EIS of different aircraft
    - A new jet fuel-powered aircraft by 2030, with an efficiency increase of 30%
    - A hydrogen aircraft by 2030, with an efficiency increase of 25%
    - A new electric aircraft by 2030, with an efficiency increase of 25%
- Single aisle: EIS of different aircraft
    - A new jet-fuel powered aircraft by 2035, with an efficiency increase of 40%
    - A hydrogen aircraft by 2035, with a 25% efficiency increase
- Twin aisle: EIS of a new jet fuel-powered aircraft design by 2040, with an efficiency increase of 25%
- Fleet renewal age of 18 years, spurred by stronger policies compared to the ambitious scenario

1.4 Model inputs

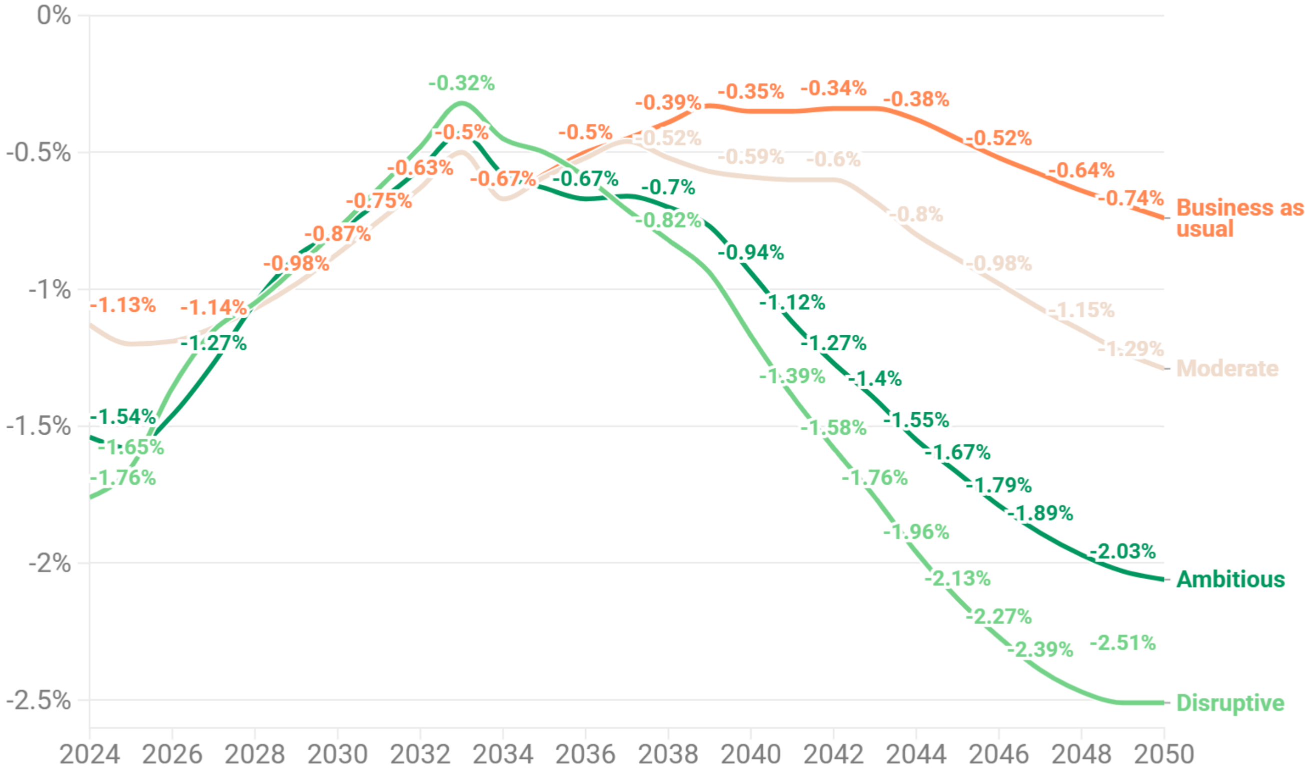
The main inputs for the fleet modelling for each of the scenarios are summarised in the table below.

[5] Efficiency increases for hydrogen aircraft are modelled to be lower than comparative traditional, jet-fuel powered aircraft, in line with existing literature on hydrogen aircraft design
[6] On top of propulsive efficiency gains due to the use of electric propulsion

Scenario		Business as usual	Moderate	Ambitious	Disruptive
Regional Aircraft	EIS Year	2037	2035	2030	2030
	Efficiency Gain	15%	20%	25%	30%
Regional Hydrogen Aircraft	EIS Year	*Not considered*	*Not considered*	2030	2030
	Efficiency Gain	*Not considered*	*Not considered*	20%	25%
Regional Electric Aircraft	EIS Year	*Not considered*	*Not considered*	2030	2030
	Efficiency Gain	*Not considered*	*Not considered*	20%	25%
Single Aisle Aircraft	EIS Year	2040	2038	2035	2035
	Efficiency Gain	20%	30%	35%	40%
Single Aisle Hydrogen Aircraft	EIS Year	*Not considered*	*Not considered*	2040	2035
	Efficiency Gain	*Not considered*	*Not considered*	25%	25%
Twin Aisle Aircraft	EIS Year	2045	2043	2040	2040
	Efficiency Gain	15%	20%	25%	30%

Efficiency improvement through fleet renewal

Relative year-over-year improvement of fleet efficiency through fleet renewal



Source: T&E • Operational efficiency improvements are additional.

2. Modelling assumptions

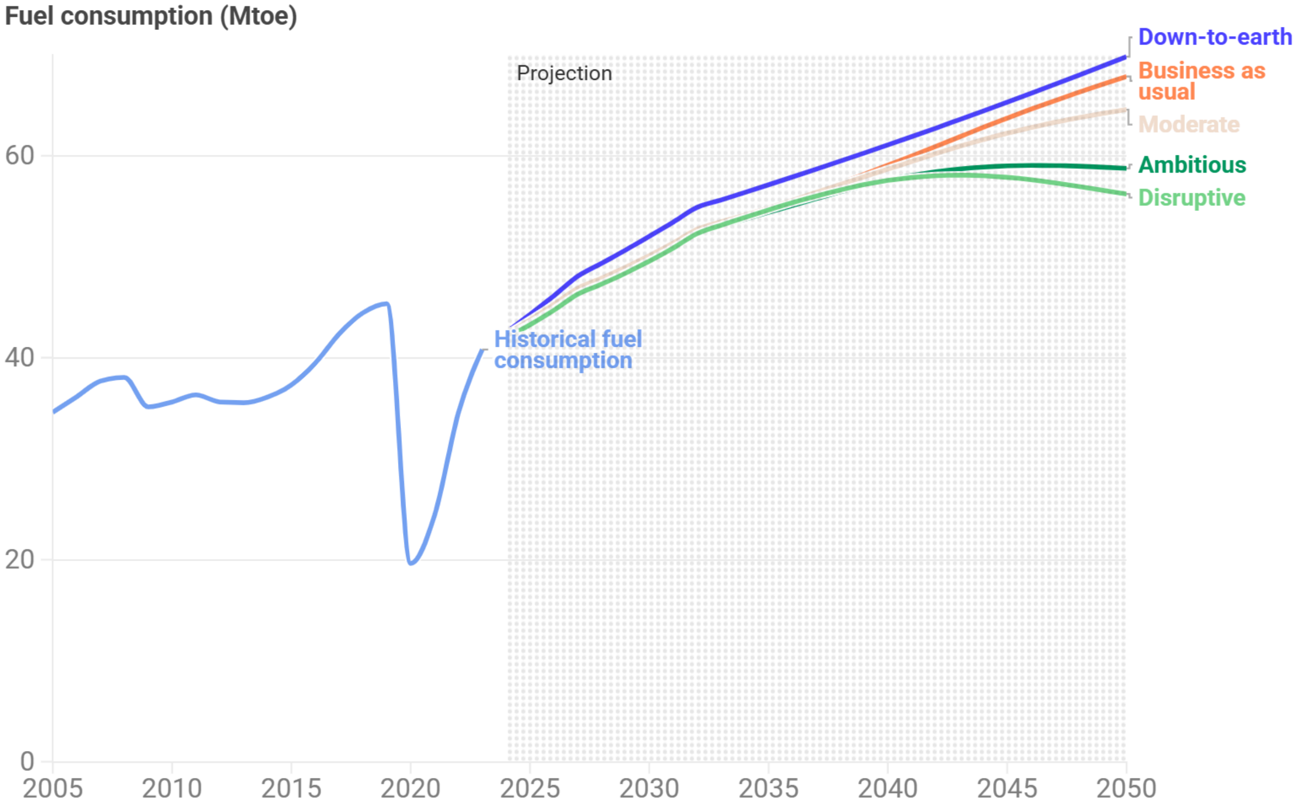
This section describes the main assumptions of the model used in our analysis, in terms of operational efficiency, air traffic demand and energy. For details on the historical emissions and air traffic forecasts, please refer to the annex of T&E's Down-to-Earth report. For comparability, we decided to use the same assumptions as in the report's *Industry High Growth Scenario* that represents an average of Airbus' and Boeing's growth forecasts.

2.1 Historical emissions and fuel consumption

Historical emissions are based on UNFCCC reporting for EU civil aviation emissions for both domestic and international aviation up until 2023. We correct these emission factors with a factor of 0.95 to obtain an estimate of civil passenger aviation emissions. We use a factor of 3.168 kg CO_2/kg jet fuel to convert from CO_2 emissions to fuel consumption. Our projections start in 2024.

EU civil passenger aviation fuel consumption

Fuel use peaks in the 2040s for the Ambitious and Disruptive scenarios, while it increases beyond 2050 for Business as usual and Moderate scenarios



Source: T&E, based on UNFCCC (2025) • Mtoe = million tonnes of oil equivalent. Down-to-earth corresponds to Down-to-earth report's industry high growth scenario.

2.2 Air traffic forecasts

The traffic forecast follows the *Industry High Growth Scenario* of T&E's Down-to-Earth report. It is based on Boeing's and Airbus' market outlooks published in July 2024.

Increased aircraft efficiency may have opposing effects on airline operating costs. On the one hand, it would reduce fuel costs, while on the other hand, higher aircraft innovation, and a possible faster fleet renewal rate, may increase aircraft purchase and rental costs.

Since the exact quantification of these two competing effects is out of the scope of the analysis, we have considered that the net change in total operating costs would be relatively small, and we have therefore assumed that they would not have an induced effect on air traffic demand.

To substantiate this assumption, we have run some high level analysis, based on IATA and Eurocontrol sources, which estimate fuel costs being 26% (24-28%) of airline operating costs, with aircraft depreciation and rentals just below 12%, and 62% for the rest.

In a hypothetical future scenario where, after adjusting for inflation, fuel costs double and the rest of costs remain constant, the previous cost breakdown changes to fuel representing 41% of total costs, aircraft 10%, and the rest 49%. Nonetheless, total operating costs would increase by 26%.

If we assume a reduction in fuel costs of 13%, stemming from the comparison between the Ambitious and Business as usual scenarios, total operating costs would be reduced by approximately 5%. This is a relatively modest increase, and would be totally offset by an increase in aircraft costs of 56%, which would maintain operating costs constant. The exact extent of increased aircraft costs has not been analysed, but some sources like the Aviation Impact Accelerator 2050 report estimate that they may be larger than the reduction in fuel costs.

2.3 Operational efficiency improvements

The analysis focuses on modelling the efficiency evolution derived from aircraft technology. Aviation as a whole also becomes more efficient through operational improvements. To study the impact a novel aircraft would have on emissions and fuel demand, we consider the same increases in operational efficiency, derived from Destination 2050, in all four scenarios. The yearly efficiency increases considered in our modelling are:

- 0.3% for load factor increases.
- 0.3% for air traffic management improvements.

The aircraft efficiency improvements themselves are based on the four scenarios outlined in section 1, derived from Boeing's Cascade Climate Model.

2.4 Energy mix forecast

For the future energy mix of European aviation, the blending mandate in Annex I of ReFuelEU has been considered. We have assumed that the blend changes every 5 years, in line with the mandate, although the actual energy mix may experience a more gradual evolution.

Year	2025	2030-2031	2032-2034	2035	2040	2045	2050
Overall SAF target	2%	6%		20%	34%	42%	70%
Synthetic fuels subtarget	/	Avg. 1.2% Min. 0.7%	Avg. 2% Min. 1.2% (2032-2033) Min. 2% (2034)	5%	10%	15%	35%

For modelling the energy requirements for e-kerosene production, we draw on Concawe's 2022 techno-economic analysis of e-fuels. We model a plant using CO_2 from point sources, alkaline electrolysers and a low-temperature Fischer-Tropsch process. Some heat is recuperated from the Fisher-Tropsch process and the rest is supplied by an electric heater powered by renewable electricity. Thanks to efficiency improvements, the energy requirements decrease over time leading to electric energy requirements of 96 MJ/kg or 26 TWh/Mt of fuel in 2030 and 87 MJ/kg or 24 TWh/Mt of fuel in 2050. This translates into efficiencies of 46% and 51% w.r.t. the lower heating value of the final fuel.

The Fischer-Tropsch process also produces a share of lighter and heavier hydrocarbons known as co-products depending on the process configuration. Given that some technology providers already offer process licences enabling 100% e-SAF, we expect large-scale e-kerosene plants to achieve high kerosene selectivities. We therefore only consider the energy requirements for the kerosene share and not that of co-products.

2.5 Future aviation emissions

We model tank-to-wing CO_2emissions. To account for production losses in e-kerosene, we model an 85% reduction in CO_2 emissions compared to fossil kerosene until 2040, followed by a linear improvement to 100% by 2050, reflecting advancements in production processes and sustainable carbon sourcing. For sustainable advanced and waste biofuels (derived from sustainable feedstocks), we assume a constant 85% reduction in emissions compared to fossil kerosene through 2050. Hydrogen and electric aircraft are assumed to be zero-emission.

2.6 Comparison of energy consumption and CO_2 emissions

2.6.1 Comparison of electricity for synthetic fuels with heat pump electricity needs

In their analysis of the largescale deployment of heat pumps by 2030 following the RePowerEU plan, the Joint Research Center calculated the yearly consumption of 52.4 million heat pumps, as the sum of the 30 million heat pump aimed at by RePower EU, the 11.4 millions heat pump already installed, and 11 million in newly constructed dwellings. These 52.4 million heat pumps would consume 173 TWh to 216 TWh of electricity in 2030, depending on the share of oil and gas boiler replacement that are combined with building envelope renovation (40% or 60%). On average, this means a yearly consumption of 3.3 MWh to 4.1 MWh per heat pump.

We use the central value (**3.7 MWh**) in this report to estimate the number of dwellings currently using oil and gas boilers that could be replaced by heat pumps, using the amount of electricity for the production of synthetic fuels that would be saved in the ambitious scenario versus the business as usual scenario (101 TWh).

2.6.2 Quantification of the reduction in area needed for renewable energy generation

We translate demand for e-fuels to comply with the ReFuelEU e-SAF sub-mandate into an area needed for renewable energy generation. We source typical area requirements per MW of renewable energy sources from a Ricardo study. We assume a mix of solar (31 MW/km², 34% full load hours) and onshore wind power (3.75 MW/km², 17% full load hours) offering 12.8 MW/km^2 with 50% full load hours in the EU based on Concawe. This results in a value of 0.0548 TWh/km² per year that we used for our estimate that 101 TWh of renewable energy per year requires 1850 km² of land.

2.6.3 Comparison of cumulative CO_2 emissions with number of cars

We assume that an average European internal combustion engine vehicle emits around 1.98t CO_2eq per year based on the 2019 EU fleet of 243.5M cars and emissions of 481 Mt CO_2eq based on T&E modelling and UNFCCC data.