Climate Action 100+
Global Investors Driving Business Transition

CLIMATE ACTION 100+ SECTOR STRATEGY: AVIATION – LANDSCAPE ANALYSIS

JANUARY 2021

Produced by
PRI Principles for Responsible Investment

Asia Investor Group on Climate Change
Ceres
Investor Group on Climate Change
IIGCC

ABOUT THIS PROJECT

There are 10 aviation focus companies in Climate Action 100+. The PRI coordinates investor engagements for nine of these companies.

In February 2020, the PRI published its Investor Expectations Statement on Climate Change for Airlines and Aerospace Companies, which was initially signed by over 122 investors with nearly $6 trillion in collective assets under management. The purpose of this statement was to publicly signal investor support for key high-level actions airlines and aerospace companies can take to manage their climate risks and opportunities.

In May 2020, the PRI commissioned Chronos Sustainability to prepare a more-detailed investor engagement guide for the aviation sector that would build upon the PRI's February 2020 statement and serve as the Climate Action 100+ sector strategy for aviation. This sector strategy consists of three documents:

- A list of recommended investor expectations for the aviation sector;
- A list of case studies aligned to these expectations; and
- An in-depth landscape report of the aviation sector.

Between June-November 2020, drafts of these documents underwent two rounds of feedback with investors, aviation companies, and aviation sector technical experts.

These documents are intended to inform Climate Action 100+ investor engagements with airline and aerospace companies by setting out recommended investor expectations for net-zero climate strategies from such companies, exploring potential pathways for the aviation sector to decarbonise by 2050 and showcasing examples of good practice by aviation companies.

For further questions or feedback on this project, please email marshall.geck@unpri.org

CONTENTS

EXECUTIVE SUMMARY

BACKGROUND

Aviation provides many economic and social benefits, connecting people and businesses across the globe and contributing both directly and indirectly to the world economy. However, it is also a significant contributor to global greenhouse gas emissions, accounting for around 2.5% of global carbon dioxide (CO_2) emissions from fossil fuel use and 12% of emissions from transport.

This proportion is set to rise significantly in the future.

As other sectors decarbonise and air transportation continues to grow, aviation is likely to consume a much greater share of the remaining global carbon budget. It is estimated that, for some countries, aviation will be the largest contributor to carbon emissions by 2050. It is also important to recognise that flying at altitude results in additional climate impacts, such as those caused by contrail and cloud formation. While there is considerable uncertainty about these 'non-CO_2' impacts, recent scientific research indicates that the overall climate impact of aviation is currently around three times the impact of its CO_2 emissions alone.

It is estimated that over three quarters of the total CO_2 emissions from the aviation value chain arise from airline activity, which is the focus of this paper, and most specifically jet fuel combustion from flight operations. Most of the remaining CO_2 emissions come from the production and transportation of jet fuel. Emissions from the operations of aerospace companies account for only around 4% of value chain emissions.

To decarbonise the sector, the focus needs to be on airlines' Scope 1 emissions, defined as those from jet fuel combustion, and the corresponding Scope 3 emissions of aerospace companies, that is, emissions arising from use of aircraft and engines over their lifetimes. Other stakeholders, including fuel producers, airports, industry bodies, policy makers and investors also have an important role to play in decarbonising aviation.

THE POLICY CONTEXT

The airline sector is exceptional in the way its emissions are regulated. Domestic aviation emissions, representing around 35% of total global aviation emissions, are the responsibility of individual states and are dealt with through national climate policies. Domestic aviation emissions are specifically included in the process for setting Nationally Determined Contributions (or NDCs) to the Paris Agreement.

In contrast, emissions from international aviation, i.e., all flights departing from one country and landing in another, representing around 65% of total emissions, are not specifically addressed in the Paris Agreement. That said, the temperature goals set apply universally and thus international aviation emissions need to be consistent with those goals.

International aviation emissions are addressed at a global level through the International Civil Aviation Organisation (ICAO), a specialist United Nations (UN) organisation. In addition to policy making at domestic and ICAO levels, there is European Union (EU) regulation, which applies to flight emissions within the European Economic Area (EEA).

The complexity of the regulatory regime has made mitigating emissions from the aviation sector challenging. Progress has been slow, particularly at the ICAO level, not least because of the large number of member states involved in negotiations. This has led to proposals for a 'dual approach' to policy making, involving both a top-down approach through ICAO and a bottom-up approach, through national and regional climate policies.

Some individual countries have taken unilateral action to introduce policies, such as flight taxes, to reduce not only their domestic aviation emissions but also international emissions relating to flights from those countries. In addition, there have been calls for international aviation emissions to be included in the NDCs of individual states, for example, from the British and French climate committees.

INDUSTRY INITIATIVES

Aviation trade bodies play a key role in international climate policy making. IATA, the International Air Transport Association, represents international airlines. Its sister organisation, ATAG, the Air Transport Action Group, represents players across the whole aviation industry (including airlines, aerospace companies, airports, and Air Navigation Service Providers (ANSPs)), and focuses on sustainability issues.

Together, IATA and ATAG work to direct the climate strategy of the industry, to coalesce and mobilise the various players and to represent the industry at ICAO and other regulatory forums. Future progress in the decarbonisation of aviation will depend, to a large extent, on the level of ambition of these industry bodies.

IATA and ATAG drew up a climate strategy for the industry in 2009. This involved three voluntary targets for international aviation:

- Short-term: to increase fuel efficiency by an average of 1.5% per year to 2020.
- Medium-term: to cap net emissions at 2020 levels, or so-called 'Carbon Neutral Growth' (CNG)
- Long-term: to reduce net emissions by 50% by 2050, based on 2005 levels.

ATAG published a new industry roadmap in September 2020 in which the industry long-term goal was expanded to cover both international and domestic aviation. ATAG has not set an explicit net zero goal but estimates that the industry can reach net zero between 2060 and 2065.

Like other aviation industry strategies, the new ATAG roadmap focuses on technological solutions rather than on any curtailment of air transport activity. It provides a number of scenarios that demonstrate how the sector can be decarbonised, primarily through technological improvements and use of Sustainable Aviation Fuels (SAF), but with some reliance on carbon offsetting, to meet any shortfall in emissions reductions arising from delays in SAF deployment.

While the ATAG roadmap is a welcome step forward, further commitments by the aviation sector are needed. Such commitments include setting a sector-wide target to reach net zero emissions by 2050 and breaking that target into emission cuts in the sector and reductions achieved through the use of offsets. Without that breakdown, it is not possible to compare the industry target directly with decarbonisation pathways that are aligned with the Paris Agreement temperature goals, as these pathways are based on reductions within the aviation sector only, and therefore exclude offsets.

ICAO has used the industry's short and medium-term voluntary targets as a basis for its own target-setting. The industry's Carbon Neutral Growth (CNG) target was adopted in full by ICAO, while the fuel efficiency target was modified upwards to 2% from 1.5% and extended from 2020 to 2050. Neither of these are sufficient to align the sector with the Paris Agreement temperature goals. ICAO does not have a long-term target.

ICAO has two policies in place to meet its targets:

The first, a **fuel efficiency standard**, requires aircraft entering service after 2028 to be on average 4% more fuel efficient than 2015 models. The second, **the Carbon Offsetting and Reduction Scheme for International Aviation** (CORSIA) aims to stabilise international aviation's net emissions at 2020 levels. However, in the midst of COVID-19 in June 2020, ICAO amended the baseline and it is now based on the higher 2019 emissions only, rather than an average of 2019 and 2020.

Under CORSIA, airlines will now be required to compensate for growth in their emissions above the amended baseline through the purchase of carbon offsets. The scheme has been criticised as lacking ambition and falling short of the Paris Agreement temperature goals and there are concerns about whether the offsets will result in real emissions reductions. In addition, the integrity of the scheme may be affected by the new higher baseline. It is estimated that airlines may now have no obligations under CORSIA for the first few years of the scheme's operation if the sector takes some time to recover from the coronavirus pandemic.

Generally, individual airlines keep step with the IATA/ATAG voluntary climate targets outlined. Recently, however, some airlines have opted for more ambitious voluntary targets. In particular, 2019 and 2020 saw a proliferation of net zero carbon targets, with several airlines committing to achieving net zero emissions by 2050 or sooner, in some cases, such as at Qantas, IAG, Finnair, Easyjet, Delta Air Lines and American Airlines (see case studies note). Aircraft manufacturers also largely keep step with the IATA/ATAG targets.

DECARBONISING AVIATION: PATHWAYS AND OBJECTIVES

There are a number of different ways to calculate the aviation sector's emissions reduction pathway but, depending on the specific goal, that is, whether holding global warming to well below 2°C or 1.5°C and the emissions reduction burden to be borne by the sector, it is estimated that in 2050 permitted direct CO_2 emissions from aviation fuel combustion will be between 230 and 800 Mt.

The lower end of this range is based on a 1.5°C scenario, using data from the Science Based Targets Initiative, while the upper end is based on the IEA's Sustainable Development Scenario, which incorporates a below 2°C temperature goal and is set out in its Energy Technology Perspectives.

In the IEA's Sustainable Development Scenario, global net zero emissions are reached by 2070. But to achieve a more ambitious 1.5°C climate goal, global net emissions need to reach zero by around 2050. Any residual emissions from the aviation sector will likely need to be offset by negative emissions in other sectors.

Regardless of the decarbonisation pathway, the actions that policymakers and other actors need to take in the short to medium term to address aviation emissions will be similar.

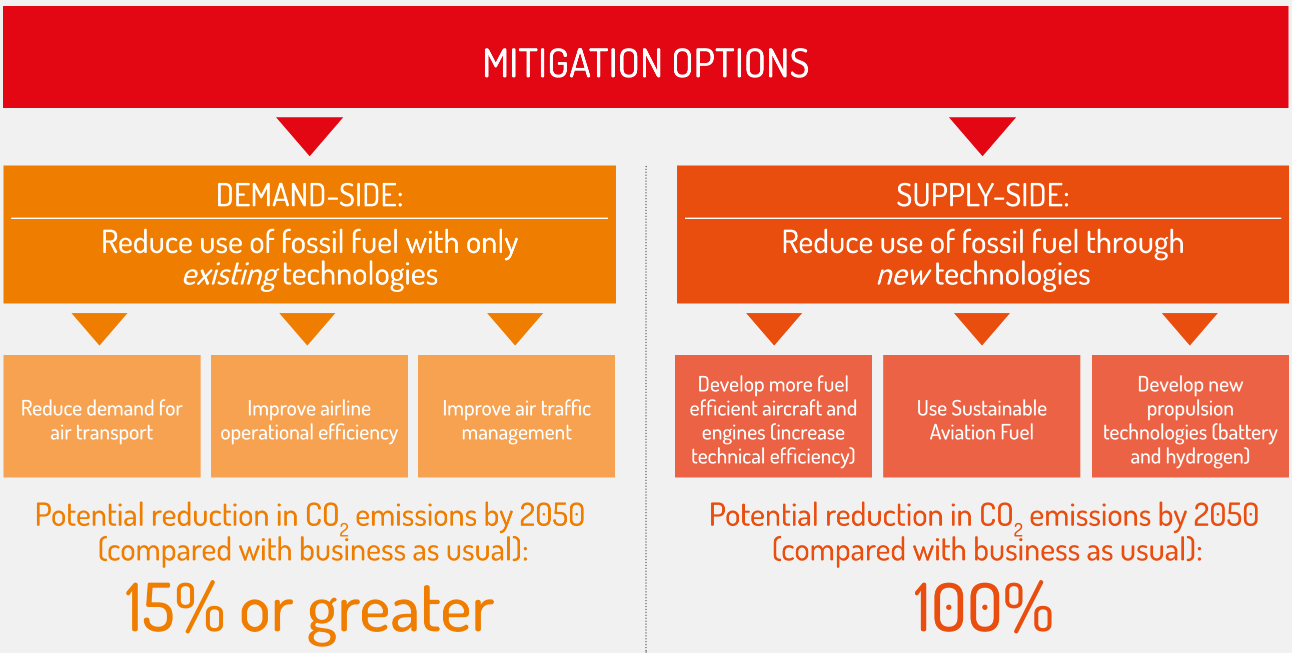
MITIGATION OPTIONS

Mitigation measures within the aviation sector may be divided into 'demand-side' and 'supply-side' approaches. Demand-side measures are those that result in reduced demand for jet fuel, without the need for new technology, which include:

- Decreasing demand for air travel, that is, through incentivising a shift to lower carbon modes of transport, through demand reduction using air passenger taxes, or through encouraging a switch from premium class to economy class seating
- Improving operational efficiency in airlines, such as by decreasing aircraft take-off weight and
- Improving Air Traffic Management (ATM).

Supply-side measures involve reducing emissions through new technologies, including more fuel-efficient aircraft and engines via technical efficiency improvements, the use of Sustainable Aviation Fuels (SAFs) and alternative propulsion technologies, such as electric or hydrogen-fuelled aircraft.

Figure 1: Demand-side and supply-side mitigation options for aviation CO_2 emissions



It has been estimated that demand-side measures have the potential to reduce carbon emissions from the aviation sector by around 15% compared to a business-as-usual scenario in 2050. Yet recent changes in flying behaviour as a result of COVID-19 indicate that the scope to reduce emissions through demand-side measures, specifically through reductions in air transport demand, may be greater than previously estimated.

In contrast, supply-side measures, *theoretically*, have the potential to reduce emissions to zero by 2050. However, this would require significant scaling-up of investment.

IEA's ETP 2020 report, published in September 2020, highlights the importance of sustainable aviation fuels (SAFs) for the decarbonisation of aviation. There are two main types of SAFs: advanced biofuels and synthetic fuels, derived from hydrogen and CO_2. By 2050, three quarters of CO_2 emissions reductions in the IEA's Sustainable Development Scenario (relative to its Stated Policies Scenario) will come from SAFs. By 2070, almost half of emissions reductions will come from synthetic fuels alone, as illustrated in Figure 2.

When considering the role of SAFs, particularly biofuels, in decarbonising aviation, it is important to take full account of the associated impacts not only in terms of total life-cycle emissions but also on wider sustainability effects. Depending on the feedstock and production methods, these could include biodiversity loss, soil degradation, and adverse impacts on food security and local communities.

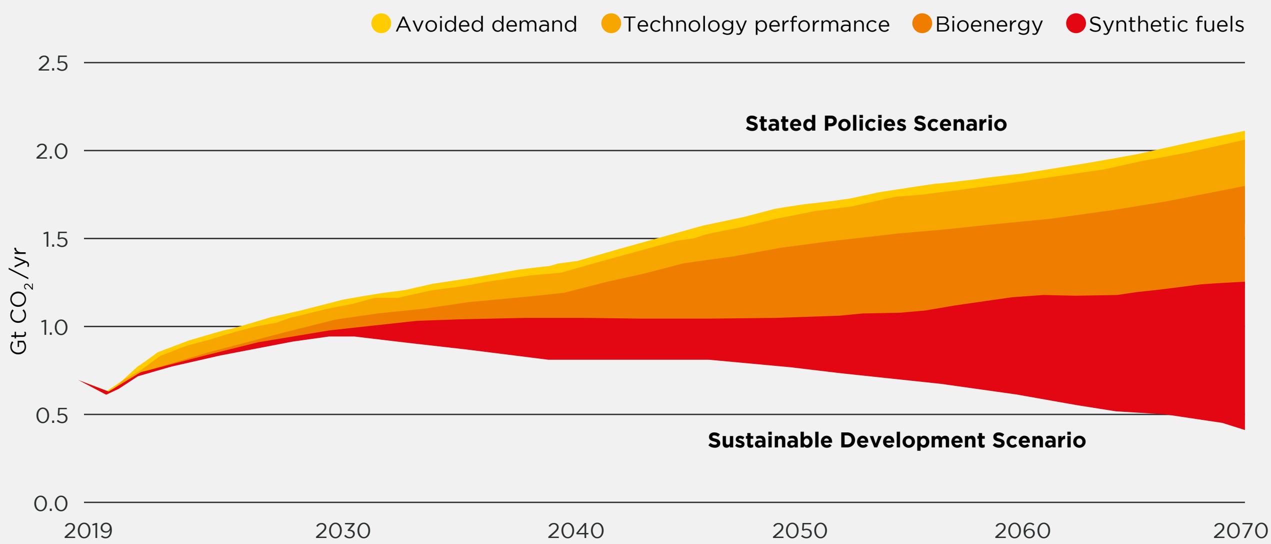
IEA indicates that biofuel policies need to include stringent sustainability criteria and recommends the use of third-party certification. The Roundtable for Sustainable Biomaterials (RSB) is one such certification body that is well-regarded by NGOs and policy makers.

Sustainability concerns have led to the development of 'advanced biofuels', such as those produced from household and industrial waste, agricultural and forestry residues, high yield energy (i.e. non-food) crops grown on marginal land and algae.

Technologies to convert feedstocks to advanced biofuels are at various stages of development. IEA analysis, provided in its ETP 2020, indicates that there will be sufficient supply of sustainably-produced feedstocks to meet the biofuel requirements set out in its Sustainable Development Scenario, provided that measures are taken to enable advanced biofuels to make a significant contribution.

The airline industry has expressed its commitment to applying rigorous sustainability criteria to biofuels. In its September 2020 roadmap, ATAG indicates that the industry's demand for biofuels to 2050 and beyond can be met using feedstocks from sustainable sources, that is, non-food crops and waste. ATAG acknowledges that it is not just the source of feedstock that gives rise to sustainability concerns but also how the crops are grown, harvested, processed and transported.

Figure 2: CO_2 emissions reductions in global aviation by mitigation measure in IEA's Sustainable Development Scenario relative to its Stated Policies Scenario



The focus of IEA's SDS (above) is on technological solutions, primarily the use of SAFs. However, IEA indicates that such mitigation measures are unlikely to be sufficient to meet a more stringent 1.5°C global temperature goal. In October 2020, IEA published its World Energy Outlook 2020, which, for the first time, includes a 1.5°C scenario ('Net Zero 2050' or 'NZ 2050').

IEA indicates that, in addition to technological solutions, wider societal changes will be required to meet a 1.5°C global temperature goal. Such measures include behavioural changes around flying, for instance, reducing business flights, long haul flights, and those less than one hour in length, which can be replaced with lower-carbon forms of transport.

Our analysis of mitigation options for the aviation sector points to three main conclusions:

- Supply-side solutions, such as new fuels and technologies, are the key to decarbonisation but these are costly and will take time to develop. Many are still at the very early stages of development and need strong policy intervention.
- Demand-side measures, such as actions to slow air transport demand, improve operational efficiencies and improve air traffic management have less overall mitigation potential. However, if combined with supply-side measures, they will reduce the overall cost of decarbonisation. Nevertheless, limiting growth in air transport demand becomes more important in a 1.5°C global warming scenario.
- Investment in SAFs, including advanced biofuels and synthetic fuels, is the most pressing priority for action. However, there are currently limits to the availability of sustainable biofuels and high demand from other sectors. The development of synthetic jet fuels, derived from low carbon hydrogen combined with CO_2, will therefore be essential.

THE ROLE OF INVESTORS

To help accelerate progress in the aviation sector, we believe investors can:

- Encourage and support airlines and aerospace companies to take effective action to manage and reduce their greenhouse gas emissions, setting ambitious targets to cut emissions and developing and implementing credible strategies to reach those goals.
- Encourage and support leadership and collaborative action. For example, by highlighting examples of countries adopting policy measures such as carbon taxes to reduce aviation emissions, of airports supporting the use of SAFs and of airlines working together, such as by forming SAF-buying alliances. Investors could seek best practices of such measures and encourage others to follow suit.
- Encourage the development of global sustainability criteria for biofuels and the use of credible third-party certification by airlines.
- Encourage greater ambition on the targets being set by ICAO.
- Encourage IATA/ATAG to set a net-zero emissions target by 2050 – along with appropriate short- and medium-term targets – for the airline industry as a whole, including both international and domestic aviation. Investors may also push for IATA/ATAG to clearly distinguish emissions reductions delivered by action within the sector, and those delivered through offsetting.
- Encourage a ‘dual approach’ to policy making; in addition to the top-down approach to decarbonising the aviation sector involving ICAO, encourage a bottom-up approach, such that national and regional policy makers include international aviation emissions in their climate plans and individual state NDCs to the Paris Agreement.
- Work with governments, companies and other stakeholders to develop financing and policy instruments that stimulate investment, R&D, deployment and scaling-up of decarbonisation technologies for aviation.
- Encourage a standard set of emissions metrics in the sector to inform investor decision-making and provide emissions data at the point of ticket purchase, based on aircraft type and seating class, to inform consumer choice.[1]

Please see the Climate Action 100+ Sector Strategy: Aviation – Recommended Investor Expectations for a list of specific expectations investors may have of aviation companies to help ensure they are sufficiently managing their climate change risks and aligning their business with a net-zero emissions by 2050 pathway. These are informed by the detailed analysis of the sector contained in this report.

For case studies providing real-world examples of how aviation companies are currently aligning with the recommended investor expectations, please see the Climate Action 100+ Sector Strategy: Aviation – Case Studies.

BARRIERS TO PROGRESS

Progress in reducing aviation emissions has been slow, despite the mitigation options available.

This is explained both by the challenges related to specific technological solutions as well as some more general barriers in the industry. The most significant of these are:

- The international nature of the aviation industry and the number of actors involved. This has resulted in a painstakingly slow rate of action, particularly at ICAO.
- The relatively low profit margins of the airline sector, which mean that airlines have only limited motivation to invest in R&D for decarbonisation, such as in sustainable fuel alternatives. This means the industry is also strongly opposed to regulation, including carbon pricing, that increases costs, particularly if these costs cannot be passed on to customers. COVID-19 has only exacerbated this dynamic.
- The tax-exempt status of jet fuel, which distorts the price between air and other modes of transport and makes the business case for investment in new technologies less attractive.
- The low oil price which reduces the incentives for the aviation sector to cut emissions, either through fuel efficiency measures or new technologies.
- Cultural and political barriers, particularly around curtailment of demand for air travel.

SECTION 1: INTRODUCTION

BACKGROUND

The aviation sector is experiencing unprecedented turmoil as a result of the COVID-19 pandemic. While recovery from this systemic event will be the main focus for the next few years, it is important that policymakers and investors keep sight of the equally present threat of climate change.

Without doubt, aviation brings many economic and social benefits. However, it also has harmful environmental effects including significant climate change impacts, noise pollution and local air pollution. Concern about the industry's climate impact has intensified in recent years. It is recognised as a sector that is hard to decarbonise, due to its dependence on fossil fuel and current lack of alternative technologies.

At present, commercial aviation accounts for around 2.5% of global carbon dioxide (CO_2) emissions from fossil fuel use[1] and 12% of emissions from transport.[2] This proportion is set to rise significantly in the future.

As other sectors decarbonise and air transportation continues to grow, aviation is likely to consume a much greater share of the remaining global carbon budget. Estimates vary, but unless more ambitious action is taken to reduce aviation emissions, the sector could account for between 12% and 25% of the annual 1.5°C global carbon budget by 2050.[3] For some countries, such as the UK, aviation is likely to be the largest contributor to carbon emissions by 2050.[4]

It is also important to recognise the unique impact that aviation can have on climate change, beyond the effects of greenhouse gas emissions. Flying at altitude results in additional climate impacts, such as those caused by contrail and cloud formation. These are often referred to as 'non-CO_2' impacts and are thought to be significant. Recent research indicates that the overall climate impact of aviation is currently around three times the impact of its CO_2 emissions alone.[5]

PURPOSE

In February 2020, the Principles of Responsible Investment (PRI) published an investor expectations statement on climate change for the aviation sector,[6] identifying the main climate change risks and opportunities for airlines and aerospace companies. Following this and in its role as one of the coordinating investor networks to Climate Action 100+, the PRI has identified the need for more detailed resources to provide guidance to Climate Action 100+ investors engaging on climate change with airlines, aerospace companies and policy makers. This Climate Action 100+ Sector Strategy: Aviation – Landscape Analysis report forms part of the investor guidance resources. Its aim is to provide investors, particularly those who may not be specialists in airlines or aerospace, with a detailed overview of these sectors and their climate change impacts (Section 2). It also seeks to provide investors with an understanding of the potential pathways to decarbonisation for aviation (Section 3), the mitigation options available, the challenges and barriers that exist, and the interventions required by stakeholders to achieve decarbonisation (Section 4).

A second paper, "Climate Action 100+ Sector Strategy: Aviation – Recommended Investor Expectations", supports investor engagement more directly. It provides a list of specific expectations investors may have of aviation companies and aims to help ensure they are sufficiently managing their climate change risks and aligning their business with a pathway to net-zero emissions by 2050. These recommended investor expectations are informed by the detailed analysis of the sector contained in this report.

SECTION 2: OVERVIEW OF THE AVIATION SECTOR

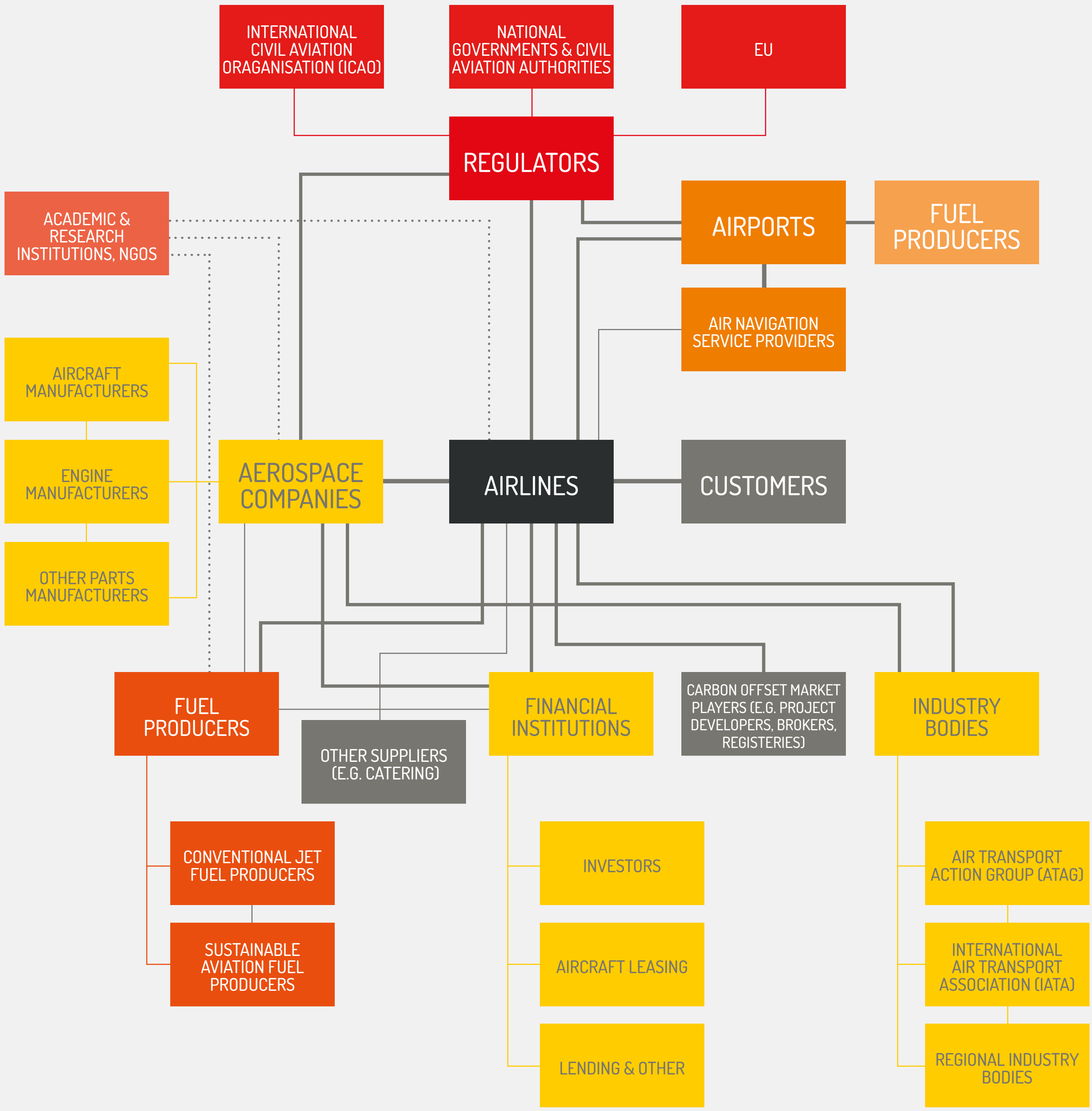
This section looks at aviation's climate impact. It sets out where emissions are concentrated in the value chain, the current level of emissions and expected future level under business as usual, that is, if no further action is taken by industry or by other stakeholders. It also outlines the policy context, both for international and domestic aviation, and considers what voluntary action has been taken so far by the industry. Finally, the section sets out the key climate risks and opportunities in the aviation and aerospace sectors.

WHAT IS THE CLIMATE IMPACT OF AVIATION?

Where do emissions occur in the aviation value chain?

There are many players in the aviation sector. The stakeholders and key relationships are set out in Figure 2.1. From a climate impact perspective, the main players are airlines, aerospace manufacturers, including aircraft manufacturers, engine and other parts manufacturers, and fuel producers. Other actors relevant to climate action, discussed further in Section 4, are Air Navigation Service Providers (ANSPs) and airports.

Figure 2.1 Map of key stakeholders in commercial aviation



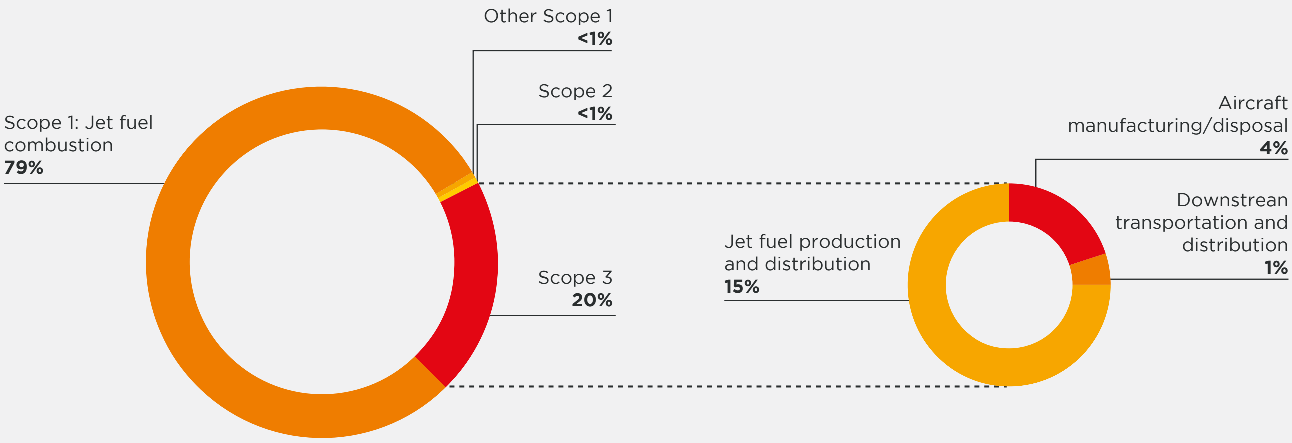
It is estimated that over three quarters of the total CO_2 emissions from the aviation value chain arise from airline activity, specifically jet fuel combustion from flight operations.[7] These jet fuel combustion emissions, also called 'direct' or 'tank-to-wheel' emissions, are included in an airline's Scope 1 reporting, and represent 98-99% of its total Scope 1 and 2 carbon emissions. Other Scope 1 CO_2 emissions, from ground vehicles and buildings, and Scope 2 emissions, from electricity use, are insignificant. Other greenhouse gases, such as nitrogen oxide and methane, are not significant relative to airlines' CO_2 emissions.[8]

Another 15% or so of emissions in the value chain arise from the production and transportation of jet fuel. These 'well-to-tank' emissions are included in airline Scope 3 reporting. Manufacturing, disposal and recycling of aircraft account for only around 4% of total value chain carbon emissions and are also included in airline Scope 3 reporting.

Emissions terminology defined	
Tank-to-Wheel emissions (TTW) or direct emissions:	Emissions from the combustion of jet fuel
Well-to-Tank (WTT) emissions:	Emissions that occur during the production and transportation of jet fuel
Well-to-Wheel or Well-to-Wake (WTW) emissions:	Total emissions from jet fuel production, transportation and combustion

Figure 2.2 below shows the breakdown of airline CO_2 emissions by scope. It indicates that **the most relevant emissions in assessing the climate impact of airlines are operational emissions, specifically carbon emissions from jet fuel combustion**. In contrast, operational emissions for aerospace companies are small, relative to jet fuel combustion emissions, so **the most relevant emissions in assessing aerospace companies are Scope 3 emissions.**

Figure 2.2 Analysis of airline CO_2 emissions by scope



Most airlines report their total CO_2 emissions from jet fuel combustion and provide a measure of fuel efficiency and hence carbon intensity. However, as there is no agreed standard reporting metric for fuel efficiency or carbon intensity, direct comparison between airlines can be difficult.[9]

An airline's carbon performance will depend on factors such as:

1. The age of its fleet
2. The payload factor, that is, the number of seats filled or cargo capacity used
3. The seating configuration of the aircraft, as premium seating reduces the total number of available seats per aircraft and so increases the carbon intensity per passenger.
4. The distances flown, as short haul flights have higher average carbon intensity per Revenue Passenger Kilometre (RPK).
5. The operational efficiency measures that have been adopted (see Section 4).

WHAT IS THE SCALE OF GLOBAL AVIATION CO_2 EMISSIONS AND HOW ARE THEY SPLIT?

Overall, the CO_2 emissions from jet fuel combustion in commercial aviation are estimated to be 918Mt for 2018, representing 2.4% of global CO_2 emissions from fossil fuel use.[10] Emissions grew 32% in the five years between 2013 and 2018, equivalent to annual growth of almost 6%.

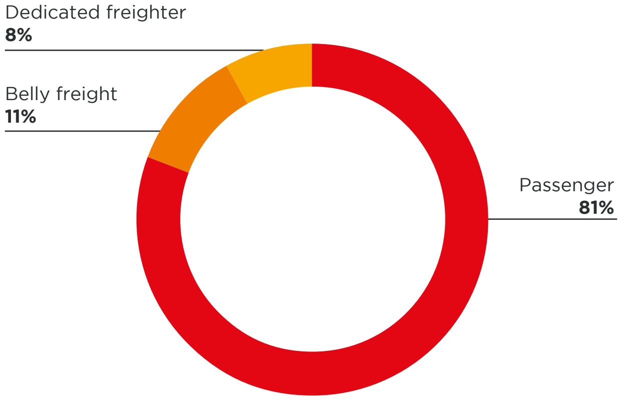
Air transport activity grew at an even faster rate than carbon emissions in the same period, with worldwide passenger traffic growing at over 7% on average per year and freight traffic growing at over 4% per year, equivalent to an overall average growth in air transport activity (in revenue tonne kilometres) of 6.5% per year.[11]

In broad terms, growth in passenger traffic is driven by growth in income and the continued rise of low-cost carriers, while growth in freight traffic is driven by economic growth. The difference between growth in air transport activity and carbon emissions is due to efficiency improvements.

IN-DEPTH: SOURCES OF AVIATION GREENHOUSE GAS EMISSIONS[12]

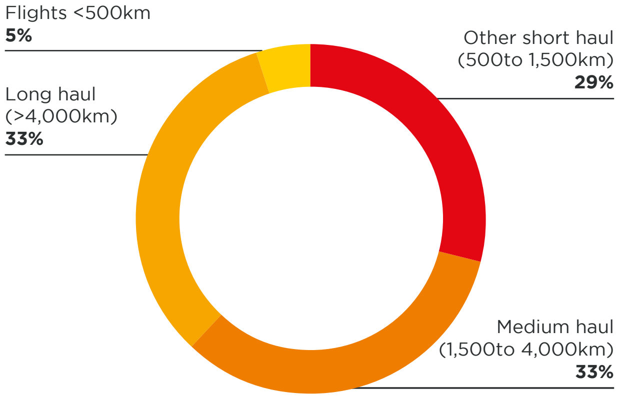
Passenger transport accounts for around 80% of commercial aviation emissions, while freight operations account for the balance. Freight may be transported either as 'belly freight' which is carried in the lower deck of passenger aircraft or on dedicated freighters. Belly freight accounts for a slightly larger share of total freight emissions than emissions from freighters.

Figure 2.3 CO_2 emissions from passenger and freight air transport



It is estimated that global emissions from passenger transport are split approximately evenly between short, medium and long-haul flights. Flights that travel less than 500km fall into another category and make a disproportionately large contribution, accounting for 5% of total passenger aviation emissions. This is because they are almost twice as carbon intensive on a passenger-kilometre basis; emissions from take-off and landing produce most carbon and make up a higher proportion of the overall emissions.

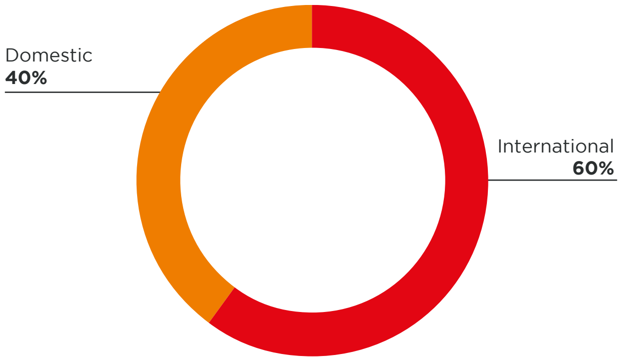
Figure 2.4 CO_2 emissions by flight length (2018)



CO_2 emissions from international air passenger transport account for 60% of total passenger emissions. When freight is included, international aviation accounts for a slightly larger share of total emissions, that is, 65%.[13]

However, some countries have a large domestic aviation sector, particularly the US and China, where domestic passenger aviation accounts for almost 70% of total passenger aviation CO_2 emissions. This means that national regulation is particularly important in these countries. For other smaller countries such as the UK, the majority of aviation emissions come from international flight departures.

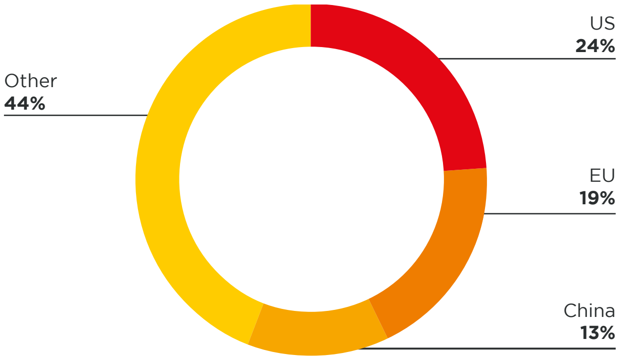
Figure 2.5 CO_2 emissions from international and domestic passenger transport (2018)



Aviation emissions are not, however, evenly distributed across the globe. Top emitting countries by departure and regions include the US, the EU and China, which together account for over half of global air passenger transport CO_2 emissions. Low and lower middle-income countries account for only 10% of passenger aviation CO_2 emissions, despite accounting for almost half of the world's population.[14]

IEA analysis indicates that even within countries aviation emissions are not evenly distributed, with a small percentage of the population responsible for most of the air travel.[15] This gives rise to equity concerns around the use of the remaining global carbon budget. It also indicates that policy measures that target aviation emissions may be an appropriate way to reduce total global emissions, while minimising unfair socio-economic impacts.[16]

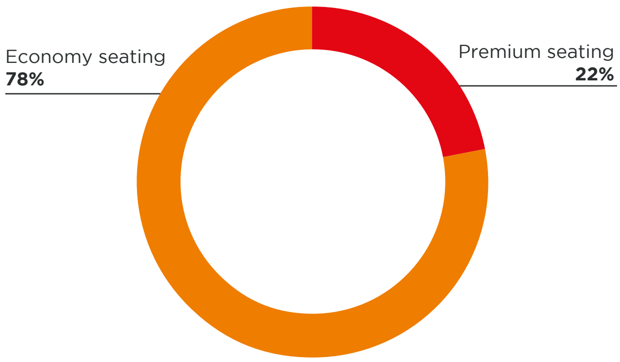
Figure 2.6 CO_2 emissions from air passenger transport by country of departure (2018)



Emissions vary significantly across seat class. A study by the International Council on Clean Transport[17] (ICCT) indicates that premium seating, that is, business and first class accounts for 22% of CO_2 emissions from air passenger transport and for nearly 20% of total CO_2 emissions from commercial aviation, which is greater than the contribution of air freight to total CO_2 emissions.[18]

In terms of carbon intensity, premium seating emits between 2.6 and 4.3 times more CO_2 than economy seating depending on the aircraft type, on a revenue passenger kilometre basis.[19] This indicates that a reduction in premium seating could have a significant effect on total aviation emissions.

Figure 2.7 CO_2 emissions from air passenger transport by aircraft seating class (2019)



WHAT IS THE FUTURE CLIMATE IMPACT OF AVIATION UNDER A "BUSINESS-AS-USUAL" SCENARIO?

It is difficult to forecast future CO_2 emissions from aviation because it depends on traffic growth and fuel efficiency improvements, both of which are uncertain. As a result, there is a wide range of estimates for future emissions from the sector. Further complication arises from how data are presented. ICAO provides projections for direct emissions from jet fuel combustion based on tank-to-wheel emissions for **international** aviation only, while the IEA provides equivalent data for both **international and domestic** aviation.[20]

ICAO forecasts that jet fuel combustion emissions from **international** aviation will grow by around 2.5% to 4% per year between 2015 and 2050, depending on assumptions made about fuel efficiency improvements from aircraft technology and operational improvements. This does not take account of any future technological breakthroughs or use of Sustainable Aviation Fuel (SAF).

On that basis, by 2050 emissions from international aviation are projected to be between 2.4 and 3.8 times their 2015 level.[21] These emissions forecasts are very sensitive to the assumptions made about growth in demand.

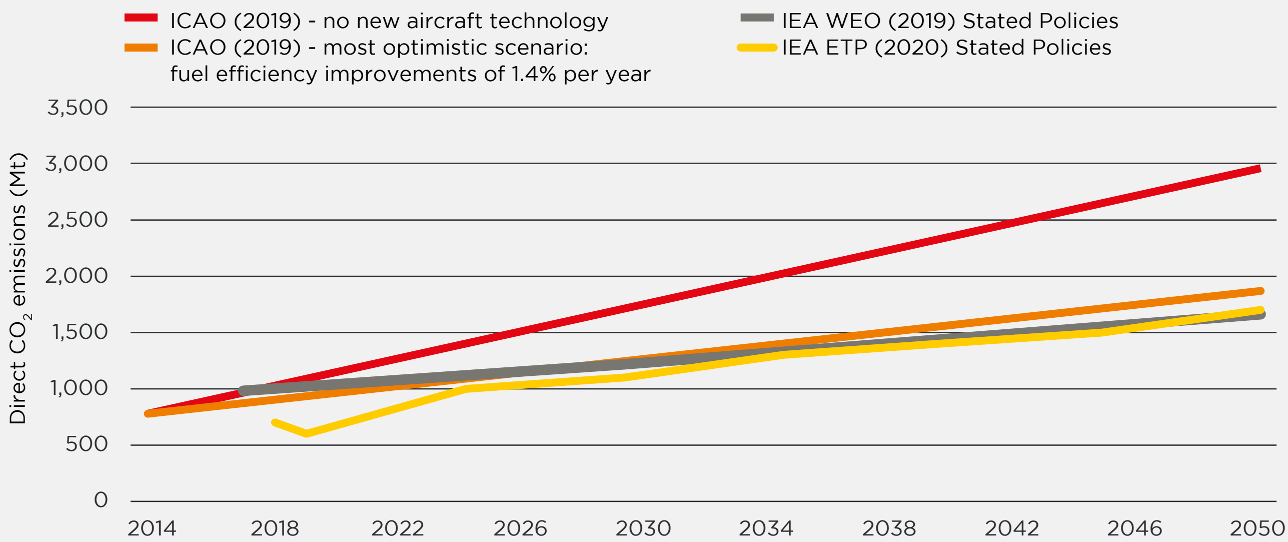
In fact, in ICAO's modelling, which pre-dates the COVID-19 pandemic, the uncertainty associated with future demand growth has a greater impact on projected aviation emissions than the uncertainty associated with fuel efficiency improvements.

The IEA also estimates future direct CO_2 emissions from aviation in its 2019 World Energy Outlook (WEO)[22] and its 2020 Energy Technology Perspectives (ETP).[23] Both of these IEA sources provide a base case, the Stated Policies Scenario, in which it is assumed that no further action to reduce aviation emissions will be taken beyond policies already in place.

Unlike the WEO 2019 data, the ETP 2020 data reflect the impacts of COVID-19 on aviation activity and emissions in the next few years. Beyond 2025 however, the Stated Policies Scenario from the two IEA sources are very similar,[24] although the IEA estimates are lower than those derived from ICAO data.

Without further action, direct emissions from aviation may be between 1,700 and 3,000 Mt by 2050, as Figure 2.8 below shows.

Figure 2.8 Projected direct CO_2 emissions from international and domestic aviation (Mt)[25,26]



Aviation's non-CO_2 emissions are expected to grow broadly in line with CO_2 emissions if no action is taken to reduce them.[27] Section 4 provides further detail on non-CO_2 impacts, including the interventions required to mitigate them (see Box 4.4).

WHAT ACTION HAS BEEN TAKEN SO FAR BY POLICY MAKERS AND INDUSTRY?

The policy context

Aviation is exceptional in the way its emissions are regulated. Domestic emissions, representing around 35% of total aviation emissions, are the responsibility of individual states and are dealt with through national climate policies. Domestic emissions are specifically included in the process for setting Nationally Determined Contributions (or NDCs) to the Paris Agreement.

In contrast, emissions from international aviation, i.e., all flights departing from one country and landing in another, or around 65% of total emissions, are not specifically addressed in the Paris Agreement. That said, the Paris Agreement global temperature goals apply universally and thus international aviation emissions need to be consistent with those goals.

International aviation emissions are addressed through the International Civil Aviation Organisation (ICAO), a specialist United Nations (UN) organisation.[28, 29] In addition to policy making at domestic and ICAO levels, there is European Union (EU) regulation which applies to flight emissions within the European Economic Area (EEA).[30]

The complexity of the regulatory regime has made emissions mitigation challenging. Progress has been slow, particularly at the ICAO level, not least because of the large number of member states involved in negotiations, each with specific national interests. As a result, there is a trend towards augmenting the policy making at ICAO with a more bottom-up approach to tackling aviation emissions, at national and regional levels (also see Section 4: General Barriers to Progress).

Recently, some individual countries have taken unilateral action to introduce policies, such as flight taxes, to reduce not only their domestic aviation emissions but also emissions on flights leaving their territory. For example, the UK, Sweden, Norway and Germany all have some form of tax in place for international aviation. Other countries, such as France and the Netherlands, plan to introduce similar taxes.[31]

In addition, there have been calls for international aviation emissions to be included in the NDCs of individual states.[32] Both the British and French committees on climate change have made such a recommendation and the EU NDC is expected to include emissions from international aviation when it is updated. There is an opportunity to call on national governments to include international aviation emissions in their updated NDCs in anticipation of the UN's November 2021 Climate Change Conference in Glasgow.

Industry wide initiatives

Aviation trade bodies play an instrumental role in international climate policy making for the sector and future decarbonisation progress will depend, to a large extent, on their level of ambition.

The International Air Transport Association (IATA) represents international airlines.[33] Its sister organisation, the Air Transport Action Group (ATAG), represents players across the whole aviation industry – including airlines, aerospace companies, airports, and Air Navigation Service Providers (ANSPs) – and focuses on sustainability issues. Together, IATA and ATAG, work to direct the climate strategy of the industry, to coalesce and mobilise the various players and to represent the industry at ICAO and other regulatory forums.

IATA and ATAG drew up a climate strategy for the industry in 2009, updated in September 2020 (see Box 2.1), which had three voluntary targets for international aviation:

- Short-term: to increase fuel efficiency by an average of 1.5% per year to 2020.[34]
- Medium-term: to cap net emissions at 2020 levels, so-called 'Carbon Neutral Growth' (CNG)
- Long-term: to reduce net emission by 50% by 2050, based on 2005 levels.

IATA indicates that the industry is on track to meet its short-term 1.5% fuel efficiency target, which expires in 2020.[35, 36] However, IEA implies that a new more ambitious efficiency target will be required to align aviation with the Paris Agreement goals.[37]

According to IEA, the actual efficiency improvements achieved in the sector between 2009 and 2019 exceeded the industry target and were 2.4% per year on average on a revenue tonne kilometre basis, but improvements have slackened over time. IEA notes that efficiency improvements will need to be greater than the IATA target of 1.5%, and indeed the ICAO target of 2%, in order to keep demand for jet fuel in check.[38]

In its World Energy Outlook 2020, published in October 2020, IEA indicates that fuel intensity will need to be reduced by around 3% per year to 2050 for aviation to be aligned with the IEA's Sustainable Development Scenario.

The IATA and ATAG industry medium term goal was adopted by ICAO (see below), but its long-term goal was not. In any case, it is not clear whether the industry's long-term target is sufficient to meet the Paris Agreement goals of well below 2°C or 1.5°C above pre-industrial global temperatures.[39] In its report on aviation, think tank the Energy Transitions Commission (ETC) indicates that one of the stakeholder actions required to get close to the 1.5°C temperature goal involves IATA updating its long-term target '*to aim for zero emissions by mid-century*'.[40]

BOX 2.1: ATAG'S ROADMAP TO 2050

A new industry roadmap, 'Waypoint 2050', was published by ATAG in September 2020. The report indicates that the industry's existing long-term goal, set in 2009, to reduce net emissions from the aviation sector by 50% by 2050 based on 2005 levels, is still in place. However, it has been extended so that it now covers both international and domestic aviation. ATAG estimates that the industry can reach net zero emissions between 2060 and 2065, but that some regions or individual airlines may reach net zero by 2050.

The ATAG report sets out a number of scenarios demonstrating how the sector can be decarbonised, primarily through technological improvements and use of SAFs, but with some reliance on carbon offsetting. The report does not quantify separately the projected use of offsets. Instead, they are grouped together with SAFs, such that offsets will be used to meet any shortfall in emissions reductions arising from delays in SAF deployment.

As a result, the industry long term target, based on net emissions reductions, is not directly comparable with the decarbonisation pathways outlined in Section 3, which are based on emissions reductions within the aviation sector, that is, excluding offsets.

While this new industry roadmap is a welcome step forward, further commitments by the aviation sector are needed to demonstrate alignment with the Paris Agreement global temperature goals, including:

- An updated fuel efficiency target, as the current target expires in 2020
- A more ambitious long-term target, to achieve net zero emissions across the sector as a whole by 2050
- Interim emission reduction targets for the short and medium term, to show the industry is on track to meet its long-term target to 2050
- A breakdown of the long-term target between projected emissions reductions produced within the sector and reductions from carbon offsetting.

Is continued growth in the sector compatible with decarbonisation?

Like other aviation industry strategies, the ATAG roadmap focuses on technological solutions rather than on any curtailment of air transport activity. ATAG forecasts that, despite the short-term effect of COVID-19, air traffic will grow by 3% per year on average to 2050.

ATAG identifies three factors that could potentially limit growth; consumer environmental concerns, government measures to limit demand and shifts to lower carbon modes of transport. However, it concludes that none will have a significant effect on air traffic growth.

In contrast to the industry-led approach to reducing emissions, environmental non-government organisations call for increased emphasis on demand management as a mitigation option, particularly in the short and medium term, while technology solutions are in development. For example, Sustainable Aviation UK's Decarbonisation Roadmap was criticised by campaigners for its reliance on SAFs and offsets, without limiting growth in UK passenger demand, which is projected to be 70% higher than current levels by 2050.[41]

ICAO targets and policies

ICAO has used voluntary industry goals as a basis for its own target-setting. The industry's targets (see Box 2.1) were adopted in full by ICAO, while the fuel efficiency target was modified upwards, from 1.5% to 2% and extended from 2020 to 2050. However, the body's fuel efficiency target to 2050 is unlikely to be met. In addition, at present, ICAO has no long-term emissions reduction target in place for international aviation, but is expected to develop one in advance of its general assembly in 2022.[42] This will need to be ambitious and supported by effective policies.

ICAO has two policies in place to meet its targets although , as we explain below, both would need to be made more ambitious to be aligned with the Paris Agreement global temperature goals.

ICAO fuel efficiency standard

This standard, introduced in 2017, requires aircraft entering service after 2028 to be on average 4% more fuel-efficient than 2015 models. There is a significant gap between the fuel efficiency requirements of the standard, which apply to new aircraft, and ICAO's target to increase fuel efficiency by 2% per year across the entire in-service flee.[43]

In fact, the fuel standard is no more likely to contribute to emissions reductions than would have taken place anyway through efficiency improvements.[44] ICAO acknowledges that its target of 2% fuel efficiency improvements per year to 2050 is unlikely to be met, even under its most optimistic scenario in which long term fuel efficiency is estimated to be 1.37% per year.[45] In any case, as noted above, the 2% target is not sufficient on its own to align the industry to the Paris Agreement global temperature goals, given the high level of air traffic growth forecast.

CORSIA

The goal of CORSIA is to stabilise international aviation emissions at 2020 levels. Under the scheme, airlines will be required to compensate for **growth** in their emissions from **international aviation** from 2020 onwards, through the purchase of carbon offsets.[46]

Effectively, this means that emissions from international aviation can continue to grow, but that net emissions are capped, because the sector will fund emissions reductions in other sectors, where mitigation is less costly.

There are two key criticisms of CORSIA. First, it is not considered to be ambitious enough to meet the Paris Agreement global temperature goals.[47] Second, there are questions over the scheme's effectiveness, that is, whether the offsets used for compliance will result in real emissions reductions.

In addition, a June 2020 decision by ICAO to amend the baseline for CORSIA after COVID-19 may have implications for the scheme's integrity. As a result of the new higher baseline—using 2019 emissions only, rather than an average of 2019 and 2020 as originally intended—it is estimated that airlines may have no obligations under CORSIA for the first few years of the scheme's operation if they take some time to recover from the pandemic.[48] Appendix 1 provides further details on CORSIA, while Appendix 3 outlines some of the issues associated with offsetting, more generally.

Policies in key domestic markets

The US and China have particularly large domestic aviation sectors. Together, their domestic aviation emissions account for 25% of global aviation emissions,[49] yet these emissions are not covered by ICAO regulation.

Currently, the US has no policies in place, either for airlines or aircraft manufacturers, to reduce aviation emissions.[50] A new CO_2 standard for US aircraft has been proposed and, at the time of writing, is under consultation.[51] This standard would match the CO_2 standard set by ICAO, however, and thus have little impact on cutting emissions, given that new aircraft already outperform the ICAO standard.[52]

While the proposed US standard is supported by Boeing, investor groups have expressed opposition, calling for greater stringency on the grounds that the standard is not aligned with the Paris Agreement climate goals and provides no incentive to invest in new technologies or operational improvements.[53]

Currently, China has no national policy in place to reduce domestic aviation emissions, but several of its regional pilot Emissions Trading Schemes (ETSs) include aviation emissions. Furthermore China's new national ETS is expected to include domestic aviation in due course, although there is no timeframe for this as yet.[54]

Recent trends in individual company action

Individual airlines tend to keep in step with the IATA/ATAG voluntary climate targets outlined above. Recently, however, some airlines have opted for more ambitious voluntary targets than those set out by IATA. In particular, 2019 and 2020 saw a proliferation of stronger targets, with several airlines committing to achieving net zero emissions by 2050, or sooner in some cases such as Qantas, IAG, Finnair and Easyjet.[55]

In addition, in September 2020 the 13 airlines in the oneworld Alliance came together to commit to achieving carbon neutrality by 2050 through collaboration and their own initiatives.[56] To meet their targets, the participating airlines expect to employ a combination of measures including new aircraft technology, operational efficiency measures, the use of SAFs and carbon offsetting, and several have already begun to invest in SAFs.[57] Airline targets and mitigation measures are discussed further in Section 4, Appendix 2 and Appendix 3 below.

Apart from individual airlines setting net zero emissions targets, some national aviation industry bodies are responding to increased climate ambition in their home countries. For example, Sustainable Aviation UK has published its own roadmap to reach net zero emissions by 2050, which covers both international and domestic flight operations in the UK.[58]

Aircraft manufacturers also largely keep in step with the IATA/ATAG targets. Airbus' and Boeing's own carbon emissions targets cover their Scope 1 and 2 emissions, but these represent less than 4% of total CO_2 emissions in the aviation sector (see Figure 2.2 above).

Airbus and Boeing do not have specific targets for Scope 3 emissions, in relation to aircraft use. Instead the aircraft manufacturers state their commitment to the industry-wide targets and that they contribute to achieving these targets through technological improvements, which result in emissions reductions. In contrast, the aircraft engine manufacturer, Rolls-Royce, has demonstrated a greater level of ambition in its recently announced targets: to become net zero in its own operations by 2030 and, more significantly, to play a leading role in enabling the sectors in which it is involved, including aviation, to become net zero by 2050, through new products and technologies.[59]

WHAT ARE THE CLIMATE RISKS AND OPPORTUNITIES FOR AIRLINE AND AEROSPACE COMPANIES?

Like all companies, those in the aviation sector face two types of climate-related risk: the risks associated with the transition to a low carbon economy and the risks related to the physical impacts of climate change. There are also opportunities associated with transition.

Transition risks

Regulation

Policy makers and industry have already started to address aviation's impact on climate change, but these are not enough to align the sector with the Paris Agreement global temperature goals. As a result, policy makers at all levels are likely to increase their focus on aviation and impose stricter emissions reductions measures. This exposes companies in the sector to regulatory risk.

At a national policy level, several countries have already taken unilateral action, imposing air passenger taxes and introducing SAF mandates or quota obligations, and this trend is set to continue.[60] At an EU level, as climate ambition is raised towards a net zero emissions goal, tighter policies for aviation are likely.

It is not just about policy makers, however. There is an increased public awareness, especially in some European countries, of the climate impact of flying. This is likely to lead to growing public support for policy action, particularly when the issue is framed as one of inequality, given that a small proportion of the global population are responsible for the vast majority of the sector's emissions.[61] Thus proposals such as the Frequent Flyer Levy in the UK, which increases the tax on each incremental flight an individual takes, are gaining traction.[62]

Market

Growing public awareness of aviation's climate impact also exposes companies to market risks. Consumer preferences are likely to change in some markets, as individuals choose to travel less or shift to other modes of transport to reduce their carbon footprints.[63]

A 2020 survey by McKinsey in 13 markets, before the coronavirus pandemic, indicated that one third of respondents planned to reduce air travel due to climate concerns. The proportion was higher for the 18-34 age group. McKinsey[64] concluded that while the future of the airline industry is uncertain following the pandemic, 'consumer preferences for environmental flying will continue'.

The market risk associated with changing consumer preferences as a result of climate change may be compounded by the impact of COVID-19 on flying habits. A 2020 survey by Citi estimated that business air travel may decline by 25% post-Coronavirus, as virtual meetings become the norm and some quarantine restrictions persist.[65] Similarly, projections by IEA indicate that business travel will be 10% lower in 2030 than previously forecast, and may be up to 25% lower in a more extreme 'Delayed Recovery' scenario[66] (see Box 4.1 for further discussion).

Nonetheless, changing customer preferences also present opportunities for airlines if, for example, they can demonstrate greater action to cut emissions than their competitors.

Reputation

Aside from market risk, airlines and aerospace companies face reputational risk from particular stakeholders, such as investors, lenders and other institutions, if it is perceived that they are making insufficient efforts to address climate issues.

This may partly explain the recent surge of net zero emission commitments in the sector, as airlines seek to demonstrate to stakeholders that they are taking action. More generally, the sector faces increased reputational risk from civil society due to growing public awareness of the climate impact of aviation and more widespread debate around high-energy consumption, including air travel.[67]

Legal

Finally, airlines and aerospace companies could face growing legal risks, as legal notions of corporate responsibility for climate change evolve. In recent years, there has been an increase in the number of litigation claims brought against companies in other sectors, for reasons including failure to mitigate their climate change impacts, failure to adapt to climate change and failure to provide adequate disclosure of material climate-related financial risks.

The climate transition risks for airlines are, to a large extent, mirrored for aircraft and engine manufacturers. When an airline is exposed to tighter regulation, market changes or reputational risk, this ultimately becomes manufacturers' market risk, as their airline customers demand more fuel-efficient aircraft or new low carbon aviation technologies.

Physical risks

In addition to transition risks, the aviation sector is exposed to physical climate change risks. Failure to address these could severely impact assets, services or overall viability.

Acute physical risks

An increase in extreme weather events, such as strong storms, fog and flooding may cause operational disruptions to airlines, including flight delays and cancellations and result in greater costs. Aerospace companies are already experiencing the effects of extreme weather. Airbus, in its Carbon Disclosure Project response,[68] highlighted the damage caused to its facilities by an extreme hailstorm in Toulouse, France.

Chronic physical risks

Longer-term physical effects of climate change include, for example, changes to jet streams, which could increase clear-air turbulence and cause flight disruption, while sustained higher temperatures may result in additional cooling and maintenance costs for aircraft and facilities.

Sustained higher temperatures and rising sea levels may damage physical infrastructure such as airports. These climate impacts will have knock-on effects on airline operations.[69]

In an ICAO aviation sector survey on climate adaptation, almost three quarters of respondents, including airlines, airports and states, said they were already experiencing the impacts of climate change and 55% of respondents said that, while some adaptation measures had already been put in place, more were needed.[70]

SECTION 3: DECARBONISING AVIATION: WHERE DO WE NEED TO GET TO?

This section considers the scale of aviation emission reductions required by 2050 to align with the Paris Agreement global temperatures goals.

DECARBONISATION PATHWAYS

There are two main approaches in modelling decarbonisation pathways for aviation. The Sectoral Decarbonisation Approach (SDA) takes account of the costs of decarbonisation in each sector, depending on technology available, and allocates the remaining carbon budget for a given temperature goal across different time periods in a way that is most cost-effective for the overall economy.

An SDA pathway may be expressed either in terms of absolute, or total, emissions or in terms of carbon intensity, that is, the carbon emissions per unit of economic activity. In the case of aviation this may be revenue tonne kilometres or revenue passenger kilometres.

The Absolute Emissions Contraction (AEC) approach applies the same rate of reduction in emissions to all sectors. The key limitation here is that it does not take account of the distinct decarbonisation challenges and abatement costs in different sectors, so it may not be the most cost-effective decarbonisation pathway for the whole economy. Nonetheless, an AEC approach may be useful in the absence of suitable SDA data.

Decarbonisation pathways for the aviation sector may vary not only as a result of the overall approach taken, but also due to other factors such as the temperature goal set, the different assumptions used particularly around growth in demand and SAFs and different starting years. As a result of these differences, a range of decarbonisation pathways for aviation are presented below which relate to absolute emissions. At present, there is insufficient data available to derive the corresponding emissions intensity pathways.

ABSOLUTE EMISSIONS PATHWAYS

The decarbonisation pathways below are based on two Paris Agreement global temperature goals: well-below 2 Degrees (B2D) and 1.5°C. There are two B2D pathways shown, (i) based on the International Energy Agency's Sustainable Development Scenario (SDS) from its World Energy Outlook,[71] and (ii) its more recent Energy Technology Perspectives.[72] The IEA uses the Standard Decarbonisation Approach.[73] Since the IEA does not currently produce a full 1.5°C scenario to 2050 for aviation (see Box 3.1), the 1.5°C pathway shown below is based on the Science Based Targets Initiative (SBTi) AEC, which applies an annual reduction in absolute carbon emissions of 4.2% across all sectors.[74]

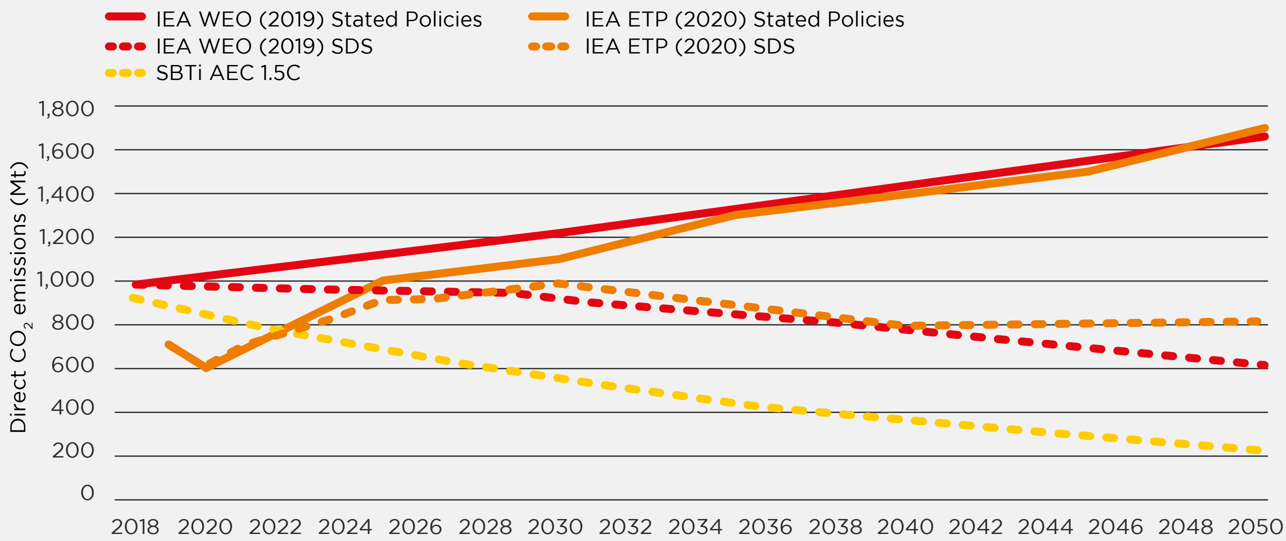
Figure 3.1 below shows that, in order for aviation to be on track for a B2D climate target, which requires that global net-zero emissions across all sectors are reached by 2070, direct carbon emissions from aviation will need to be broadly in the range of 600 to 800 Mt by 2050, as shown by the dashed orange and dashed red lines.[75]

This implies that by 2050 emissions need to be 52-62% lower than the baseline case for that year, meaning the level of emissions projected on the basis of existing policies but without further action. In the case of the ETP 2020, the length of the SDS pathway has been extended from 2050 to 2070, compared with the WEO 2019.

It shows that by 2070 aviation will still have residual direct emissions of around 400Mt, which will need to be covered by negative emissions technologies, including Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Capture (DAC).[76]

Under the 1.5°C scenario shown below, direct emissions from aviation in 2050 are estimated to be around 230 Mt, which represents an overall reduction in absolute emissions of around 75% between 2018 and 2050.[77]

Figure 3.1 Range of 2018 to 2050 decarbonisation pathways for international and domestic aviation[78,79]



The decarbonisation pathways shown above diverge considerably, with estimated direct aviation emissions in 2050 ranging from 230 to 800 Mt due to different approaches and goals used. **Regardless of the decarbonisation pathway, the actions that policy makers and other actors need to take in the short to medium term to address aviation emissions will be similar.** These are discussed in Section 4 below.

None of the decarbonisation pathways above make it possible to cut aviation CO_2 emissions to zero by 2050. There is likely to be residual aviation emissions which need to be offset by negative emissions in other sectors to reach net-zero across the economy as a whole under the 1.5°C global temperature goal. The role of offsetting in the aviation sector is outlined in Section 4 and Appendix 3 below.

BOX 3.1 NOTE ON IEA'S NET ZERO 2050 SCENARIO

IEA's principal low carbon scenario is its Sustainable Development Scenario (SDS), which is presented in the WEO 2019 and ETP 2020, with the latter updated for COVID-19 impact. That scenario incorporates a Below Two Degrees global temperature goal with some wider sustainability goals. Under the SDS, 'global' net zero CO_2 emissions are reached by 2070.[80]

IEA's WEO 2020, published in October 2020, includes a more ambitious 1.5°C scenario (Net Zero 2050 or NZ 2050) for the first time.[81] Under this scenario, global net zero emissions are reached 20 years earlier than the principal scenario.

Unlike the SDS, which focuses on the technological solutions (see Section 4), the NZ 2050 also outlines the wider societal changes required to meet a more stringent global temperature goal. The focus of the NZ 2050 scenario is the next ten years, that is, it considers what needs to happen by 2030 to be on a path to net zero emissions globally 20 years later.

While the NZ 2050 does not provide a detailed decarbonisation pathway for aviation, it provides some key insights on what NZ 2050 would mean for the sector:

- A further acceleration in the development of lower-carbon aviation technologies beyond that modelled in the SDS would be required. This would be extremely challenging for the sector as it recovers from the effects of COVID-19 (see Box 4.1);
- Even if technological development could be accelerated, this would not be sufficient to align the sector with a NZ 2050 pathway, which would require significant commitments from policy makers, the finance sector and citizens;
- Such commitments include significant behavioural changes around flying. IEA provides an illustrative scenario indicating that, in 2030, aviation emissions could be 520 Mt, or 60%, below the SDS level if

(i) business travel[82] was reduced by 25% compared with business as usual

(ii) long haul flights lasting more than 6 hours were reduced by 75% and

(iii) all flights of less than one hour were replaced by lower carbon forms of transport;

- However, IEA recognises that reduced demand for air travel may limit airlines' motivation to invest in newer, more efficient aircraft, which may make it more difficult to reduce emissions.

EMISSIONS INTENSITY PATHWAYS

Decarbonisation pathways can also be expressed in terms of emissions intensity, that is, carbon emissions per unit of economic activity in each year. Intensity pathways are useful to determine what is required in terms of fuel efficiency improvements and carbon emission intensity in the future, relative to historic improvements. Intensity pathways are also useful in assessing the adequacy of individual airline targets.

One issue in using intensity pathways is that, if activity turns out to be greater than projected, the absolute sector carbon budget may not be met, even if the sector is aligned with a certain intensity pathway. In the case of aviation, this may arise if air traffic growth is greater than projected in the models, or if shifts to other modes of transport, as projected by the IEA, for example, do not take place. Hence, intensity pathways need to be used in conjunction with absolute pathways.

At present, there are no aviation activity data available from the IEA which would allow the calculation of intensity pathways corresponding to the absolute pathways shown above.

SECTION 4: ACTIONS REQUIRED FOR DECARBONISATION: HOW DO WE GET THERE?

This section provides an overview of the decarbonisation options available, discussed in more detail in Appendix 2. We also outline some of the general barriers to progress and set out the interventions needed to enable more rapid decarbonisation.

SUMMARY OF MITIGATION OPTIONS

Mitigation measures within the aviation sector may be divided into 'demand-side' and 'supply-side' approaches.[83] Here, demand-side measures encapsulate those that reduce the demand for jet fuel without relying on new technologies, such as SAFs. Demand for jet fuel can be cut through:

- reduced demand for air transport, for example, through a shift to lower carbon transport, air passenger taxes, or encouraging a switch from premium class to economy class seating
- operational efficiency improvements in airlines
- improvements in Air Traffic Management (ATM).

Supply-side measures involve reducing emissions through new technologies and fuels, including:

- more fuel-efficient aircraft and engines, that is, technical efficiency improvements
- use of SAFs, such as advanced biofuels or synthetic fuels.
- alternative propulsion technology, such as electric or hydrogen-fuelled aircraft.

It has been estimated that demand-side measures have the potential to reduce emissions in the aviation sector by around 15% compared to a business-as-usual scenario in 2050.[84] Yet, recent changes in flying behaviour during COVID-19 indicate that scope, specifically through reductions in air transport demand, may be greater than previously estimated (see Box 4.1).

In contrast, supply-side measures, theoretically, have the potential to reduce emissions to zero by 2050.[85] However, this would require significant scaling-up of investment. In addition, the timing and success of new technologies is uncertain. It is therefore likely that there will be residual emissions from aviation in 2050 which will need to be offset by negative emissions in other sectors in order to reach net zero emissions for the economy as a whole, as shown in Section 3. The role of carbon offsetting in aviation is outlined in Box 4.2 below, with further detail provided in Appendix 3.

The table below summarises the mitigation options available in the aviation sector and outlines, for each option, the actions taken to date, the specific barriers to further progress and the likely interventions required to maximise the mitigation potential of each option. The analysis draws primarily on the work of the ETC, which focuses on how aviation could reach net zero emissions by 2050.

Figure 4.1 Summary of mitigation options and interventions required[86]

Mitigation option		CO_2 Mitigation potential by 2050		Timescale/ technology readiness	Key challenges/ barriers	Lever available/Actions to date	Further interventions required
Demand side							
Reduce demand for air transport	Modal shift (to High Speed Rail (HSR) for passengers)	10%		2020	• Low cost-competitiveness of rail fares • Rail /intermodal hub infrastructure	• Price: Air passenger tax • Informational measures: change consumer preferences	• Carbon pricing (tax on air fares) • Removal of jet fuel tax exemption • Investment in HSR • Collaboration on intermodal hubs • Improved information to help consumers reduce emissions (e.g. choosing economy seating, taking direct flights, reducing luggage)
	Reduced demand for leisure travel	7%		2020	• Price inelasticity of air fares • Lack of political support for air fare price increases • Leakage/competitiveness issues	• Price: Air passenger tax • Informational measures: change consumer preferences/ increase support for other measures • Limit airport capacity	
	Reduced demand for business travel and premium class seating	~2% (but may be 8% in certain scenarios)	15%[87]	2020	• Price inelasticity of air fares • Poor emissions disclosure of carbon intensity by seat class and aircraft type	• Video-conferencing • Changes in flying behaviour post-COVID-19	• Commitments from companies to reduce business air travel (Scope 3) • Improved disclosure of carbon intensity by seat class and aircraft type at point of ticket purchase • Carbon pricing based on carbon intensity of seat class and aircraft type
	Modal shift (to sea/ rail) for freight	small[88]			• Opportunities limited to less time-critical components of supply chains	• Carbon pricing	• Commitments from manufacturing companies to reduce supply chain emissions (Scope 3)
Increase operational efficiency	Airline operations	5%		2020	• Low impact of operational measures relative to other mitigation options • Limited future potential - measures that produce the biggest fuel efficiency savings may have already been put in place, limiting further opportunities	• Fuel cost savings	• Provision of fuel efficiency data to consumers at point of ticket purchase • Improved airline disclosure of impact of efficiency measures
	Air Traffic Management (ATM)			2020s	• Large number of stakeholders involved	• Fuel cost savings • Airspace harmonisation initiatives (e.g. SESAR, NextGen)	• Greater collaboration among stakeholders • Leadership from national governments, IATA and ICAO to accelerate progress
Supply side							
New aircraft/ engine design (technical efficiency improvements)		30-45%		2025 onwards	• High cost/risk and long lead times of investment in new aircraft technologies means manufacturers favour incremental improvements to existing designs • Weak fuel efficiency standards	• Fuel cost savings • Some multi-stakeholder initiatives in place (e.g. UK's Aerospace Technology Institute)	• More ambitious fuel efficiency standards • R&D funding • Use of carbon shadow pricing in airline fleet upgrade decisions • Role of lenders: linking cost of capital to fuel efficiency/establish initiative like Poseidon Principles for shipping finance[89] • Role of investors in monitoring R&D spend of aircraft manufacturers
SAFs	Biofuels	~63%[90]		Market ready	• Cost relative to conventional jet fuel • Scale of investment in production facilities • Lead time for development of production plants (3-4 years) • Availability of biofuels that deliver **substantial** life cycle emissions reductions • Availability of certified sustainable feedstock (using robust criteria, e.g. Roundtable for Sustainable Biomaterials) and second generation biofuels • Competition with other sectors and other land uses	• One dedicated aviation biofuel plant in production (US); several more planned (small scale) • Airline action: use of biofuel (but currently very limited). Off-take contracts can help increase demand certainty • EU incentives: Renewable Energy Directive II, R&D funding, proposed ReFuel Aviation policy • National policies (e.g. Norway's blending mandate) • Industry action, (e.g. SAF roadmap produced by Sustainable Aviation UK; IATA SAF Symposium)	**Short/medium term** • Niche market development using fuel mandates: airport coordination or individual country action • Part public funding of new SAF facilities • Coordination on SAF sustainability standards and sustainability certifications • Partnering with finance industry (e.g., venture capital for scale up of SAF facilities) • Expansion of fuel mandates (extend to large airports and more countries) • Procurement commitments and stakeholder alliances (e.g., oil company/ airline consortia, off-take agreements, buyer alliances) • New consumer products including SAF premium (e.g., 'Green tickets' or 'advanced offsets'), some of which already exist (e.g. Lufthansa)[91]. • Reallocation of biofuel subsidies from road to air transport • Reduction in cost of new renewable energy for production of synthetic fuels **Longer term** • Use of zero emissions mandates/carbon pricing through ICAO • Large scale investment and conversion of oil refineries (with government support) • Removal of biofuel blending limits (certification of 100%) • Government support for CCUS (and other new SAF technologies)
	Synthetic fuels	100%		Late 2020s	• Cost relative to conventional jet fuel, which is dependent on the cost of renewables and CO_2 capture. • Quantity of renewable energy required (without diverting from other sources of demand) • Large scale of investment in refineries	• Demonstration facility planned in Norway for 2023. Additional pilot projects in Netherlands and Canada • Airbus/AIREG collaboration in Germany to develop synthetic fuel[92]	
	SAF with CCUS	>100%		Late 2020s	• Technology readiness • Lack of incentives	• Some US government incentives already in place • Velocys plans to integrate CCUS into its biofuel facility in Mississippi	
Alternative propulsion technologies	Fully electric (short haul)	5-15% (i.e. 100% of flights<500km or 1,000 km)		2030s onwards	• Technology readiness • Infrastructure • Market conditions	• ~170 electrification projects in development • Proposed innovation centre in Norway to encourage collaboration	**Short term** • Public funding of R&D for electric aircraft (especially post-Coronavirus) • Support for niche markets through public procurement of electric aircraft for use on specific routes • Collaboration among stakeholders for hydrogen development (airlines, airports, shipping companies and renewable energy companies)
	Hybrid electric (short haul)	4% (short and long haul)		2020s			
	Hydrogen combustion	100% (short haul)		2040s	• Technology readiness • Infrastructure	• Some initiatives already in place (e.g. Danish green hydrogen project)	**Medium/Long term** • Investment in infrastructure (i.e., recharging/refuelling) with government support • Financing of new electric/hydrogen aircraft through alternative funding models

IEA Energy Technology Perspectives (ETP) 2020

The table above shows the individual potential of each mitigation measure to reduce CO_2 emissions from aviation. By contrast, IEA, in its ETP 2020 report, provides an analysis of how such mitigation measures may be combined to put the aviation sector on a decarbonisation pathway. Specifically, IEA shows aviation emissions reductions by mitigation measure in the Sustainable Development Scenario (SDS), compared with the Stated Policies Scenario.[93] The IEA analysis differs from the analysis of think tank the Energy Transitions Commission (ETC) in that:

- It includes data to 2070, rather than 2050
- It is based on a less ambitious global temperature goal. The Sustainable Development Scenario is compatible with limiting global warming to 1.8°C with a 66% probability, while the analysis of ETC is based on achieving net zero emissions by 2050, broadly equivalent to limiting global warming to 1.5°C.

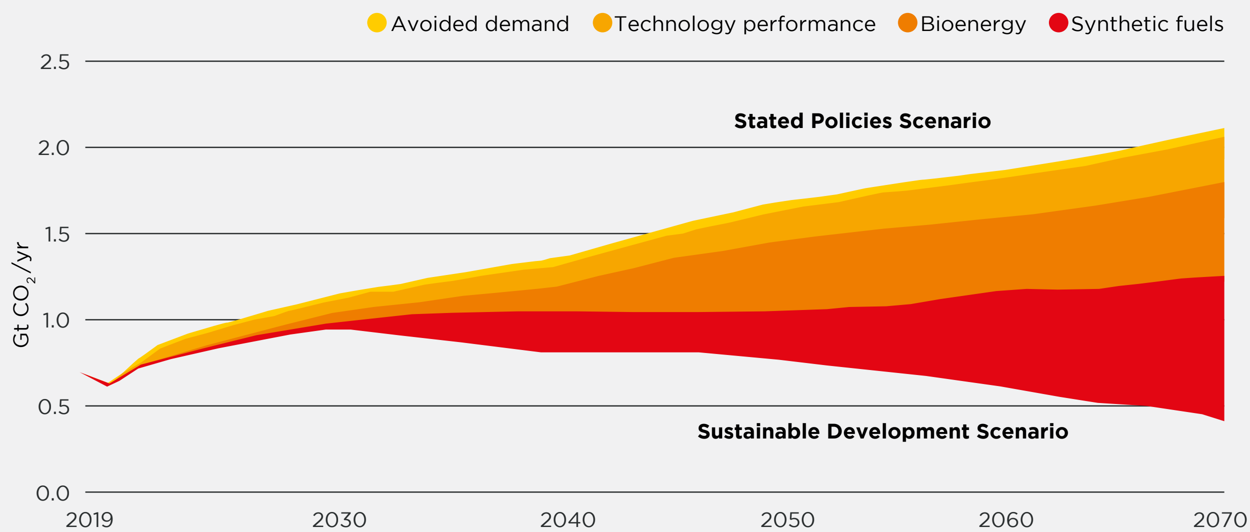
By 2050, in order to be aligned with the Sustainable Development Scenario, aviation emissions will need to be around half of those under the Stated Policies Scenario for the same date, as shown in Figure 4.2 below from IEA's ETP 2020.[94]

Of these emissions reductions:

- almost one quarter (22%) comes from improved technology performance, mainly new aircraft and engines[95]
- 44% comes from sustainable biofuels
- 33% comes from synthetic fuels
- only a small proportion comes from a reduction in demand for air transport (see Box 3.1 for discussion of the bigger role of demand reduction in a more stringent 1.5°C scenario).

By 2070, the contribution of technology performance to emissions reductions in the IEA's SDS will be less significant than SAFs, in relative terms. By that date, synthetic fuels alone will represent around half of the emissions reductions compared to the Stated Policies Scenario.

Figure 4.2 - CO_2 emissions reductions in global aviation by mitigation measure in the IEA's Sustainable Development Scenario



Synthetic fuels do not face the same supply constraints as biofuels in terms of availability of sustainable feedstocks and competing demand from other sectors, but it is estimated that production of synthetic fuels will consume 8% of all electricity produced worldwide in 2070.

Many of the technologies required to reduce aviation emissions are still in the very early stages of development, such as the prototype or demonstration phase. The IEA highlights the importance of innovation for decarbonisation and the crucial role of policy makers in enabling such innovation.[96]

Despite the growth in SAFs, conventional jet fuels will still account for almost one quarter of jet fuel demand in 2070. The related emissions of around 400Mt will need to be covered by negative emissions technologies, including Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Capture (DAC).[97]

GENERAL BARRIERS TO PROGRESS

Progress to reduce aviation emissions has been slow despite the mitigation options available. This is not only due to specific technological challenges, but also to some more general barriers in the industry.

International nature of the aviation industry

One key barrier is the international nature of the aviation industry. On the face of it, this would indicate that a global approach to decarbonisation is preferable. However, progress at an international level in ICAO has been painstakingly slow and its ambition has been diluted due to the number of actors. This raises the question of whether transition should be accelerated more rapidly through other forums and mechanisms.

One alternative would be to adopt national or regional approaches to decarbonisation, but the airline industry has strongly resisted any regional or unilateral regulation on competition grounds. Airlines compete directly with other airlines from outside their home country and as a result, want to ensure that they are subject to the same regulatory costs.

In addition, national or regional approaches risk carbon leakage, when carbon emissions are shifted from one source to another to avoid regulation. For example, leakage may occur if passengers were to choose to fly from an airport in another country to avoid the tax, or if airlines were to swap older less fuel-efficient aircraft with newer ones on routes that do not impose fuel taxes, thereby merely displacing emissions. However, a 2018 UK Department of Transport study found that measures such as passenger taxes that discourage flying would not risk competitive disadvantage or carbon leakage, in the UK at least.[98]

In fact, as a result of the challenges involved in regulating aviation, a dual approach may be required to accelerate decarbonisation in the sector.[99] This would involve policy makers and other actors advocating for more ambitious international policy instruments, while at the same time supporting the use of national polices as a temporary measure.[100]

Profitability of the airline sector

Another barrier to mitigation efforts relates to the profitability of the airline sector, which tends to operate on low profit margins. This has two consequences:

1. Airlines have only limited motivation to invest in R&D for decarbonisation, such as SAFs.
2. Airlines are strongly opposed to regulation including carbon-pricing because it increases costs, particularly if these cannot be passed on to customers.

The issue of low airline profitability is exacerbated by the effects of COVID-19 (see Box 4.1). The challenge of low profitability may be partly overcome through the formation of coalitions within the industry, such as with airports, to increase mitigation efforts.

BOX 4.1: THE IMPACT OF COVID-19 ON AIRLINE SECTOR DECARBONISATION

Impact on passenger activity

The aviation sector has been severely affected by the pandemic and the current view is that recovery will take some time. The industry estimates that air passenger demand and airline passenger revenue for 2020 may both be around half that of 2019, and recovery will be slow due to overall economic conditions and travel restrictions.[101]

The IEA[102] models the potential effects of COVID-19 on air traffic. In its base case, known as the Stated Policies Scenario, IEA assumes that air passenger activity will recover to 2019 levels by 2024, but there will be lasting changes in flying habits, resulting in business travel being 10% lower than pre-COVID-19 projections. In an alternative Delayed Recovery Scenario, IEA assumes that by 2030 business passenger activity will be 25% lower and personal travel will be 10% lower than estimated previously.

Impact on carbon emissions

The immediate impact of the reduction in air transport on aviation carbon emissions is positive: IATA estimates that emissions from international aviation in 2020 may revert to the same level as they were 25 years ago.[103]

Longer term, however, the pandemic may have an adverse effect on decarbonisation. First, the fuel efficiency of airlines is likely to be impacted; while airlines with excess capacity may retire less fuel-efficient aircraft early, they are less likely to upgrade their fleets to newer, more efficient aircraft because of financial restraints. At an operating level, fuel efficiency may also be adversely affected if airlines facing lower passenger demand choose to fly planes at low payload factors.

Second, R&D in the sector is likely to come under pressure from COVID-19. As airlines suffer a collapse in revenues (particularly from profitable business class seating) and accumulate debt to survive, they are less likely to focus on developing low carbon solutions like SAFs. Aircraft and engine manufacturers are also suffering from the fallout, with delayed and cancelled orders, so they too may be less willing to fund R&D.

Third, as outlined in Section 2, the impact of COVID-19 may affect the integrity of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

Overall, IEA estimates that aviation emissions in 2030 will be 10% lower than previously modelled in its Stated Policies Scenario, but will be around 8% higher than the previous Sustainable Development Scenario (see Figure 3.1).

It is worth noting that ATAG's September 2020 roadmap for the aviation industry indicates that the industry is committed to its climate targets, despite the effects of COVID-19.

The potential for a 'green recovery' for aviation?

Airlines across the globe have called on governments to provide financial support to help them survive. Observers viewed this as an opportunity to boost climate action by linking government bailouts to carbon commitments. In fact, the alternative - unconditional airline bailouts – was forthcoming. These have been rated poorly as a fiscal policy by economists, both in terms of impact on economic and climate recovery.[104] In fact, several countries are considering postponing the introduction of flight taxes in an effort to support the airline industry.[105]

One exception to the trend is the French government's financial support for Air France. The €7 billion package requires the airline to reduce its domestic flights, increase the use of SAFs and cut its carbon intensity 10% by 2030 from today's levels.[106] However, in reality the climate impact of these conditions may be low.[107]

Some of the proposals for a green aviation recovery include:

- The introduction of taxation on jet fuel or airline tickets which could be used to ramp up investment in new technologies.[108]
- New in-use fuel efficiency standards to accelerate the retirements of old inefficient aircraft.[109]
- In a UK context, the inclusion of international aviation emissions in the national carbon budget.[110]
- Support to retrain people whose jobs in aviation are at risk.[111]

IEA has expressed support for conditional bailouts for airlines linked to targets for SAF use, as a way to boost production of these fuels.[112] IEA also indicates that if recovery from COVID-19 is delayed, there are opportunities for governments to invest counter-cyclically in R&D to mitigate the impacts of the pandemic on private investment in new technologies.[113]

Tax-exempt status of jet fuel

Another significant barrier to decarbonisation is the tax-exempt status of jet fuel used for international aviation. This distorts the price between air and other modes of transport and hinders the business case for investment in new technologies. Most countries apply tax to fossil fuel for road transportation as a way to reduce emissions and as a source of tax revenue.

However, the scope to tax fossil fuel for use in aviation is much more limited. Countries are free to tax jet fuel for use on domestic flights but, under international agreements, jet fuel for use in international aviation is exempt from tax.[114] One way to circumvent the exemption would be to introduce bilateral or multilateral agreements between individual countries to tax jet fuel used on flights between them.[115]

At present, the EU Energy Tax Directive also prohibits the taxation of jet fuel for use in international aviation, but this is being reviewed as part of the European Green Deal.[116] Removing the jet fuel tax exemption could reduce EU aviation emissions by 11% and provide €27 billion in revenue each year, according to an EU-commissioned study.[117]

Another recent study proposed an interim solution, whereby the EU countries with the largest aviation emissions would enter into bilateral agreements to implement a jet fuel tax on flights between those countries. The study estimates that even a small number of such agreements could cover almost 60% of intra-EU flights and raise €3.7 billion in tax revenue per year.[118] There may be a stronger case for such tax reforms in the wake of the pandemic, given the large government bailouts that airlines have already received and the current strain on public finances.[119]

Given the restrictions in taxing jet fuel directly, several countries have levied a tax on air passengers. These generally apply to both domestic and international flights and are distance-based. Examples include the UK's Air Passenger Duty, and similar levies in Sweden, Norway, France and Germany. Others are planned. The main advantage of a passenger tax is that it reduces demand, although it is considered a weaker climate measure than a jet fuel tax, because it provides no incentive for airlines to reduce emissions and passes the cost straight to consumers.[120] Some in the industry argue that revenues from passenger taxes should be ring-fenced to fund R&D in the sector.

Low price of oil

The current low price of oil acts as a barrier to decarbonisation of aviation in a similar way to the tax exemption of jet fuel, as it reduces the incentives for the aviation sector to cut emissions, either through fuel efficiency measures or new technologies. That said, the current low oil price could be used as an opportunity to introduce jet fuel tax reforms.

Cultural and political barriers

Finally, there are cultural and political barriers to decarbonising aviation, which are particularly relevant to a 1.5°C global warming scenario. IEA indicates that in order to reach net zero emissions globally by 2050, significant behavioural changes will be required, including a reduction in the growth of aviation activity.[121]

However, it may be politically challenging to introduce measures that curtail flying, particularly if they are not deemed to be fair to people. Measures such as frequent flyer levies, which only affect the small percentage of people who fly most often, or ticket taxes based on carbon intensity of seating class[122] may be more acceptable than less differentiated forms of carbon pricing.

Air traffic growth can also be curtailed by limiting airport expansion, but this may face political opposition particularly in emerging markets. Nevertheless, in other regions there are indications of growing opposition to airport expansion due at least in part to climate concerns.[123]

INTERVENTIONS REQUIRED

Given the mitigation options available and the associated barriers, this section considers what further action is needed to decarbonise the aviation sector. Appendix 2 provides more detail.

Demand-side interventions

Demand-side interventions involve changing consumer behaviour. This can be done through pricing or other mechanisms and via reducing airlines' fuel use, either through better operational efficiencies or air traffic management (ATM) systems. It is estimated that the overall cost of decarbonising the aviation sector by 2050 could be reduced by up to 60% if strong demand-side interventions are made at the same time as investment in new technologies.[124]

Reducing demand for air transport

Curbing demand growth for air transport is difficult and is resisted by the industry and by segments of the public. However, many academics, NGOs and policy makers argue that demand reduction measures should be pursued alongside technological solutions because the higher the demand growth, the greater the burden on new technologies and carbon offsetting[125] to reduce emissions.[126]

Interventions to reduce demand for air transport include:

1. **Use of carbon pricing:** for example, through air passenger taxes, to reduce demand for air travel and shift demand to High Speed Rail (HSR). Some campaigners propose a progressive form of taxation on air travel, such as a Frequent Flyer Levy.[127] To a lesser extent, carbon pricing can also be used to shift air freight traffic to sea or rail.
2. **Removal of jet fuel tax exemptions:** to make rail more cost-competitive with air travel
3. **Investment in HSR infrastructure:** potentially using any taxes raised from air passengers
4. **Collaboration among stakeholders to develop intermodal transport hubs**: this would need to include airports, rail operators and national and regional policymakers. France and Germany have already made progress in this area.
5. **Commitments from companies in all sectors to reduce business travel and avoid selecting premium class seating:** as part of their efforts to manage their own Scope 3 emissions.
6. **Commitments from companies in manufacturing sectors to reduce their supply chain emissions by switching from air transport to sea/rail freight for less time-critical components.**
7. **Improved information for consumers:** to build awareness of the carbon footprint of flying, particularly for premium seating, and consumer products delivered by air freight. More awareness would also build support for other policies to reduce demand for air travel, such as taxation.

Airline operational efficiencies

Some interventions that would spur airlines to boost operational efficiency include:

1. **Removal of jet fuel tax exemptions:** to raise the cost of jet fuel and prompt fuel savings.
2. **Provision of standardised fuel efficiency data to consumers at the point of ticket purchase:** this would allow consumers to compare the carbon performance of airlines on a specific route and encourage them to compete on fuel efficiency. Some travel companies are already beginning to provide such data, e.g. Skyscanner's Greener Choice Label.
3. **Improved disclosure of operational efficiency measures by airlines**: this would allow investors to determine the impact of such measures, relative to the airline's total emissions, and to establish whether there is scope for further operational efficiencies.

Air Traffic Management (ATM) improvements

Improvement and harmonisation of ATM aims to reduce airport congestion, minimise flight distances and optimise routing. It requires stakeholders such as governments, airlines, Air Navigation Service Providers (ANSPs) and airports to work together. There are already initiatives in place to reduce aircraft emissions through improved use of air space.

In the EU, the Single European Sky (SES) initiative and its research programme SESAR aims to modernise and harmonise ATM systems across Europe. Investment in the programme has been significant, but progress has been slow. This has led to frustration in the airline industry, particularly, because improved ATM will result in fuel cost savings.[128] The equivalent initiative in the US is Next Generation Air Transport System (NextGen). SESAR and NextGen are working together to harmonise airspace across the Atlantic.[129] A similar scheme, Seamless Asia Sky, is in development in the Asia-Pacific region with the support of IATA.

More widely, ICAO has an initiative in place, the Global Air Navigation Plan (GANP), with the aim of achieving a global ATM system.[130]

Progress in this area involves:

1. **Improved coordination between stakeholders:** to ensure that ATM is harmonised as soon as possible
2. **Leadership from national governments, IATA and ICAO:** to drive such coordination.

Supply side interventions

Supply-side interventions, in broad terms, involve stimulating investment in new low-carbon aviation technologies. The type of intervention required depends on the stage of development of each technology. For technologies that have already been proven and are close to market, the goal is to remove economic barriers, or in other words, to create some market certainty for the new product by enabling it to compete with the incumbent.

This can be done through carbon pricing, which levels the playing field for low carbon aviation technologies, through regulation, such as quotas/fuel mandates, or through voluntary purchasing commitments. For technologies in the early stages of development, the barrier to investment relates to the risk that the technology will fail or that there is no infrastructure in place for it to be implemented. Effective interventions in this case relate to risk-sharing, for example, through collaboration among stakeholders in R&D or public funding of demonstration plants and infrastructure.[131]

Many of the new lower-carbon technologies in the aviation sector are in the early stages of development. They either have a low level of technological readiness or have not entered the market at scale.[132]

Aircraft and engine technology

The development of newer, more efficient airframes and engines is already driven by existing market incentives, that is, airlines' demand for new technologies that reduce fuel costs.[133] Other interventions include:

1. **R&D funding:** public funding of R&D is essential to accelerate the development of new aircraft technologies. Many publicly-funded R&D programmes are already in place, such as the EU's Clean Skies 2 programme, the UK's Aerospace Growth Partnership and that of the Aerospace Technology Institute.
2. **Use of carbon shadow pricing by airlines:** aircraft upgrades require a significant capital investment for airlines. Currently, low carbon prices through for example the Carbon Offsetting and Reduction Scheme for International Aviation or the European Union Emissions Trading System (EU ETS)) and the absence of taxes on jet fuel make it difficult to demonstrate a business case for upgrades to more fuel-efficient aircraft. One way to accelerate fleet turnover and the adoption of new aircraft technologies is for airlines to incorporate carbon shadow pricing, based on expected future carbon prices, in their financial decision-making.[134]
3. **Role of lenders:** fleet upgrades could be accelerated if airlines' cost of capital is linked to the fuel efficiency savings of new aircraft. Financial institutions active in the aviation sector could establish an initiative similar to the Poseidon Principles put in place by shipping financiers, which links lending decisions to the carbon performance of vessels.
4. **Role of investors:** investors can hold aerospace companies accountable for their R&D spending. Since 2008, R&D as a percentage of commercial aviation revenue has fallen and in 2018 was around 5% for both Airbus and Boeing.[135]

Sustainable Aviation Fuels (SAFs)

SAFs, which include advanced biofuels and synthetic fuels, are considered to be the primary solution to aviation carbon emissions. This is because they are drop-in fuels, which can be used with existing aircraft and engines, and many are market-ready.

In particular, SAFs are seen as the key abatement option for emissions from long-haul flights, which are unsuited to electric batteries or hydrogen technologies. However, production and use of SAFs need to be scaled up significantly in the next decade. A number of interventions have been identified to overcome the challenges associated with increasing the use of SAFs. In the short and medium term, these mainly involve developing niche SAF markets through practical coordination between a small number of stakeholders and countries, while at the same time developing stringent sustainability standards for SAF biofuels.

In the longer term, the emphasis will shift to international regulation to create a full-scale market for SAFs. This could occur, for example, through carbon pricing[136] or fuel mandates.[137]

When considering the role of SAFs, particularly biofuels, in decarbonising aviation, it is important to take full account of the associated impacts, not only in terms of total life cycle emissions but also the potential wider sustainability effects. Biofuels emit similar levels of CO_2 during combustion to conventional jet fuel but they absorb CO_2 during the feedstock growth phase, which can compensate for these emissions.

However, biofuels require additional energy use during production and may also result in emissions through deforestation or other land use changes, either directly or indirectly. Thus, depending on the feedstock and conversion pathway used, life-cycle emissions savings from biofuels can currently range from 26% to 94%.[138]

In terms of wider sustainability, biofuels can also lead to increased use of fertilisers and pesticides, biodiversity loss, and soil degradation. They may also cause adverse effects on food security, water systems and local communities. IEA indicates that biofuel policies need to include stringent sustainability criteria and recommends the use of third-party certification.[139] The Roundtable for Sustainable Biomaterials (RSB) is one such certification body that is well-regarded by NGOs and policy makers.

Sustainability concerns have led to the development of so-called advanced biofuels, such as those produced from household and industrial waste, agricultural and forestry residues, high yield energy non-food crops grown on marginal land, such as miscanthus and carinata, and algae.

Technologies to convert feedstocks to advanced biofuels are at various stages of development. Recent IEA analysis indicates that there will be enough sustainably-produced feedstocks to meet the biofuel requirements set out in its Sustainable Development Scenario, provided measures are taken to enable advanced biofuels to make a major contribution. ATAG, concludes that there will be sufficient availability of sustainable biofuels to meet its long-term goal, based on work performed by the World Energy Forum's Clean Skies for Tomorrow project.[140]

Synthetic fuels are an alternative to biofuels that have the potential for net-zero emissions and do not face the same sustainability issues as biofuels, though these are still considerably more expensive than biofuels (see Appendix 2).

Short-term interventions

1. **SAF fuel mandates through airport coordination or individual country action:** This involves cooperation between a small number of countries, supported by airports, to impose fuel mandates requiring that a certain proportion of jet fuel purchased at an airport be SAF.[141] Having a number of airports involved minimises the risk that they will lose business through rerouting to refuel at another airport where costs are lower. Similarly, individual countries can set fuel mandates, involving low SAF blending percentages, with minimal risk of leakage or competition issues.

   Norway, for example, has such a policy in place, which requires that by 2020, 0.5% of the fuel sold for use in both domestic and international aviation is advanced biofuel. This is set to increase to 30% by 2030. The EU is currently considering a similar policy as part of its 'ReFuelEU Aviation' initiative.

2. **Public funding of new SAF plants:** The UK government is providing grant funding for a new SAF project, which will be a joint venture between Velocys, British Airways and Shell. Government support could potentially be funded through the recycling of any taxes on airline tickets or jet fuel.
3. **Government support for new SAF technologies, including Carbon Capture Utilisation and Storage (CCUS) technology combined with SAF production:** Financial incentives are already in place for CCUS in the US, and Velocys has announced plans to integrate CCUS into its biofuel production facility in Mississippi. Sustainable Aviation UK[142] has called for similar incentives to support the development of CCUS clusters in the UK.
4. **Coordination on SAF sustainability standards:** SAF should be certified by sustainability certification standards against robust environmental, social and economic sustainability criteria to ensure that production, processing and consumption is sustainable. ICAO has SAF sustainability standards in place, but they are not considered sufficiently robust.[143] Ongoing cooperation between stakeholders is required to agree to suitable standards. An example of a best-in-class certification standard for aviation biofuels is the Roundtable for Sustainable Biomaterials (RSB).
5. **New consumer products:** Airlines can develop 'Green Ticket' or 'Advanced Offsetting' options, which would involve consumers paying a premium to cover the cost of using SAF on the flight. This could replace traditional voluntary offsetting, which instead of reducing aviation emissions, reduces emissions or produces negative emissions in other sectors. Air France-KLM, Lufthansa and Finnair already have such initiatives in place.

Medium-term interventions

SAF production will need to be scaled up significantly in the medium term. By 2040, SAF will account for 25% of aviation's fuel demand, under the IEA's Sustainable Development Scenario.[144] This is significantly greater than the capacity of SAF production plants in the pipeline. Potential interventions include:

1. **Partnerships with the finance industry:** Financial institutions can provide venture capital to increase investment in SAF production facilities.
2. **Expansion of SAF fuel mandates to more airports/countries:** Scaling up SAF fuel mandates could focus on the busiest airports, as around 5% of airports host 90% of global air traffic. This would likely require coordination by ICAO to ensure that a level playing field is maintained between airlines and airports.
3. **Procurement commitments and stakeholder alliances:** To establish a SAF market and reduce production costs. Some ways this could be accomplished include:
   i. Airlines forming consortia with oil producers to accelerate the development of SAFs, allowing each to work towards their climate targets.
   ii. Airlines committing to buying SAFs from producers at an agreed price through off-take agreements.
   iii. Buyer alliances forming to make joint purchase commitments from SAF producers. These could include travel agencies or corporates wishing to reduce their carbon footprint from business travel e.g. the SAF producer, SkyNRG's 'Board Now' initiative
   iv. Other stakeholder alliances, such as the World Economic Forum-led Clean Skies for Tomorrow Coalition, which brings together stakeholders across and beyond the aviation value chain to accelerate the transition to SAF, e.g. through investment funds and the establishment of tradable SAF credits.[145]
4. **Reallocation of biofuel subsidies from road to air transport:** Given that road transport has more decarbonisation options, governments could ensure that aviation is given first priority for biofuels. This may be done by providing subsides for SAF production instead of biofuels for road transport.

Long-term interventions

In the long term, aviation needs to achieve net zero emissions, which will require full scale adoption of SAF at least on long-haul flights. This may involve:

1. **Use of zero-emission fuel mandates or carbon pricing to grow the SAF market:** this will require regulation at an international level through ICAO. Any carbon price would need to be sufficiently high to ensure a switch from conventional jet fuel.
2. **Full scale investment in SAF plants:** this could be accelerated through government support to convert traditional refineries into SAF facilities.
3. **Certification for use of 100% advanced biofuels, to replace the current blending ratio limits.**[146]

Alternative propulsion technologies

Alternative propulsion technologies include battery electric and hydrogen technologies, but these are not yet ready for aviation use. In addition to technology constraints, they also face economic barriers such as the cost of renewable energy for hydrogen production as well as infrastructure hurdles, such as the lack of recharging facilities. Potential interventions required to scale them up include:

Short-term interventions:

1. **Government funding of R&D for electric aircraft:** Although both Airbus and Boeing have invested in electric and hybrid electric projects the expectation is that, post-coronavirus, R&D in these technologies will rely more heavily on government funding. This could potentially be financed via air passenger taxation.
2. **Procurement of electric aircraft to support market niches:** Governments could provide support to purchase electric aircraft on certain short-haul routes, say for services to off-shore islands to enable new technology to be tested in niche markets. This can be later extended to other short-haul routes particularly where modal shifts are not possible and where strong climate targets have already been set, such as in Norway.
3. **Collaboration among stakeholders:** To develop the market for new hydrogen technologies[147]

Medium/Long-term interventions:

1. **Government support for infrastructure:** Electric and hydrogen technologies will require new recharging/refuelling facilities in airports and new distribution systems, which will likely need public funding.
2. **Financing of new aircraft:** Electric and hydrogen technologies require large investments in new types of aircraft. This could be accelerated by public-private funding or other alternative funding models.

BOX 4.2: THE UNIQUE ROLE OF CARBON OFFSETTING IN THE AVIATION SECTOR

Aviation is recognised as being one of the hardest sectors to decarbonise because of the high costs involved and the low technological readiness of potential solutions. As a result, carbon offsetting is used as part of the sector's mitigation efforts. Offsetting involves airlines purchasing emissions reductions or removals from other sectors with lower decarbonisation costs to compensate for aviation emissions. Airlines may purchase carbon offsets for **compliance** purposes, that is, to cover their obligations under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) or for **voluntary** purposes, that is, to meet their own emissions reductions targets.

Recently, a number of airlines announced net-zero emissions targets by 2050 or earlier which rely to some extent on offsetting. While the increased ambition in target-setting is welcomed, the use of voluntary offsetting needs to be examined from the perspective of both quality and quantity.

Quality: The key question in terms of quality relates to the effectiveness of an offset, that is, whether it actually reduces emissions or results in a real environmental benefit.

Quantity: A key concern is that airlines become over-reliant on offsetting to meet their emissions reductions targets at the expense of investment in mitigation measures required for aviation to be aligned with the Paris Agreement global temperature goals (see Section 3).

Implications for investors

Investors need to monitor airlines' offset strategies and demand greater disclosure around net emissions targets.[148] This will allow investors to establish whether airlines are being ambitious enough in their emissions reductions and whether offsets are only being used to compensate for residual emissions at a level consistent with those set by the sector's decarbonisation pathways.

Few of the recent net zero emissions targets announced by airlines provide details of how the target is split between gross and net emissions reductions. One exception to this is IAG (see Box 4.3).[149]

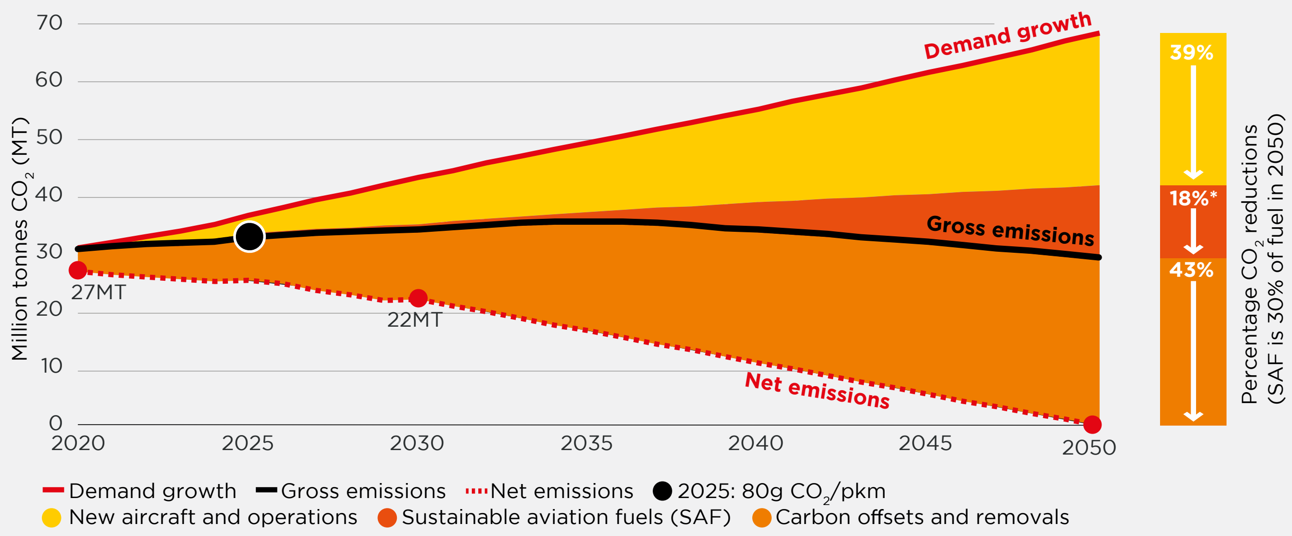
For a more detailed discussion of offsets, please see Appendix 3.

BOX 4.3: IAG CASE-STUDY

The advantage of having disaggregated data for airline net zero emission targets can be seen from IAG's disclosures. IAG provides an analysis of gross emissions to 2050 and the corresponding net emissions as shown in the chart. It does not, however, show the split between its reliance on carbon offsetting and removals, presumably carried out via Bioenergy with Carbon Capture and Storage, which would provide deeper insight.

Interestingly, the chart indicates that IAG's gross absolute emissions in 2050 will be only slightly lower than those in 2020 as a result of demand growth, so IAG's reliance on offsets and carbon removals will be significant. The implication is that if demand growth were to be limited, IAG's net zero emissions target could be largely met through SAFs, new aircraft and operational efficiency measures, without any need for offsetting or removals. This highlights a key problem: **the more the aviation sector grows, the greater its reliance on carbon removals and offsetting**.

Breakdown of IAG's net zero emissions targets to 2050 (IAG, 2019).



BOX 4.4: ASSESSING THE FULL CLIMATE IMPACT OF AVIATION, INCLUDING NON-CO_2 EFFECTS

Aviation's climate impact is not limited to CO_2 emissions. Flying at altitude has non-CO_2 effects such as contrail and cloud formation which are potentially significant, particularly in the short-term. It is estimated that when non-CO_2 impacts are taken into account, the overall warming effect of aviation is currently around three times that of its CO_2 impact alone.[150] However, unlike CO_2 effects, non-CO_2 impacts are not well understood scientifically and there is a high level of uncertainty around them. As a result, policy makers and industry have largely concentrated their mitigation efforts on aviation's CO_2 emissions, leaving non-CO_2 effects unregulated.

A number of technological and operational options have been identified to mitigate non-CO_2 effects, including developing more efficient aircraft engines to reduce particulate emissions and altering the altitude of flights to reduce contrail formation.

Given the potential scale of non-CO_2 effects, greater commitment is needed from stakeholders to address the issue. Governments need to increase scientific research funding, the aviation industry needs to continue researching mitigation options for non-CO_2 impacts and to commit to a solution delivery timescale, while investors need to engage with both industry and policy makers to accelerate progress. Without this, the full climate impact of aviation will not be reflected in decision making.

For a more detailed discussion of the non-CO_2 effects of aviation, please see Appendix 4.

APPENDIX 1:
OVERVIEW OF THE CARBON OFFSETTING AND REDUCTION SCHEME FOR INTERNATIONAL AVIATION (CORSIA)

Under CORSIA, airlines will be required to compensate for **growth** in their CO_2 emissions from **international aviation** from 2020 onwards through the purchase of carbon offsets. Effectively, this means that emissions from international aviation can continue to grow, but that net emissions are capped because the sector will fund emissions reductions in other sectors where mitigation is less costly (see Appendix 3 for further details on offsetting). CORSIA is due to run from 2021 until 2035. It is seen as a stop gap until new technology is developed to reduce emissions within the aviation sector itself.

While CORSIA has been hailed as the first global market-based instrument in any sector, it has also been widely criticised, with some arguing that it is susceptible to political interests.[151] The two key areas of concern relate to the scheme's level of ambition and its effectiveness.

AMBITION

The goal of CORSIA is to stabilise, rather than reduce, international aviation CO_2 emissions. This goal is unlikely to be achieved because adherence to the scheme is voluntary until 2027 and there are a number of exemptions. So far, only around half of the ICAO member states have agreed to participate in the early phases of CORSIA, and it is expected that over its full 2021 to 2035 lifespan, only 80% of the growth in international aviation emissions will be offset.[152] As CORSIA only applies to growth in international aviation CO_2 emissions, it is estimated that by 2030 it will cover only around 12% of overall domestic and international aviation emissions.[153]

A further limitation of CORSIA is that it does not cover non-CO_2 impacts, which need to be addressed to take account of the full climate impact of aviation (Appendix 4).

Some argue that CORSIA's current low level of ambition may increase over time, once its structure is fully in place.

EFFECTIVENESS

There has been much debate about the quality of the offsets that will be allowed for compliance under CORSIA, particularly in terms of whether they result in real emissions reductions; emissions should be 'additional' to what would have occurred anyway and not double counted elsewhere, and they should be permanent.[154] In addition, given the current low price of carbon offsets, it is unlikely that CORSIA will act as an economic incentive for the aviation industry to invest in R&D to develop technology solutions that lower emissions within the sector itself.

CORSIA AND COVID-19

When CORSIA was developed, the baseline was set as the average of 2019 and 2020 emissions in order to smooth out the effects of any unexpected shocks on emissions in a single year. However, a shock on the scale of COVID-19 was not anticipated, and the stability and integrity of the scheme could be implicated. Under the original rules, the sharp fall in aviation emissions in 2020 as a result of COVID-19 would have had the effect of reducing the baseline for CORSIA, thereby increasing airlines' obligations under the scheme in all future years to 2035.

The airline industry sought to have the baseline calculation revised so that it would be based on 2019 emissions only, arguing that otherwise some states may pull out of the voluntary phase of the scheme if compliance became too costly for their airlines.[155] This amendment to the baseline was agreed by ICAO in June 2020.[156] However, some NGOs argued that the baseline should have remained unchanged, at least for now.

A recent analysis by the Environmental Defence Fund indicated that changing the baseline to 2019 emissions only means that airlines are unlikely to have any offsetting obligations for at least the first three years of the scheme's operation, assuming it takes a number of years for air traffic to recover after COVID-19.[157]

CORSIA AND THE EU EMISSIONS TRADING SYSTEM (ETS)

Historically, the EU has set more ambitious targets than those of ICAO for aviation. Since 2012, aviation emissions have been included in the EU Emissions Trading System (EU ETS). This has given rise to tensions in international climate policy-making.

Originally it was intended that the EU ETS would apply to CO_2 emissions from **all** flights arriving at and departing from EU airports, but this was strongly contested by non-EU airlines at the time, particularly, those from the US and China. Consequently, the EU decided to '*stop the clock*' and to allow time for an alternative policy to regulate emissions from non-EU flights, namely to allow CORSIA to be developed. The EU has questioned the level of ambition of CORSIA and has stated that it will review its derogation decision in 2023, based on its assessment of its effectiveness. In this way, the EU seeks to drive progress on aviation emissions at an international policy level.

APPENDIX 2:
EXPANDED DISCUSSION ON MITIGATION OPTIONS TO REDUCE THE AVIATION SECTOR'S CLIMATE IMPACT

Mitigation measures within the aviation sector may be divided into demand-side and supply-side approaches. Demand for jet fuel can be reduced without relying on new technologies through measures such as:

- Managing demand for air transport, including passengers and air freight.
- Operational efficiency improvements in airlines.
- Improved Air Traffic Management (ATM).

Supply-side measures would reduce emissions through new technology, including:

- More fuel-efficient aircraft and engines.
- Use of Sustainable Aviation Fuels (SAFs), including advanced biofuels and synthetic fuels.
- Alternative propulsion technologies, such as electric or hydrogen-fuelled aircraft.

It is estimated that demand side measures have the potential to reduce emissions by around 15% compared to a business-as-usual scenario in 2050.[158] Supply-side measures, theoretically, have the potential to reduce emissions to zero by 2050. However, this would require significant scaling-up of investment and, furthermore, the timing and success of new technologies is uncertain.

DEMAND-SIDE MEASURES

Reduced demand for air transport

Air traffic has grown significantly in recent years. In the five years between 2013 and 2018, it has grown by over 6% per year on a tonne per kilometre basis. Reducing demand for air transport is challenging but it may be curtailed to some extent through:

- Modal shifts: shifting demand to lower carbon modes of transport, such as High Speed Rail (HSR) or sea, in the case of freight.
- Reduced demand for leisure travel: for example, through taxation or informational measures.
- Reduced demand for business air travel: for example, through video conferencing.

Modal shift

There is potential to shift both passenger and freight air traffic to other lower carbon modes of transport. Passenger traffic could be moved to HSR for some short-haul journeys. This could save an average of 80% in energy and carbon emissions per kilometre.

Overall, however, the scope to reduce aviation emission in this way is limited because medium and long-haul travel accounts for the majority of the sector's emissions and HSR's potential is limited to regions of high population density, such as Europe and Japan. The ETC[159] estimated that even if one third of all short haul passenger journeys were shifted to HSR, this would only reduce overall global aviation emissions by no more than 10% by 2050. This would require significant investment in rail infrastructure and the development of inter-modal transport hubs. It would also require rail fares to be made cost-competitive with airfares, for example, through the introduction of carbon pricing and taxes.

Carbon emissions from air freight represent around 20% of total air transport emissions.[160] There is potential to shift some air freight traffic to sea or rail, both of which are much more carbon-efficient modes of transport on a tonne per kilometre basis than air transport.[161]

However, this shift away from air freighting may be limited to markets where cargo is less time sensitive and has lower monetary value.[162] In such cases, cargo owners can be incentivised to shift to lower carbon modes through carbon pricing measures and as part of company commitments to reduce emissions in their supply chains.

Reduced demand for leisure air travel

Other demand side measures look at reducing demand for air travel completely, rather than substituting it with other modes. Consumer behaviour may be changed through pricing or informational measures.

However, higher prices may have only a moderate impact on the growth in air travel. Overall, it is estimated that a moderate tax on air fares has the potential to reduce global aviation emissions by around 7%. Imposing significantly higher taxes may not be politically feasible.[163]

Demand may also be curtailed by limiting airport capacity but this is unlikely to gain widespread political support, particularly in emerging economies whose aviation industries are still growing rapidly and in countries where there is potential for carbon leakage and competition issues if capacity is curbed unilaterally.

Consumer behaviour may be changed through campaigns to inform the public of the climate impact of air travel and to highlight ways to reduce emissions, such as carrying less luggage or taking only direct flights. Evidence to date has suggested that informational measures would have no more than a marginal direct impact on emissions reduction, but could be used as a complementary measure to gain support for other policy instruments such as taxation.[164]

However, the growth of the recent 'flight shame' movement suggests that consumer behaviour is changing, particularly in some European markets, and that informational measures may become more effective.

Reduced demand for business air travel

While leisure travel may be reduced to some extent through pricing, business travel is less price elastic. Instead, demand in this segment may be reduced through greater use of video conferencing. Business travel represents around one third of air passenger travel. The ETC[165] estimated that if 5% of business travel was switched to video conferencing, this would result in global aviation emissions reductions of less than 2% in 2050 compared with business as usual.

However, this estimate was based on flying behaviour before the coronavirus pandemic. The widespread use of video conferencing now suggests that there is greater scope to reduce emissions in this way. A 2020 study by Citi indicates that business travel could fall by 25% going forward as a result of virtual meetings and travel restrictions such as quarantining.[166] In this case, the overall impact on emissions reductions could be closer to 8%. (See Box 3.1 and Box 4.1 for further discussion of the impact of COVID-19 on flying behaviour).

In addition, emissions from the business travel segment can be reduced by incentivising corporate travellers to switch from premium class to economy class tickets. Premium class seating configurations take up more space on an aircraft than economy seating and as a result, emissions per premium class passenger can be at least double those per economy passengers on the same flight.[167] More recent research indicates that premium seating emits between 2.6 and 4.3 times more CO_2 than economy seating, depending on aircraft type, on a revenue passenger kilometre basis.[168]

OPERATIONAL EFFICIENCIES AND IMPROVED ATM

Operational efficiency measures adopted by airlines can reduce fuel demand. Such measures include: increasing the proportion of seats that are filled, called the payload factor; decreasing take-off weight by reducing extra fuel carried and other supplies on board; changing pilot behaviour to optimise the efficiency of flying and taxiing.

As fuel accounts for 20-30% of operating costs, airlines are motivated to adopt fuel efficiency measures for financial reasons aside from any goal to reduce emissions. However, recent research indicates that airlines may, at present, only be capturing 50% of the potential operational efficiencies available to them[169] so there is scope for further savings.

Nonetheless, the impact of operational efficiencies on reducing overall emissions is small; it is estimated that, together with improvements in Air Traffic Management (see below), they have the potential to reduce global aviation emissions by around 90Mt by 2050, or a reduction of around 5% compared to business as usual.[170]

Another way to reduce aviation fuel use is to improve and harmonise Air Traffic Management (ATM), which reduces airport congestion, minimises flight distances and optimises routing through GPS-based navigation systems. This requires stakeholders such as governments, airlines, Air Navigation Service Providers (ANSPs) and airports to work together, which makes progress slow.[171] Overall, the climate impact of improved ATM is low (see above).

Overall, demand-side measures could deliver a reduction of 15% in aviation emissions by 2050 compared to business as usual. While this is relatively modest, the advantage is that some measures can be adopted in the short term at low cost. However, it is clear that these measures alone will not be sufficient to reduce aviation emissions significantly and that supply-side measures are essential.

SUPPLY-SIDE MEASURES

Aircraft and engine fuel efficiency improvements

New aircraft and engine designs have the potential to deliver significant fuel efficiency improvements in the sector. From the early 2020s, incremental improvements to existing aircraft designs, such as using composite materials and new engines, could result in emissions reductions of 10-20%.

Further design improvements have the potential to reduce CO_2 emissions by 30-45% by 2050 compared with a business-as-usual scenario. Such improvements include open-rotor engines and laminar flow control, more radical redesign of aircraft such as blended wings, or improved airport infrastructure such as fixed electrical ground power units.[172]

The speed of deployment of new aircraft technologies will depend on the rate at which airlines upgrade their fleets. This in turn depends on an aircraft's lifespan, which for passenger aircraft may be over 20 years. An alternative to upgrading would be to retro-fit existing aircraft with new engine design, although the scope to reduce emissions here is only in the range of 6-9%.[173]

While redesign of existing aircraft and engine technologies will advance the sector some way towards decarbonisation, clearly new breakthrough technologies are also needed.

Decarbonisation technologies

Broadly speaking, decarbonisation technologies in the aviation sector fall into two categories:

- Sustainable aviation fuels (SAFs), including advanced biofuels and synthetic fuels.
- Alternative propulsion technologies, including full electrification, hybridisation and use of hydrogen.

Sustainable Aviation Fuels (SAFs)

SAFs are considered to be the primary solution to aviation carbon emissions, at least in the short to medium term. Unlike breakthrough technologies which require new aircraft designs, such as electrification, SAFs are 'drop-in' fuels that can be used with existing aircraft engines and fuelling infrastructure. They may also be blended with conventional jet fuel.[174] This is a considerable advantage given the 10-years or more duration of the production cycle for new aircraft and the subsequent 20-or-more-year duration of an aircraft's life. In particular, SAFs are seen as the key abatement option for emissions from long-haul flights which are unsuited to electric batteries or hydrogen technologies, as discussed below.

There are two types of SAFs: biofuels and synthetic fuels.

Biofuels

Biofuels are made from many different organic feedstocks. They have the potential to be a low carbon alternative to conventional jet fuel because, although they emit similar levels of CO_2 during combustion this is compensated for by the CO_2 previously absorbed as the plant was growing.

However, biofuels are not carbon neutral because energy is required during their production and conversion to fuel. It is therefore important when assessing the climate performance of biofuels or indeed any SAF to take a complete life-cycle approach.

Life-cycle emissions savings from biofuels compared with conventional jet fuels vary considerably depending on the feedstock, and can currently range from 26% to 94%.[175] In some cases, life cycle emissions from biofuels may even be higher than from conventional jet fuel.

Some first-generation biofuels faced issues around climate performance, or the emissions savings over the full life cycle of the fuel. In addition, these crop-based biofuels faced wider sustainability issues; competition with food production, in the case of biofuels derived from corn or sugarcane feedstocks, indirect land use impacts from palm oil production which can displace old growth rainforests, and effects on local communities.[176]

Efforts have been made by the EU, ICAO and the aviation industry itself to resolve some of these issues by establishing criteria around the climate performance and sustainability of biofuels, including land use, water use, energy use, and biodiversity.

This has led to the development of 'advanced biofuels', which aim to avoid the sustainability problems of their predecessors. Examples of 'advanced biofuels' include those produced from household and industrial solid waste, agricultural and forestry residues, algae and miscanthus, which is cultivated on marginal land.

While biofuels have been proven technically feasible, their use to date in the aviation sector has been minimal. The key challenge involved in large-scale use of biofuels has been characterised as a 'chicken-and-egg' problem.[177] In terms of production, current levels are small and producers are reluctant to scale up investment in the absence of greater market certainty. This limits economies of scale, keeping costs high.

Currently, there is only one production plant dedicated to SAFs. This is operated by World Energy in California and has an annual production equivalent to less than 0.01% of the jet fuel consumed globally each year.[178] Several other biofuel plants are in development or have recently been announced, but their combined production capacity still represents only a tiny fraction (<1%) of overall jet fuel demand.[179]

In terms of market demand, uptake is low. Airlines have few incentives to purchase SAFs because they are currently 50%-100% more costly than conventional jet fuel.[180] It is estimated that this cost difference would increase the cost of a long-distance economy flight by 10-20%, which given the highly competitive nature of the industry would be difficult to pass on to customers.[181] Further, neither CORSIA nor voluntary offset markets are likely to provide any incentive for airlines to replace fossil fuels with SAFs, given the current low cost of carbon offsetting in relative terms.

To date, a few airlines have flown a limited number of flights using a blend of biofuel and conventional jet fuel and several have signed off-take contracts with biofuel producers to secure SAF supply over the next 10 years. However, the projected use of biofuels falls well short of what is required to decarbonise the sector. To be on track to reach net zero emissions by 2050, biofuels need to account for 10-20% of all aviation fuels by 2030, according to McKinsey.[182]

In principle, 100% of the aviation sector's fuel demand could be met through sustainable biofuels by 2050, which would reduce carbon emissions in the sector by 63% compared to a business-as-usual scenario.[183] However, this would require:

- The equivalent of around 170 new bio-refineries to be built each year from 2020 to 2050 at a capital cost of between US$15 billion to US$60 billion per year.[184]
- Optimum levels of agricultural productivity and availability of land for feedstock cultivation.
- Aviation to be given priority over other sectors such as road transport, to use the limited supply of biofuel available in the economy.[185]

Synthetic fuels

Synthetic fuels, also known as synfuels, electro fuels, or 'power-to-liquid' fuels, are alternatives to biofuels. Synthetic fuels have the potential to have net-zero, or close to net-zero, life-cycle emissions and may be more sustainable than biofuels, as they do not rely on feedstocks.[186] Synthetic fuels may be produced using renewable electricity and water to produce 'green' hydrogen,[187] which is combined with CO_2 when it is captured directly from the air or from the point of source.

While they are technically viable, synthetic fuels are estimated to be several times more expensive than conventional jet fuel and so have not yet been commercialised. However, the costs for these fuels are expected to fall in the future in line with the cost of renewable energy and of capturing CO_2.[188]

There is scope to integrate Carbon Capture, Utilisation and Storage (CCUS) technology into production of SAFs, both biofuels and synthetic fuels. This involves taking CO_2 from the air through direct air capture and has the effect of reducing the life cycle emissions of the SAF or producing negative emissions. While this is costly, some biofuel producers in the US have already started to integrate CCUS into fuel production, largely thanks to financial incentives in place for this.[189]

In summary, due to significant barriers, interventions from policy-makers and other stakeholders will be essential to support SAF commercialisation.

Alternative propulsion technologies

Electric and hybrid-electric aircraft

Aircraft may be electrified in two ways: either through electric engines driven by a battery or by a hydrogen fuel cell which converts hydrogen stored in a tank into electricity. The key issue with these technologies is their low energy density compared with jet fuel. An aircraft would need to carry battery weight of around 30kg to replace one kg of jet fuel.[190]

Also, unlike fuel, battery weight does not burn off during the flight so additional energy is required to carry the weight for the entire flight. Given these energy density constraints, electric flights are only suitable for smaller aircraft on short-haul flights, at least in the short-to-medium term. In the longer term, with a breakthrough in battery technology there may be potential to extend the flight range and aircraft size.

Hydrogen fuel cell aircraft face similar challenges to battery driven aircraft. While hydrogen has an advantage over batteries in terms of weight, this is offset by its high volume, and hence the larger amount of storage capacity required. Unless there is a breakthrough in aircraft design which increases the energy storage capacity, the potential for hydrogen fuel cell aircraft will be limited to short-haul flights.

Currently, there are over 170 projects involving electrification of aviation in development, with some small electric aircraft for example with 20 seats aiming to reach the market in the early 2020s. There is potential for short-range electric aircraft to be cost competitive by the mid-2020s.[191]

However, in the short term, the scope for electric aircraft to reduce aviation emissions is limited. Even if all flights of 500 kms or less were fully electric, this would reduce current aviation emissions by only 5%.[192] If the range could eventually be extended to all passenger flights under 1,000 kms, for example, this could reduce overall aviation emissions by around 15%.[193]

Aside from the technological challenges of electric aircraft, there are also infrastructure barriers. Currently, airport infrastructure is based on the use of kerosene, so electrification will require investment in new facilities for recharging, in the case of battery aircraft, or refuelling, in the case of hydrogen fuel cell planes.[194] For hydrogen aircraft, a scaling-up of hydrogen production and distribution systems would be required.

While full electrification of aircraft is still some way off and limited in application, hybrid technology offers additional potential to reduce emissions. This involves aircraft being fitted with both traditional engines and electric engines which can be used during pushback and taxiing. It is estimated that electric taxiing has the potential to reduce fossil fuel consumption by around 4% on average per flight.[195]

In summary, the main challenges for electrified and hybrid electric aviation are technological readiness and infrastructure needs.[196] In addition the current market conditions, as a result of COVID-19 and low oil prices, are likely to present more barriers to their development. Recently, it was announced that Airbus and Rolls-Royce axed their hybrid-electric demonstrator project, EFan-X.[197]

Hydrogen combustion

Aside from using hydrogen in fuel cells to produce electricity, it may also be burned directly in hydrogen turbine engines to fuel an aircraft. Hydrogen, if produced from renewable energy, has the potential to eliminate carbon emissions because no CO_2 is emitted during the flight. However, it may have negative climate impacts due to the high levels of water vapour produced, which causes contrail and cirrus cloud formation. Flight altitudes would need to be lowered to reduce such effects.[198]

As hydrogen turbine technology has similar drawbacks to hydrogen fuel cells, primarily with regards to the need for a totally new fleet of aircraft with sufficient energy storage volume, the potential for this technology is limited to short haul flights until at least 2050.

Supersonic aircraft

Most of the new aviation technologies in development are focused on reducing emissions. However, some new technologies may exacerbate aviation's climate impact. Supersonic aircraft are of particular concern, due to their high fuel burn.

It is estimated that if widespread reintroduction of supersonic aircraft takes place in the 2030s, this could result in a significant increase in annual CO_2 emissions from the sector, equivalent to around 10% of the CO_2 emissions from aviation in 2018.[199] In addition, non-CO_2 effects may be greater for subsonic aircraft because they fly at higher altitudes.[200] Policy makers need to address these issues by setting new standards for supersonic aircraft emissions.

APPENDIX 3:
THE UNIQUE ROLE OF CARBON OFFSETTING IN AVIATION

Aviation is recognised as one of the hardest sectors to decarbonise because of the high costs involved and the low technological readiness of potential solutions. As a result, carbon offsetting is used as part of the sector's mitigation efforts. Offsetting involves airlines purchasing emissions reductions or removals from other sectors with lower decarbonisation costs to compensate for their emissions. In principle, offsetting is a cost-effective way of reducing emissions across the economy as a whole. In practice, however, there are key challenges to consider.

Broadly, the carbon market can be divided into **compliance** and **voluntary** products. On the compliance side, airlines are required to purchase 'allowances' under the EU Emissions Trading System (ETS), and from 2021, 'emissions units' under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). Together, the EU ETS and CORSIA cover only a small fraction of international and domestic aviation emissions. The former covers intra-Europe flights only, while the latter covers some of the growth in international aviation emissions post-2020.

Overall, it is estimated that by 2030 the two schemes will cover no more than around 20% of total aviation emissions globally.[201]

Aside from purchasing offsets for regulatory purposes, airlines buy offsets to meet their own voluntary targets. Recently, several airlines announced net-zero emissions targets by 2050 or earlier. These targets rely to a greater or lesser extent on offsetting.[202] While more ambitious target-setting is welcome, the use of voluntary offsetting needs to be examined from the perspective of both quality and quantity.

OFFSET QUALITY

Offsets can involve a variety of projects at different scales, such as renewable energy development, avoided deforestation or reforestation. The key question in terms of quality relates to the effectiveness of an offset, that is, whether it actually reduces emissions or results in a real environmental benefit. A high-quality offset is one that:[203]

- Is **additional** – representing an emissions reduction or removal which would not have taken place in the absence of a market for offset credits. This is difficult to demonstrate for certain projects, such as renewable energy development.
- Is **not over-estimated** – through inaccurate measurement of baseline emissions or failure to take account of indirect emissions such as by 'leakage' of deforestation to another area not covered by the project.
- Is **permanent** – that is, will not involve the emissions reduction/removal being reversed in the future for example through forest fires.
- Is **not claimed by another entity** – this relates to the issue of double-counting where another entity, such as a company or government, claims the offset as part of its own emissions reductions efforts.
- Does **not have adverse effects** in terms of wider sustainability or social issues.

There are a number of carbon-offset certifying organisations, such as The Gold Standard and The Verified Carbon Standard, which aim to ensure that the offset programmes they manage are of good quality. They do this using standard methodologies for measuring emissions reductions, regular monitoring of projects and use of offset registers. Nonetheless, there are still poor-quality offsets on the market.

Some of the ways that airlines can avoid low quality offsets include

- Carrying out adequate vetting of projects.
- Limiting offset purchases to certain low risk project types (e.g. industrial gas destruction projects).
- Avoiding old vintage offsets e.g. Clean Development Mechanism credits.
- Being cautious of low price offsets, which may sometimes, but not always, signal that they are non-additional.[204]

QUANTITY

Most commentators agree that there is a hierarchy in terms of emissions reductions. Airlines should aim first to reduce their own emissions, then those within the aviation value chain such as through SAF and Bioenergy with Carbon Capture and Storage (BECCS), and finally use offsets as a last resort to compensate for any residual emissions.

The concern however is that offsets can act as a 'perverse incentive', meaning that airlines may become over-reliant on offsetting as a way of meeting targets and avoid investing in solutions within the sector, thereby creating a risk of being locked in to existing aircraft technologies for decades to come.[205]

In addition, the widespread use of offsetting and net-zero emissions targets may distract policy makers from taking stronger policy action to reduce aviation emissions.

The question therefore is: what is a reasonable level of offsetting for airlines? This can be addressed by looking at the sector's decarbonisation pathways set out in Section 3. These pathways show the emissions reductions that are required within the sector, excluding the use of offsets, and the level of residual emissions to 2050 that are consistent with the Paris Agreement global temperature goals.

Thus, for an airline to be aligned with these goals, its **gross** emissions need to be consistent with these pathways and its use of offsetting should be limited to compensating for its residual emissions only. In other words, even if an airline has a net zero emissions target, **this needs to be disaggregated into a target for gross emissions and a target for net emissions. Few of the recent net zero emissions targets announced by airlines provide this split.** The exceptions to this are IAG and American Airlines (see case study in Section 4).

APPENDIX 4:
ADDRESSING NON-CO_2 IMPACTS

Aviation's climate impact is not limited to CO_2 emissions. Flying at altitude also has non-CO_2 effects which are potentially large, particularly in the short-term. Unlike CO_2 effects, non-CO_2 impacts are not well understood scientifically and there is a high level of uncertainty around them. As a result, policy makers and industry have largely concentrated their mitigation efforts on CO_2 emissions, leaving non-CO_2 effects unregulated. This needs to be addressed to take full account of the climate impact of aviation.

Aviation's non-CO_2 effects are caused by emissions of particles, water vapour and nitrogen oxides from jet aircraft exhausts, which freeze to form ice cloud contrails and contrail cirrus that affect atmospheric conditions. These non-CO_2 pollutants have an overall warming effect. In a 2020 paper, it is estimated that the overall climate impact of aviation is currently three times the impact of its CO_2 emissions alone.[206]

MITIGATION OPTIONS

A number of technological and operational options have been identified to mitigate non-CO_2 effects from aviation. Technological options include developing more efficient aircraft engines to reduce particulate emissions and introducing standards to limit emissions.[207] In addition, some SAFs may have lower particulate emissions than conventional jet fuel and may therefore have lower non-CO_2 impacts.

However, recent research suggests this benefit may only apply to pure SAFs rather than to fuel blends.[208] Battery electric planes are likely to have a favourable effect on non-CO_2 impacts, as they do not produce contrails.[209] In contrast, hydrogen technology may increase non-CO_2 effects due to the high level of water vapour produced during flight.[210]

Operational measures can also reduce non-CO_2 impacts from aviation. Air Traffic Management can be used to re-route traffic to reduce the time spent in airspace with high humidity, which increases non-CO_2 emissions.[211] However, such operational measures may involve greater fuel burn and CO_2 emissions, so there is some degree of trade-off between CO_2 and non-CO_2 mitigation. Altering the altitude of flights is another effective measure. A recent study found that a small proportion of flights cause the vast majority of contrail formation, so changing the altitude of less than 2% of flights could reduce 60% of contrail formation.[212]

FURTHER RESEARCH AND ACTION REQUIRED

More work is required to understand non-CO_2 impacts and to properly quantify them. One key piece of necessary work is the development of a metric to compare CO_2 and non-CO_2 impacts.

Unlike CO_2, non-CO_2 climate impacts are short-lived and localised, impeding comparison of the two effects. Some progress has been made in this area with the use of newer Global Warming Potential (GWP) metrics, such as the one known as 'GWP*', but challenges remain in finding a standard CO_2-equivalent multiplier that can be applied across different decarbonisation pathways.[213] Without such a metric it is difficult to assess potential mitigation strategies and any trade-offs between them.

Despite the lack of certainty over non-CO_2 emissions and the difficulties of expressing them in terms of CO_2 equivalents, there should be some 'headroom' built in to aviation carbon budgets to allow non-CO_2 impacts to be included at a later date based on the precautionary principle.[214]

Given the potential scale of non-CO_2 effects, greater commitment is needed from stakeholders to address the issue. Governments need to increase funding of scientific research, the aviation industry needs to continue researching mitigation options and commit to a timescale for delivering solutions, while investors need to engage with both industry and policy makers to accelerate progress.

ENDNOTES AND ADDITIONAL REFERENCES

1. Graver, et al 2019
2. IEA, 2020b
3. Graver, et al 2019; Pidcock, et al 2016
4. UK Parliament POST, 2020.
5. Lee, et al, 2020
6. PRI, 2020
7. This is based on information disclosed in International Airlines Group's Annual Report 2019 (IAG, 2019). IAG is one of the few airlines that provide comprehensive Scope 3 data. For certain airlines, some emissions from jet fuel combustion are reported under Scope 3 emissions, where they relate to franchise operations. For simplicity, in the pie chart displayed all jet fuel combustion emissions are included in Scope 1.
8. Transition Pathway Initiative (TPI), 2019.
9. Many airlines report CO_2 per Revenue Passenger Kilometre (RPK) that is, the number of revenue-earning passengers multiplied by the distance carried, while others use CO_2 per Revenue Tonne Kilometre (RTK) to take account of both passengers and freight transported. A minority use CO_2 per Available Seat Kilometre passenger, which reflects the available seating capacity rather than the passengers carried, and therefore does not indicate how well an airline uses its capacity,
10. Graver, et al., 2019
11. ICAO, 2018
12. Graver, et al., 2019, 2020
13. ICAO, 2019
14. Graver, et al., 2019; Zheng, 2019.On a per capita basis, the countries with the highest aviation emissions in 2018 were Singapore, Finland, Iceland, Australia and the UK (ICCT, 2019). The analysis includes an adjustment to distinguish between residents travelling abroad and foreign visitors travelling to that country.
15. IEA, 2020c
16. Graver et al, 2020.
17. ICCT, 2020b.
18. Graver et al, 2020.
19. Graver et al, 2020.
20. There are other apparent differences between the two sources. For example, IEA indicates that its data do not include emissions from dedicated freighters (IEA, 2020c), which represented around 8% of total aviation emissions in 2018.
21. ICAO, 2019
22. IEA, 2019
23. Historically, IEA has provided aviation emissions data on a well-to-wheel basis. While not explicit, its WEO 2019 and ETP 2020 (IEA, 2020c) appear to present CO_2 emissions data on a tank-to-wheel (i.e. direct) basis.
24. While not explicit, the assumptions used in the ETP 2020 to model the impact of COVID-19 in the Stated Policies Scenario appear consistent with those used in the later-published WEO 2020: air passenger activity will recover to 2019 levels by 2024, but lasting changes in flying behaviour will mean business travel will be 10% lower than assumed in pre-COVID-19 projections (see Box 4.1 for further discussion of estimated impacts as set out in the WEO 2020).
25. ICAO provides projections for direct emissions from international aviation, only. For comparison with IEA data, ICAO data have been adjusted to include domestic aviation emissions, based on ICAO's assumption that the relative contributions of international and domestic aviation to total aviation emissions will remain stable between 2015 and 2050, at 65% and 35%, respectively (ICAO, 2019). For simplicity, emissions growth is assumed to be linear between 2015 and 2050.
26. Source for IEA ETP (2020) data: IEA, Global CO_2 emissions reductions in aviation by abatement measure in the Sustainable Development Scenario relative to the Stated Policies Scenario, 2019-2070, IEA, Paris https://www.iea.org/data-and-statistics/charts/global-co2-emissions-reductions-in-aviation-by-abatement-measure-in-the-sustainable-development-scenario-relative-to-the-stated-policies-scenario-2019-2070. Note the aviation emissions figure for 2019 is lower than that provided in other IEA sources.
27. EASA, 2019
28. The International Maritime Organisation is the equivalent UN organisation for shipping.
29. ICAO's regulatory responsibility for international aviation emissions is contested by some NGOs. Under the Kyoto Protocol in 1997, countries were requested to work through ICAO to reduce aviation emissions, but there is no reference to ICAO in the later Paris Agreement and ICAO does not have legal powers to enforce any policies it puts in place. (https://www.transportenvironment.org/newsroom/blog/planes-and-ships-cant-escape-paris-climate-commitments)
30. EU member states, plus Iceland, Liechtenstein and Norway.
31. Green Air, 2019
32. Transport & Environment, 2018b.
33. Most regions have their own airline association, such as Airlines for Europe (A4E), Airlines for America (A4A) and the Association of Asia Pacific Airlines (AAPA), which in turn are members of IATA. Also, there are some national aviation trade bodies active in climate policy, such as Sustainable Aviation UK.
34. This target also applied to domestic aviation. IEA, 2020.
35. IATA, 2020b; IATA, 2020c.

36. While this fuel efficiency target is expected to be met globally, efficiency improvements vary across regions. A 2020 analysis by ICCT indicates that many US airlines are set to miss this fuel efficiency target as a result of operating older fleets than the industry average (Graver, 2020).
37. IEA, 2020
38. IEA, 2020
39. IATA's long-term goal set in 2009, which applies to international aviation only, is based on net emissions reductions, so includes the use of carbon offsets purchased from other sectors (see Section 4). IATA does not provide an equivalent gross emissions target which could be compared with the decarbonisation pathways set out in Section 3.
40. ETC, 2019
41. Early, Catherine. 2020
42. ICAO, 2020a
43. IEA, 2017
44. Larsson, et al., 2019
45. ICAO, 2019
46. Airlines are also permitted to use SAFs to meet their CORSIA obligations, but there is currently little incentive to do so, given the cost differential between SAFs and carbon offsets.
47. IEA, 2020. The IEA states that 'many analysts agree that the goal [of CORSIA] is not aligned with the Paris Agreement of the UNFCCC, for which climate neutrality (and not carbon-neutral growth from a given year) needs to be achieved as soon as possible in the second half of the century to minimise catastrophic changes in our climate' (IEA, 2020). Moreover, in practice, not all growth in international aviation emissions will be covered by CORSIA because not all ICAO member states will opt to participate in the scheme's voluntary phase, so net emissions from international aviation are, in fact, likely to continue to rise after 2020.
48. ICAO, 2020
49. Graver, et al., 2019
50. ICCT, 2020
51. EPA, 2020
52. Grist, 2020
53. Ceres, 2020
54. International Carbon Action Partnership, n.d.
55. For clarity, these net zero targets are more ambitious than the CORSIA target; the aim of CORSIA is to cap net emissions from international aviation at 2020 levels (i.e. to achieve 'carbon-neutral growth' from that date onwards), rather than move towards net zero emissions (i.e. 'carbon neutrality').
56. Green Air, 2020c
57. For example, United Airlines has invested $30 million in a company that converts waste to jet fuel (https://hub.united.com/entertainment-for-all-2646885831.html) and KLM Royal Dutch Airlines has signed a 10 year off-take commitment with a European biofuel company, which is due to start production in 2022 (https://news.klm.com/klm-skynrg-and-shv-energy-announce-project-first-european-plant-for-sustainable-aviation-fuel/).
58. Sustainable Aviation, 2020
59. Rolls-Royce, 2020
60. For example, Sweden is one of several European countries that has introduced an aviation tax, while Norway has a fuel mandate in place since January 2020. This mandate requires that all jet fuel sold in Norway includes 0.5% advanced biofuels, including waste and vegetable oils, but excluding palm oil. The requirement applies to any aircraft that is refuelled in the country.
61. IEA, 2020c; Graver et al, 2020
62. UK Parliament POST, 2020
63. Initiatives such as the 'Count Us In' project, launched in 2020, may contribute to changing consumer preferences around flying. The project encourages individuals to commit to reducing their carbon footprint through a range of steps including flying less (https://www.count-us-in.org/project/).
64. McKinsey & Company, 2020 p. 4
65. Financial Times, 2020
66. WEO, 2020
67. Gössling, et al., 2019
68. Airbus. 2018
69. For example, airports at high elevations are adversely affected by high temperatures. Changes in the surface air density as a result of high temperatures may restrict the maximum take-off weight of departing aircraft. In a 2015 study, researchers at Columbia University predicted that by 2050 there could be four times as many weight restriction days at the most at-risk airports in the United States (Coffel and Horton, 2015).
70. ICAO, 2019
71. ICAO, 2019
72. IEA, 2020c. The SDS replaces the B2D Scenario, used in earlier IEA publications. The SDS incorporates the B2D temperature goal with some wider sustainability goals. Under the SDS, global net zero CO_2 emissions are reached by 2070. If they were to remain at net zero beyond 2070, this would correspond to limiting the global temperature rise to below 1.8°C by 2100, with a 66% probability. If CO_2 emissions were to fall below net-zero after 2070, through carbon removal, then this could increase the possibility of reaching 1.5°C by 2100 (IEA, 2020).
73. The Science Based Targets Initiative (SBTi) also uses this approach in its Sector Based Method.
74. This pathway has been estimated using, as a starting point, 2018 emissions from jet fuel combustion of 918 Mt (Graver, et al., 2019).

75. IEA data are based on direct emissions from aviation, that is, emissions from jet fuel combustion. In line with the IPCC guidelines, no CO_2 emissions are assigned to the combustion of biofuels, on the basis that the equivalent emissions are absorbed during the plant growth phase. Any emissions arising from the production of biofuels are assigned to either the agricultural sector or the 'other energy transformation' sector. Implicitly, the combustion emissions from synthetic fuels are treated in the same way as those from biofuels. Also, the IEA notes that any emissions arising from the production of hydrogen or the capture of CO_2 are accounted for under 'other energy transformation' (IEA, 2020c).
76. IEA, 2020c
77. It is worth noting that as this pathway is based on an AEC approach, it does not take account of the high cost of decarbonising aviation compared with other sectors, and so a 1.5°C pathway for aviation based on a Sectoral Decarbonisation Approach may allow for a comparatively higher level of emissions for 2050 than 230Mt.
78. For clarity, the emissions projections based on ICAO's various fuel efficiency scenarios, presented in Figure 2.8, have not been included in this graph, as there are no corresponding B2D/SDS or 1.5ºC emissions pathways provided by ICAO.
79. Source for IEA ETP (2020) data: IEA, Global CO_2 emissions reductions in aviation by abatement measure in the Sustainable Development Scenario relative to the Stated Policies Scenario, 2019-2070, IEA, Paris https://www.iea.org/data-and-statistics/charts/global-co2-emissions-reductions-in-aviation-by-abatement-measure-in-the-sustainable-development-scenario-relative-to-the-stated-policies-scenario-2019-2070. Note the aviation emissions figure for 2019 from this source is lower than that provided in other IEA sources.
80. IEA modelling covers the energy sector only, that is, emissions from the combustion of fossil fuel including from transport and from industrial processes. It does not cover emissions from agriculture, forestry and other land use (AFOLU). Thus 'net zero' in an IEA context means net zero emissions within the energy sector, such that any residual positive emissions need to be offset by negative emissions from Bioenergy with Carbon Capture and Storage (BECSS) and Direct Air Capture (DAC) only, rather than by nature-based negative emissions, which are accounted for separately in the AFOLU sector and not modelled by IEA.
81. IEA, 2020d.
82. IEA estimates that 25% of passenger flights are for business purposes, 50% are for personal leisure and 25% are for visits to friends and family.
83. ETC, 2019
84. ETC, 2019
85. ETC, 2019
86. Adapted from ETC (2019). Note that the percentages shown in this column represent the individual potential of each mitigation option to reduce CO_2 emissions relative to future business-as-usual levels and therefore the percentages do not sum to 100%. Further, these mitigation options do not take into account the non-CO_2 effects described in Box 4.4 and Appendix 4.
87. The figure of 15% shown for the total mitigation potential from demand-side levers is based on ETC's demand management scenario (ETC, 2019). This does not include the full potential of all demand-side levers in the column to the left. As a result, the sum of the percentages provided for each of the individual levers is greater than 15%.
88. It is difficult to quantify the potential CO_2 emissions savings, but they are likely to be small given that, currently, less than 20% of aviation emissions come from freight transport, and that the scope to shift to other modes of transport will be limited to non-time critical freight.
89. See: https://www.poseidonprinciples.org/
90. Estimates for the mitigation potential of biofuels vary. ETC estimates that, in principle, biofuels have the potential to mitigate 100% of aviation CO_2 emissions by 2050 (ETC, 2019). However, ICAO states that even if all of the aviation sector's fuel demand was replaced with sustainable biofuels by 2050, life cycle emissions would be reduced by 63% versus business as usual (ICAO, 2019). This is because there are limits to the availability of sustainable biofuel and life cycle emissions savings from using biofuels vary considerably depending on the feedstock used and the fuel conversion process.
91. See: https://lufthansa.compensaid.com/#belief
92. See: https://www.sustainableaviation.co.uk/wp-content/uploads/2020/02/SustainableAviation_FuelReport_20200231.pdf
93. IEA, 2020c
94. This corresponds to the decarbonisation pathway 'IEA ETP (2020) SDS' shown in Figure 3.1, but is extended here from 2050 to 2070.
95. In the ETP 2020, the 'technology performance' category includes emissions reductions from operational efficiency improvements, that is, through airline practices and improvements in air traffic management, in addition to emissions reductions from new aircraft and engines. The ETC analyses those two categories separately but given that operational efficiency improvements have only a small potential to reduce emissions relative to other measures, the difference between the IEA and ETC approaches does not have a significant impact overall.
96. IEA, 2020c
97. IEA, 2020c
98. UK Parliament POST, 2020
99. Larsson, et al., 2019

100. Larsson, et al., 2019
101. IATA, 2020
102. WEO, 2020d
103. IATA, 2020a
104. Carbon Brief, 2020; Carbon Market Watch, 2020
105. Green Air, 2020
106. (ICCT, 2020a)
107. Transport & Environment, 2020
108. Transport & Environment, 2020; Aviation Environment Federation, 2020
109. ICCT, 2020a
110. Aviation Environment Federation, 2020
111. New Economics Foundation, 2020
112. IEA, 2020c
113. IEA, 2020d
114. Under the Chicago Convention on International Civil Aviation (1944) it is forbidden to tax fuel in tanks of arriving aircraft. ICAO extended the restriction in 1993, prohibiting tax on any fuel taken on board for use during a flight. It has been argued that the ICAO restriction could have been removed, but that there was no appetite for this amongst ICAO Member States and instead the CORSIA scheme was developed (Larsson, et al., 2019). The restriction on jet fuel taxation also extends to some 'next best' policy options such as carbon-related landing charges or a per-plane tax based on aircraft weight, which would incentivise airlines to fly full planes (Larsson, et al., 2019).
115. Larsson, et al., 2019
116. European Commission, 2019
117. Euractiv, 2019
118. Hemmings, et al., 2020; Transport & Environment, 2020
119. Transport & Environment, 2020
120. Larsson et al., 2019
121. IEA, 2020d
122. Graver et. al., 2020
123. Darby, 2019
124. ETC, 2019
125. For example, the UK's Committee on Climate Change recommends that, in order to meet the country's national target to reach net zero emissions by 2050, UK airline passenger demand should not grow more than 25% between 2019 and 2050 (Committee on Climate Change, 2019).
126. Bows-Larkin, 2015; ETC, 2019; Transport & Environment, n.d.
127. a free ride, n.d.
128. Green Air, 2020a; SESAR, 2018
129. SESAR, 2018a
130. ICAO, 2019
131. Victor, et al., 2019
132. Victor, et al., 2019
133. ETC, 2019
134. McKinsey & Company, 2020
135. Graver, et al., 2020.
136. The IEA's ETP 2020 indicates that at a carbon price of USD $150/tonne, SAFs begin to be cost-competitive with conventional jet fuel (IEA, 2020).
137. The primary sources for this section are a study by Victor et al, 2019 (commissioned by the UK's Department for Business Energy and Industrial Strategy and supported by the Energy Transitions Commission) and a recent aviation report by McKinsey and Company (McKinsey & Company, 2020).
138. EASA, 2019. However, in some cases, life cycle emissions from biofuels may even be higher than those from conventional jet fuel.
139. IEA, 2020c
140. ATAG, 2020
141. Note, however, that fuel mandates may have negative impacts if they are not properly designed. Volumetric mandates in particular, which seek to maximize the volume of SAF utilized rather than the carbon abated, should only be considered where sufficient sustainability standards are put into place. Failing this, an increase in demand for biofuels may outpace the availability of sustainable feedstocks and result in unsustainable practices or feedstocks used to meet demand, leading to only marginal or negative emissions benefits.
142. Sustainable Aviation UK, 2020
143. Under CORSIA, airlines are permitted to use 'eligible' SAFs to meet their obligations. The sustainability criteria for these fuels have been criticised by NGOs. For example, alternative fuels that provide only a 10% reduction in life- cycle emissions are eligible and as yet, there are no rules in place to cover issues such as biodiversity, water rights or food security (T&E, 2019).
144. IEA, 2020c
145. WEF, 2019
146. Technically, SAFs can be blended with conventional jet fuel in any ratio between 0% and 100%, but currently the maximum blending ratio certified for SAFs is 50%, depending on the type of SAF. In the long term, to enable full scale-up of SAFs the blending ratio limits will need to be removed.
147. For example, the Clean Sky 2 Joint Undertaking, a public-private partnership between the EU and the aeronautics industry, is working with another European public-private partnership, the Fuel Cells and Hydrogen 2 Joint Undertaking, to determine the actions required to develop hydrogen technologies for aviation (Green Air, 2020d).
148. TPI, 2020
149. Also, see the Climate Action 100+ Sector Strategy: Aviation – Case Studies for a discussion of the American Airlines target, which provides a similar breakdown between gross and net emissions reductions.
150. Lee et al, 2020

151. UK Parliament POST, 2020
152. Green Air, 2020b
153. Larsson, et al., 2019
154. In 2020, ICAO issued an initial list of approved carbon offset projects, which includes some Clean Development Mechanism projects, which have issues around additionality (Carbon Market Watch, 2020a).
155. IATA, 2020a
156. ICAO, 2020
157. Green Air, 2020b
158. ETC, 2019
159. ETC, 2019
160. Graver, et al., 2019
161. IPCC, 2014
162. IPCC, 2014
163. ETC, 2019
164. Larsson, et al., 2019
165. ETC, 2019
166. Financial Times, 2020
167. ICAO, 2018
168. Graver, et al, 2020
169. McKinsey & Company, 2020
170. ETC, 2019
171. McKinsey & Company, 2020
172. ETC, 2019
173. ETC, 2019
174. Currently, biofuel blending ratios of between 10% and 50% are certified for commercial use depending on the feedstock. Use of 100% biofuels have been tested in controlled environments.
175. EASA, 2019
176. A fuller discussion of the sustainability issues related to SAFs is provided by the Roundtable on Sustainable Biomaterials (RSB) (RSB, 2020)
177. McKinsey & Company, 2020
178. Note that there are some other biofuel plants that produce biofuel for aviation on an ad hoc basis or as a by-product.
179. The availability of biofuels may also be affected by policy decisions. For example, the EU decision to exclude biofuels derived from palm oil from renewable transport targets and to eliminate subsidies related to palm oil will limit the availability of biofuel for road transport, which may have a knock-on effect on prices of biofuels in other markets such as aviation.
180. ETC, 2019
181. ETC, 2019
182. McKinsey & Company, 2020
183. ICAO, 2019
184. This assumes growth in capacity is linear. Alternatively, investment could be lower in earlier years and ramp up by 2035 (ICAO, 2019).
185. ETC, 2019
186. Larsson, et al., 2019
187. Synthetic fuels can also be based on ‘grey’ or ‘blue’ hydrogen, but these are less attractive from a climate perspective. Grey hydrogen is produced using natural gas, which results in significant CO_2 emissions. Blue hydrogen is cleaner than grey, as the CO_2 is captured and either stored or used for other purposes.
188. McKinsey & Company, 2020
189. Sustainable Aviation, 2020
190. Larsson, et al., 2019
191. Victor, et al., 2019
192. Larsson, et al., 2019
193. This broad estimate is based on ICCT data (Graver, et al., 2019) which indicates that the proportion of passenger aviation emissions arising from flights of 1,000km or less was 18% in 2018 and that passenger transport accounts for around 80% of total aviation emissions.
194. Victor, et al., 2019
195. Safran, n.d.
196. ETC, 2019
197. Airbus, 2020
198. Larsson, et al., 2019
199. ICCT, 2019
200. Transport & Environment, 2018b
201. This broad estimate is based on the assumptions that (1) CORSIA will cover around 12% of total domestic and international aviation emissions in 2030 (Larsson, et al., 2019) (2) the proportion of global aviation emissions covered by the EU ETS remains at the current level of around 7% (based on 2018 data (Graver, et al., 2019) and (EASA, 2019)) and (3) no credit is given to airlines for emissions that fall within both the EU ETS and CORSIA. The rules around how the two schemes will interact have not yet been finalised, but some credit is likely. If credit is given this would imply that the EU ETS and CORSIA together will cover less than 20% of total aviation emissions in 2030.
202. In addition, offsets may be purchased by airline customers either directly or through the airline itself to offset their flight emissions. However, uptake of these is generally very low, typically less than 1% of an airline’s customers.
203. The Stockholm Environment Institute (2019) provides an in-depth discussion of these issues and useful advice to those seeking to buy high quality offsets in its publication ‘Securing Climate Benefit: a guide to using carbon offsets’.
204. Stockholm Environment Institute, 2019
205. Stockholm Environment Institute, 2019
206. Lee et al, 2020
207. Aviation Environment Federation, 2019
208. Kärcher, 2018
209. ICAO, 2019
210. Larsson, et al., 2019
211. Larsson, et al., 2019
212. Teoh, et al., 2020
213. See Lee et al, 2020 for further discussion
214. Aviation Environment Federation, 2019

ADDITIONAL REFERENCES

a free ride. n.d.. Introducing the frequent flyer levy. afreeride.org. [Online] n.d. http://afreeride.org/

Airbus. 2018. Airbus CDP Climate Change Response. cdp.net. [Online] 2018. https://www.cdp.net/en/responses/21770?page=1&per_page=5&sort_by=project_year&sort_dir=desc.

—. 2020. Our decarbonisation journey continues: looking beyond E-Fan X . airbus.com. [Online] 24 April 2020. https://www.airbus.com/newsroom/stories/our-decarbonisation-journey-continues.html.

Aviation Environment Federation. 2019. Aviation 2050 Green Paper: response from the Aviation Environment Federation. aef.org.uk. [Online] 20 June 2019. https://www.aef.org.uk/uploads/2019/06/Strategy-response.pdf

—. 2020. Briefing: Building back better for aviation. aef.org.uk. [Online] June 2020. https://www.aef.org.uk/uploads/2020/06/Building-back-better-aviation-.docx.pdf

—. 2020a. The Sixth Carbon Budget and Welsh emissions targets: Call for Evidence - Response from the Aviation Environment Federation. aef.org.uk. [Online] February 2020a. https://www.aef.org.uk/uploads/2020/02/AEF-response-to-6th-carbon-budget-call-for-evidence.pdf

Air Transport Action Group, 2020 https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050/
Bows-Larkin, Alice. 2015. All adrift: aviation, shipping, and climate change policy. Climate Policy. 2015, Vol. 15, 6.

Carbon Brief. 2020. Leading economists: Green coronavirus recovery also better for economy. Carbon Brief. [Online] 05 May 2020. https://www.carbonbrief.org/leading-economists-green-coronavirus-recovery-also-better-for-economy?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_medium=email&utm_source=Revue%20newsletter

Carbon Market Watch. 2020. Airline Bailout Tracker. carbonmarketwatch.org. [Online] 08 May 2020. https://carbonmarketwatch.org/wp-content/uploads/2020/05/Airline-bailout-tracker_8_May_2020.pdf

—. 2020a. Six lessons from ICAO's carbon market expert group report. carbonmarketwatch.org. [Online] March 2020a. https://carbonmarketwatch.org/wp-content/uploads/2020/03/Six-lessons-from-ICAO-carbon-market-expert-group-report.pdf.

Ceres. 2020. Letter to Administrator Andrew Wheeler (US Environmental Protection Agency): Re. Control of Air Pollution from Airplanes and Airplane Engines: GHG Emission Standards and Test Procedures; Docket No. EPA-HQ-OAR-2018-0276. [Online] 19 October 2020. https://www.ceres.org/sites/default/files/Oct%2019%20Final%20Aviation%20GHG%20Rule%20Investor%20Letter.pdf

Coffel, E. and Horton, R.. 2015. Climate Change and the Impact of Extreme Temperatures on Aviation. Weather, Climate and Society. 2015. Vol. 7. No. 1. Pages 94–102. [Online] https://journals.ametsoc.org/view/journals/wcas/7/1/wcas-d-14-00026_1.xml?tab_body=fulltext-display

Committee on Climate Change. 2019. Net-zero and the approach to international aviation and shipping emissions. theccc.org.uk. [Online] 24 September 2019. https://www.theccc.org.uk/wp-content/uploads/2019/09/Letter-from-Lord-Deben-to-Grant-Shapps-IAS.pdf.

Darby, Megan. 2019. Marseille airport expansion stalled on climate grounds. Climate Home News. [online] 30 July 2019. https://www.climatechangenews.com/2019/07/30/marseille-airport-expansion-stalled-climate-grounds/

Early, Catherine. 2020. Future of flight or flight of fancy? UK aviation industry launches net zero roadmap. [Online] 4 February 2020. https://www.businessgreen.com/news/4010017/future-flight-flight-fancy-uk-aviation-industry-launches-net-zero-roadmap

EASA. 2019. European Aviation Environmental Report. European Union Aviation Safety Agency. [Online] 2019. https://ec.europa.eu/transport/sites/transport/files/2019-aviation-environmental-report.pdf.

EPA. 2020. Notice of Proposed Rulemaking: Control of Air Pollution from Airplanes and Airplane Engines: GHG Emission Standards and Test Procedures. [Online] 2020. https://www.epa.gov/regulations-emissions-vehicles-and-engines/notice-proposed-rulemaking-control-air-pollution

ETC. 2019. Mission possible: reaching net-zero carbon emissions from harder-to-abate sectors by mid-century. Sectoral Focus: Aviation. Energy Transitions Commission. [Online] 2019. https://www.energy-transitions.org/wp-content/uploads/2020/08/ETC_MissionPossible_FullReport.pdf

Euractiv. 2019. Jet fuel tax hopes lifted by leaked EU report. euractiv.com. [Online] 13 May 2019. https://www.euractiv.com/section/aviation/news/jet-fuel-tax-hopes-lifted-by-leaked-eu-report/

European Commission. 2019. European Green Deal Communication. ec.europa.eu. [Online] 11 December 2019. https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf.

Gössling, Stefan, et al. 2019. Can we fly less? Evaluating the 'necessity' of air travel. Journal of Air Transport Management. October 2019, Vol. 81.

Graver, Brandon. 2020. Many U.S. air carriers miss their first climate goal. [Online] 9 September 2020. https://theicct.org/blog/staff/us-air-carriers-miss-first-climate-goal-sept2020

Graver, Brandon, Rutherford, Dan and Zheng, Sola. 2020. CO_2 emissions from commercial aviation, 2013, 2018 and 2019. The International Council on Clean Transportation. [Online] October 2020. https://theicct.org/sites/default/files/publications/CO2-commercial-aviation-oct2020.pdf

Graver, Brandon, Zhang, Kevin and Rutherford, Dan. 2019. CO_2 emissions from commercial aviation, 2018. The International Council on Clean Transportation. [Online] September 2019. https://theicct.org/sites/default/files/publications/ICCT_CO2-commercl-aviation-2018_20190918.pdf.

Green Air. 2019. Nine countries call on European Commission to find a common approach on EU-wide air passenger taxation. greenaironline.com. [Online] 18 November 2019. https://www.greenaironline.com/news.php?viewStory=2641

—. 2020. IATA starts discussions with ICAO on changing the CORSIA baseline to exclude 2020 emissions. greenaironline.com. [Online] 21 April 2020. https://www.greenaironline.com/news.php?viewStory=2686.

—. 2020a. Airline chiefs slam European countries over green taxes and overdue reform of inefficient airspace. greenaironline.com. [Online] 06 March 2020a. https://www.greenaironline.com/news.php?viewStory=2677.

—. 2020b. Airlines unlikely to have any CORSIA offsetting obligations for at least three years if baseline rule changed, finds Environmental Defense Fund analysis. greenaironline.com. [Online] 15 May 2020b. https://www.greenaironline.com/news.php?viewStory=2694.

—. 2020c. Members of international airline alliance oneworld commit to net zero carbon emissions by 2050. [Online] 15 September 2020. https://www.greenaironline.com/news.php?viewStory=2726

—. 2020d. The EU kick-starts a hydrogen revolution with ambitions for hydrogen-powered commercial aircraft by 2035. [Online] 14 July 2020. https://www.greenaironline.com/news.php?viewStory=2717

Grist. 2020. Trump's EPA just introduced a historic CO_2 rule for planes. Wait, what? grist.org. [Online] 2020. https://grist.org/climate/trumps-epa-just-introduced-a-historic-emissions-standard-for-airplanes-wait-what/.

Hemmings, Bill, et al. 2020. Taxing Aviation Fuel in Europe. Back to the Future? transportenvironment.org. [Online] March 2020. https://www.transportenvironment.org/sites/te/files/publications/2020_06_Study_for_TE_Taxing_aviation_fuel_final.PDF.

IAG. 2019. Annual Report 2019. International Consolidated Airlines Group S.A. [Online] 2019. https://www.iairgroup.com/~/media/Files/I/IAG/documents/IAG%20Annual%20report%20and%20accounts%202019.pdf.

IATA. 2020. COVID-19 Puts Over Half of 2020 Passenger Revenues at Risk. International Air Transport Association. [Online] 14 April 2020. https://www.iata.org/en/pressroom/pr/2020-04-14-01/

—. 2020a. COVID-19 and CORSIA: Stabilizing net CO_2 at 2019 "pre-crisis" levels, rather than 2010 levels. International Air Transport Association. [Online] 19 May 2020a. https://www.iata.org/contentassets/fb745460050c48089597a3ef1b9fe7a8/covid19-and-corsia-baseline-190520.pdf.

—. 2020b. Aviation and Climate Change. [Online] July 2020. https://www.iata.org/en/iata-repository/pressroom/fact-sheets/fact-sheet--climate-change/#:~:text=In%202019%2C%20civil%20aviation%20as,lessen%20this%20impact%20extremely%20seriously.

ICAO. 2018. Presentation of 2018 Air Transport Statistical Results: Annual Report 2018. International Civil Aviation Organization. [Online] 2018. https://www.icao.int/annual-report-2018/Documents/Annual.Report.2018_Air%20Transport%20Statistics.pdf.

—. 2018a. ICAO Carbon Emissions Calculator Methodology: Version 11 [Online] June 2018. https://www.icao.int/environmental-protection/CarbonOffset/Documents/Methodology%20ICAO%20Carbon%20Calculator_v11-2018.pdf

—. 2019. ICAO Environmental Report 2019. International Civil Aviation Organization. [Online] 2019. https://www.icao.int/environmental-protection/Documents/ICAO-ENV-Report2019-F1-WEB%20%281%29.pdf.

—. 2020. ICAO Council agrees to the safeguard adjustment for CORSIA in light of COVID-19 pandemic. International Civil Aviation Organization. [Online] 30 June 2020. https://www.icao.int/Newsroom/Pages/ICAO-Council-agrees-to-the-safeguard-adjustment-for-CORSIA-in-light-of-COVID19-pandemic.aspx.

—. 2020a. Feasibility of a long term global aspirational goal for international aviation. [Online] 2020. https://www.icao.int/environmental-protection/Pages/LTAG.aspx

ICCT. 2019. Noise and climate impacts of an unconstrained commercial supersonic network. International Council on Clean Transportation. [Online] 30 January 2019. https://theicct.org/sites/default/files/publications/Supersonic_Impact_Working_Paper_20190130.pdf

—. 2020. Standards to promote airline fuel efficiency. International Council on Clean Transportation. [Online] 2020. https://theicct.org/sites/default/files/publications/Airline-fuel-efficiency-standard-2020.pdf

—. 2020a. Five ways for governments to green airline bailouts. International Council on Clean Transportation. [Online] 05 May 2020a. https://theicct.org/blog/staff/five-ways-governments-green-airline-bailouts

IEA. 2017. Energy Technology Perspectives. IEA. [Online] 2017. https://www.iea.org/reports/energy-technology-perspectives-2017

—. 2019. World Energy Outlook 2019: Energy and the Sustainable Development Goals. IEA. [Online] 2019. https://doi.org/10.1787/0efa47e9-en.

—. 2020. Aviation. International Energy Agency. More Efforts Needed. [Online] 2020. https://www.iea.org/reports/aviation

—. 2020a. Tracking Transport 2020. IEA. [Online] 2020a. https://www.iea.org/reports/tracking-transport-2020.

—. 2020b. Global CO_2 Emissions in Transport by Mode in the Sustainable Development Scenario, 2000-2070. [Online] 2020. https://www.iea.org/data-and-statistics/charts/global-co2-emissions-in-transport-by-mode-in-the-sustainable-development-scenario-2000-2070

—. 2020c. Energy Technology Perspectives 2020. [Online] IEA, 2020. https://www.iea.org/reports/energy-technology-perspectives-2020

—. 2020d. World Energy Outlook 2020. [Online] IEA, 2020. https://www.iea.org/reports/world-energy-outlook-2020

Intergovernmental Panel on Climate Change [IPCC]. 2014. Transport. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Online] 2014. https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter8.pdf

International Carbon Action Partnership. n.d.. Scope & Coverage. icapcarbonaction.com. [Online] n.d. https://icapcarbonaction.com/en/scope-and-coverage.

Kärcher, Bernd. 2018. Formation and radiative forcing of contrail cirrus. nature communications. May 2018, Vol. 9, 1824.

Larsson, Jorgen, et. al. 2019. International and national climate policies for aviation: a review. Climate Policy. 2019, Vol. 19, 6.

Lee, et. al. 2020. The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. Atmospheric Environment. https://doi.org/10.1016/j.atmosenv.2020.117834

McKinsey & Company. 2020. How airlines can chart a path to zero-carbon flying. McKinsey & Company. [Online] May 2020. https://www.mckinsey.com/industries/travel-logistics-and-transport-infrastructure/our-insights/how-airlines-can-chart-a-path-to-zero-carbon-flying

New Economics Foundation. 2020. Crisis support to aviation and the right to retrain. neweconomics.org. [Online] 10 June 2020. https://neweconomics.org/2020/06/crisis-support-to-aviation-and-the-right-to-retrain

Pidcock, Roz and Yeo, Sophie. 2016. Analysis: Aviation could consume a quarter of 1.5C carbon budget by 2050. Carbon Brief. [Online] 08 August 2016. https://www.carbonbrief.org/aviation-consume-quarter-carbon-budget.

PRI, 2020. Investor expectations on climate change for airlines and aerospace companies. The PRI. [Online] 8 February 2020. https://collaborate.unpri.org/system/files/2020-09/pri_investor_expectations_statement_on_climate_change_for_airlines_and_aerospace_companies_9_september_2020.pdf

Rolls-Royce. 2020. Rolls-Royce puts net zero carbon by 2050 at the heart of future innovation and growth. Rolls-Royce. [Online] 05 June 2020. https://www.rolls-royce.com/media/press-releases/2020/05-06-2020-rr-puts-net-zero-carbon-by-2050-at-the-heart-of-future-innovation-and-growth.aspx.

Roundtable on Sustainable Biomaterials [RSB]. 2020. Sustainable Aviation Biofuels. [Online] 28 September 2020. https://rsb.org/aviation/

Safran. n.d.. Aircraft taxiing along with their engines shut down: Safran believes this is a winner! safran-landing-systems.com. [Online] n.d. https://www.safran-landing-systems.com/systems-equipment/electric-taxiing-0

SESAR. 2018. SESAR is delivering but we need to stay focused, says IATA's CEO. sesarju.eu. [Online] 18 July 2018. https://www.sesarju.eu/news/sesar-delivering-we-need-stay-focused-says-iatas-ceo

—. 2018a. US-Europe provide snapshot of progress on joint aviation modernisation efforts. sesarju.eu. [Online] 25 September 2018a. https://www.sesarju.eu/news/us-europe-provide-snapshot-progress-joint-aviation-modernisation-efforts

Skyscanner Greener Choice Label. Travel with a conscience. skyscanner.net. [Online] https://www.skyscanner.net/environment

Stockholm Environment Institute. 2019. Securing climate benefit: a guide to using carbon offsets. sei.org. [Online] 13 November 2019. https://www.sei.org/publications/guide-to-using-carbon-offsets/

Sustainable Aviation. 2020. Decarbonisation Road-Map: A Path to Net Zero. Sustainable Aviation. [Online] February 2020. https://www.sustainableaviation.co.uk/wp-content/uploads/2020/02/SustainableAviation_CarbonReport_20200203.pdf

Teoh, Roger, et al. 2020. Mitigating the Climate Forcing of Aircraft Contrails by Small-Scale Diversions and Technology Adoption. Environmental Science & Technology. 2020, Vol. 54, 5

The Climate Group. 2020. Future of Business Travel up in the Air: Overseas Trips Could Be Cut by at Least a Third. [Online] 2020. https://www.theclimategroup.org/our-work/press/future-business-travel-air-overseas-trips-could-be-cut-least-third

Transition Pathway Initiative (TPI). 2019. Carbon Performance assessment of airlines: note on methodology. [Online] October 2019. https://www.transitionpathwayinitiative.org/tpi/publications/44.pdf?type=Publication

—. 2020. TPI State of Transition Report 2020. Transition Pathway Initiative. [Online] March 2020. https://www.transitionpathwayinitiative.org/tpi/publications/50.pdf?type=Publication

Transport & Environment. 2018a. Aviation and shipping emissions and national climate pledges. [Online] May 2018. https://www.transportenvironment.org/publications/aviation-and-shipping-emissions-and-national-climate-pledges

—. 2018b. Climate risks from the return of supersonic aircraft. transportenvironment.org. [Online] May 2018. https://www.transportenvironment.org/sites/te/files/2018_05_TE_Supresonic_briefing_0.pdf

—. 2019. Why ICAO and Corsia cannot deliver on climate: A threat to Europe's climate ambition. [Online] September 2019. https://www.transportenvironment.org/sites/te/files/publications/2019_09_Corsia_assessement_final.pdf

—. 2020. Air France bailout: climate conditions explained. transportenvironment.org. [Online] June 2020. https://www.transportenvironment.org/sites/te/files/publications/2020_06_air-france-rescue_final_1.pdf

—. 2020a. Taxing airlines could raise €3.7bn a year and help prevent return to pollution growth - new analysis. transportenvironment.org. [Online] 22 June 2020a. https://www.transportenvironment.org/press/taxing-airlines-could-raise-€37bn-year-and-help-prevent-return-pollution-growth-new-analysis

—. 2020b. Kerosene taxation. How to implement it in Europe today. transportenvironment.org. [Online] June 2020b. https://www.transportenvironment.org/sites/te/files/publications/2020_06_Kerosene_taxation_briefing.pdf

—. n.d.. How to reduce airline emissions. transportenvironment.org. [Online] n.d. https://www.transportenvironment.org/what-we-do/aviation-and-eu-ets

UK Parliament POST. 2020. Climate Change and Aviation. UK Parliament POST. [Online] 11 February 2020. https://researchbriefings.files.parliament.uk/documents/POST-PN-0615/POST-PN-0615.pdf

Victor, David G, Geels, Frank W and Sharpe, Simon. 2019. Accelerating the Low Carbon Transition: The Case for Stronger, More Targeted and Coordinated International Action. [Online] 2019. www.energy-transitions.org/sites/default/files/Accelerating-The-Transitions_Report.pdf.

World Economic Forum [WEF]. 2019. The world needs carbon-neutral flying. Here's how to bring it one step closer. [Online] 15 August 2019. https://www.weforum.org/agenda/2019/08/carbon-neutral-flying/

Zheng, Sola. 2019. Not Every Tonne of Aviation CO_2 is Created Equal. [Online] 16 October 2019. https://theicct.org/blog/staff/not-every-tonne-of-aviation-CO2

ACKNOWLEDGMENTS

Editor and lead authors:

- Rhoda Byrne, Chronos Sustainability
- Dr. Rory Sullivan, Chronos Sustainability
- Robert Black, Chronos Sustainability
- Marshall Geck, PRI
- Ben Pincombe, PRI

Contributors:

- Nicky Amos, Chronos Sustainability
- Amanda Williams, Chronos Sustainability
- Elisabeth O'Leary, copy editor
- Perivan, report designer

With feedback and input from:

- Patrick Peura, Allianz SE
- Danny Magill, InfluenceMap
- Maxime Molenaar, SkyNRG
- Brad Schallert, WWF
- John Holler, WWF
- Adam Kanzer, BNP Paribas Asset Management
- Elke Pfeiffer, PRI
- Andrew Murphy, Transport & Environment
- Ned Molloy, GSCC Network
- Boeing representatives

PRI Principles for Responsible Investment

The Principles for Responsible Investment (PRI)

Although this document forms part of the Climate Action 100+ sector strategy for aviation, the report and its contents were produced by the PRI.

The PRI is an investor initiative in partnership with the UN Finance Initiative and UN Global Compact. The PRI works with its international network of signatories to put the six Principles for Responsible Investment into practice. Its goals are to understand the investment implications of environmental, social and governance (ESG) issues and to support signatories in integrating these issues into investment and ownership decisions. The PRI acts in the long-term interests of its signatories, of the financial markets and economies in which they operate and ultimately of the environment and society as a whole.

The six Principles for Responsible Investment are a voluntary and aspirational set of investment principles that offer a menu of possible actions for incorporating ESG issues into investment practice. The Principles were developed by investors, for investors. In implementing them, signatories contribute to developing a more sustainable global financial system.

More information: **www.unpri.org**

CHRONOS INTELLIGENT SUSTAINABILITY

Chronos Sustainability

The PRI commissioned Chronos Sustainability to develop this document.

Chronos Sustainability was established in 2017 with the objective of delivering transformative, systemic change in the social and environmental performance of key industry sectors through expert analysis of complex systems and effective multi-stakeholder partnerships. Chronos works extensively with global investors and global investor networks to build their understanding of the investment implications of sustainability-related issues, developing tools and strategies to enable them to build sustainability into their investment research and engagement.

For more information visit **www.chronossustainability.com** and @ ChronosSustain.

Produced by

PRI Principles for Responsible Investment

Asia Investor Group on Climate Change

Ceres

Investor Group on Climate Change

IIGCC