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Climate Change and Aviation

Aviation has a growing impact on climate change, as demand for air travel increases globally. This POSTnote examines options for mitigating greenhouse gas (GHG) emissions from aviation, including new technologies, demand reduction and emissions offsetting. It also outlines UK and global policy frameworks for implementing measures to do so.

Overview

- Aviation is responsible for 7% of the UK's greenhouse gas (GHG) emissions.
- Reducing aviation emissions is difficult because of the long lifetime of aircraft and a lack of zero-carbon alternatives.
- Technologies that could reduce emissions include new aircraft and engines, electric aircraft, and alternative (low-carbon) fuels. They will not bring emissions to zero, and further mitigation will be required.
- Low-carbon aviation fuels are perceived as promising solutions by the industry.
- Reducing demand for flying faces social and political acceptance challenges.
- Emissions offsetting is a key, but highly debated approach, to mitigating emissions.
- Aviation policy is primarily agreed globally, but UK policy can also reduce emissions.

Background

Commercial flights departing from the UK account for 7% of national GHG emissions.[1] Burning jet fuel releases carbon dioxide (CO_2) and non-CO_2 emissions (Box 1).[2] In the UK, 96% of these emissions come from international, mainly long-haul, flights.[1] Passenger numbers in the UK have tripled since 1990 and are forecast to grow by 49% between 2018 and 2050.[3] Due to this growth, and the expected decrease in emissions in other sectors, aviation is likely to be the largest contributor to UK emissions in 2050.[1]

Assessments of air travel have demonstrated its economic and social benefits, but also its wider challenges, such as air pollution and noise.[4–7] The UK has a large aviation sector, comprising airlines, aerospace manufacturers, fuel producers and navigation service providers.[7] The sector is mature but constantly in search of cost reductions and opportunities to improve efficiency; particularly airlines, which are sensitive to costs.[8]

Under current projections, global air passenger numbers are expected to quadruple and aviation emissions to triple by 2050, relative to 2015.[9] As aviation is the most difficult transport mode to reduce emissions from, it has featured widely in recent discussions on climate change. There are a wide range of technologies that help reduce emissions, but they are unlikely to bring them to zero by 2050. Some technologies can be installed on existing aircraft, while others can only be installed when new aircraft are designed.[10,11] Many technologies lack the required investment under current policies. Most international emissions mitigation activities rely on fuel efficiency improvements and emissions offsetting (see *Emissions Offsetting*).

The coordination of reducing aviation emissions occurs mainly at the global level. It is managed by the International Civil Aviation Organization (ICAO), a specialised UN agency.[12] ICAO operates the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), a global carbon offsetting scheme for airlines.[13] It also sets a CO_2 standard for new aircraft that defines a maximum allowable fuel burn per kilometre of flight.[14] Other emissions reduction measures are implemented by the EU.[15]

Under the UK's 'net zero' emissions legislation, net UK GHG emissions (emitted GHGs minus GHGs removed from the atmosphere) must be zero by 2050.[16,17] Emissions from international air travel are currently excluded from the legislation, and the UK Government has yet to clarify how they will be accounted for. The Committee on Climate Change (CCC, an independent body that advises the UK government on climate issues) and others have suggested that aviation

Box 1: Effects of Air Travel Emissions in the Atmosphere

Aircraft in motion release two main types of emissions:

- Carbon dioxide (CO_2) emissions that directly cause warming, and
- Non-CO_2 emissions that cause overall warming by affecting atmospheric composition and cloudiness.

Most of the non-CO_2 global warming impact is due to:

- The net warming effect caused by the production of ozone through emissions of nitrous oxides (NOx) and
- The formation of condensation trails and cirrus clouds through emissions of water vapour and soot in cold, humid regions of the atmosphere.[1,20,21] These reflect sunlight and trap heat radiated by the Earth, with the overall effect being to warm the atmosphere.[22]

CO_2 emissions are well understood and directly related to the amount of fuel burned. Non-CO_2 emissions are less well understood, but evidence suggests that they may roughly double the historical warming impact caused by aircraft CO_2 emissions.[22] The Department for Transport (DfT) has identified CO_2 as a priority for mitigation and recommends further research into non-CO_2 effects. Short flights emit more per kilometre than long-haul, as they cruise a shorter distance, while still burning similar amounts of fuel during ascent and descent.[23]

emissions should be explicitly included in the UK's net zero target.[18,19] In September 2019, the CCC also recommended that the UK increase efforts to mitigate emissions from aviation.[19] There are several approaches to doing so, including new technologies, more efficient operations, demand reduction and emissions offsetting.

Technologies for Reducing Emissions

The aviation sector has been making technical improvements to aircraft and engines for several decades.[21] These have sought to improve the efficiency of fuel consumption, reducing the fuel costs that make up 20%–25% of airlines' operating expenses.[24,25] The CCC estimates that by 2050, technologies could reduce emissions per aircraft by 40% relative to the year 2000 (excluding low-carbon aviation fuels) in the UK.[1,18] Some stakeholders suggest that this figure is optimistic.[26,27] Fuel efficiency improved by about 21% between 2000 and 2017, but further improvements may be smaller given the mature nature of the technologies involved.[28–30] Low-carbon aviation fuels could generate further emissions reductions.

In the UK, several established and emerging government-industry partnerships aim to help develop emissions reduction technologies in the UK.[31–33] To date, these partnerships have focused on improving fuel efficiency and, more recently, electric aircraft. Industrial stakeholders highlight that technological development should be based on a long-term vision with clear targets from government. Some suggest that this vision should promote multiple solutions that can work together.[34]

Low-carbon Aviation Fuels

Jet fuel can be replaced by alternative fuels to reduce GHG emissions from existing aircraft.[35] Most of these fuels are in early stages of development, and there are differing views on the extent to which they could replace jet fuel. They are considered in more detail in POSTnote 616. The main types of low-carbon aviation fuels are:

- **Biofuels**, converted from energy crops or organic waste by burning or other chemical processes;
- **Electro-chemical fuels**, made by reacting hydrogen (produced using low-carbon electricity) with CO_2;
- **Hydrogen**, which can power aircraft engines either in liquid form or by being converted to electricity.

The aviation industry refers to biofuels and electro-chemical fuels as 'sustainable aviation fuels'. Biofuels could reduce UK aviation CO_2 emissions by 5%–32% by 2050, and electro-chemical fuels could generate further emissions reductions.[3,28,35–37] If blended with at least 50% jet fuel, these fuels are 'drop-in', requiring minimal changes to current aircraft. They can be used in long-haul flights, which cannot be feasibly electrified (see below). Many stakeholders believe that drop-in low-carbon aviation fuels have significant potential for reducing emissions in the near and medium-terms.[38–40] However, they are not price competitive with jet fuel and some will produce indirect GHG emissions across their lifetime.[41,42]

Aircraft and Engine Improvements

Incremental changes to engines, aircraft structures and materials have significantly increased the fuel efficiency of newer aircraft. These changes include progressive improvements to the efficiency of engines and wings, and the use of lighter materials, such as carbon composite materials, to build aircraft. There is scope for further improvements in the efficiency of wings and the further use of lighter aircraft materials. These incremental changes could improve fuel efficiency by another 10–17%.[37,43]

More fundamental changes, such as radical aircraft designs and new generations of engines, could enable greater fuel efficiency improvements.[43] An example of radical designs are blended wing bodies (tailless aircraft with no division between the wings and aircraft body).[44] They are lighter and more efficient than traditional aircraft and can operate on electricity or hydrogen instead of jet fuel.[45] In addition, new ultra-efficient engines will increase the proportion of air flowing through the engine fan, improving fuel efficiency.[43,46]

Developers are currently designing new ultra-efficient engines,[47] but no radical aircraft designs have progressed past concept stage. This is because new designs incur high costs and take a long time to complete.[48,49] In the interim, manufacturers often fit new engines onto existing aircraft, rather than design a completely new aeroplane.[50] Radical designs may also be incompatible with existing infrastructure such as airport runways.[51,52] As a result, fuel efficiency has tended to improve incrementally, rather than fundamentally, over the past 30–40 years.[48]

Fully Electric and Hybrid Electric Aircraft

Electric aircraft use batteries or fuel cells to power electric motors. They can be hybrid (using a mix of electric motors and jet engines) or fully electric (using only electric motors). Jet fuel savings range from 19% in hybrid aircraft to 100% in fully electric aircraft.[53,54] These savings depend on aircraft batteries being charged with zero-carbon electricity. Electric aircraft are the subject of substantial research and investment in the UK.[33,55,56]

The main challenge for electrification is the weight of the batteries needed to power the aircraft.[39,57] This makes full electrification unlikely for large aircraft and flights longer than 300–500 km without a breakthrough in battery technology.[40,58] Industry estimates suggest that small (150–200-seat) hybrid electric aircraft will become available on short-haul routes around 2040,[39] and fully electric after 2050. Smaller fully electric aircraft (20–130 seats) may be used by 2040 on domestic routes, particularly in remote or island areas.[35] There is potential for very small fully electric aircraft to be used for intra-urban transport by 2025.[59–61] These aircraft would likely replace ground transport, rather than short-haul air travel.[39] Airspace congestion over urban areas could present significant regulatory challenges. These early electric aircraft could assist the development of larger designs in later decades.

Early-stage research is ongoing on 'structural power materials', which can act both as an aircraft structure and a battery. For example, an aircraft wing made from this material could store electricity and deliver it to the motors when needed. Using these materials would eliminate the need for a standalone battery and reduce the weight of electric aircraft.[62,63] The technology is unlikely to be commercially available before 2040.[64]

Operations and Airspace Management

Flight operations can be changed to conserve fuel and emit less. Small changes, such as lighter internal fittings, lead to fuel efficiency improvements of 2%–5%. Larger changes include flying in direct paths and avoiding aircraft being held before landing due to airport congestion ('stacking'). In the UK, these changes could save around 5% in fuel consumption per aircraft.[43,65] The UK's airspace management system is relatively old, and a programme is underway to improve its efficiency and allow for larger-scale operational changes.[7,66,67] The positive impact of these changes may be reduced by airlines' cost-saving practices. Some airlines transport more fuel than necessary for financial reasons, thus burning more fuel.[68]

Operational changes could also help avoid the formation of condensation trails, by re-routing the aircraft to avoid areas where trails are most likely to form.[69] In many conditions this could lead to extra fuel use and more CO_2 emissions, but it is unclear whether there would be an overall net climate benefit.[22] More research on these operational changes would be needed to determine their potential impact.

Managing Demand for Air Travel

The projected growth in passenger numbers, and plans to expand airport capacity (Box 2), have prompted discussions on managing demand for air travel.[70] Broadly, this could be done by curtailing demand for flying and/or providing alternative means of transport. No explicit demand management policies for aviation are currently planned in the UK. They would require robust data on passenger behaviour and decision-making. There is also an opportunity to connect demand management for passenger and cargo aviation. While most cargo is transported on passenger aircraft,[71] the two sectors may be able to reduce their impact by sharing knowledge and methods for emissions reduction.

Box 2: Airport Expansion and Emissions Reduction
There are currently plans to expand airport capacity in many UK airports to accommodate expected demand growth. Airport capacity expansion can increase demand for air travel, though the relationships between capacity expansion and demand growth are complex, creating challenges for demand management.[72] In 2018, the UK Government set out its National Policy Statement for expanding airport capacity in the south-east of England, outlining plans to build a third runway at Heathrow Airport.[73] The resulting growth in air travel may put pressure on other sectors to reduce their emissions more quickly to compensate for the increase in aviation emissions.[74] Increased air travel can also cause a growth in emissions in other sectors, such as road transport, due to increased traffic to and from airports.[75,76] In 2019 the CCC stated that the UK Government should re-assess its airport capacity strategy in light of the net zero target.[18]

Demand Curtailment

Demand curtailment involves discouraging flying through fiscal measures such as emissions taxes, or non-economic approaches such as information campaigns. Many academics and non-governmental stakeholders suggest that demand curtailment should be implemented alongside technological solutions to meet climate targets.[27,54,77–80] The CCC has advised that in order to meet the net zero target, passenger demand should not grow more than 25% between 2019 and 2050.[1]

Fiscal measures can help incorporate the cost of emissions in airline ticket prices, for example by taxing jet fuel, which is directly related to aircraft CO_2 emissions. Increasing jet fuel prices could incentivise the development of alternative fuels and fuel-saving technologies. However, jet fuel used in international flights is tax exempt under the 1944 Chicago Convention on International Civil Aviation and bilateral air service agreements.[81–84] Many countries do apply taxes to airline tickets, such as the UK's Air Passenger Duty that charges passengers depending on flight distance and class of travel.[85] Recently, Sweden and France have used airline ticket taxation systems to set additional climate levies aimed at curbing demand.[86–88]

In 2013, 15% of the UK population took 70% of international flights and a flat rate of emissions tax on all air passengers would disproportionately affect less well-off travellers.[89,90] A "frequent flyer levy" (a tax that goes up the more flights a passenger takes in a year) has been proposed to reduce demand while addressing this equity concern.[91] Some researchers have suggested discontinuing frequent flyer reward programmes.[78] Emerging evidence also indicates a change in public attitude towards flying in the UK, accelerated by social cues from high-profile figures.[92–96] This attitude change has not yet led to a measurable reduction in demand for air travel in the UK, but it has elsewhere.[97] These trends, plus an increase in climate-related concern from airline shareholders, could lead to a reduction in the forecast growth in demand for flying.[98,99]

Demand curtailment faces many challenges. The industry argues that if other countries do not also introduce demand curtailment measures, then UK industry could face competitive disadvantage and risk carbon leakage.[100–103] Carbon leakage occurs where companies move their operations abroad and increase emissions in other countries.[104] Some analysts argue that carbon leakage may occur if, for example, airlines respond to policies by swapping their fleets to use the most fuel-efficient aircraft on routes that tax fuel.[105] However, recent research commissioned by the Department for Transport (DfT) suggests that discouraging passengers from flying would not risk carbon leakage or competitive disadvantage.[105]

Transport Modal Shift

Some analysts and campaigners have argued that short-haul aviation could be reduced, if not eliminated, by providing feasible alternative means of transport. Short-haul flights make up a relatively low proportion of all air travel emissions but emit nearly twice as much CO_2 per kilometre travelled as the average flight (Box 1).[23] Some airlines advise their customers to use different transport modes, but this is relatively rare.[106]

Implementing modal shift relies on 'inter-modal' transport systems, which comprise many transport modes that travellers can easily switch between. These systems require a holistic view of the transport system and have been attempted in several countries.[107] For example, French and German national rail operators are designated as airlines by the International Air Transport Association (IATA), to increase the ease of connecting transport modes.[108]

Emissions Offsetting

Given the projected growth in demand for aviation, emissions offsetting (Box 3) is a major part of mitigation plans for global and UK aviation.[37,109] The main offsetting scheme for international airlines is ICAO's CORSIA, a global scheme starting in 2021 (on a voluntary basis until 2027).[110] Critics view it as lacking ambitious targets and being susceptible to political interests. Some supporters see it as a stop-gap while technologies for direct emissions reduction are developed.[1,79,111–114] CORSIA will operate until 2035, after which it is intended that direct emissions reductions will replace it, but offsets may still be required in the long term.[35]

There are concerns around the quality of some offsets. In one of the most established offsetting schemes, the Clean Development Mechanism (CDM) (POSTnote 290), many purchased offsets were shown to be ineffective at mitigating CO_2.[115,116] Concerns around the CDM's potential inclusion in CORSIA have been raised.[117] Newer, accredited voluntary offsetting schemes assess offsets more rigorously before accepting them. Another concern is that offsetting allows aviation to grow, increasing pressure on other sectors to reduce emissions quicker. UK aviation is likely to require offsetting in order to reach net zero emissions. Some stakeholders argue that future emissions offsetting should be done through domestic Greenhouse Gas Removals (GGR), rather than being made in other sectors or countries (Box 3).[1]

Box 3: Emissions Offsetting

Offsetting happens when a business compensates for its emissions by paying for emissions reductions (offsets) to occur elsewhere. Many schemes, such as the Clean Development Mechanism (CDM), currently use conventional offsets, such as afforestation projects, primarily in developing countries. For example, an airline or a passenger can offset their CO_2 emissions by funding renewable energy projects or the protection of rainforests that absorb CO_2 from the atmosphere.[118] Offsetting schemes can be either voluntary (POSTnote 290) or regulated (e.g. the CDM).[116]

There are challenges associated with some conventional offsets, such as a lack of additionality (where the offset reduces emissions that would have been reduced anyway). Afforestation and other traditional offsets are limited in scope and constrained by land availability. The CCC advises that aviation should use appropriate GGR offsets, rather than traditional offsets, to reach net zero emissions. These will mostly be based on carbon capture and storage (CCS), will need to be scalable, and will likely be costlier than traditional offsets.[18]

Policy Context

Policy development will play a key role in accelerating the reduction of emissions from air travel.[1,36] In the UK, DfT is responsible for most policy on air travel, while the Department for Business, Energy and Industrial Strategy (BEIS) is responsible for energy and climate change mitigation policy and the major funding of research and development in aviation. Fiscal policy affecting aviation is overseen by the Treasury.

Global and Regional Regulation

ICAO has overarching responsibility for global policy on reducing international aviation emissions. The CORSIA scheme is based on industry targets set by IATA.[119] IATA has also committed to a goal of reducing global aviation CO_2 emissions by 50% by 2050, relative to 2005 levels.

The EU has set a more ambitious target to reduce CO_2 emissions per kilometre flown by 75% by 2050, relative to 2000 levels.[15] It also operates the EU Emissions Trading Scheme (EU ETS, a form of emissions offsetting scheme) (POSTnote 354) that has applied to all flights within the European Economic Area since 2012.[120,121] There are challenges aligning the EU ETS and CORSIA.[122] ICAO is concerned about potential double-counting between the two schemes, while the EU is critical of CORSIA's level of ambition. The EU ETS requires airlines to offset emissions above 2004–2006 levels, while CORSIA requires offsetting above 2020 emissions levels, which will be higher.[113,122]

UK Policy on Aviation Emissions

The UK has significant innovation and industrial capability in the aviation sector. Many stakeholders suggest that the UK can help shape international agreements, but can also take independent action to reduce its own aviation emissions. The CCC estimates that by implementing technologies and low-carbon fuels and capping demand growth at 25% above current levels, aviation emissions could be reduced by 20% by 2050, relative to today.[123] Existing transport policies can support emissions reduction. The Renewable Transport Fuel Obligation (RTFO), which provides incentives for the production and use of alternative transport fuels, was recently updated to include aviation fuels.[124,125] The UK is also a leader in aerospace manufacturing and an authority on the certification of aviation fuels.[126] Some UK-based international airlines have set themselves more ambitious mitigation goals, outside of regulatory requirements.[127]

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