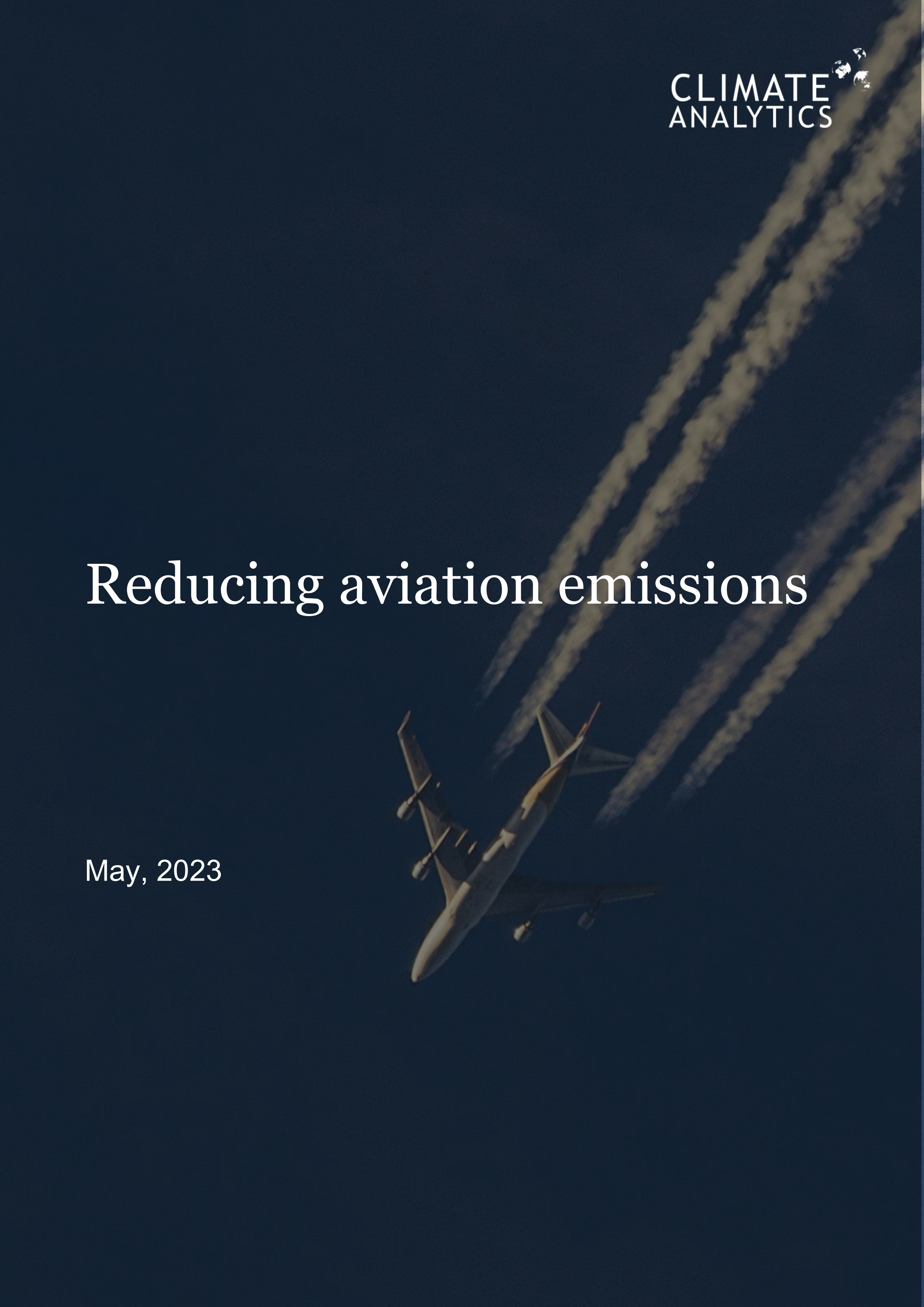

Reducing aviation emissions

May, 2023

AUTHORS
Andrzej Ancygier, Olivia Waterton, Sepideh Rabiee.

We would like to express our gratitude to the consortium members for their review and guidance in shaping this document.

CITATION AND ACKNOWLEDGMENTS

This document may be cited as:
Climate Analytics (2023). Reducing aviation emissions

Cover image: Anton Kudryashov

Supported by:

Federal Ministry for Economic Affairs and Climate Action

European Climate Initiative EUKI

on the basis of a decision by the German Bundestag

This project is part of the European Climate Initiative (EUKI) of the German Federal Ministry for Economic Affairs and Climate Action (BMWK). It is the overarching goal of the EUKI to foster climate cooperation within the European Union (EU) in order to mitigate greenhouse gas emissions. The opinions put forward in this publication are the sole responsibility of the author(s) and do not necessarily reflect the views of the Federal Ministry for Economic Affairs and Climate Action (BMWK).

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CLIMATE ANALYTICS

Supporting science based policy to prevent dangerous climate change enabling sustainable development

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Aviation

Banning domestic flights

Short haul flights (often defined as those less than 700 km or shorter than five hours, although definitions vary) are one of the most carbon-intensive forms of travel (Boner, 2020; Noack, 2019). Researchers estimate that short haul flights emit over 250 grams per kilometre, a rate higher than for long distance flights. The intense fuel usage during take-off and landing explains why short-haul flights emit more than longer flights. In 2020, domestic flights accounted for 22% of all air travel despite ongoing pandemic warnings (*Air Transport Statistics*, 2021). The top ten airport pairs (journeys between airports) were *all domestic* and five out of ten airport pairs were within French territories (*Air Transport Statistics*, 2021). A ban on journeys with less emissions-intensive alternatives would significantly reduce emissions in passenger transport. Most proposals for bans on short haul flights focus on domestic connections, which train journeys often replace.

Domestic flight ban examples

As a condition for a 600 million EUR bailout during the Covid-19 pandemic, Austria required Austrian Airlines to cut emissions and halt flights that a three-hour or shorter train journey could replace feasibly (Grüll, 2020; Morgan, 2020). Austrian Airlines also added up to 30 train services per day between Vienna's airport and Salzburg's main station to facilitate air travel and reduce domestic connections. Direct cooperation between the rail service and airlines facilitates booking and rerouting in case of delays or cancelled flights, a major challenge for long distance multi-modal trips.

France banned all short domestic flights which a rail journey under 2.5 hours could replace. Although government leaders heralded the ban, this legislation excluded the Roissy-Charles de Gaulle hub (Jacquot, 2021). The ban would only affect five out of a total of 108 current domestic routes (Jacquot, 2021). Researchers estimate that this ban would only decrease emissions from domestic flights by 6.6% (*Climat*, 2020). Bans on domestic flights must be on a large scale to have the desired impact (*Climat*, 2020).

Improving train and plane connections

If international flights are needed, encouraging train trips to the international airport would reduce emissions during the journey. Short haul flights are one of the most carbon intensive ways to travel, while rail is relatively efficient (Robinson, 2021). Replacing short haul flights with rail trips and coordinating between rail companies and airlines can reduce logistical barriers to multimodal international journeys. Strategies to increase multimodal journeys include:

- Adapting infrastructure to encourage connections between intercity rail services and airports. Lufthansa found that as of 2020 only five German airports connect to Deutsche Bahn's high speed intercity rail network (Lufthansa Group, 2020). For many air passengers, the frequency of domestic rail connections often did not suit their travel needs (Lufthansa Group, 2020). Policymakers should increase express rail trips between cities and international hubs. Policymakers should also increase train frequency to coincide reasonably with flights.
- Rail connections to international airports should also support international travel where possible (*Intermodality*, 2020).
- Increasing ticketing and mileage infrastructure convenience. In many cases, rail and airline ticketing infrastructures are separate and hard to navigate. Railways and airlines should provide a more seamless connection between the two and facilitate easier replacement and rebooking in the case of cancellations, delays, or other travel plan changes.
- Airlines and rail services can ease multimodal traffic by sharing information regarding baggage and connections (Intermodal Transport Hubs, 2022).

Rail infrastructure can have long-lasting impacts on local wildlife habitats and ecosystems (*Plane and Train*, 2021). Rail and air multimodality projects, especially constructing new rail and air infrastructure, should reduce emissions from both sectors and complement each other to provide the most efficient transportation (*Plane and Train*, 2021).

Air-rail connection examples

Lufthansa coordinated with Deutsche Bahn to facilitate connection between major cities and international airports. The Rail&Fly program allows Lufthansa passengers to add specific train tickets for the day before and/or after Lufthansa flights (To Your Flight with Rail&Fly, n.d.). Lufthansa also offers Lufthansa Express Rail, a programme that provides timed connections, reasonable transfers, and automatic rebooking (in case of cancellations or delays) between most major cities and Frankfurt Airport (Lufthansa Express Rail, n.d.).Customers receive one ticket for their Lufthansa Express Rail journey and can check in for both journeys simultaneously.

Swiss International Air Lines and SBB jointly created the "Airtrain" between Basel, Lugano, Geneva, and Zurich International Airport (Airtrain, n.d.). The service facilitates connections between major cities and Swiss International Air Lines' principal hub. "Airtrain" has a maximum duration of 3 hours and offers up to 20 trains per day on the most in-demand routes. Customers benefit from an integrated ticketing and rewards mileage system, as well as door-to-door luggage service coordinated by rail and airline partners (Flight Luggage, n.d.).

Plane Electrification

Electrified planes remain particularly challenging compared to other modes of transport. The high weight of batteries limits electric planes to short flights. However, for general aviation and short-haul flights up to 500 miles, estimates for plane electrification are optimistic. Solid-state batteries could increase an electric plane's effective range to 1,000 miles (Liebriech, 2020).

Nonetheless, in 2018, Norway announced that it wants all *short-haul* flights in the country to be electric by 2040 ('Norway Aims for All Short-Haul Flights to Be 100% Electric by 2040', 2018). Sweden and Denmark committed to making domestic flights fossil-fuel-free by 2030 ('Denmark to Make Domestic Flights Fossil Fuel Free by 2030', 2022). Sweden wants to electrify international flights by 2045. For longer distances, aircraft with hybrid power systems (battery and conventional fuel) could decrease emissions. Hybrid planes are essential in the near-term pending battery technology improvements. Electric flights also offer significantly lower fuel costs and noise pollution. Reduced noise pollution can extend airline operations beyond the current limits determined by noise pollution requirements.

Electric planes have a huge potential for long-term returns on investment. Researchers forecast the eVTOL (electric vertical take-off and landing) and air taxi market to be worth $1.5 trillion by 2040 (Schreier, 2021). Significant global public and private investment supports the market on all levels. European states provide much of this investment and innovation. The British Government and private industry committed GBP 84 million (97,292,244 EUR) towards a 'green aviation revolution' (*New Grants for Aerospace Projects*, 2021). Britain's government also created a GBP 3 million (3,474,723 EUR) competition to fund pioneering research into electric and hydrogen aircraft development (*Zero Emission Flight Competition*, 2021). The US government announced 33 million USD (31,809,162 EUR) in funding for 17 hybrid/electric aviation projects (*Carbon Neutral Hybrid Electric Aviation*, 2020). The EU, citing potential innovation across several fields, also funds a project which develops prototype planes using electric motors and modular power-generation systems (Bailey, 2020)

Other recent advancements in the field include:

- Scandinavian regional airline Widerøe and Rolls Royce plan to electrify the airline's regional fleet by 2026 (Bailey, 2020).
- In 2021 Safran (France) and Boeing recently announced a joint venture to develop batteries for urban air mobility and electric aircraft projects.
- German-based Lilium Aviation has already conducted over 1000 electric plane test flights. Lilium Aviation plans to disrupt the market with electric air taxis for everyday travel (Schreier, 2021).
- Israeli aerospace company Eviation has taken significant steps towards flying the world's first all-electric passenger plane, 'The Alice'. Currently, the plane can carry nine passengers up to 440 nautical miles (814 km). The Alice has a top cruising speed of 250 kts (463 kph). As battery technology improves,

Eviation forecasts that passenger planes that can carry 20-40 individuals will be ready in seven to ten years (Korn, 2022).

Removing tax breaks

A leaked European Commission study showed that EU Member States chronically under-tax the aviation sector compared to global aviation markets (Dornier, 2019). Member States effectively subsidised one of the most emissions-intensive forms of transport possible. The report found that Member States can tax the aviation industry at 10% without impacting GDP.
Policymakers must reconsider airline taxation in three key areas:

- Ticket taxes: Member States levy ticket taxes unevenly. Taxes depend on destination, fare class and collection method. Within the EU/EEA, ticket taxes average at 11 EUR per ticket, which is relatively low compared to global markets. Policymakers must adjust ticket taxes to account for air travel's intense emissions.
- Value Added Tax: Before the Union's inception, VAT on passenger flights within Europe was zero-rated. EU Directive 2006/112/EC grandfathered in that system (COUNCIL DIRECTIVE 2006/112/EC, 2006). Although member states have taxed domestic and extra-EU flights, rates remain low at an average of 4 EUR per ticket.
- Kerosene taxes: Fuel exemptions and subsidies artificially deflate costs and increase demand. Policymakers must reform these exemptions and subsidies to reflect the actual cost of air travel (Hemmings, 2018a).

Such low taxation rates and continued fuel subsidies artificially deflate air travel costs. These costs do not reflect air travel's actual environmental and social cost. Policy makers must reform ticket taxes, VAT, and fuel subsidies to encompass air travel's total cost.

Aviation tax reform examples

Australia has a comprehensive airline taxation regime, particularly regarding ticket taxes. Australia institutes a Passenger Movement Charge (PMC) at a flat rate of AUD 60 (roughly EUR 40) for international departures, in addition to other taxes and charges. Domestic departures are subject to a different rate of taxation, but all classes of flights within and outside of Australia are subject to several taxes regardless of destination (Australian Taxation Office, n.d.).

The United Kingdom recently reformed flight taxation, cutting Air Passenger Duty taxes on domestic flights from GBP 13 (15 EUR) to GBP 6.50 (7.40 EUR) while increasing APD on ultra-long haul international flights to a minimum of GBP 91 (103 EUR) per ticket (N. Murphy, 2021).

Introducing additional charges

Europe is particularly notorious for low-cost air travel, which often incentivises air travel over much more efficient alternatives (e.g. train travel). Additional carbon charges or "eco-taxes" would disincentivize unnecessary air travel. Extra aviation fuel taxes can outweigh cheap European ticket prices.

The European Commission makes no secret that passengers will pay for reducing CO_2 emissions. Additional charges will reduce the demand for sky travel. Airlines are calling for incentives instead of penalties (*Bruksela da szlaban na tanie latanie*, 2021). The announced 'Fit for 55' package of proposals includes aviation fuel taxes and withdrawing free carbon emission rights for the aviation industry. As fuel taxes increase and subsidies decrease, researchers expect airlines to pass on most, if not all, of the increased cost to consumers. Although governments may introduce airline taxes, the taxes will effectively place the incidence, or tax burden, on consumers. Demand will likely drop as consumers face higher prices and better alternatives.

Governments may also institute additional consumer fees, or "green fees", to disincentive air travel. "Green fees'' could include (Hemmings, 2018b):

- taxation based on the distance for flights out of Europe.
- taxation based on the carbon content and emissions of a particular flight and fuel.

Taxing flights and tickets by their environmental impact can nudge airlines and customers toward environmentally friendly decisions. Customers could potentially use more efficient forms of transportation.

'Eco-tax' examples

In 2020, France introduced an 18 EUR "eco-tax" per business ticket for international (non-EU) travel. A subsequent proposal could raise these fees to an additional 1.50 EUR per economy ticket - again, only for non-EU flights. The tax office expects the resulting revenue to be close to EUR 180 million per annum. However, a proposed tax on diesel and aeroplane fuel was vehemently opposed by airlines, resulting in very little forward motion in this area (Chappell, 2019).

In 2018, Sweden introduced an aviation tax based on the flight's destination and distance. Flights to Appendix I countries (continental Europe, the United Kingdom, and Iceland among others) have a fee of 64 SEK (~6 EUR) per passenger, flights to Appendix 2 countries are subject to a 265 SEK (~25 EUR) fee, and all other destinations incur a 424 SEK (~40 EUR) tax (*Swedish Aviation Tax*, 2022).

Germany's Aviation Tax was introduced on 1st January 2011 and remains payable on departures from all German airports at a cost of 7.50 EUR, 22.43 EUR, or 42.18 EUR depending on the distance flown (Borbely, 2019). Considering Borbely's results, the 12.5% travel performance feedback is not an unrealistic assumption. Most of the airports in Germany included in the study experienced a more pronounced decline in passenger numbers. However, when examining the impact on travel performance, it should be borne in mind that the German airline ticket tax has had its greatest impact on relatively short, holiday-type trips.

Reducing airport subsidies

A still-active 2014 EC revision of the EU's Aviation Guidelines permits state subsidies for regional airports and the mostly low-cost airlines servicing them. Airports with annual traffic below 3 million passengers per year can receive exemptions from state aid limits until 2024. Airports serving fewer than 700,000 passengers per year can receive subsidies that cover up to 80% of operating losses. Starting in March 2020, the European Commission approved several state aid schemes for regional airports owing to the pandemic (2014/C 99/03, 2014).

Regional airports - often owned by local authorities - benefit from local public subsidies, regardless of performance indicators, proximity to other airports, alternative means of transport, or other factors. Regional airports have no incentive to perform if subsidies are available. Subsidies mainly function as direct subsidies and tax exemptions for local public administrations. These subsidies and other factors (e.g. competition between low-cost airlines) prevent rail from competing on short-haul routes.

The pandemic might have created an opportunity to discuss European regional airports' economic and emissions performance. Post-pandemic recovery might require years of additional public subsidies. Investments through the RRF, other European and national funds in domestic train routes (infrastructure, electrification, rolling stock), and citizens' concerns about climate change might also incentivize reducing subsidies for underperforming regional airports. The Commission should toughen guidelines for regional airports. National level transport strategies should also change. Both National and EU frameworks should level the playing field between planes and trains.

Governments should also incentivize multimodal regional airports over equivalent, non-multimodal airports. This measure will impact emissions and load factors for both trains and aeroplanes.

Stopping the construction of new airports

Reducing the number of flights, due to their high emissions intensity, is critical to reducing passenger transport emissions. Stopping the construction of new airports, especially where they undermine railway competitiveness, is essential to reduce the air travel's activity levels.

The movement to stop new airport construction significantly impacted recent airport expansion and construction plans. Some cities stopped airport expansion projects. In Paris, residents successfully blocked construction due to arguments around meeting national emissions reduction targets (EJOLT, 2021). The new terminal was unnecessary for managing current air traffic, and nearby residents would suffer from increased air and noise pollution (*Noise Pollution in Cities to Blame for 1 in 20 Heart Attacks, Study Shows*, 2022). However, the French government remains committed to a new terminal project and favours a future increase in air traffic at Roissy airport. Lisbon authorities blocked the construction of a new local airport due to environmental concerns. The Portuguese government intends to change the law to stop local authorities from vetoing the airport and similar projects “of national and strategic interest”(Sampson, 2021).

Paris Agreement obligations increased the likelihood of litigation against the new airport construction. For example, environmentalists sued an expansion of London's Heathrow airport based on the UK’s Paris Agreement obligations ([2020]UKSC 52, 2020). The threat of litigation will increase costs and slow down airport construction or expansion (M. Clarke, 2021).

Vienna International Airport also faced significant controversy and litigation following the proposed addition of a third runway. Vienna International Airport’s parent company first proposed the expansion in 2001. The airport initially submitted the plan for review by the relevant regional regulatory bodies in 2007. Environmental activists then sued the regional regulatory body. Lower federal courts originally approved the expansion before the Federal Administrative Court overturned the expansion. The Administrative Court found that the development would do more public harm than good, citing Austria's national and international climate change commitments. However, the Constitutional Court, the highest relevant body, rejected this argument and approved the expansion. Despite continued citizen climate activism, the third runway is now expected to be opened in 2028, a seven-year delay from the planned 2021 opening (‘Austria’s Top Court Overturns Ban on Vienna Airport Expansion’, 2017; Sabin Center for Climate Change Law, 2021).

Carbon offsetting

Carbon offsetting is one of the strategies airlines use to "neutralise" their emissions. Many airlines (e.g. EasyJet, Ryanair, British Airways) argue that they partly or fully compensate for their emissions by investing in projects that mitigate carbon emissions (*Carbon Neutral | Leapfrog*, n.d.; *Carbon Offsetting*, 2022; *Ryanair Goes Greener With New Carbon Calculator*, 2021). However, the EU Commission found that up to 85% of offsets under the UN Clean Development Mechanism did not fully deliver claimed emission reductions. One of the most popular forms of offsets - tree planting – has limited usefulness (Cames et al., 2016).

The carbon offsets market continues to grow in both the compliance and voluntary sectors (Irfan, 2020). In compliance markets, entities can purchase and trade offsets to comply with legal emissions caps. Firms, individuals, and other groups typically sustain the voluntary markets. These groups often pursue net-zero or low emissions goals. Carbon offsets tend to support renewable energy ventures, energy efficiency projects, or carbon removal efforts (Anderson, 2012). However the extent and successfulness of these goals remains highly questionable (Anderson, 2012).

Carbon offsets are indirect and multifaceted. It is often difficult to measure the impact any one carbon offset may have. The voluntary offset market also shifts attention away from current issues and innovations (Anderson, 2012). This distraction weakens the drive for a zero-carbon future (Anderson, 2012). Thus, **carbon offsetting cannot be recommended as a measure**, especially considering that customer willingness to pay remains very low (Jou & Chen, 2015).

If a policymaker must consider a carbon offset, the offset must meet several criteria to ensure it is at least not additionally harmful.

- The offset must meet the principle of additionality. Under additionality, policymakers must ask, "Would this project occur without the money from the offset?" If the answer is yes, the offset is not a valid offset of emissions ('The Additionality Problem of Carbon Offset Projects', n.d.). The offset did not lead to additional emissions reduction ('The Additionality Problem of Carbon Offset Projects', n.d.). The principle of additionality requires rigorous outside accounting and is a high, often unmet bar.
- Offsets must reduce carbon levels permanently. Suppose offsets do not result in a permanent reduction of greenhouse gas emissions (Wise et al., 2019). In that case, they are essentially counterproductive – reduced emissions must be permanent to be effective.
- Offsets must address leakage. When leakage happens, protecting one area results in the overuse of another (Jenkins et al., 2013). Emissions would not decline (Jenkins et al., 2013). For example, if an offset protects one area of forest from deforestation, the offset must also ensure that other forested areas are not stripped due to those protections.
- The offset must not be double counted. Registries must be meticulously kept and ensure an offset is counted for its entire lifespan. Given the already contentious accounting of an offset's emissions reductions, preventing double-counting remains thorny (Pra & Brotto, 2018).

Offsets can be counterproductive if they mislead consumers to believe that the comparably low price of tCO_2eq purchased as an offset fully neutralises a flight's negative environmental impact. This deception encourages an increase in activity levels.

Biofuels

Drastically scaling up sustainable aviation fuels is necessary to decrease emissions. However, it is not certain that biofuels are the best long-term alternative. Currently, biofuels make up only 0.01% of global aviation fuel. While some research has shown that biofuels from organic matter and live plants are more compatible with modern jet engines than fossil fuels, biofuels still face a significant scalability problem. Sustainable biofuel production technologies already exist. However, scaling up production without having a destructive environmental impact is currently unfeasible. Biofuels must meet stringent sustainability criteria. Current crop-based biofuels do not meet these criteria (Panoutsou et al., 2021; *SLOCAT Transport and Climate Change Global Status Report - 2nd Edition*, 2022). **Crop-based biofuels should not be supported now as a sustainable alternative**.

Synthetic aviation fuels

Synthetic aviation fuels are an option to reduce aviation fossil-fuel dependency. One example of synthetic fuel is e-kerosene or PtL (power-to-liquid). Fuel producers can blend PtL with regular jet fuel to reduce overall flight emissions. Adding PtL could potentially decrease emissions by up to 80%. E-kerosene is also generally more sustainable than other fuel alternatives, such as biomass fuels or crop-based fuels. Synthetic fuel production currently accounts for only 0.1% of the jet fuel market and faces both high start-up costs and the need to scale production (A. Murphy, 2021). Current production processes require large amounts of CO_2 and electricity (Scheelhaase et al., 2019).

Blending mandates, which would require airlines to mix a specific amount of synthetic fuel with standard A-1 jet fuel for future flights, could spur production. The mandate would guarantee a certain level of airline and industrial consumption. Additionally, mandating demand will decrease the price of e-kerosene down, addressing another implementation issue (Transport & Environment, 2020).

ICAO established an Alternative Fuels Task Force, which predicts that the aviation industry could entirely switch to low-emission fuels by 2050. This switch would reduce emissions by 63%. However, the switch would require unprecedented levels of investment. Additional deterrents against unnecessary air travel must complement sustainable fuel policies (*SLOCAT Transport and Climate Change Global Status Report - 2nd Edition*, 2022).

Bio-aviation fuel examples

In its July 2021 Fit for 55 package, the European Commission proposed a blending mandate beginning in 2025. The mandate would initially require 2% of all jet fuels to be sustainable, climbing up to 63% by 2050. The proposal includes a sub-mandate, which would require e-kerosene to account for 0.7% of all jet fuel purchases in the EU by 2030. EU airports would be required to implement the necessary infrastructure to store and blend the fuels to meet the mandate.

In 2021, Atmosfair, a climate organisation in Germany, opened a plant producing e-kerosene made from sustainable materials in northern Germany. Atmosfair uses these materials, including CO_2 captured from the air and a biogas plant that runs on food waste and local solar and wind energy, to produce e-kerosene. Current production is at eight barrels (one ton) of crude paraffin per day (Atmosfair, 2022). Atmosfair refines this paraffin into A1 jet fuel and sends the jet fuel to Hamburg Airport (Atmosfair, 2022).

Hydrogen

Hydrogen offers a viable option to reduce aviation emissions. Hydrogen could serve either as power in a fuel cell or through combustion. However, despite recent technological improvements, hydrogen still faces significant limitations to the fuel's near-term feasibility (Henderson, 2021).

Hydrogen is gaseous at normal atmospheric pressure and temperature. People must liquify hydrogen to store hydrogen as a fuel. Hydrogen becomes liquid below -252.87 °C. Liquid hydrogen has greater energy by mass, but only around a quarter of the energy density of regular jet fuel. Storage tanks for liquid hydrogen are complex, heavy, and, as a result of the density problem, need to be about four times the size of a standard fuel tank to deliver the same amount of energy. This limitation creates a significant engineering question for aeroplane manufacturers and airlines (Air Liquide, 2017; Ben-Achour, n.d.). These groups loathe sacrificing seats and revenue for fuel tanks (Ibid.).

Fuel-cell options are not well suited for current aircraft. Although hydrogen fuel cells can be quickly recharged and adapted for use on the ground, they would be far too heavy for aircraft. Hydrogen fuel cells were initially developed for ground technology. Therefore, short-term adjustments for aircraft will be challenging. However, for short-haul aviation, smaller planes can be powered by hydrogen (Furchgott, 2021).

Engineers have proposed hybrid solutions to solve the problems presented by hydrogen-only systems. Such systems would combine hydrogen fuel cells and hydrogen combustion to power flights. This hybrid system could potentially give planes a greater range than just hydrogen combustion or fuel cells alone. Hybrid hydrogen-electric systems are likely to be the most common, using electric propulsion and hydrogen fuel (Liebreich, 2020).

Hydrogen pricing complicates the feasibility of hydrogen planes. Current hydrogen production costs around USD 6/kg (5.78 EUR/kg) when produced by electrolysis from renewable sources. The price must drop to under USD 2/kg (1.93 EUR/kg) to compete with conventional fuel, which typically sits below USD 1/kg (0.96 EUR/kg) (DiChristopher, 2021; EuroControl, 2021; IATA, n.d.).

Hydrogen aeroplane examples

Airbus is currently aiming to introduce the world's first commercial hydrogen plane by 2035 (Leiden, n.d.). The company has three different models of hydrogen planes proposed, all driven by hybrid-hydrogen engines (Leiden, n.d.).

Zeroavia already has two hydrogen-powered planes for up to 6 passengers (Henderson, 2021).

Electrifying airport vehicles

Unlike electrifying aeroplanes, electrifying airport vehicles and equipment presents a viable, short-term solution to reduce emissions. Airport ground support equipment (GSE) includes vehicles necessary to the functioning of an airport, such as tugs and tractors or buses – all of which usually run on diesel (*Ground Support Equipment Glossary*, 2020)

Airports have already begun shifting to battery powered electric GSE (e-GSE), which reduces on-site carbon emissions (Lay, 2020). GSE electrification is particularly effective due to the nature of GSE work (Johnson, 2017). Airport ground support has numerous starts, stops and short-distance pushing or pulling over short distances, which is perfectly suited to the low-end torque generated by electric engines (Johnson, 2017). Electric charging stations are safer than diesel pumps and can be placed in more locations around the airport, facilitating easy charging.

E-GSE additionally helps reduce particulate matter in the air, are quieter, and reduce energy costs overall. E-GSE leads to a healthier, quieter, and more efficient work environment for ground support staff. The most common GSE already have electric alternatives, and diesel-to-electric conversions are relatively common. Electrifying all can save significant emissions and energy in the air transport sector. Electrification can also increase reliability and flexibility within the GSE fleet.

Electric ground support examples

Amsterdam Schiphol Airport designed and implemented electric ground support units (GSU) in association with Nissan and ITW GSE (*Electricity Replaces Diesel for Aircraft at Royal Schiphol Group Airports*, 2019). This project was part of Schiphol's 'Smart and Sustainable' action plan to reduce airport emissions (*Electricity Replaces Diesel for Aircraft at Royal Schiphol Group Airports*, 2019). These units power aircraft located on the apron and charge the batteries in electric ground support vehicles. The electric ground support vehicles use already existing battery technology usually used in cars. Compared to diesel GSE and earlier GSU, the e-variants reduced carbon emissions by 90% and NOx emissions by over 95% (Lay, 2020). In addition, Amsterdam Schiphol uses e-GSE such as buses, pushback trucks, and stairs as part of their goal to become carbon neutral by 2030.

Singapore Changi Airport uses over 80 electric baggage tractors supported by a shared pool of charging stations to facilitate ease of use and support further electrification (*Changi Takes Big Steps to Go Green*, n.d.). One terminal already has an entirely electric fleet. That transition has saved 627 tonnes of carbon emissions to date, and the Changi Group plans to transition all terminals to all e-GSE by 2030 with the support of its ground service partners (*Sustainable Changi*, 2022).

Avoiding "ghost flights"

Most large European airports have instituted slot rules for take-offs and landings. Slot rules ostensibly protect competition, and primarily coordinate take-offs and landings efficiently. The EC provides airlines a certain number of take-off or landing slots. Airlines must use at least 80% of those slots to qualify for the same number of places in the same scheduling season. If airlines use less than 80% of their slots, the EC reallocates unused slots to another airline for the next scheduling season (EEC No 95/93, 1993; European Parliamentary Research Service, 2022). This rule is called the "80/20" or the "use-it-or-lose it" rule.

COVID-19 exposed a fundamental flaw in this system. To avoid losing the slots, airlines in some cases have resorted to flying empty or unprofitable flights, or "ghost flights". The EC suspended the rule in 2020 due to COVID 19, but restored the rule at the 64% level at the end of 2021 (Neslen, 2022; Ngutjinazo, 2022). The Lufthansa group (which includes Swiss, Brussels Airlines, Austrian Airlines, and Eurowings) claims that as a result of this reintroduction, the group flew an estimated 18,000 "ghost flights" (Neslen, 2022; Ngutjinazo, 2022). The United Kingdom's Civil Aviation Authority reports that in 18 months from March 2020, almost 15,000 empty or near-empty flights left the United Kingdom (Carrington, 2022).

The 80/20 rule requires airlines to maintain their slots at any cost. This incentive leads to unnecessary emissions, threatens emissions reduction goals, and contributes to the climate crisis. To address this situation in the short term, governments should abolish the 80/20 rule or decrease the requirement to use the landing slots significantly. This abolition or reduction would remove the incentive to fly empty planes. Airlines will be free to cancel less full or empty flights without concern for losing their slots. The policy would enable airlines to operate only necessary flights and increase the load factor on these flights.

The Worldwide Airport Slot Board recommends continuing "Justified Non-Utilisation of Slots" (JNUS) rules. Airlines can protect their slots even when not using them due to extenuating circumstances related to COVID-19 (Worldwide Airport Slot Board, 2022). Policymakers could potentially include JNUS exceptions for climate reasons. JNUS exceptions for climate reasons could enable airlines to protect their landing slots without using 'ghost flights'.

Increasing planes' energy efficiency

Improving aeroplane energy efficiency could significantly reduce air travel's emissions and facilitate the scaling-up of alternative fuels. Currently, engineers typically improve fuel efficiency in one of two ways:

- Redesign the plane from the ground up. Examples include improving aerodynamics, using lighter materials, or designing better engines. The redesigned Boeing Dreamliner 787, for example, improved energy efficiency by up to 27% (Aschwanden, 2020; Paur, 2009).
- Increase the fuel efficiency of the engines. Fuel efficiency increases can decrease the plane's energy consumption by around 10%.

Very small and very large planes tend to be less fuel efficient compared to the common twin-engine widebody model (e.g. Boeing 787) (Rutherford, 2018). Improvements in range and efficiency have allowed twin engine planes to make ultra-long-haul and transoceanic flights with less fuel than their massive, quad-engine predecessors. When possible, airlines should phase out heavy, inefficient quad-engine planes in favour of lighter and much more efficient twin-engine planes.

Addressing air traffic control inefficiencies can reduce air and ground traffic jams. Reducing these jams would decrease emissions. Traffic control can achieve reduce inefficiencies in three ways:

- Improving route efficiency.
- Managing departure queues, so planes and travellers do not burn fuels for long periods while sitting on the tarmac.
- Managing traffic so that planes can land with minimal wasted distance (*Accelerating Air Traffic Management Efficiency*, 2012).

Communicating constraints or congestion quickly between all associated authorities helps reduce fuel waste and can achieve the above measures. Flight planning can also significantly impact fuel demand (*Perfect Flight*, 2022). For example, headwinds may make the most direct route more fuel-intensive than a longer route with a tailwind (*Perfect Flight*, 2022). Contrails generally form where it is humid and cold and can change how radiation enters and leaves the earth (Timperley, 2021). That radiation change is a critical component of the greenhouse effect (Timperley, 2021). A 2020 study modelled Japanese airspace and found that just 2% of all flights contributed 80% of the contrail warming effect (Teoh et al., 2020). Changing routes could reduce this impact by 60% (Teoh et al., 2020).

Energy efficiency examples

Both Airbus and Boeing have continued to improve their planes' efficiency (Rutherford, 2018). The Boeing 787-9, 777, and Airbus A330 operate at above-average efficiencies, with ongoing annual efficiency improvements. The airline industry has generally supported these improvements. For example, Qantas used the Covid-19 pandemic and unprecedented drop in demand to accelerate its shift away from the Boeing 747, 787 and the Airbus A321neo as part of their goal to reach net-zero emissions (*Reducing Emissions*, n.d.).

Within the EU, Eurocontrol and the German Aerospace Institute are testing the feasibility of shifting routes and changing other operational methods to reduce contrails (*A Unique Opportunity to Accelerate Development*, 2020). Finnair's and Finntraffic Air Navigation Service's Perfect Flight Project uses a data-driven methodology to optimize flight paths and thereby reduce the environmental impact of air travel (*Perfect Flight*, 2022). The Perfect Flight Project intends to coordinate this system with a global panel of indicators and international aviation authorities.

The United States Federal Aviation Administration (FAA) is implementing the Next Generation Air Transportation System (NextGen) to upgrade the current airspace management system and to mitigate air travel's environmental impact (*NextGen Key Programs*, 2021). The NextGen program has built new metrics and tools to measure noise and carbon pollution (*Environment and Energy Research & Development*, 2017). The program also funded research into alternative fuels and efficiency improvements (Ibid.).

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