Introducing an Air Ticket Tax in Switzerland: Estimated Effects on Demand

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Executive Summary

The full climate impact of aircraft emissions amounts to three times that of the direct carbon dioxide (CO_2) emissions, due to the other components of these emissions that have an effect on the climate (water vapour, nitrogen oxides, sulphur dioxide, soot).[1] With this factor three, international air travel by Swiss residents accounted for more than a quarter of the climate impact of Swiss emissions in 2019. Nonetheless, Switzerland had no specific climate policy for international aviation until 2020. Swiss residents are frequent flyers and travel by plane almost twice as often as residents of neighbouring countries. Even under an optimistic technology development scenario and somewhat slower passenger growth post-COVID-19, the global warming impact of Swiss aviation could grow by a third by 2050 relative to 2019. This would be difficult to square with the net-zero objective of the Federal Council.

When revising the CO_2 Act of 2011, the Swiss Parliament introduced an air ticket tax of CHF 30 to 120, depending on the travel class and distance travelled. We estimate the possible impact of such a tax on future air travel volume. To that end, we developed and calibrated an original dynamic model of air travel demand and its climate impact. The main parameters are demand elasticities, which we derived from a review of the international literature. We use the model to simulate the impact of different air ticket tax schedules on the demand for air travel under the simplifying assumption of isoelastic demand and perfectly elastic supply.

In a slight simplification of the proposed tax schedule, our baseline simulations assume that short-haul flights will be subject to a ticket tax of CHF 30 in economy class and CHF 60 in premium class, while a tax of CHF 90 in economy class and CHF 120 in premium class will be applied to long-haul flights.[2] Our simulations suggest that such a tax schedule would reduce the number of passengers by 13% to 21%, depending on assumed elasticities. It appears plausible that after the COVID-19 experience demand elasticities for air travel will be closer to the upper bound, especially for work-related travel. In that case, passenger numbers would decrease by 21%. In that case, CO_2 emissions from aviation would decrease by 16% – somewhat less than the decrease in passenger numbers, since the tax schedule of the CO_2 Act increases the price of long-haul flights less, in relative terms, than that of short-haul flights. Since long-haul flights account for 60% of the climate impact of aviation yet represent only 20% of passengers, the climate impact of a ticket tax tends to increase with the progressivity of the tax schedule, and this despite the lower price elasticities in the long-haul segment.

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[1] In past assessments, also by us, the factor commonly used was two, but new knowledge of the radiative forcing by the non-CO_2 components in aircraft emissions led to the revision of this factor.

[2] The simplification is that we do not consider medium-haul flights as a separate category.

Considering the full climate impact of the average short-haul flight in economy, a CHF 30 air ticket tax is equivalent to a price of CHF 92 per ton CO_2eq, close to the rate of the existing CO_2 levy on heating and process fuels (CHF 96 per ton CO_2). As the average long-haul flight in premium with a stopover is more than 16 times more polluting than the average short-haul flight in economy, there is no way that a tax restricted to a range from CHF 30 to 120 could adequately reflect the climate impact of the different flight segments. Furthermore, adding CHF 30 for premium over economy, regardless of the flight distance, is a rather crude approximation of the additional climate impact attributable to wider seats. As a result, the average long-haul flight in premium would only be taxed at an implicit rate of CHF 24 per ton CO_2eq under the proposed schedule, whereas the average short-haul flight in premium would be taxed at an implicit rate of CHF 123 per ton CO_2eq.

The discrepancy in the implicit carbon prices on emissions represented by the ticket tax schedule of the CO_2 Act is even stronger when one considers that the CO_2 emissions from flights to destinations in the European Economic Area are included into the emissions trading system, i.e. airline companies face a marginal price for these emissions that reached EUR 50 per ton CO_2 in May 2021. Long-haul flights are exempted. This implies that a third of the climate impact of a short-haul flight is already priced in. The CHF 30 tax on short-haul flights in economy class therefore implies a total price of CHF 138 per ton CO_2 for the average European flight, and the CHF 60 for short-haul flights in business class amounts to CHF 184 per ton CO_2.[3]

We also simulate the implications of alternative tariffs. We find that by lowering the rate for short-haul flights and raising it for long-haul flights, particularly in a premium class, it would be possible to attain a greater reduction in the climate impact of aviation (which is, after all, the purpose of this tax) with a smaller reduction in passenger numbers. The revenues of the air ticket tax would be nearly the same for the two schedules: around 1 billion francs per year, of which roughly CHF 350 million would be returned to the population. This corresponds to a refund of about CHF 40 per person.

In addition to simulating the effects of a range of air ticket tax schedules, we evaluate the advantages and disadvantages of that instrument and discusses alternative climate policy instruments such as fuel taxes, personal carbon trading, synthetic kerosene quotas, a change of social norms through policy nudges as well as the promotion of night- and high-speed train travel.

The purpose of this white paper is only to assess the air ticket tax introduced with the new CO_2 Act as an instrument of Swiss climate policy. There is no judgment about whether air transportation in general is important. Nor is there an assessment of the impact on airline companies, airports, employment, international trade, etc., of the proposed air ticket tax or other possible measures discussed in this paper for leading aviation toward decarbonisation.

[3] The fact that the ETS only considers the direct CO_2 emissions and not the full climate impact of aircraft emissions justifies an air ticket tax in addition to the inclusion in the ETS. The same holds for CORSIA.

1 Introduction

Greenhouse gas emissions from anthropogenic sources are accumulating in the atmosphere and leading to a warming of the earth's climate. In order to mitigate the adverse effects of global warming, 196 countries signed the Paris Agreement in December 2015, an international treaty which aims to limit the rise in average global temperature to well below 2°C above pre-industrial levels, with efforts to restrict the increase to 1.5°C. To meet the latter goal, global CO_2 emissions would need to fall by about 45 percent until 2030 relative to 2010, reaching 'net zero' around 2050 (Figure 1, IPCC, 2018). 65 countries, including Switzerland and the European Union Member States, have pledged to reduce their CO_2 emissions to net-zero by 2050 (United Nations, 2019).

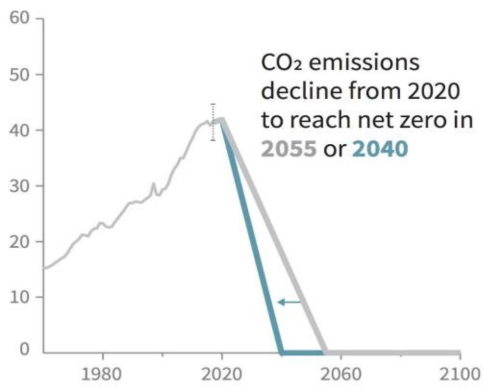

Figure 1: Stylized net global CO_2 emission pathways ($GtCO_2$/year). Global CO_2 emissions needed to reach net zero by the middle of the century (IPCC, 2018)

In Switzerland, aviation is the only sector whose CO_2 emissions have continued to grow over the past decade. Implicit CO_2 emissions from kerosene sales at Swiss airports were 75% higher in 2019 than in 1990, and they grew by an annual rate of 3.2% in the most recent period 2010-2019 (data from FOEN, 2021).

The implication of these numbers is clear: the growth of aviation emissions needs to be significantly curtailed if Switzerland is to meet its agreed climate targets. There are two ways of achieving this aim: either flying becomes cleaner, or people fly less.

Given the undoubted economic, social and personal benefits that air travel procures, the preferred option would be for flying to be made cleaner. Progress has been achieved: improved aircraft engineering has yielded considerable gains in fuel efficiency, and dynamic pricing strategies have increased load factors. In the coming years, biofuels and synthetic kerosene might contribute to powering aircrafts in carbon neutral fashion.

These technological developments are welcome and deserve further encouragement. However, it appears overwhelmingly likely that technological change alone will not suffice to reverse or even significantly slow the rising global warming impact of aviation.[4] Two numbers underlie this assessment: while Swiss air travel emissions increased on average by 3.2% annually between 2010 and 2019, passenger numbers increased by 4.6% (FSO, 2020a). Hence, environmental efficiency gains have only managed to offset about a third of passenger growth. The likelihood that such gains could reverse the growth of aviation's global warming impact in the near future therefore appears close to zero. Technological improvements are simply swamped by the increase in passenger numbers.

To reduce greenhouse gas emissions from aviation, the Swiss Parliament introduced into the new CO_2 Act an air ticket tax in the range of CHF 30 to 120, which could become effective in 2022 (Swiss Parliament, 2020). Furthermore, on January 1, 2020, the Swiss emissions trading system was coupled with the European Union Emission Trading System (EU ETS), and covers all air travel between Switzerland and the European Economic Area.[5]

We provide first-pass estimates of the impact of an air ticket tax on the demand for air travel and corresponding greenhouse gas emissions. The tax decided – CHF 30 to 120 per air ticket – would significantly curb demand. It could reduce air traffic by up to 21% and associated greenhouse gas emissions by up to 16%. This would cut Switzerland's total global warming impact by about 4%. We do not simulate distributional impacts of the air ticket tax, but note that the tax foreseen by Parliament would generate revenues of up to CHF 1 billion per year.

Since long-haul flights account for an estimated 60% of emissions but only 20% of passenger volume, the mitigating impact on emissions could be strengthened through a more progressive tax schedule, featuring top rates well above the ceiling of CHF 120, particularly for premium seating. Such an improved emissions outcome could be attained with a smaller drop in passenger numbers compared to our interpretation of Parliament's baseline scenario.

After describing the context and providing some background information on aviation and its climate impacts (ch. 2), this white paper introduces and discusses briefly a range of instruments that have been proposed to reduce emissions or that exist in the European Union and Switzerland (ch. 3). A detailed discussion of possible measures is relegated to the end of the paper (ch. 6). Indeed, this white paper concentrates on the new air ticket tax. In order to simulate its possible effects, we need an estimate of the responsiveness (or "elasticity") of air travel demand to rising prices (ch. 4). With

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[4] According to one optimistic scenario, synthetic kerosene might account for 5% of fuel use "soon after 2030" (Patt, 2019).

[5] In order to reduce administrative effort, non-commercial aircraft operators emitting less than 1 000 tonnes of CO_2 per year are exempted.

this information, we show how air travel from Switzerland could respond to different imaginable air ticket tax schedules (ch. 5). We conclude by comparing the proposed air ticket tax with possible alternative and complementary measures (ch. 7).

2 The contribution of air travel to global warming

2.1 Full climate impact of aviation

Air travel is one of the most energy-intense forms of transportation (IEA, 2019b). This is due to the high energy demand for generating sufficient aerodynamic lift for the take-off of an airplane. Currently, kerosene is the most widely used aviation fuel in Switzerland, with annual sales of 1,874,428 tonnes in 2019, equal to 18.2% in weight of all petroleum product sales (Avenergy Suisse, 2020). Kerosene is a hydrocarbon of fossil origin that is obtained by refining crude oil. It has a carbon content of 73.3 tCO_2/TJ fuel, which is slightly more than gasoline, but still below diesel (Umweltbundesamt, 2016). During the combustion of kerosene in the most widely used turbofan jet engines, chemical energy is converted into mechanical energy to accelerate the air coming out of the engine and thus generating thrust. As a result of the combustion of a litre of kerosene, fixed amounts of CO_2 and water vapour are generated. Also, several by-products such as nitrogen oxides and aerosols arise due to the incomplete nature of the combustion process.

While the atmospheric properties of CO_2 are well documented, those of other combustion products are much less so. Indeed, a number of methodological difficulties arise. First, these combustion products exert radiative forcing both directly and indirectly through their interaction with other atmospheric constituents, sometimes in opposite ways and with feedback effects. Second, unlike CO_2, other emissions do not mix well in the atmosphere, meaning that their greenhouse effect is strongly dependent on the altitude, the geographic location and the weather among other factors. Third, combustion products do not have the same lifetime, nor do they decay at the same rate; hence, the time horizon considered will influence their relative climatic effect.

Nitrogen oxides (NO_x) have an indirect global warming potential (GWP) by reducing the atmospheric concentrations of methane (CH_4) and increasing ozone (O_3) when being emitted in the higher atmosphere. Water vapour has a considerable GWP at high altitudes due to the formation of linear contrails and the induced cirrus cloudiness. While the level of scientific understanding of the induced GWP is high for CO_2 and medium for NO_x, it is still low for the effects of aerosols, water vapour, and linear contrails. According to the current state of knowledge, contrails and the induced cirrus clouds cause the most significant climate impact of non-CO_2 emissions, substantially higher than the effect of CO_2 itself (Neu, 2021).

To account for these non-CO_2 effects, the Radiative Forcing Index (RFI) has been developed, which is equal to the total aviation radiative forcing (RF) divided by the radiative forcing coming from CO_2 emissions alone (IPCC, 1999). Despite its imperfections, the RFI is widely used by carbon offsetting firms and policy-makers to account for the effects of non-CO_2 gases. An RFI of 2 on total aircraft CO_2 emissions was recommended in the past, based on the interpretation of scientific publications (ESU-services, 2018). More recent research, based on a better understanding of the climate forcing effects of aircraft emissions at high altitudes, concludes that this RFI is about correct for the 100-year horizon of UNFCCC greenhouse gas inventory reporting, but that substantially higher RFIs should be used for assessing the climate impact of individual flights (Lee, 2021). The Swiss Academy of Natural Sciences recently examined the newest evidence on behalf of the Federal Office for the Environment (Neu, 2021). It now recommends a factor of 3 for the compensation of flights from Swiss airports, and this is the value we shall use to calculate the CO_2 equivalent emissions of air trips.

Despite these important and scientifically grounded considerations, the public debate around the climate impact of aviation remains primarily focused on carbon dioxide. For instance, the International Air Transport Association (IATA), the leading trade association of the world's airlines, only discusses CO_2 on their fact sheet on climate change, ignoring any non-CO_2 warming effects (IATA, 2021). Similarly, the International Civil Aviation Organization (ICAO) recognizes the need to reduce emissions that contribute to global climate change, however without mentioning any other greenhouse gas than CO_2 in their latest resolution on climate change (ICAO, 2019c). The IATA states that in 2019, "civil aviation as a whole emitted around 915 million tonnes of CO_2, which is a little more than 2% of man-made carbon emissions". With an RFI of 3, aviation's responsibility is closer to 6% of man-made global warming.

Even with the RFI, our estimates are still an incomplete assessment of the climate impacts of aviation. Indeed, they abstract from the full lifecycle greenhouse gas emissions of jet fuel (extraction, production and transport in addition to combustion), never mind of the aviation sector as a whole (construction and maintenance of aircraft and infrastructure for instance). Moreover, given the aim of this white paper, we only consider the climate effects of emissions and do not discuss the adverse health and environmental consequences of polluting emissions generated by flying.

2.2 Climate impact of Swiss air travel

In 2019, CO_2 emissions from domestic and international aviation amounted to 5.81 million tonnes. Furthermore, significant amounts of other pollutants such as 28,368 tonnes of NO_x, 6,449 tonnes of carbon monoxide (CO), 810 tonnes of hydrocarbons (HC), 32 tonnes of black carbon (BC) and 44 tonnes of particulate matter (PM) were emitted (FSO, 2020b). The estimation of the amount of pollutants is based on the fuel quantity actually filled up in Switzerland and does not include connecting flights abroad. With this estimation method, the emissions from all flights departing from Swiss airports are included. Some airlines, especially for short-haul flights, might not refuel their planes in Switzerland to avoid differences in fuel taxes and carry more fuel than required from their airport of origin. The statistical relevance of this practice called *fuel tankering* is, however, unclear. As international flights are exempted from fuel taxes in Switzerland, it is probably limited.

Total CO_2 emissions from aviation have increased by 86% between the first emissions data of 1990 and 2019, with an average yearly growth rate of 2.3% (data from FOEN, 2021). Emissions growth was particularly strong in recent years up to 2020, with 3.2% on average for 2010-2019. Historically, CO_2 emissions only decreased after the New York terrorist attacks in 2001, after the financial crisis in 2007-2008 and during the current COVID-19 pandemic.

Emissions from Swiss inland aviation accounted for 0.11 million tonnes CO_2 in 2019, which represents the last available data. This amount is negligible compared to the 5.69 million tonnes of CO_2 that result from international aviation (Figure 2).

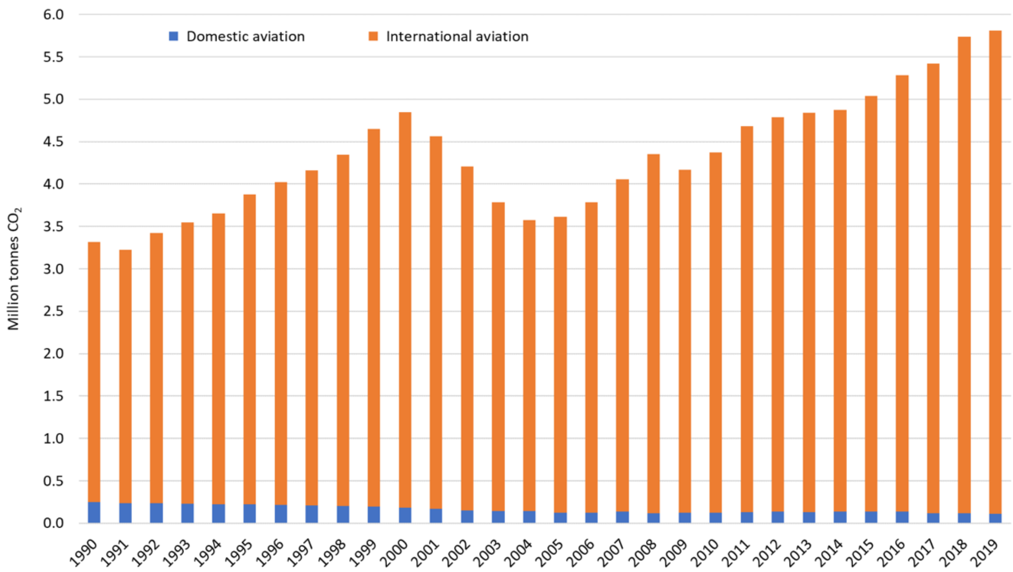

Figure 2: Historical evolution of CO_2 emissions from aviation in Switzerland. Own figure with data from FOEN (2021), no correction for full climate impact

When evaluating the global warming impact of different economic sectors in Switzerland, that of all sectors but aviation is best measured by their greenhouse gas emissions. For aviation, its CO_2 emissions must now be multiplied by the RFI of 3. Therefore, we multiply the commonly measured CO_2 emissions implicit in kerosene sales at Swiss airports by three and add this to the Swiss inventory of greenhouse gas emissions.[6] As a result, aviation becomes the most important contributor to Switzerland's climate impact, accounting for 27.4% of the total (Figure 3). In 1990, it was only the fourth contributor with 15.6%, behind ground transportation, industry and residential buildings.

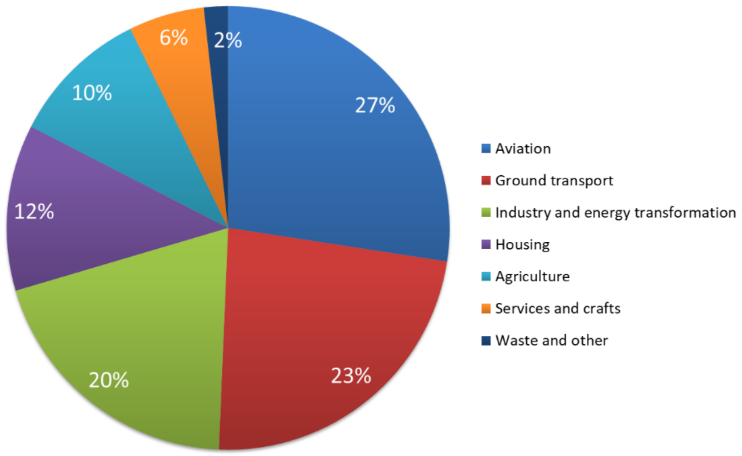

Figure 3: Total global warming impact of main source sectors in Switzerland in 2019, including international aviation (RFI=3). Own figure with data from FOEN (2021)

2.3 Characteristics of air travel from Switzerland

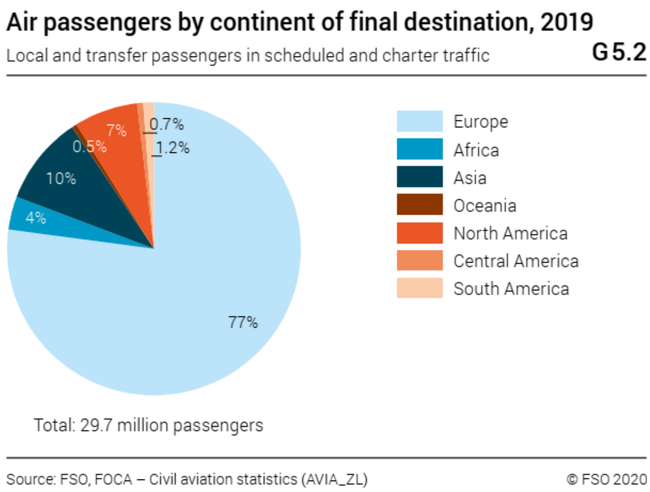

Figure 4: True destination by continent of air passengers in Switzerland in 2019 (FSO, 2020c)

In 2019, 77% of Swiss passengers travelled to European countries, while 10% travelled to Asia and 7% travelled to North America. Africa, Oceania, Central and South America accounted together for

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[6] In the UNFCCC framework, international aviation is not included in national totals, only inland aviation is. More precisely, we multiply the CO_2 emissions of inland aviation by three and add three times the CO_2 emissions of international aviation as reported in the Swiss greenhouse gas inventory.

6% of all air passengers (Figure 4). Consequently, about 77% of all passengers travel on short- or medium haul flights, while 23% travel on long-haul routes.

In terms of flight distance, 20% of passenger-kilometres (pkm) result from flights shorter than 1,000 km and 60% are under 7,000 km (Figure 5). In contrast, air transport of freight is mainly used for long distances over 5,000 km. In Switzerland, freight transport makes up roughly 20% of total pkm equivalents.

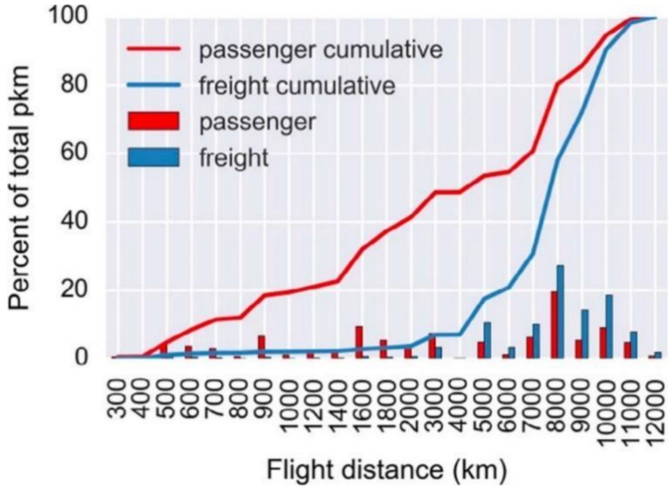

Figure 5: Share of pkm from each flight distance for passenger and freight transport (Cox et al., 2018)

Compared with other European countries, Switzerland is a frequent flyer nation. While the average number of flights per capita was 3.3 in the European Union in 2017, it was 6.3 in Switzerland (Figure 6). In Europe, only Norway has a higher number of flights per capita, which however is due to its particular geography and thus high number of domestic flights. Of the neighbouring countries, Austria had an average number of flights per capita of 3.3, Germany 2.9, Italy 2.9 and France 2.7. These values, however, do not directly indicate the "willingness to travel" of the Swiss resident population, as the numbers include transfer traffic (Zurich airport is an important hub) and incoming traffic (business and holiday travel from abroad to Switzerland) (Intraplan Consult, 2015).

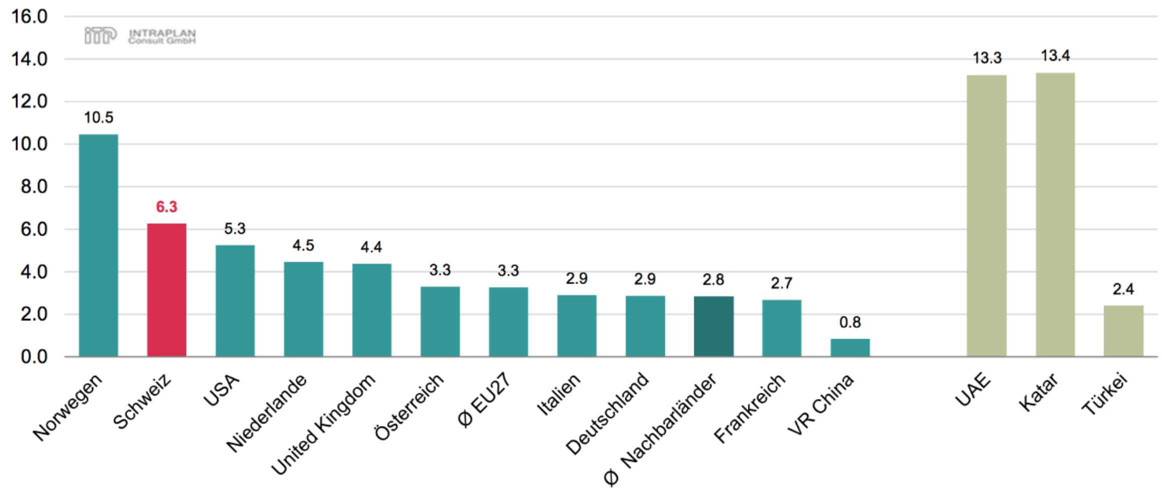

Figure 6: Air passengers per capita in 2017 for selected countries, including transfer passengers (Intraplan Consult, 2018)

The level of passenger air travel demand is linked to income and economic activity. Air travel is considered a luxury good with an income elasticity higher than 1. An analysis with U.S. data produced route-level income elasticities generally in the range of +1.8 for short-haul flights, which increased up to +2.2 for ultra-long-haul flights (InterVISTAS, 2007). The income dependency of air travel is clearly visible in Switzerland. On average, Swiss citizens living in a household with an income of less than CHF 4,000 per month only take 0.3 flights per year. On the other hand, Swiss citizens living in high-income households earning more than CHF 12,000 per month take 1.7 flights per year, which is 5.67 times the travel frequency of the lowest income class (Figure 7).[7]

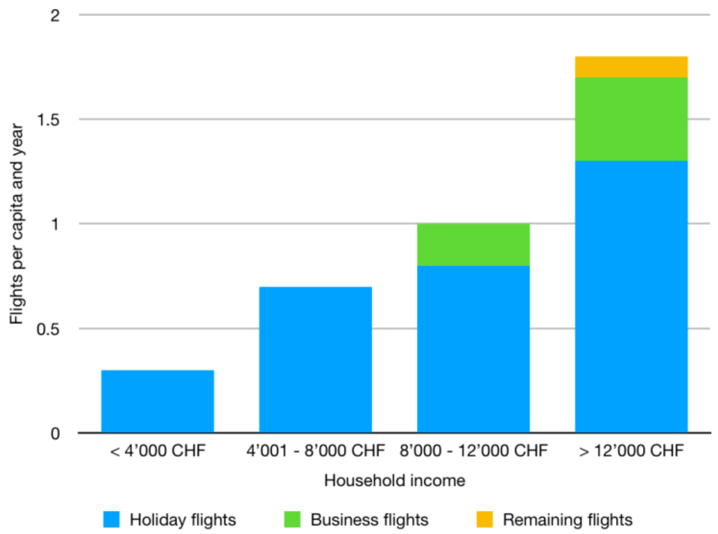

Figure 7: Distribution of number of flights per capita in Switzerland in 2015 by income and motive (FSO and ARE, 2017)

[7] "Remaining flights" are flights for which no motive was given.

According to passenger survey data of 2019 for Zurich airport, 63% of passengers indicated leisure as their main purpose of air travel and 11% some other private motive. Work was the main purpose of travel for 26% only of passengers (Zurich Airport, 2020).

2.4 Projections of demand

Swiss air transport demand (passenger and freight) has been increasing at an average rate of 2.4–3.4% per year since the 1950s. The majority of this demand growth has been for passenger transport (3.4–4.2%), while freight growth has been slower (0–1.8%) (Cox et al., 2018). A demand forecast carried out for the Federal Office for Civil Aviation in 2015 predicted yearly growth of 3.2% in air passengers and 2.1% in number of flights for the period 2013-2030 (Figure 8). Similarly, the European Environment Agency had predicted 1.5% annual growth in the number of flights for EU28+EFTA countries before the COVID-19 pandemic (European Environment Agency, 2019). Of course, these projections are being revised downward, but it is not clear whether air travel demand will return to the pre-COVID trend in a number of years or remain permanently reduced.

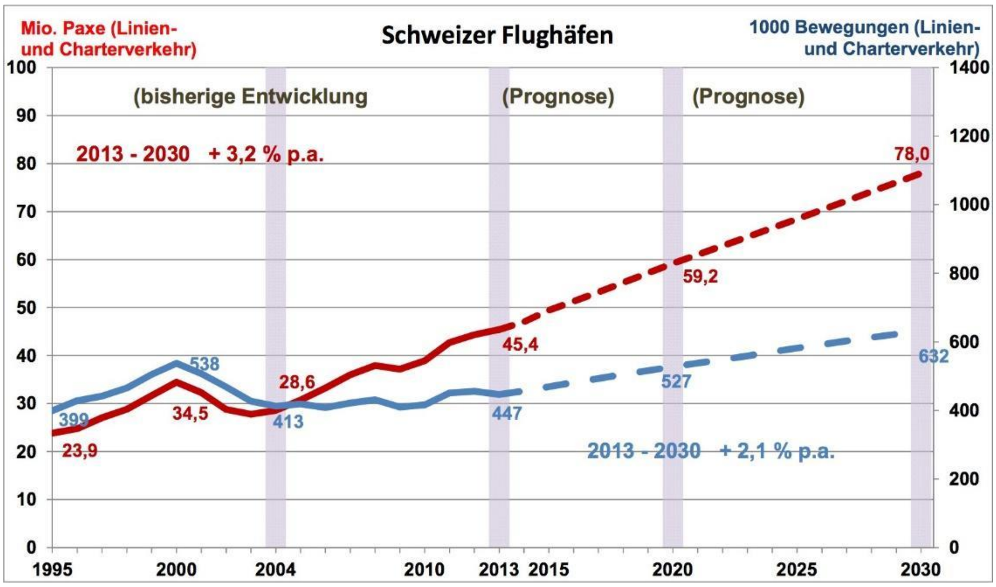

Figure 8: Air passenger demand (red) and flight number (blue) projections for Switzerland until 2030 (Intraplan Consult, 2015)

2.5 Projections of fuel efficiency

To accurately predict future emissions, fuel efficiency improvements have to be considered in addition to the anticipated growth in demand. While fuel efficiency in international aviation improved by 3.6% on average per year between 2002 and 2010 worldwide (Figure 9), it slowed to only 1.6% per year between 2010 and 2019 (data from IEA, 2020a).

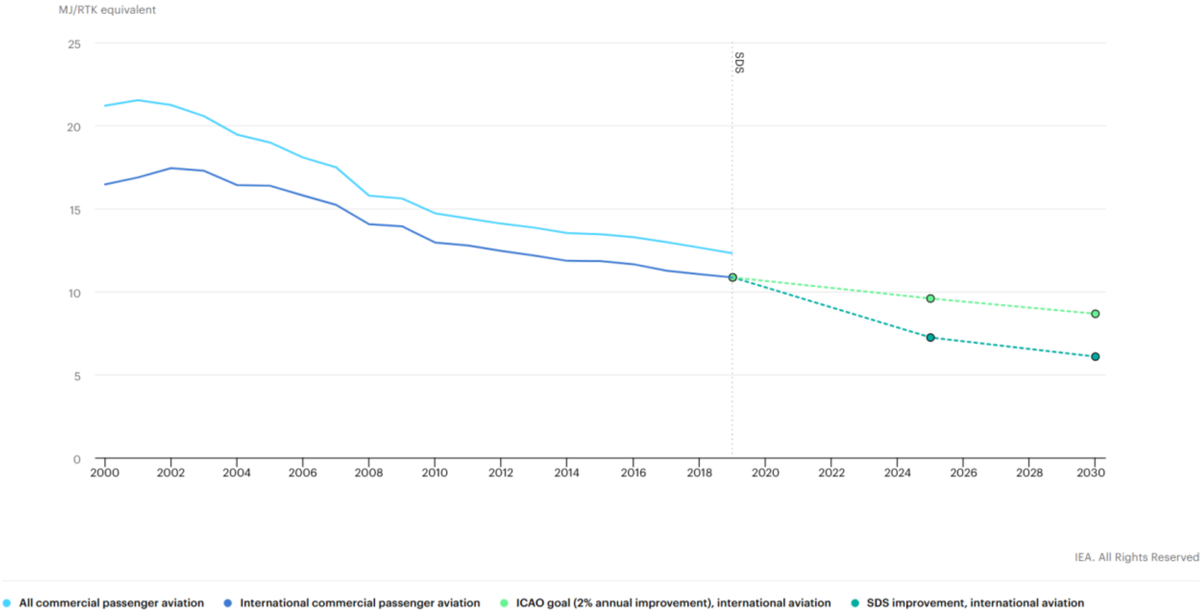

Figure 9: Energy intensity of passenger aviation in the Sustainable Development Scenario 2000-2030 (IEA, 2020a)

In the sustainable development scenario (SDS) of the IEA, aviation energy intensity would need to improve by 2.7% per year until 2030 from the 2019 level. In 2010, the ICAO adopted a resolution targeting a 2% efficiency improvement per year between 2013 and 2050 (ICAO, 2010).

Considerable differences in fuel efficiency exist between airlines. Low-cost airlines such as EasyJet and Ryanair are the most fuel-efficient airlines operating in Switzerland (Figure 10), closely followed by Swiss (Intraplan Consult, 2018). Airlines with high fuel efficiency tend to have high load factors (few seats remain empty) as well as the most modern fleets (newer aircrafts are more efficient). There seems to be a clear potential for lagging airlines to improve their fuel efficiency.

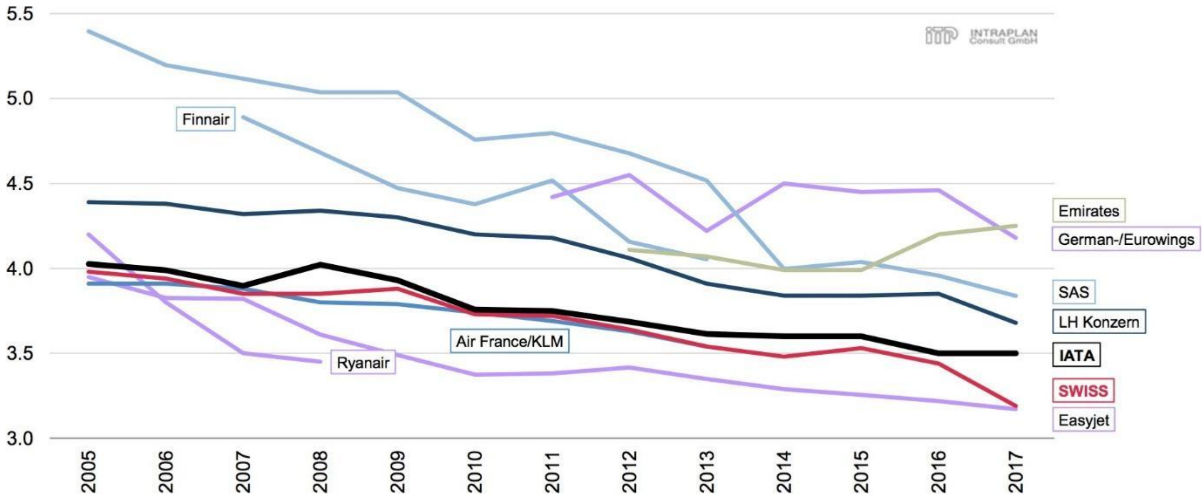

Figure 10: Fuel use in litres per 100 pkm in comparison with selected airlines (Intraplan Consult, 2018)

2.6 Projections of emissions

A research group at the Paul Scherrer Institute (Cox et al., 2018) conducted a complete life-cycle assessment of the Swiss commercial aircraft fleet (including the construction of airplanes), and its potential development from 1990 to 2050. For predicting emissions until 2050, they established a business-as-usual (BAU) and optimistic (OPT) technology improvement scenario that were analysed under low (3%) and high (4.5%) annual air passenger growth. The optimistic scenario with a low 3% annual growth in air passenger demand is based on the following technological assumptions: (1) a 1.5% annual improvement of aircraft fuel consumption, (2) significant changes to aircraft design that lead to an aerodynamic improvement of 1.5% per year and (3) a 0.80% annual operating weight reduction.

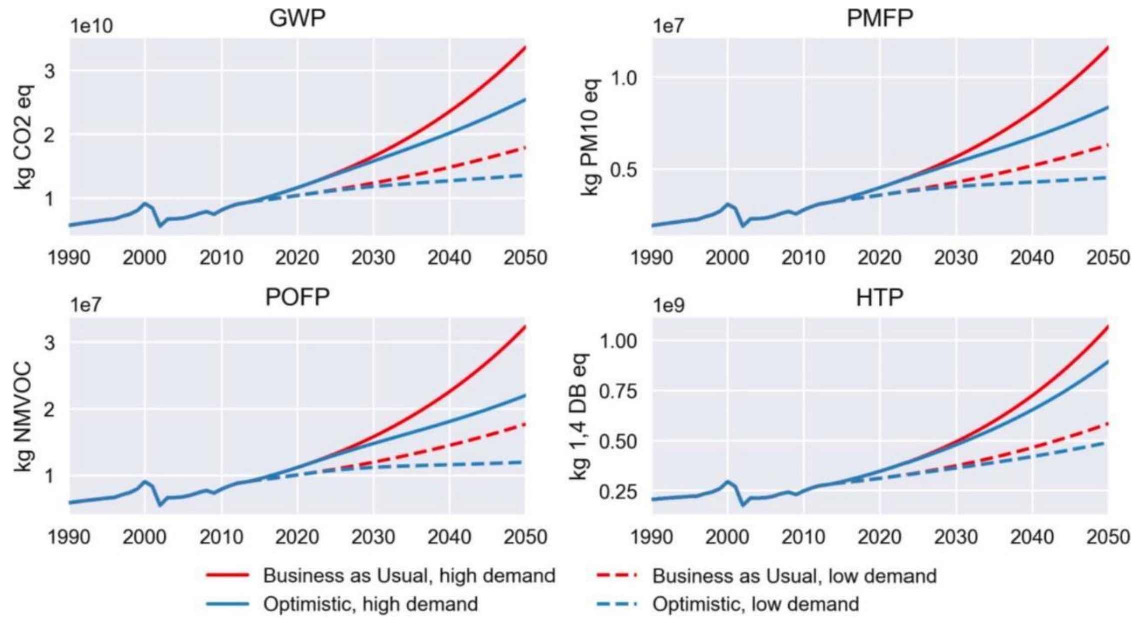

Figure 11: Predictions of the environmental impact potential of entire commercial Swiss air transport sector until 2050 (Cox et al., 2018)

Under this optimistic scenario, the global warming potential (GWP) of Swiss aviation would grow by 46% until 2050 (Figure 11). In a business-as-usual scenario with high demand growth, the GWP could even increase by 243% until 2050. No scenario that resulted in zero growth or a decrease in greenhouse gas emissions was found. The authors, however, excluded future changes to fuel production (biofuels, synthetic fuels), future engine technologies, such as aircraft powered by liquefied hydrogen, as well as policy measures (demand reduction by taxation) from the scope of their analysis.

2.7 Decomposition of emissions from air transport

The growth in CO_2 emissions from air transport is directly related to growing kerosene use, which is itself a result of more planes carrying more passengers over longer distances. The rising number of passengers is the reflection of a growing population, a greater share of this population traveling by plane and passengers flying more often. Kerosene consumption depends also on the fuel efficiency and the load factor of airplanes.

The following decomposition shows how all these factors can be related to account for overall CO_2 emissions from air transport:

$$CO_2 \text{ emissions} = \text{population} \times \frac{\text{passengers}}{\text{population}} \times \frac{\text{pkm}}{\text{passengers}} \times \frac{\text{seats} \times \text{km flown}}{\text{pkm}} \times \frac{\text{energy use}}{\text{seats} \times \text{km flown}} \times \frac{CO_2 \text{ emissions}}{\text{energy use}}$$

The first ratio is the share of the population that takes a plane; the second ratio is the average distance flown by these passengers; the third ratio is the inverse of the load factor; the fourth ratio is the inverse of airplane fuel efficiency; the last ratio is the carbon content of aviation fuels.

This decomposition suggests the following **levers** for reducing the CO_2 emissions from air transport:

1. Fewer travellers
2. Fewer km per traveller (fewer and/or shorter flights)
3. Higher load factors
4. Higher fuel efficiency
5. Energy carriers with lower carbon intensity (e.g. biofuels, synthetic fuels from renewable electricity, renewable electricity)

The first two levers relate to travel demand, the third to capacity management by airline companies and the last two to technology. These levers move with socio-economic conditions such as demographics, incomes, travel preferences, fuel prices, intensity of competition, availability of alternatives. They can be moved through policy measures of the types discussed in chapters 3 and 6.

In a simplified form for which data are available every year in Switzerland:

$$CO_2 \text{ emissions} = \text{population} \times \frac{\text{passengers}}{\text{population}} \times \frac{CO_2 \text{ emissions}}{\text{passengers}}$$

Between 2004 and 2019, CO_2 emissions from aviation increased by 3.3%/year on average in Switzerland. This is the sum of 1.0% population growth and 4.0% more flights per inhabitant, partly offset by 1.6% reduction in CO_2 emissions per passenger.

Here is an even more simplified decomposition:

$$CO_2 \text{ emissions} = (\text{passengers} \times \text{kilometres}) \times \frac{CO_2 \text{ emissions}}{\text{pkm}}$$

This decomposition separates clearly the levers dependent on supply and demand (terms appearing in parentheses) from the technology levers represented by the ratio.

3 How the global impact of aviation can be curbed – First principles and existing policies

3.1 First principles

If we assume that reducing the volume of air travel is the policy aim, how could that aim be attained most efficiently? Among the various regulatory tools available, market-based instruments are usually preferred, as they are economically efficient: pollution abatement is achieved at the least cost for society as a whole. Typically, policy makers choose between two market-based instruments: they can either regulate the volume of air travel through cap-and–trade systems (i.e. setting quotas), or they can influence the price of air travel through taxes. The former, commonly referred to as the quantity instrument, sets a limit to emissions and lets the market determine the corresponding price. The latter, commonly known as the price instrument, sets a price for emissions and lets the market determine the corresponding amount of emissions.

Neither of the two mechanisms clearly dominates the other. Generally speaking, when deviations from the optimal emissions level are more harmful in environmental terms than in purely economic terms, quotas are to be preferred; otherwise, taxes are better suited.[8] Outside the world of economic models, this theoretical distinction is difficult to quantify and to operationalise. Hence, actual choices of policy instruments largely rely on the practicality of implementation and their political acceptance.

Individual flying quotas would represent the most direct measure to reduce air travel demand. Every Swiss resident would receive the right to emit a given amount of CO_2, or to fly a certain number of kilometres per year. To allow for differences in preferences and travel needs, such quotas would be made tradable. The total amount of quotas could be gradually reduced over time, allowing precise control of the volume of air travel – independently from changes in fuel prices and other cyclical factors. The main drawback of such a measure lies in its implementation: keeping track of individual air travel would be administratively costly, intrusive and effectively applicable only to long-term Swiss residents.[9]

Taxes therefore appear as the more realistic demand-side policy tool – especially within a small open economy like Switzerland. Environmental taxes are a textbook case for potentially desirable government intervention in the market economy. Global warming clearly generates large and

[8] See Weitzman (1974) and Baumol and Oates (1988).

[9] An administratively less onerous solution would involve quotas for offered transport capacity (flights and seats) from Swiss airports, a refinement of the existing landing or take-off slots.

rapidly rising costs, but in a free market economy nobody is asked to pay to mitigate these costs. The reason behind this “market failure” is that the earth’s climate is not the property of any particular individual or group of individuals, and so no private individual or group can claim compensation from those who cause damage to the climate. The government thus has to step in and to ensure that, as the saying goes, “the polluter pays”.

This is the motivation behind proposals for a Swiss air ticket tax. The federal parliament decided the introduction of such a tax ranging between CHF 30 and 120 per air passenger departing from a Swiss airport, except for passengers in transit or transfer. Differential rates are envisaged according to the length of flights (short-haul vs. long-haul) and according to the type of ticket (economy vs. premium). A minority of parliamentarians had suggested applying the CHF 30-120 range only to economy class tickets, and allowing for higher tax rates on premium (business and first class) tickets. The proposed tax rates are higher than those in force in most other European countries.[10] The exception is the United Kingdom, whose Air Passenger Duty can go as high as GBP 180 in 2021 (for long-haul flights in premium).

3.2 Existing policies of ICAO

On a global scale, the International Civil Aviation Organization (ICAO) launched its Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) in October 2016. The member states agreed on the objective of CO_2-neutral growth of international aviation from 2021 on (ICAO, 2019a). Originally, the baseline emissions were set to be the average emissions between 2019 and 2020. However, due the impact of the Covid-19 pandemic on reducing air travel considerably in 2020, the ICAO decided in June 2020 to select 2019 as the baseline emission year.

As air travel growth is widely expected to exceed the increases in fuel efficiency from more efficient airlines, carbon-neutral growth as advanced by the ICAO is obtained by reducing emissions in other economic sectors. Such emission reduction certificates (carbon credits) can then be bought by airlines with an increase in their emissions after 2020 (Figure 12). Alternatively, airlines buy low-carbon "CORSIA-eligible" fuels, which is, however, subject to debate among the member states (Carbon Brief, 2019). At this stage, it is not clear what types of reduction certificates will be accepted by the ICAO.

CORSIA is implemented in a first pilot phase from 2021 to 2022, a second voluntary phase from 2023 to 2026 and will then be followed by a third mandatory phase from 2027 to the end of 2035.

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[10] Similar taxes have been implemented in Austria, Croatia, Finland, France, Germany, Greece, Italy, Norway, Poland, Romania, Slovakia, Spain, Sweden and the United Kingdom. Average per-ticket tax rates range from EUR 0.60 (Slovakia) to EUR 40 (United Kingdom). See European Commission (2019).

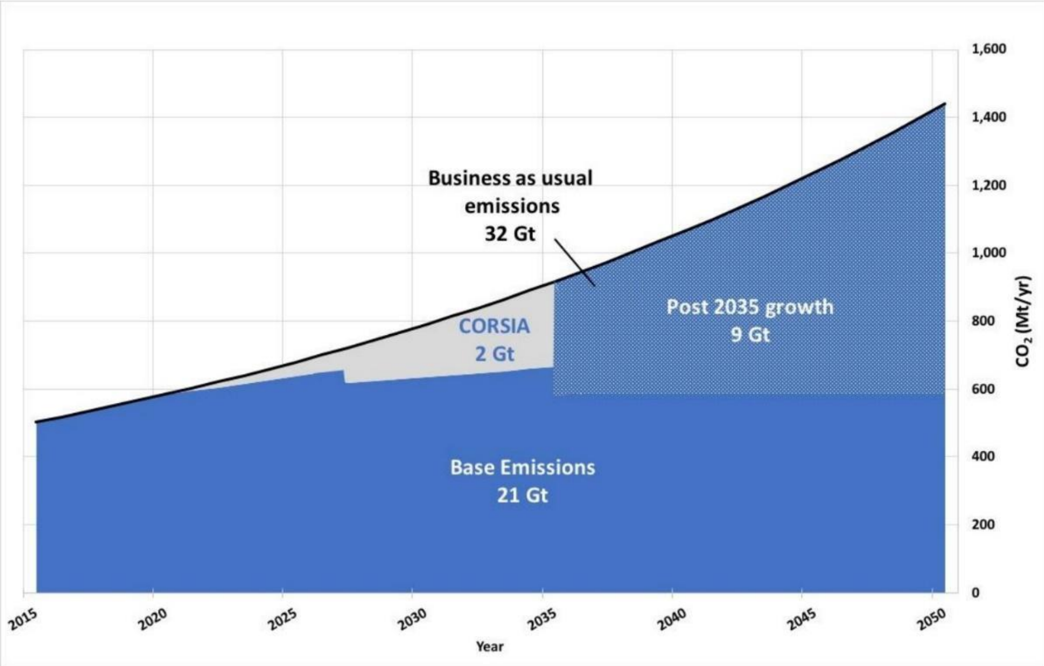


Figure 12: Annual and cumulative CO_2 emissions from international aviation, 2015 to 2050. Only a small part of emissions is covered by CORSIA (ICSA, 2018)

The CORSIA plan has been criticized by environmental NGOs for several reasons (Carbon Brief, 2019). First, the emission reduction goal of "carbon-neutral growth from 2020 on" has never been validated scientifically. For instance, the Intergovernmental Panel on Climate Change (IPCC) outlined that world CO_2 emissions need to reach net-zero by around 2050 if global warming is be limited to 1.5 degree Celsius. While the International Maritime Organization (IMO) has established a sector-wide goal to reduce international shipping emissions by 50% until 2050 (compared to 2008 levels), the ICAO currently only aims to compensate additional international air travel emission growth (IMO, 2018). Second, several globally important emitters such as China, Brazil, and India decided not to participate in the pilot phase that started in 2021. These members states might not join CORSIA before the mandatory phase starting in 2027. Third, there is concern about the quality of the compensation certificates. Projects of the UN's Clean Development Mechanism (CDM) are favoured by member states such as Brazil (that has a lot of unused CDM certificates), while other member states like China object to UN bodies like the ICAO deciding on the eligibility of projects.

An internal report commissioned by the European Commission from September 2020 concludes that "CORSIA is unlikely to materially alter the direct climate impact associated with air travel as the price signal that airlines will face under the scheme is, on its own, not expected to provide sufficient financial incentives for them to reduce emissions materially." (ICF Consulting et al., 2020) The report further noted that under CORSIA, airlines were likely to purchase carbon credits rather than purchasing cleaner fuels. Furthermore, the authors of the report pointed out that CORISA lacks a robust system for enforcing participation or compliance with its rules.

3.3 Existing policies of the European Union

Currently, the European Emission Trading System (EU ETS) only applies for flights between airports located in the European Economic Area (EEA), leaving intercontinental flights exempt from the EU ETS. Furthermore, for the most recent phase of the EU ETS (2013-20), 82% of allowances within the EEA were granted for free to aircraft operators, while only 15% were auctioned (European Commission, 2019). The average price for auctioned allowances has increased from EUR 5.8 per tonne in 2017, to EUR 25.33 per tonne in 2019 (Sandbag, 2021). It has been rising steeply since November 2020, passing EUR 50 in May 2021.

As part of the European Green Deal proposed in December 2019, the European Commission announced its intention "to reduce EU ETS allowances allocated for free to airlines" and "look closely at the current tax exemptions including for aviation fuels". The European Commission is expected to decide in June 2021 on the future of aviation in the EU ETS.

The aforementioned internal report by the European Commission outlined several options for reforming the EU ETS. The most impactful option for reducing emissions calls for the EU ETS to cover all flights to, from and within the EEA. If fully implemented, the EU ETS would cover 23.5 % of worldwide aviation emissions by 2025.

3.4 Existing and planned policies in Switzerland

Until 2019, Switzerland had no climate policy for international aviation. However, local airport charges for NOx and noise emissions have the indirect effect of reducing the climate impact of aviation (FOCA, 2020). Initially, aviation was only mentioned in the current CO_2 Act (Federal Act on the Reduction of CO_2 Emissions) of 2011 with the precision that "Emissions from the use of aviation fuel on international flights are not taken into account". In 2019, the obligation for airline companies to participate in the emissions trading system was added. Indeed, since January 1, 2020, the Swiss emissions trading system (ETS) is linked with the EU ETS. As a result, airlines operating flights from Switzerland to the European Economic Area (EEA) and back are required to participate in the coupled ETS. Flights outside the EEA remain exempted. Even at the current high price of about EUR 50 per tonne CO_2 (Sandbag, 8 May 2021), a one-way economy class trip from Geneva to London, for which emissions of 97.9 kg CO_2 per passenger are counted (ICAO, 2016), the needed certificates would cost only an average of EUR 0.74, as 85% of certificates are granted for free.

In an impact assessment conducted for the Swiss Federal Office for the Environment, INFRAS estimated that the EU ETS integration would only reduce emissions very slightly (INFRAS, 2009). In the current form of the EU ETS, the decline is only 0.2 to 0.3% compared to the reference scenario of unconstrained growth of 17.1 million tonnes CO_2eq (including non-CO_2 effects) in 2030. Consequently, the climate impact of Swiss aviation would still increase by 48.7% until 2030.

The greenhouse gas emissions of international aviation are not counted in the mitigation targets for 2020 or 2030. Nevertheless, the Federal Council intends to include its emissions in the net-zero target for 2050. How this could be achieved is shown in the new Energy Perspectives 2050+ (Prognos et al., 2020): there is no measure to slow down the growth in passenger numbers – they increase by 53% between 2019 and 2050 – but, thanks to accelerated fuel efficiency improvement, energy use decreases by 22% and, more importantly, kerosene is entirely replaced by synthetic fuels[11] between 2045 and 2050.

In its latest revision of the CO_2 Act of 25 September 2020, the Swiss parliament introduced an air ticket tax of at least CHF 30 and at most CHF 120. The tax will apply to flights departing from Switzerland, with the notable exception of transfer and transit passengers. Infants below the age of two, people in charge of aviation security, or passengers requiring air transportation for urgent medical reasons, as well as military flights will also be exempted from the tax. The Federal Council will have to determine the exact amount of the tax, based on the travel class and distance of the flight, in such a way as to achieve the Swiss climate goals, while also considering the level of taxes in other countries. In order to maximise the salience of the tax and thus its potential to affect behavioural change, the tax payable on a given flight will be indicated separately from the ticket price by airline companies, in addition to an estimate of the emissions in CO_2eq generated by the trip. On the other hand, general aviation will be subject to a different regime, namely a tax per flight of at least CHF 500 and at most CHF 3,000 possibly depending upon the authorised weight at take-off. In addition to the exceptions mentioned above, the tax on general aviation will not apply to light planes (weighing less than 5,700 kg), training flights, cargo flights, factory flights, flights related to air work or whose fuel is subject to the mineral oil tax (domestic flights). 49% of the revenues from the air ticket tax would be paid into a new climate fund, while 51% would be redistributed to the population and businesses.

The effect of the air ticket tax on the emissions from aviation will depend on the responsiveness (i.e. the elasticity) of travellers to this price signal. This is what we seek to estimate in the following two chapters, starting with a review of existing estimates of the general responsiveness of air travel to price changes.

[11] Synthetic fuels are discussed in section 6.5.

4 Effects of an air ticket tax – the role of demand elasticity

4.1 Demand elasticities

The extent to which an air ticket tax will affect the volume of air travel depends to a large extent on a simple parameter: the price elasticity of demand.[12] This parameter quantifies consumers' sensitivity to changes in the price of flying. The elasticity is undoubtedly negative: the higher the tax, the lower will be the demand for flying. We shall, however, show values for this elasticity in absolute value, to simplify the notation. Much more uncertain is the magnitude of the elasticity. The larger it is (in absolute value), the more a given increase in taxation will lower demand for air travel. If it is small, i.e. demand is inelastic, tax-induced price raises will hardly translate into substantial declines of passenger numbers, while with an elastic demand even moderate price increases will trigger a strong reduction in passenger numbers.

Typically, the more flexible a customer is, the more sensitive she is to the price. When alternatives abound, price raises get harshly punished by clients who simply switch to another transport mode (e.g. high-speed and night trains) or to another activity (e.g. video conference, holidays closer to home). Empirical studies confirm this: passengers are more price sensitive for short flights (where other transport modes are available) and for economy class flights (as trips for personal reasons are generally more flexible than work-related trips).

4.2 Literature on air travel demand elasticities

We now discuss the existing literature on price elasticities before explaining which estimates we use and why. The literature on this issue is rather small, but we have been able to review more than 20 empirical studies. Most of these studies have been conducted before 2000, with recent studies focusing on online fares and literature reviews.

In a meta-analysis conducted by Brons et al. (2002) that includes 34 studies and 204 elasticity estimates, the main explanatory variables explaining the differences in elasticity estimates include income, transfer distance, geographic scope, and travel class. Premium passengers were found to be less sensitive to price (0.6 difference in elasticity), while long-haul flights only have a slightly higher elasticity level. Furthermore, the estimation of air travel elasticity demand varies considerably with

[12] The elasticity of supply will also play a role. The lower that elasticity, the larger will be the share of the tax that will be absorbed by airlines (e.g. through lower pre-tax prices and thus lower profit margins) and not shifted to consumers (see section 5.6). Given the competitive nature of the European airline industry, we abstract from these effects and assume perfectly elastic supply.

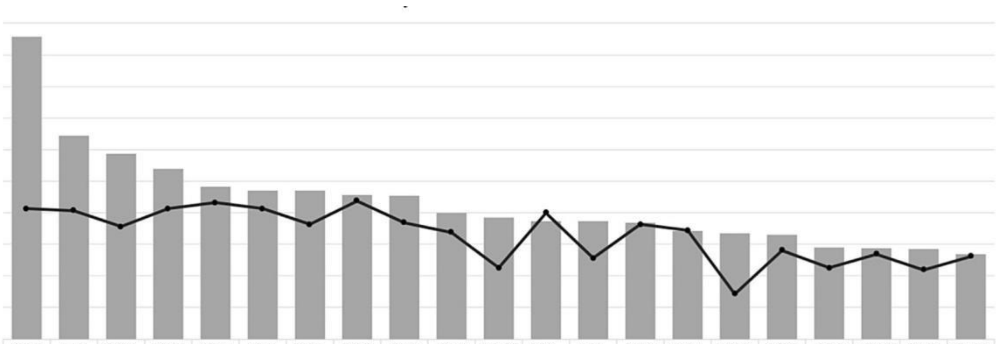
the aggregation level of data. Elasticity estimates tend to be higher when estimated at the level of individual flights than when estimated at the level of entire markets or routes (InterVISTAS, 2007). At the level of entire destination countries, elasticity estimates are found to be even lower than at the market or route level. For the purpose of this white paper, we are mainly interested in using nation-level elasticity estimates.

An extensive review of the existing literature was conducted by Gillen et al. (2003), including 254 elasticity estimates from 24 studies. They found median elasticity values of 0.265 for long-haul business, 0.7 for short-haul business, 1.040 for long-haul leisure and 1.52 for short-haul leisure routes. A study by InterVISTAS (2007), commissioned by IATA, found national-level elasticity values of 1.23 for short-haul routes within Europe, 0.96 for long-haul trans-Atlantic routes and 0.48 for long-haul Europe-Asia routes.

A more recent study from CE Delft, produced for the European Commission, uses the findings from InterVISTAS (2007) and Brons et al. (2002) to obtain elasticities for passengers departing from Europe. For short-haul flights, the premium class elasticity is estimated to be 0.57 and the economy class elasticity is estimated to be 1.12. The corresponding intercontinental elasticities are 0.25 for premium tickets and 0.8 for economy tickets (CE Delft, 2019).

In an overall estimate for residents of the United Kingdom, the UK Department for Transport (2017) estimated elasticities of 0.2 for business travellers and 0.7 for leisure passengers (including short- and long-haul flights). For all flights departing from the United Kingdom, the elasticity is estimated to be 0.6 on average.

When estimating flight-level air travel elasticities by using online fares, a wide range of elasticity values are found. While flight-level elasticities tend to be higher than route or national-level elasticities (InterVISTAS, 2007), such estimates can prove useful when evaluating the impact of an air ticket tax for destinations where only few airlines are competing with one another and flight-level elasticities will be close to route-level elasticities.



	SPU	LIS	PRG	BRS	GLA	BFS	NCL	BOD	EDI	FCO	MAN	BSL	LPL	SEN	GVA	MXP	STN	LTN	LGW	SXF	HAM
Coefficient	-1.915	-1.286	-1.175	-1.076	-0.965	-0.941	-0.940	-0.914	-0.909	-0.798	-0.770	-0.747	-0.745	-0.735	-0.685	-0.672	-0.659	-0.578	-0.575	-0.568	-0.535
Leisure Index	-0.024	-0.025	-0.033	-0.024	-0.021	-0.024	-0.032	-0.02	-0.031	-0.036	-0.054	-0.026	-0.049	-0.032	-0.035	-0.067	-0.045	-0.054	-0.047	-0.055	-0.048

Figure 13: Flight-level elasticity estimates for different routes of EasyJet (Morlotti et al., 2017)

An estimate of flight-level elasticities for the US airline company JetBlue yielded estimates in the range from 0.57 to 3.21, with 1.32 as a median (Mumbower et al., 2014). A similar analysis was undertaken for EasyJet, for which the overall flight-level elasticity was estimated at 0.753, ranging from 0.535 for the business-oriented route of Hamburg to 1.915 for the leisure-oriented route of Split (Figure 13, Morlotti et al., 2017). The price elasticity tends to be higher for reservations made several days in advance. The authors also measured a higher elasticity for reservations during weekends, lunchtime and the summer period.

In a study for the Swiss government, INFRAS recommended an elasticity value of 1.2 for short-haul and 1 for long-haul flights in economy class, and 0.5 for short-haul and 0.4 for long-haul flights in premium (INFRAS, 2009). This white paper applies values taken from InterVISTAS (2007).

To summarize the above literature discussion, Table 1 provides an overview of the findings of the most important of the aforementioned studies.

Table 1: Overview of price elasticities found in the literature

Publication	Scope	Aggregation	Short-haul economy	Long-haul economy	Short-haul premium	Long-haul premium
Gillen et al. 2003	Worldwide	National level	1.52	1.04	0.7	0.265
Intervistas 2007	Europe	National level	1.23	Trans-Atlantic: 0.96 Trans-Pacific: 0.48	-	-
INFRAS 2009	Europe	National level	1.2	1	0.5	0.4
UK Department for Transport 2017	United Kingdom	National level	Overall: 0.6	Overall: 0.2	-	-
CE Delft 2019	Europe	National level	1.12	0.8	0.57	0.25
Mumbower et al. 2014	USA	Flight-level (JetBlue)	1.32	-	-	-
Morlotti et al. 2017	Europe	Route-level (EasyJet)	0.753	-	-	-

4.3 Elasticities used for our simulations

In what follows, we will focus on the most comprehensive study of air travel price elasticities, which was the one commissioned by IATA, the trade association of the world's airlines, in 2007.[13] According to this study, the price elasticity for short-haul economy class flights within Europe equals approximately 1.2. This means that when prices increase by 1%, passenger demand will decline by 1.2%. This same study reports an elasticity estimate for long-haul intercontinental economy class flights of around 0.9. The corresponding estimates for short- and long-haul premium flights amount to 0.6 and 0.3, respectively. Quite strikingly, these estimates imply that within-Europe economy class passengers are four times as price sensitive as inter-continental premium class passengers.

These numbers, however, must be considered to be lower bound estimates. The reason is that they stem from econometric estimations that typically ignore – like most estimates in the related academic literature – an important methodological pitfall: price changes are not random and reflect underlying demand conditions. If, for example, the price increases by 1%, this may be due to seasonal factors (summer weather, Christmas rush) or to the business cycle (general increase in activity). Even if such a price increase is associated with, say, a 1%-drop in demand, this may well under-estimate the actual demand sensitivity, as the demand decline will be attenuated by the favourable conditions that have led to a price increase to start with. Put differently, if one were able to control for all such context-related factors, one would likely find elasticity estimates that are substantially larger.[14] The authors of InterVISTAS (2007) were aware of this methodological problem and, for a subset of elasticities, proposed alternative estimates that circumvent the statistical issue by exploiting exogenous variation. In these estimates, the elasticities found are magnified by 75%, leading almost to a doubling of the effects. We therefore also consider "upper-bound" elasticity estimates that are augmented by this factor.

Table 2 summarises the range of lower-bound and upper-bound estimates for short- and long-haul and economy and business flights that we use for our simulations.

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[13] InterVISTAS (2007). This study has since been used as reference for policy reports both for Switzerland (Peter et al., 2009) and for the EU (European Commission, 2019). We are not aware of a more recent and methodologically more accomplished (ideally quasi-experimental) study. There is a glaring lack of research in this area.

[14] Technically, the problem is attenuation bias due to endogeneity. Price changes are both cause and consequence of demand changes, but what we seek to estimate is only the causal link from price changes to demand changes.

Table 2: Demand elasticities

Elasticity estimates	Short-haul economy	Long-haul economy	Short-haul premium	Long-haul premium
Lower bound	1.2	0.9	0.6	0.3
Upper bound	2.1	1.5	1.0	0.5
Upper bound post-COVID-19	2.1	1.5	1.2	0.9

Notes: For the lower-bound, the short-haul economy estimates correspond to the averages of the InterVISTAS (2007) estimates of 1.23 and 1.12; the long-haul economy estimates are given by the average of the following four InterVISTAS (2007) estimates: 1.06; 0.96; 0.79; 0.72. The premium estimates correspond to the aforementioned economy averages minus the business class elasticity reduction estimated in Brons et al. (2002). For the upper bound, the four aforementioned values are each multiplied by 1.75, based on the difference between IV and OLS estimates reported in InterVISTAS (2007). The elasticities in the Table apply for leisure-related flights in economy and work-related flights in premium.

An important question is how the COVID-19 pandemic may affect demand elasticities for flights. One could speculate that the rise of convenient means of online communication (videoconferencing, webinars, etc.) may shift the demand curves for flights to the left – now that we have seen that many tasks can be performed efficiently without the need for in-person meetings, fewer business trips may be undertaken at the same ticket prices. IATA, for instance, anticipates that it will take until 2024 to attain the global volume of air traffic of 2019 (Pearce, 2020).

However, what matters for our simulations is not the position of the demand curve but its slope. According to standard microeconomic reasoning, the price elasticity of demand for a particular good or service increases when closer substitutes for that good or service emerge. Following that logic, the price sensitivity especially of business travel can be expected to increase, now that online communication has been established as a closer substitute for travel than it had been before the pandemic. However, while appearing highly plausible, this is pure conjecture at this stage, as no empirical evidence exists yet.

Our attempt at taking account of changed air travel demand after the COVID-19 pandemic is very simple: We assume that the price elasticity of premium passengers will rise (in absolute values) to the lower-bound economy class elasticities reported in Table 2. This means that the upper bound of the short-haul premium elasticity will change from 1.0 to 1.2, and the upper bound of the long-haul premium elasticity will change from 0.5 to 0.9. The fact that we assume the long-haul elasticity to change more strongly post-COVID-19 than the short-haul elasticity conforms with business forecasts according to which video conferencing is particularly likely to substitute for long-distance business travel (e.g. The Economist, 2021). However, we make no adjustment for COVID-19 to assumed economy class elasticities, assuming the pandemic to have no significant long-term consequences for that demand segment.

5 Effects of an air ticket tax – simulations

We use the estimated demand elasticities for a first-pass estimation of the impact of a range of possible tax schedules on passenger numbers, kilometres flown and emissions caused. The specific question we ask is how passenger numbers and emission volumes would have differed in 2018 if a given ticket tax schedule had been in force. We also extrapolate this question to 2023, assuming that by then the pandemic will have no more effect except in modified flying habits. This chapter begins by describing the model employed, as well as the data and calibration procedure. Then the different tax schedules simulated and the resulting changes in passenger volumes and emissions are presented.

5.1 Modelling framework

The model segments the aviation market across three dimensions, namely flight distance (short-haul, short-haul with a transfer to long-haul, or long-haul), travel class (economy or premium) and reason for flying (private or work). The tax schedule may incorporate only two of the three dimensions, distance and travel class, which results in six choice variables. Indeed, since the reason for flying is private information, the regulator cannot impose a tax that differs between personal and work-related reasons. On the other hand, elasticities of demand distinguish between all three dimensions. This results in one value per market segment, as shown in the previous chapter (Table 2).

Our model may be summarised by the following equations. Since demand (number of passengers by segment) is only characterized by an elasticity parameter, this amounts to assuming the following iso-elastic form for the demand function:

$$Q_{d,c,r} = Q0_{d,c,r} \times (P_{d,c})^{\varepsilon_{d,c,r}},$$

where $Q_{d,c,r}$ is the number of passengers for trips of distance category d (short-haul, short-long-haul, long-haul) in class c (economy, premium) for reason r (personal, work), $P_{d,c}$ is the price of a representative trip in distance category d and class c, ε is the demand elasticity for that segment (Table 2), and $Q0$ is a scaling parameter corresponding to the number of trips demanded for a price equal to 1.

When the new air ticket tax $Tax_{d,c}$ is added to the average price of those trips, we obtain the following proportional change in the number of passengers:[15]

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[15] Note that the model really calculates changes in air travel demand, not actual travel, but since these are reductions, there are no capacity limits on the supply side to hinder these changes (for a discussion, see section 5.7).

$$\frac{\Delta Q_{d,c,r}}{Q_{d,c,r}} = \left(\frac{P_{d,c} + Tax_{d,c}}{P_{d,c}}\right)^{\varepsilon_{d,c,r}} - 1\,.$$

Passenger-kilometres *PKM* are obtained by multiplying numbers of passengers by the average distance D_d of the representative flight in distance category d (Table 6 below):

$$PKM_{d,c,r} = Q_{d,c,r} \times D_d.$$

Passenger-kilometres determine CO_2eq emissions E when they are multiplied by the emissions factors $F_{d,c}$ specific to each distance category and travel class (Table 5 below):

$$E_{d,c,r} = PKM_{d,c,r} \times F_{d,c} = Q0_{d,c,r} \times (P_{d,c})^{\varepsilon_{d,c,r}} \times D_d \times F_{d,c}.$$

This allows us to compute the change in the climate impact of air travel on routes of type d, in class c and for reason r as the number of passengers changes in response to the price increase caused by the introduction of the air ticket tax:

$$\frac{\Delta E_{d,c,r}}{E_{d,c,r}} = \frac{\Delta Q0}{Q0} + \frac{Tax_{d,c}}{P_{d,c}} \times \varepsilon_{d,c,r} + \frac{\Delta D_d}{D_d} + \frac{\Delta F_{d,c}}{F_{d,c}}. \qquad (1)$$

These changes apply to the average emissions per segment of Table 6. Finally, we calculate the total impact of the air ticket tax on the climate impact of aviation as the weighted average of these proportional changes per segment, using the weights of Table 3.

In our static simulations, we compare emissions in a given year (2018) with the level they would have attained if the air ticket tax had been levied in that year. In this static view, we assume that the average distances travelled per distance category are the same without and with tax, as are the corresponding emission factors. As a result, the level of emissions is only affected through the number of passengers:[16]

$$\frac{\Delta E_{d,c,r}}{E_{d,c,r}} = \frac{Tax_{d,c}}{P_{d,c}} \times \varepsilon_{d,c,r}\,.$$

In our dynamic simulations, we assume that air travel activity and aircraft characteristics evolve through time, so we need the full set of determinants of equation (1). Under the assumption of

[16] Two values will always be calculated, using the lower and upper bound estimates of the demand elasticity in each segment (Table 2).

continued growth of activity, these are the price increases needed merely to keep the climate impact of aviation from rising:

$$\frac{Tax_{d,c}}{P_{d,c}} = \left(\frac{\Delta Q0}{Q0} + \frac{\Delta D_d}{D_d} + \frac{\Delta F_{d,c}}{F_{d,c}}\right) \times \frac{1}{-\varepsilon_{d,c,r}}.$$

If the growth rates of underlying (price-independent) passenger numbers $Q0$ and of average distance D are constant, possibly mitigated by a constant improvement in the emissions factors F, then the percentage increases in the prices required for a constant climate impact are also constant, which implies that the tax must rise continuously, but at a decreasing rate.

5.2 Data and calibration

5.2.1 PASSENGERS

As discussed in section 3.4, only passengers on scheduled and charter flights will be subject to the air ticket tax considered herein, and among them, transfer and transit passengers would be exempted. Hence, we solely consider local passengers departing from a Swiss airport. In 2018 – the reference year of our simulation exercise – they numbered 24.4 million, not counting 4.6 million transfer passengers. A yearly survey conducted among a sample of passengers departing from Zurich airport shows that 44% of them (in 2018 and 2019) are residents of Switzerland (Zurich Airport, 2020). As this includes transfer passengers and as Zurich is presumably used by a higher share of transfer passengers than the other airports, it is a plausible guess that one half of local passengers are Swiss residents. That would imply 12.2 million resident local passengers departing from a Swiss airport in 2018.

Passenger growth was assumed to be 3.2% per annum until 2030 by Intraplan Consult (2015) (Figure 8). This growth rate is somewhat lower than the estimated 3.7% global annual growth rate in IATA's latest 20-Year Air Passenger Forecast (IATA, 2020). Nevertheless, we assume a somewhat more modest growth rate considering the consequences of the 2020-2021 COVID-19 crisis, particularly as we extrapolate it to 2050: 2.5% per year.

In order to allocate passengers across the different market segments, we proceed as follows. Regarding the distance dimension, we rely on data from FSO (2019): passengers whose final destination is located in Europe are assigned to the short-haul group, passengers boarding an aircraft flying to another continent are assigned to the long-haul group, while passengers whose final destination is located outside of Europe but are on board of an aircraft flying to a European destination are assigned to the short-long-haul group.[17] Regarding the travel class – economy or

[17] We use this terminology to avoid confusion with transfer passengers at Swiss airports.

premium – and the reason for travelling – personal or work – we employ the data published by Zurich Airport (2019) for 2018. Passengers are allocated to the market segments proportionally (Table 3). These shares are assumed to remain constant through time and expected to provide a meaningful approximation of the aviation market in the future.

Table 3: Local passenger shares per market segment (2018, %)

	Economy		Premium	
	Personal	Work	Personal	Work
Short-haul	53.2	19.7	5.3	1.9
Short-long-haul	1.8	0.7	0.2	0.1
Long-haul	11.5	4.3	1.1	0.4

5.2.2 DISTANCES

The typical distance of a flight departing from a Swiss airport is computed based on FSO (2020a) data. We infer the distance in kilometres from the number of passenger-kilometres and passengers flown to Europe and to the rest of the world. We obtain an average one-way distance of 930 km for flights to European destinations and 6,405 km for intercontinental flights. Assuming the location of the hub is random relative to the final destination, the typical distance of a short-long-haul flight is simply assumed to be the sum of those two values.

One important pitfall is that these distances are based on the services provided by aircraft landing or departing in Switzerland only, and therefore do not include subsequent legs of passengers' journey (typically those taking place after a transfer located outside of Europe). Nevertheless, in line with existing regulation in other jurisdictions, a tax should be set as a function of passengers' final destination, given that they will be exempted from local taxes due to their "transfer passenger" status. While it seems reasonable to assume that the number of passengers whose trips end in Europe but do not fly there directly is negligible, it is more limiting for intercontinental journeys (e.g. flying to Australia typically hinges on a stop-over in South East Asia). Therefore, in order to obtain an approximation of the total distance flown by passengers, we match the cities listed as final destinations by FSO (2019) with geographic coordinates (latitude/longitude) from the Simplemaps (2020) database. The matched destinations resulting from this procedure represent 86% of outbound passengers. Given the lack of detailed data on transfers and their locations, we then compute the great circle distance (GCD) between each of the three Swiss national airports and the matched destination cities, weighted by corresponding passenger flows. The resulting intercontinental distance stands at 7,080 km, some 675 km more than when only directs flights are considered.[18]

[18] In order to verify the consistency of our procedure, we also perform the analysis for cities within Europe: a coherent distance of 960 km is obtained, based on matched cities representing 87% of passengers.

Because this value represents the shortest distance between Swiss airports and passengers' final destination, it should be considered as a lower bound, assuming there exists no correlation between matching and GCD. However, although the figure may seem low, multi-stage journeys by plane tend to be structured such as to minimize the distance flown and may not differ significantly from the shortest route. In addition, only a minority of passengers travelling to other continents are transferred to a subsequent flight outside of Europe.

Finally, because all aforementioned distances refer to GCDs, a correction is added to them to account for delays, indirect flight routes and adverse weather conditions following ICAO (2017) recommendations: 100 km for short-haul flights, 125 km for long-haul flights and 225 km for short-long-haul flights. Travelling preferences in terms of location are expected to remain identical, on average, in the future.

All that remains is to add up the full GCD distance with this correction (last column of Table 4). These are the numbers used to calculate the climate impact of typical short-haul, short-long-haul and long-haul flights, depending on the travel class. When we calculate the contribution of aviation to the climate footprint of Switzerland, we use these numbers. To account for the fact that only about one half of passengers departing from Swiss airports are residents involves division by two. However, nearly all residents who fly away from a Swiss airport fly back some time in the future, so the distance should be multiplied by two. The two corrections cancel out.

Table 4: Typical distances (km)

	First leg (GCD)	Full journey (GCD)	With correction
Short-haul	930	930	1 030
Short-long-haul	930	8 010	8 235
Long-haul	6 405	7 080	7 205

5.2.3 CLIMATE IMPACT

The emissions factors are derived from the ICAO Carbon Emissions Calculator (ICAO, 2016). We start by collecting the tool's outputs for a sample of 84 representative routes originating from the three Swiss national airports, among which the top 10 most popular destinations, both located within Europe and on other continents. We then proceed to make a number of adjustments. To start with, we multiply the amount of fuel burnt in kilograms by a factor of 3.14 to obtain CO_2 emissions in kilograms, in line with FSO (2020b). Second, given that aircrafts are primarily operated for moving people rather than freight, we attribute the entire fuel consumption and corresponding emissions to passengers. On the other hand, we keep ICAO passenger load factors, since they cannot be directly adjusted to those published by FSO (2020a), yet appear to be similar in magnitude. Additionally, in line with technical documentation published by aircraft manufacturers (Airbus, 2020) and information shared by airline companies (Swiss, 2020), we estimate that aircraft models operating at Swiss airports in 2018 were 20% more efficient than the ones considered by ICAO, given the ongoing fleet renewal by major airline companies active in Switzerland, also in response to the landing fee structure at Swiss airports, which penalizes more polluting aircrafts. Yet, we assume that only a third of the fleet in operation is modernized by the end of 2018. Finally, emissions per passenger-kilometre are obtained by dividing emissions per passenger by the distance flown, i.e. the GCD plus the relevant ICAO correction for delays, indirect flight routes and adverse weather conditions.

So far, the computed values reflect the emissions of a standard economy class passenger. Next, emissions per passenger-kilometre are adjusted to reflect the greater space taken up by premium seats relative to their economy counterparts. We use the values of DBEIS (2019) and a comparison between reports published by aircraft manufacturers and airlines' typical cabin layouts (Airbus, 2020; Swiss, 2020). Relative space and weight, as well as the prevalence of seats in each class, are factored in. Accordingly, we set the emissions per premium passenger (business) to 1.5 times those of an economy passenger for short-haul flights. For long-haul flights, the emissions per premium passenger (business, first) are three times those of an economy passenger. Our estimates are in line with the average value published by Lufthansa (2019) for its fleet.

Table 5: Emission factors (kgCO_2 per passenger-kilometre)

	Economy	Premium
Short-haul	0.1054	0.1581
Short-long-haul	0.0792	0.2217
Long-haul	0.0754	0.2308

For our dynamic simulations, we assume that the emissions factors decrease by 1.5% per year on average, following ICAO's most optimistic scenario (ICAO, 2019b). This reflects continued efficiency gains, be it through better air traffic management, operational improvements or enhanced aircraft technology. It does not include the gradual replacement of fossil-based fuels by low-carbon fuels, but, on the other hand, it does not consider either that airlines serving Swiss airports are already more fuel efficient than the world average, which reduces the potential for improvement (cf. section 6.5.3).

As an assessment of the quality of the above calibration, we confront the CO_2 emissions implied by our data with the official data published in the Swiss Greenhouse Gas Inventory for 2018. Considering departing passengers and the first leg of their journey, we obtain 5.62 MtCO_2, which, as expected, is slightly below the official figure of 5.74 MtCO_2. Indeed, while the scheduled and charter traffic segment is without any doubt the largest consumer of fuel, a share of this total must be attributed to the general aviation segment of Swiss aviation.

As discussed in section 2.1, the combustion of jet fuel generates various other emissions that together have a net positive effect on radiative forcing. Based on that discussion and the most recent scientific literature, we shall multiply the CO_2 emissions by a Radiative Forcing Index (RFI) of 3 to account for this effect and estimate the full climate impact of individual trips in CO_2eq units.

Multiplying the emission factors of Table 5 by the RFI of 3 and the corresponding distances of each market segment (last column of Table 4) yields emissions ranging from 326 kgCO_2eq for the representative short-haul flight in economy to 5,477 kgCO_2eq for the representative short-long-haul flight in premium (Table 6).

Table 6: Climate impact of a typical flight (kgCO_2eq)

	Economy	Premium
Short-haul	326	489
Short-long-haul	1 956	5 477
Long-haul	1 630	4 989

Multiplying the climate impacts of the typical flights of Table 6 by the passenger shares per segment of Table 3 yields the weighted average footprint of departing passengers in 2018: 667 kgCO_2eq per passenger, or 19.4 million tons for all local passengers. The share of each segment is represented in Figure 14.

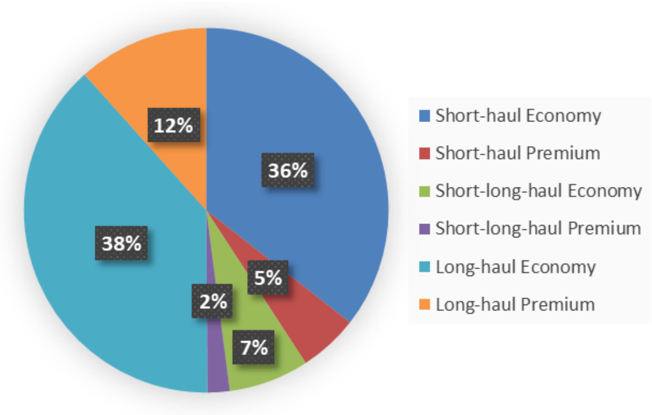

Figure 14: Shares of the different segments in the total climate impact of local passengers departing from Swiss airports (own estimates, 2018)

Even though three quarters of all trips are short-haul economy trips (73%, Figure 15), they account for a third only of all emissions (36%). Long-haul trips, including here short-long-haul trips, are carried out by 20% of all passengers but account for 60% of emissions. Most striking is the impact of long-haul flights in premium (incl. through hubs), which, with less than 2% of the passengers cause 14% of the emissions. Figure 16 shows that this is not a specificity of Switzerland or our data, but that in Europe also the share of long-haul flights in emissions (over 1,500 km) is three times their share in passengers.[19]

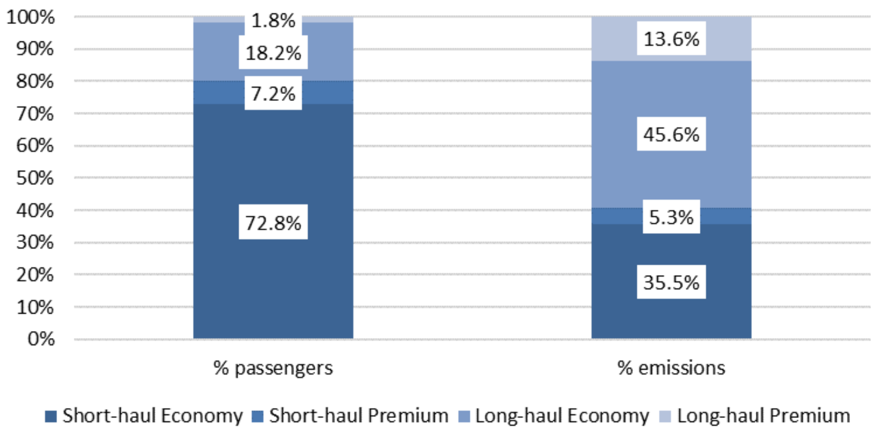

Figure 15: Shares of passengers departing from Swiss airports by flight distance and attributable climate impact (own estimates, 2018)

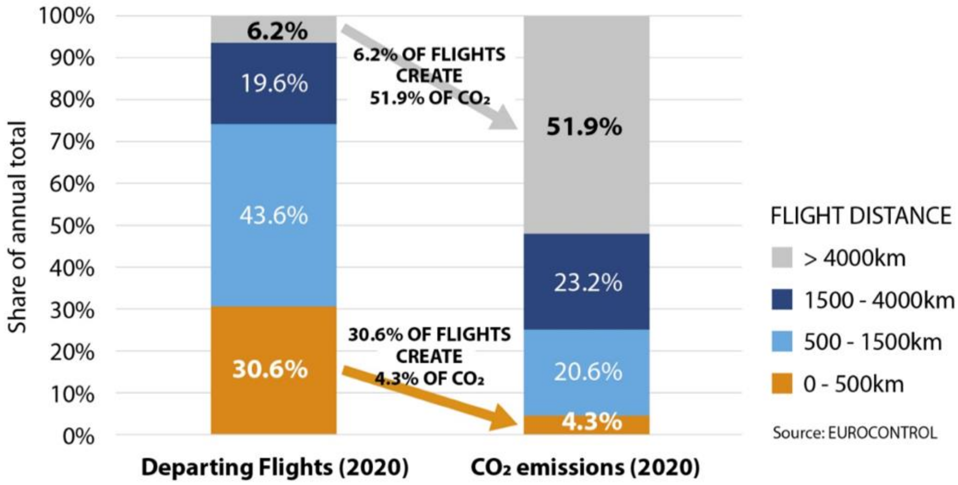

Figure 16: Shares of passengers departing from European airports by flight distance and attributable climate impact (EUROCONTROL 2021)

As a consequence, the impact of the air ticket tax on total emissions will depend to a significant extent on the tariff for long-haul flights, particularly in premium class, and on the elasticity of demand in these segments.

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[19] The statistics shown are for departures from airports in the 40 European States which participate in the EUROCONTROL Central Route Charges process zone.

5.2.4 PRICES

When choosing whether to fly or not, a potential customer evaluates the cost incurred by the trip, which leads to two methodological requirements: first, the return price, rather than the one-way price, should be considered; and second, the cost of flying to the final destination of the trip, rather than that of the first leg only, is pertinent. Hence, in order to obtain representative prices for the considered market segments, we focus on the ten most popular airports in 2018 listed as passengers' final destinations by FSO (2019), both within and outside Europe. For short-haul flights, the ten destinations we consider[20] account for 32% of short-haul departures in terms of local passengers flows (6.1 million). For long-haul flights, which represent a minority of passenger flows, the ten destinations selected[21] represent 30% of long-haul departures in terms of local passenger flows (1.5 million). Moving from destinations to city pairs, we consider flights originating from the three Swiss national airports (BSL, GVA, ZRH) to each destination, as the volume of departures taking place at regional airports is negligible.

The typical price of a given route was extracted from Google-Flights (2020) data when we started the modelling, in June 2020.[22] For the reason described above and because airlines usually impose a penalty on passengers who book single journeys, return-ticket prices were collected. The duration of the stay abroad is assumed to be seven days (15th to the 21st day of each month), because airlines typically penalize short stays. In a first step, the mean of the typical "low" and typical "high" values of the best offers for a given month and class are retained. The advantage of using the featured price range, unlike the actual tickets listed for purchase, is its robustness to effects concerning the day of departure, as well as its month-specific nature. Next, the monthly means per class are averaged over the year. Finally, the average price of a given route is weighted by the corresponding flow of passengers. The adopted methodology allows us to obtain representative fares by both avoiding dynamic pricing effects and controlling for seasonal patterns.

For short-haul flights, the standard economy and business classes are considered consistently with the seating classes offered by airlines.[23] For long-haul flights, the following classes are considered: economy, business and first. In order to obtain a representative premium class price, the latter two were considered jointly, weighted according to their average prevalence following DBEIS (2019). Finally, the above procedure is repeated except that we allow for a transfer to take place during the

[20] London Heathrow, Amsterdam Schiphol, Barcelona, London Gatwick, Porto, Madrid Barajas, Berlin Tegel, Wien, Lisboa, Palma de Mallorca.

[21] Tel Aviv Ben Gurion International, Suvarnabhumi Bangkok International, New York JFK, Dubai, Hurghada, Toronto Lester Pearson International, New York Newark International, Marrakech, Singapore Changi, Muscat.

[22] To account for the effect of COVID-19, we corrected some of these prices by comparison with a smaller sample collected in February 2020. Short-haul prices were taken as such. Direct long-haul prices were corrected by a factor 1/0.95 in economy and 1/0.9 in premium. Indirect long-haul prices were corrected by a factor 1/0.97 for both classes.

[23] Airlines only offer the choice between standard economy and business travel classes on short-haul flights.

trip to characterize short-long-haul flights. As a result, we obtain the six representative prices shown in Table 7.

Table 7: Ticket prices (CHF)

	Economy	Premium
Short-haul	155	570
Short-long-haul	490	2 745
Long-haul	700	4 570

5.2.5 ELASTICITIES

The elasticities listed in Table 2 of the previous chapter do not distinguish by reason for travelling, even though it must be assumed that the price-sensitivity of demand is not the same for leisure- and work-related flights. Therefore, we assume that the elasticities in Table 2 apply to the typical motive in each segment: personal for flights in economy, work for flights in premium. The elasticities for work flights in economy and flights for personal motives in premium are interpolated. Thus, the estimated 25% of passengers travelling in economy class for work reasons are assumed to have a price sensitivity that is intermediate between that of personal flights in economy and that of work-related flights in premium. For short-long-haul flights, we assume the same elasticities as for long-haul flights. The resulting elasticities are described in Table 8.

Table 8: Demand elasticities for all market segments

	Economy		Premium	
	Personal	Work	Personal	Work
	Lower bound			
Short-haul	1.20	0.90	0.90	0.60
Short-long-haul and long-haul	0.90	0.60	0.60	0.30
	Upper bound pre-COVID-19 (until 2019)			
Short-haul	2.10	1.55	1.55	1.00
Short-long-haul and long-haul	1.50	1.00	1.00	0.50
	Upper bound post-COVID-19 (from 2020)			
Short-haul	2.10	1.65	1.65	1.20
Short-long-haul and long-haul	1.50	1.20	1.20	0.90

5.3 Tax schedule scenarios

5.3.1 TAX SCHEDULE OF CO_2 ACT AND IMPLICIT CO_2 LEVY

The new CO_2 Act does not specify a schedule for the air ticket tax, it only sets a lower and upper bound – CHF 30 and 120, respectively – and mentions the possibility to differentiate by travel class and flight length. It exempts transfer flights from the air ticket tax, even though they account for 15% of all passengers departing from Swiss airports. It is the role of the Federal Council to propose a schedule in an ordinance. It did so in April 2021. The proposed schedule, which at the time of writing is only in the wide consultation phase, provides for a tax of CHF 30 on flights in economy class within Europe, except for some destinations on the edge of Europe considered as medium-haul. The rate is CHF 60 for medium-haul flights, and CHF 90 for long-haul flights, which include all destinations east of the Ural, south of the Mediterranean border countries or beyond the Atlantic. The rates are the same for short-long-haul flights. A surcharge of CHF 30 is applied for the same flight in a premium class.

Our model does not distinguish medium- from long-haul flights, so we shall only consider the CHF 30 and 90 rates, augmented by CHF 30 in premium (Table 9).[24] Dividing these rates by the corresponding average climate impacts of the flight segment (Table 6) yields the implicit CO_2 levy displayed in the last column of Table 9.

Table 9: Air ticket tax of CO_2 Act and implicit CO_2 price

		Air ticket tax (CHF)	Implicit CO_2 levy (CHF/ton CO_2eq)
Short-haul	Economy	30	92
Short-haul	Premium	60	123
Short-long-haul	Economy	90	46
Short-long-haul	Premium	120	22
Long-haul	Economy	90	55
Long-haul	premium	120	24

Just considering the implicit carbon levy for flights in economy reveals that it is about twice as high for short-haul flights than for long-haul flights. Remember that we considered the full impact of short-haul flights, including the greater relative importance of take-off and landing. So, another explanation needs to be found for the very unequal treatment of short- and long-haul flights, when the CO_2 Act stipulates that the climate impact must be considered in setting the rates (art. 44). It

[24] Some medium-haul destinations listed in the draft ordinance are European, so we would count them as short-haul, and some are Southern Mediterranean destinations, which we would count as long-haul. Therefore, there is no clear bias from our ignoring this segment.

lies in the fact that the Parliament imposed the bounds of CHF 30 to 120, i.e. a maximum rate only 4 times larger than the minimum rate when the climate impact of the average short-long-haul flight in premium is over 15 times larger than that of the average short-haul flight in economy (Table 6). There can be an argument, though, for taxing short-haul flights higher because substitutes such as night and high-speed trains exist.

Adding CHF 30 for premium over economy is also a very crude approximation of the extra climate impact attributable to these wider seats. For short-haul flights, it is rather excessive, because premium does not have double the climate impact of economy. For long-haul flights, it significantly underestimates the additional climate impact of the premium classes. As a result, the average long-haul flight in premium is only taxed at a rate of CHF 24 per ton CO_2eq when the average short-haul flight in premium is taxed at a rate of CHF 123 per ton CO_2eq.

5.3.2 TAX SCHEDULE SCENARIOS TO BE SIMULATED

We consider four scenarios, the first two of which being compatible with the principles of the new CO_2 Act, the other two designed to obtain greater emissions reductions. These scenarios are summarised in Table 10.

Table 10: Air ticket tax rate scenarios (CHF)

		Scenario		
		CO_2 Act	UK Duty	CO_2 levy
Short-haul	economy	30	17	24
Short-haul	premium	60	34	36
Short-long-haul	economy	90	107	145
Short-long-haul	premium	120	234	405
Long-haul	economy	90	107	121
Long-haul	premium	120	234	369

Tax scenarios:

(1) CO_2 Act: our interpretation of the schedule envisioned by Parliament in the new CO_2 Act, flights through European hubs being treated like long-haul flights.

(2) CO_2 Act with growth: tax rate as in scenario (1), but rising by 4.7% per year until 2050, the rate needed to keep the climate impact constant despite growing passenger numbers.

(3) UK Duty: tax rate equivalent to UK Air Passenger Duty 2021.

(4) CO_2 levy: tax rate proportional to climate impact (CO_2 emissions × 3 × 74 CHF/ton CO_2eq).

In the first tax scenario, short-haul economy class passengers pay the minimum tax of CHF 30, and short-haul premium class passengers pay CHF 60. For long-haul flights these amounts are set at CHF 90 and 120, respectively. Long-haul flights with a transfer in a European hub are taxed like long-haul flights.

The second tax scenario starts off with the tax rates of the first scenario, but the rates are not constant until 2050. Instead, they are raised by 4.71% every year, a rate computed under the constraint that total CO_2 emissions in 2050 are equal to those of 2018. Note that the model uses constant baseline ticket prices, so the progression can be interpreted as in real terms.

The third scenario imitates the tariff of the UK Air Passenger Duty, the highest in Europe. That air ticket tax ranges from GBP 13 for short-haul flights in economy to GBP 180 for long-haul flights in premium. We use a value of CHF 1.30 for the GBP/CHF exchange rate.

The fourth scenario considers a tax of CHF 74 per ton of CO_2eq, using the RFI of 3 to account for the climate impact of high-altitude emissions, in line with the current scientific consensus estimate (section 2.1). The emissions of the return flight are not considered. This rate of CHF 74 was chosen so that the ticket tax for long-haul flights in economy is about equal to the maximum rate of the CO_2 Act, i.e. CHF 120. It is lower than the CHF 96 per ton of CO_2 charged on heating fuels under the current Swiss CO_2 Act (rate for 2018 to 2021). On the other hand, no CO_2 levy is charged on land transport fuels. Air ticket tax rates proportional to the climate of impact of flights would differ substantially from those of the new CO_2 Act. They would be much higher for long-haul flights, particularly in premium. Indeed, the range set in the CO_2 Act for the air ticket tax – CHF 30 to 120 – cannot be squared with the range of CO_2 emissions from the different types of flights (section 5.3.1). Particularly the CHF 30 surcharge for flights in premium compared to flights in economy is very far from reflecting the extra emissions commonly attributed to premium passengers on long-haul flights.

5.4 Model simulations

The key driver of change in passenger numbers and ensuing climate impacts is the percentage increase in price caused by the new air ticket tax. We assume that the tax is entirely passed onto passengers, i.e. that airline companies cannot absorb part of it with a view to mitigating the impact on demand (for a discussion, see section 5.6). Under this assumption, simulated percentage changes in prices for the average prices assumed (Table 7) and the different tax schedules (Table 10) are represented in Table 11.

Table 11: Price changes induced by air ticket tax rates in the four scenarios (2018, except "CO_2 Act with growth")

		CO_2 Act	CO_2 Act with growth **2050**	UK Duty	CO_2 levy
Short-haul	economy	+19%	+84%	+11%	+16%
Short-haul	premium	+11%	+46%	+6%	+6%
Short-long-haul	economy	+18%	+80%	+22%	+30%
Short-long-haul	premium	+4%	+19%	+9%	+15%
Long-haul	economy	+13%	+56%	+15%	+17%
Long-haul	premium	+3%	+11%	+5%	+8%

5.4.1 Tax schedule as in CO2 Act

The first tax scenario raises the price of short-haul flights in economy, the most important segment in terms of passengers, by 19% (Table 11). Prices of long-haul flights increase less, particularly those in premium, a segment that has a disproportionate impact on CO_2 emissions. As a consequence, the impact on emissions of the proposed tax schedule will be less than its impact on passenger numbers. The effects of this scenario are shown in Table 12. It entails a reduction in CO_2 emissions of between 10% (lower bound elasticity) and 16% (upper bound). The effects are nearly constant through time since the tax schedule remains unchanged. The somewhat higher upper-bound elasticities assumed post-COVID-19 for some smaller segments increase the impact on CO_2 emissions from -15.7% to -16.2%. Tax revenues increase through time, from about CHF 1 billion in 2018 to 2 billion in 2050, due to the trend rise in passenger numbers.

Table 12: Effects of tax schedule as in CO_2 Act

	2018	2030	2050
	Lower-bound elasticities		
Passengers	-13%	-13%	-13%
CO_2 emissions	-10%	-10%	-10%
Tax revenue (MCHF)	948	1 274	2 088
	Upper-bound elasticities		
Passengers	-21%	-21%	-21%
CO_2 emissions	-16%	-16%	-16%
Tax revenue (MCHF)	858	1 146	1 877

5.4.2 TAX SCHEDULE AS IN CO2 ACT WITH GROWTH

Our second tax scenario starts off with the same tariff as the first, that of the CO_2 Act, but raises it every year by 4.71%, the rate needed to keep CO_2 emissions at their level of 2018 all the way to 2050, despite the growth in passenger numbers partly offset by 1.5% fuel efficiency improvement per year.[25] In the reference scenario without air ticket tax, passenger numbers grow by 2.5% per year. This growth rate is lowered to 1.9% in the first year of implementation for the lower-bound elasticities and to 1.5% for the upper-bound elasticities. Over time, these growth rates decline under the effect of the rising air ticket taxes, down to 1.0% and 0.3% respectively in 2050.

The impact on prices, assumed to remain constant, is substantial by 2050 (see Table 11). Nevertheless, the price increase for premium flights remains quite small. If this segment, which contributes disproportionately to emissions (section 5.2.3) and is particularly inelastic, is also to reduce its emissions, a different rate structure is needed, for instance that of the fourth scenario.

For 2018, this tax schedule has the same impact as that of the CO_2 Act, but as the air ticket tax rises, the effects become stronger (Table 13). In 2050, the number of passengers is 42% to 48% lower than in the absence of air ticket tax, depending on the elasticity of demand, but still 45% to 69% higher than in 2018. The effect on CO_2 emissions is less, but they are still 26% to 38% below the level without tax.

Table 13: Effects of tax schedule as in CO_2 Act with growth

	2018	2030	2050
	Lower-bound elasticities		
Passengers	-13%	-20%	-37%
CO_2 emissions	-10%	-15%	-29%
Tax revenue (MCHF)	948	2 023	6 451
	Upper-bound elasticities		
Passengers	-21%	-32%	-53%
CO_2 emissions	-16%	-25%	-43%
Tax revenue (MCHF)	858	1 704	4 552

[25] As the impact of the air ticket tax on CO_2 emissions is not the same for the lower- and upper-bound elasticities, the condition of constant emissions is applied to the average of the emissions in the two elasticities scenarios.

5.4.3 TAX SCHEDULE ANALOGOUS TO UK DUTY

The UK Air Passenger Duty 2021 ranges from GBP 13 to GBP 180, which implies that it is about half as high as that of the CO_2 Act for our largest segment – short-haul economy flights – but about twice as high as that of the CO_2 Act for long-haul premium flights (Table 10). This reflects, naturally, in the induced price changes, which are somewhat greater but still quite moderate for long-haul premium flights (Table 11).

The results of this simulation are not very different from those of the CO_2 Act tax schedule (Table 14). One difference is that the negative impact on CO_2 emissions is closer to that on passenger numbers than in scenario 1, because of the steeper tax schedule.

Table 14: Effects of tax schedule as UK Duty

	2018	2030	2050
	Lower-bound elasticities		
Passengers	-9%	-9%	-9%
CO_2 emissions	-8%	-8%	-8%
Tax revenue (MCHF)	844	1 135	1 859
	Upper-bound elasticities		
Passengers	-15%	-15%	-15%
CO_2 emissions	-13%	-14%	-14%
Tax revenue (MCHF)	785	1 049	1 718

5.4.4 TAX SCHEDULE BASED ON CO2 LEVY

This tax scenario amounts to setting the ticket tax rate in proportion to the climate impact of flights. It is lower than the schedule of the CO_2 Act for short-haul flights, but adds a larger tax to long-distance flights, particularly in premium and particularly through hubs (Table 11). As these are the most kerosene-intensive flights, this tax schedule achieves greater reduction in CO_2 emissions than scenario 1, but the difference is not huge (Table 15 compared to Table 12). However, as the CO_2 levy is expected to rise,[26] so would an air ticket tax transposing the same carbon price to flying, which implies that the effect of this schedule on emissions could become much more substantial in coming years.

[26] The CO_2 Act of 2020 sets the ceiling at CHF 210 per ton CO_2.

Table 15: Effects of tax schedule based on CO_2 levy

	2018	2030	2050
	Lower-bound elasticities		
Passengers	-12%	-12%	-12%
CO_2 emissions	-10%	-10%	-10%
Tax revenue (MCHF)	1 060	1 425	2 335
	Upper-bound elasticities		
Passengers	-19%	-19%	-19%
CO_2 emissions	-17%	-17%	-17%
Tax revenue (MCHF)	969	1 291	2 115

We do not show it here, but very similar results can be obtained with a 15% tax on ticket prices. This rate is a rough average of the price increases resulting from the air ticket tax of the CO_2 Act (Table 11).

5.4.5 ALL SCENARIOS COMPARED

The main results of all tax schedules for 2023 are compared in Table 16, under the assumption that the air ticket tax is fully operational in that year and that air transportation is back on its upward trend of pre-2020. It does so only for the post COVID-19 upper-bound elasticities. As before, all numbers are deviations from the baseline without any air ticket tax for the same year.

Table 16: Comparing the tax scenarios in 2023 (post-COVID-19 upper-bound elasticities)

	CO_2 Act	CO_2 Act with growth	UK Duty	CO_2 levy
Passengers	-21%	-26%	-15%	-19%
CO_2 emissions	-16%	-19%	-14%	-17%
Tax revenue (MCHF)	964	1 146	882	1 086

It is interesting to note that, although our four tax schedules are defined quite differently, they end up affecting air transportation by similar magnitudes. This is the case for the early years, but as the air ticket tax rises in scenarios (2) and possibly (4), the results drift apart. One might also note the differences in air ticket tax revenue, ranging from CHF 0.88 to 1.15 billion. Incidentally, the latter number is close to the actual revenues of the CO_2 levy in 2020 (CHF 1.26 billion from Accounts of Confederation). It is smaller than the CHF 1.30 billion of revenues from the air ticket tax estimated by Sigrist et al. (2019), who assumed a tax of CHF 120 on all long-haul flights.

Overall, our simulations suggest that introducing an air ticket tax within the CHF 30-120 range of the new CO_2 Act could cut CO_2 emissions by up to 16% in 2023. Such a decrease in 2019 would have implied a reduction of aviation's share in Switzerland's total global warming emissions (section 2.2) from 27% to 24%. This may look like a small improvement, but it is equivalent to 2.5 million tons of CO_2 per year. At the rate at which kerosene sales were rising in the 10 years before 2020 (3.2% per year), these emissions savings would have been offset by growth in demand within six years (but after these six years, they would still be 16% lower than without any air ticket tax or other measure). At the more moderate growth rate we assume post COVID-19 (2.5%) and with continued fuel efficiency improvement (1.5% per year), it would take 18 years until emissions are back to the level before introduction of the air ticket tax.

Our simulations also show that with long-haul flights accounting for an estimated 60% of emissions, yet representing only 20% of passenger volume, the mitigating impact on emissions could be strengthened through a more progressive tax schedule, featuring top rates well above the ceiling of CHF 120, particularly for premium flights. Steepening the tax schedule would yield greater emissions reductions with a smaller drop in passenger numbers, despite the smaller elasticities in the long-haul segment.

5.5 Distributional effects of the air ticket tax

Our simulations are too crude to allow for a quantification of the distributional impact of the different air ticket tax scenarios. While the air ticket tax is independent of passengers' income, long-haul and premium class passengers typically have higher incomes than short-haul and economy class passengers. Therefore, the higher rates for these flights compared to short-haul and economy could suggest some progressivity of the proposed air ticket tax. However, the proposed tax schedule, when measured in implicit tax per ton CO_2, is quite favourable for long-haul flights, particularly in a premium class (Table 9).

Whether the overall effect of the tax is progressive will also depend on how the tax revenues are used: the greater the weight of lump-sum redistribution to the population (via health insurance premia), the more redistributive will be the direct effect of the policy. Depending on the schedule of the ticket tax and the elasticity of demand, tax revenues could be about CHF 1.0 billion (Table 12) – a little less than the revenues of the existing CO_2 levy on heating fuel (CHF 1.26 billion in 2019, from Accounts of Confederation). The law prescribes that 51 percent of the revenues of the air ticket tax must be redistributed to the population and businesses, or about CHF 0.5 billion. The share for the population is equal to its estimated contribution to the total revenues. In our model, 72% of the revenues are attributable to flights for personal reasons and 28% for work reasons. If we take this split, about CHF 350 million would be redistributed to the population. For an estimated population of 8.8 million in 2023, this would amount to CHF 40 per capita. Thus, anybody taking more than one short-haul flight in economy would pay more in air ticket tax than the refund.

Sigrist et al. (2019) estimated tax revenues of CHF 1.3 billion, from which they derived a refund of CHF 60 per capita. With their assumption of a ticket tax of CHF 30 for short- and 120 for long-haul flights, it is easy to identify which households would pay more than the refund, namely those that undertake one long-haul flight or more than two short-haul flights per year. These are typically higher-income households.

Bosshardt et al. (2020) used the data of the microcensus 2015 to estimate the net effect on household incomes of a simplified version of the air ticket tax. Their tax was assumed to be equal to CHF 30 for short-haul flights and CHF 120 for long-haul flights irrespective of the travel class. Furthermore, it was assumed that 51% of the revenues was redistributed to the population, including the share that would actually be refunded to businesses. The authors found that 90% of the population would obtain a larger refund (CHF 84) than what they paid (CHF 18 per capita on average), thanks mostly to the contributions of passengers who do not reside in Switzerland, and thus are not entitled to the refund, while they pay the air ticket tax when leaving the country. The 10% with a negative balance are frequent flyers, who can be found in all income classes. Nevertheless, as the frequency of flying increases with income, the average balance per income class is positive and highest for the lowest income class (about CHF 70) and gradually decreases to slightly below zero in the income class with CHF 16,000+ income per month. Compared to incomes, there is, therefore, an overall progressivity in the net refund, but of course there may be many frequent flyers with low or middle income who pay a net balance.

5.6 Limitations of the simulations

Our simulations abstract from supply-side reactions, from income effects, from tax-induced deadweight losses and from dynamic and indirect effects. They are, therefore, to be considered as rough and partial approximations rather than as a comprehensive evaluation.

In reality, the supply curve is not perfectly elastic, and the tax burden will be shared between the airlines and passengers, thus reducing the impact of the air ticket tax (Figure 17). Indeed, as supply is not perfectly elastic, the tax is not simply added to the initial price ($P_0 + t$), but rather shared between airlines and passengers, resulting in a lower post-tax price P_1' than with full pass-over as assumed in our simulations, and a smaller decrease in air travel. The determination of the exact shape of the supply curve should be a priority for further research to better understand the impact of air ticket taxes on travel volume.

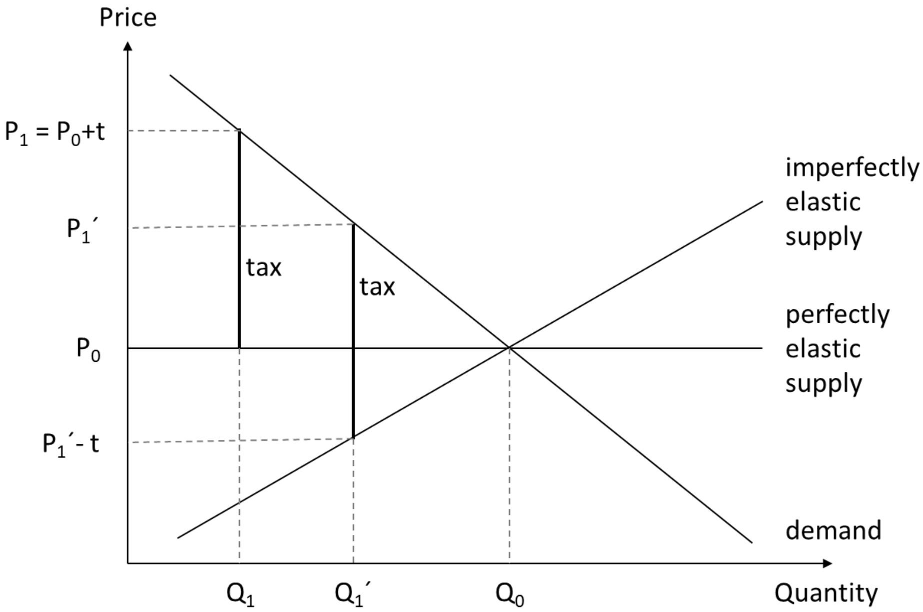

Figure 17: Splitting of air ticket tax between airlines and passengers (own figure)

5.7 Discussion of these results

An impact assessment based on air travel demand elasticities shows a clear effect of an air ticket tax on air passenger demand. It is however possible that some passengers would start their journey from neighbouring airports in order to avoid the Swiss air ticket tax. An increasing number of European countries and all neighbouring countries of Switzerland have already introduced an air ticket tax (Figure 18). However, they are mostly much lower than the proposed Swiss tax of CHF 30 to 120.

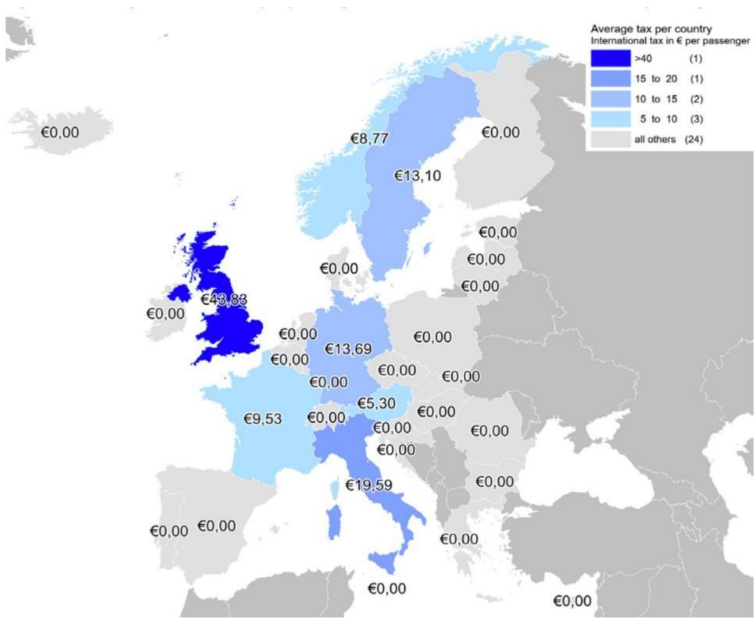

Figure 18: Average aviation taxes per passenger in the EU and EFTA, for international passengers (CE Delft, 2019)

Another argument against air ticket taxes put forward by the airline industry states that taxes have a negative impact on the environment, as they limit the ability of airlines to invest in new aircraft technology. This effect is moderated when companies can pass the tax to their customers, as we assume in our model, and when the air ticket tax is reduced for companies that reduce their climate impact, as is provided for in the CO_2 Act.

The air ticket tax could reduce the load factors of airplanes, without reducing the number of flights (IATA, 2019b), but in a competitive market one would expect airlines to reduce flights eventually. Moreover, many airlines might simply pass on the costs of air ticket taxes to less price-sensitive customers such as premium class passengers to limit an overall demand reduction. Finally, as transfer and transit passengers are exempt from taxation under the current draft legislation, Swiss airlines might offer cheap connecting flights to their hubs in Switzerland to compensate for the reduction in local passenger demand.

The use of the revenues from the air ticket tax is another interesting question. While redistributing revenues to the population might increase the social acceptability of air travel taxes, directing the revenues towards subsidizing night trains or synthetic fuels might help to reduce emissions more effectively.

6 Further measures to reduce the climate impact of aviation

6.1 Overview

While this white paper focuses on the direct effects of an air ticket tax, other, complementary policy instruments exist. Money matters, but it is obviously not the sole motivator of human behaviour. Information campaigns, for example, played a major role in countering adverse effects of tobacco. Similarly, public information on the global warming effects of flying combined with the negative message that the ticket tax itself sends could potentially magnify its impact. Citizens who understand and accept the purpose of a regulation not only makes the latter more effective because there is less effort to circumvent it, it is also a condition for support of the regulation in a democracy in the first place.

The provision of attractive alternatives to air travel will also facilitate adjustment in travel behaviour. The availability of high-speed long-distance train connections could reduce the wedge in travel speed between planes and trains. Night trains seem to hold particular potential. A general increase in the price of flying, e.g. through an air ticket tax, would enhance the price competitiveness of alternative travel modes even without additional public subsidies, which have a negative effect on public budgets.

Finally, technological innovation in the aviation sector should continue. Apart from public support to research and development in this sector, rules for minimum contents of "green" aviation fuels may be worth considering.

In order to organise this overview of policy measures available to public authorities that wish to reduce the climate impact of aviation, we refer to the decompositions of CO_2 emissions from air transport in section 2.7. These decompositions showed the levers that could be moved, such as the number of passengers, the distances travelled, the load factors, the fuel efficiency of airplanes, the climate impact of fuels used. The decomposition that will serve as the reference for structuring this chapter is the following:

$$CO_2 \text{ emissions} = (\text{passengers} \times \text{kilometres}) \times \frac{\text{aircraft mass displaced}}{\text{pkm}} \times \frac{CO_2 \text{ emissions}}{\text{aircraft mass displaced}}$$

The first term is the total number of kilometres travelled by air in a given period. It can be reduced through a reduction of air travel demand (section 6.2) and/or a reduction of air travel supply (section 6.3).

The second term is the average quantity of aircraft mass that is displaced for this travelling activity. Aircraft mass is used rather than number of planes, because it is a more direct determinant of energy use. Two airplanes filled with 250 passengers each do not burn twice the energy of one large airplane carrying the 500 passengers. This ratio can be lowered by increasing the load factor of airplanes (section 6.4). Airplane fleet management and operation is the key to this determinant of the climate impact of aviation.

The last term is the average quantity of CO_2 emissions from displacing aircraft mass. It depends on the fuel efficiency of airplanes and the carbon content of airplane fuels. It can, therefore, be reduced with more fuel-efficient airplanes and by replacing fossil-based fuels with (nearly) climate-neutral ones (section 6.5). Depending on the system boundaries, carbon offsets could also be counted as emission reductions. Technology is the key to this determinant of the climate impact of aviation.

There exist many policy measures that could be used to move these levers. They will be organized in the following five standard families:

1. Voluntary approaches, i.e. measures designed to push ("nudge") the actors towards the desired changes without punishing them in any form for not acting on the push or measures that actors take to reduce their environmental impact without this being directly profitable to them. These measures are also called soft law.

2. Regulatory measures, i.e. measures that impose or forbid specific actions, assuming that the enforcement mechanisms are sufficient to actually obtain compliance. These measures are also called command & control.
3. Quantity measures, i.e. measures that impose a ceiling on some undesirable action such as pollution. They can be flexible in the sense that individual actors can trade their allowed quantity (or 'quota'). In such a case, they become price measures.
4. Price measures, i.e. measures that render a given option relatively cheaper or more expensive. Such measures are also called market instruments.
5. Other measures that do not fit into this characterization, for instance the promotion of alternatives to the undesired options.[27] These measures include service and infrastructure instruments, as well as liability related measures.

This chapter addresses the main levers of CO_2 emissions from air transport – demand and supply (which primarily impact the first term of the decomposition equation above), passenger load management (which impacts the second term) and technology (which impacts the third term) – in turn, and shows how each lever can be moved by policy measures grouped in the above five families.

6.2 Reduce air travel demand

6.2.1 Voluntary approaches

Use social campaigns to make flying less socially acceptable

Flygskam is the neologism for "flight shame" that gained popularity in Sweden, a country of frequent flyers, in 2019. It is believed that the number of local passengers decreased by 9% in 2019 as a result of the societal debate around flying, while the number of international passengers decreased by 2% (Swedavia, 2020). This movement has become influential across Western Europe and is beginning to influence the behaviour of consumers across the region. For instance, academics are flying less.

While the flight shaming movement has developed organically so far, we believe that there is a case for a government sponsored campaign in Switzerland to educate the public about the negative impacts of flying on the environment. This could help to directly reduce the growth in air travel demand. Perhaps more importantly, it would help to build support for other measures to reduce air travel demand (such as an air ticket tax) or to reduce supply (such as bans on short-haul routes). This would be especially true for travel for personal reasons, which accounts for the majority of air travel from Swiss airports. 63% of air passengers departing from Zurich airport indicated "leisure"

[27] An air ticket tax renders air travel more expensive relative to alternatives, so it is a classic price measure. A subsidy for high-speed trains also renders air travel on the routes serviced by these trains more expensive relative to the alternative, but it is not generally considered as a (direct) price measure, so it will be discussed under 'other measures'.

as their principal purpose of travelling in 2019, while 26% indicated "business" and another 11% some other motive (Zurich Airport, 2020).

A campaign to persuade consumers to take the train instead of flying on short-haul routes where there is good rail connectivity may be a good starting point. This is likely to enjoy popular support and could be followed in due course by campaigns to reduce long-haul air travel.

6.2.2 REGULATORY MEASURES

Impose constraints on advertising

The World Health Organization (WHO) calls for a total ban on direct and indirect advertising, promotion and sponsorship for tobacco products, arguing that such a ban "can substantially reduce tobacco consumption and protect people from industry marketing tactics" (WHO, 2020). This shows that advertising can no longer be defended as merely informing consumers or pulling them from one brand to another. It can, rather, push consumers to start consuming a product or increase their consumption.

Short of an outright advertising ban, air travel commercials could be required to include a warning on the impact of air travel on climate change. Booking platforms could be forced to display an assessment of the full climate impact (with RFI = 3) of the advertised trips. For a better understanding, the climate impact could be put into perspective with the average emissions of Swiss citizens and the maximum per capita emission level compatible with the national climate goals.

6.2.3 QUANTITY MEASURES

Institute individual flight quotas

The simplest and most direct measure to reduce air travel demand would be to restrict it quantitatively at the aggregate level and to split this quantity up in the form of individual quotas for air transport. They could but need not be equal quotas per capita. Businesses could also be granted quotas in relation to their size and international activities.

One drawback of fixed uniform quotas is that some people may have good reasons to fly frequently, think of high-level artists or athletes, as well as people whose family members live abroad. The former would have to relocate out of Switzerland if strict quotas prevented them from showcasing their talent on international scenes.

Enforcing strict upper limits on flying at the individual level – typically through a law that sets a maximum number of flights, kilometres travelled or greenhouse gas emissions generated for instance – imposes unnecessary welfare reductions on society. Indeed, in aggregate, the exact same environmental outcome could be achieved by letting people decide whether they prefer to fly or sell this right on a dedicated market.[28]

To allow for differences in desire and need to travel, the quotas should therefore be made tradable (Thalmann, 2019). At the beginning of the year, each citizen would receive a quota that would allow her to travel by aircraft for a pre-defined distance per year. Citizens who wish to travel more than their quota could buy some of the quota of other citizens who fly less than their quota. Quotas could also be saved over several years and used for a special occasion, e.g. a round-the-world honeymoon trip. Each year, the individual flight quotas would be reduced as required, in conjunction with other measures, to meet emissions goals. Note that the correlation between distance flown and emissions would not be perfect, however, as short-haul flights emit more per pkm than long-haul flights, given the relatively higher importance of take-off for fuel consumption.

This ETS-like mechanism would curtail air travel demand quite effectively. Furthermore, it would reward citizens who fly little or not at all. Among its other advantages is the progressive nature of such a scheme, as individuals who tend to fly more usually have a high income and they will compensate those individuals who fly less and have a lower income. In Switzerland, high income households fly 5.7 times more than low income households (Figure 7). Further, unlike the forms of taxation discussed below, the amount of emissions is clearly determined in advance by the total amount of quotas, rendering it independent from potential declining kerosene prices and other economic factors that could dampen the effect of a tax.

The main drawback of this measure is the relative difficulty in implementing it (tracking flights, including from foreign airports, holding quota accounts, etc.), and the open question regarding whether and how the population would engage in trades. If only flights from Swiss airports were included in the quota, this would cover only part of the Swiss residents' air travel. Furthermore, it would be relatively easy for them to evade these quotas by travelling overland to a nearby airport in another country and flying from there.

No country has implemented individual flight quotas so far. In November 2016, Norway considered limiting Norwegian citizens to ten flights a year, but this has not been implemented. In Switzerland, Roger Nordmann, a member of the federal parliament, proposed in a podium discussion[29] individual flight quotas, which caused some stir in the media, but did not attract much support.

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[28] Consider a simple example of a country with 10 inhabitants, where a legally binding upper limit on flying is set to 1000 km per year. Assume that three citizens do not like flying, four citizens fly exactly 1000 km but are indifferent between flying and taking the train and three citizens have a strong desire to fly 2000 km to visit their families more often (no train connexions). Under this law, the population would fly 7000 km, below the aggregate maximum of 10,000 km. Now, suppose that instead of a law, a cap-and-trade system is put in place. In order to achieve the same environmental outcome, individual quotas of 700 km are distributed. At present, it is possible for the last group of citizens to buy the rights of the first group (and possibly even second group) to see their families, while at the same time making the other group better off (financially).

[29] Swiss Energy Foundation (SES), Fossil phaseout congress, 30 September 2019. "NZZ am Sonntag" called Roger Nordmann's proposal a "Tabubruch", the breaking of a taboo (05.10.2019).

6.2.4 PRICE MEASURES

Impose a frequent flyer tax

A frequent flyer tax, which would progressively rise for each additional flight during the same year (Figure 19), could reduce emissions more equitably than a uniform air ticket tax, as a small number of citizens are responsible for a disproportionately high amount of air travel trips. In Switzerland, the top 5 percent of frequent fliers account for around one third of total CO_2 aviation emissions (Bosshardt et al., 2020). Similarly, in the United Kingdom, 15% of the population account for 70% of the flights (UK Department for Transport, 2014). Therefore, taxing frequent flyers disproportionately could be more equitable and garner public support. Ideally, a frequent flyer tax would need to be adjusted for the flight length (or could even be structured around total distance flown or emissions rather than number of flights), as an additional intercontinental flight would generate considerably more emissions than an additional short-haul flight. This is the concept of the progressive air miles levy.

As with any ticket tax, it would be relatively easy for Swiss residents to evade this tax by going overland to a nearby airport in another country and flying from there. In addition, the implementation of such a tax schedule would be administratively costly, as is the case for individual flight quotas. So far, no country has implemented a frequent flyer tax, probably because of practical challenges such as these.

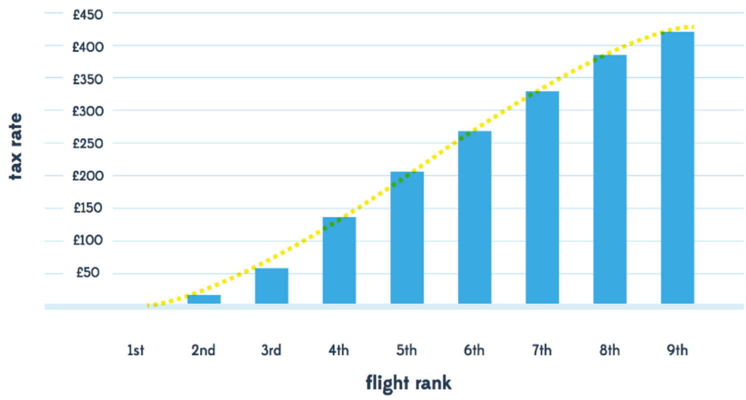

Figure 19: Tax schedule for a potential frequent flyer tax in the United Kingdom (New Economics Foundation, 2015)

6.2.5 OTHER MEASURES

Improve the competitiveness of rail for short-haul trips

High-speed and night trains are possible substitutes for short-haul flights within Europe. While daytime high-speed rail is best suited for distances up to 1,000 kilometres, night trains can cover distances up to 2,000 kilometres. While there is good potential to encourage substitution from air travel to high-speed rail for distances of up to a thousand kilometres, very long-distance night trains are still facing regulatory challenges in Europe for their implementation, such as disproportionately high track access charges (DB International, 2013).

Considerable investments in high-speed train networks in France, Spain and Germany led to significant reductions of air travel demand on the destinations covered. The Paris-Strasbourg route saw a decrease of air travel demand by more than 80%; the Paris-London route by almost 60% and the Madrid-Barcelona route by more than 20% (Figure 20).

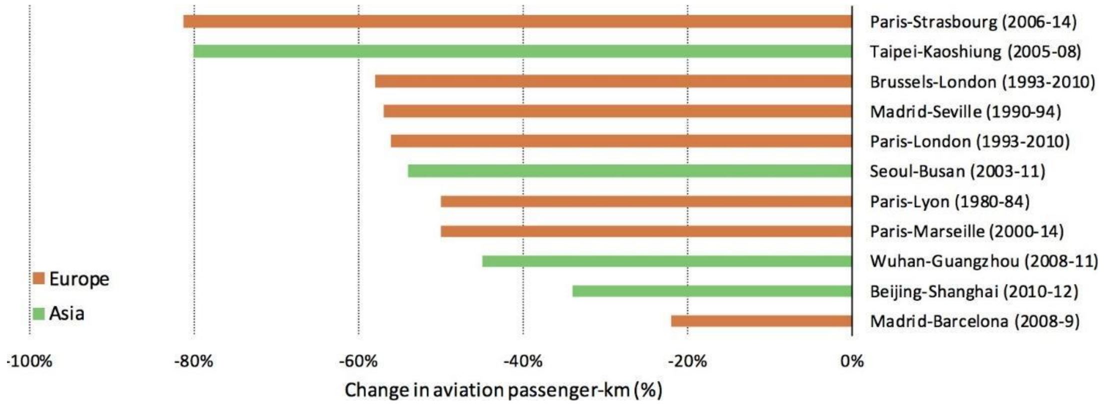

Figure 20: Average change in passenger activity on selected air routes after high-speed rail implementation (IEA, 2019c)

This suggests that where fast, convenient and affordable high-speed rail alternatives exist, consumers are likely to switch from air travel to rail, because rail features advantages such as more central location of railway stations compared to airports, and the convenience of faster boarding and more on-board space. The government can facilitate this by ensuring that train schedules on existing high-speed rail lines are convenient and that there is sufficient capacity to handle passengers wishing to switch from air travel to rail. This may require targeted subsidies or tax and fee reductions to allow rail operators to increase service frequency on some routes. The government may also wish to support investments in new high-speed rail alternatives where there is good potential for attracting air travellers.

The availability of night-train services in Europe has declined significantly in the last decade, primarily because of intense competition from budget airlines, which offered services that were faster, cheaper and more comfortable. Research conducted for the European Parliament in 2017 suggests that this will continue to be the case (Directorate-General for Internal Policies, 2017). While there is some evidence that environmentally conscious leisure travellers are willing to use night trains even if they are less convenient and more expensive than air travel (Kantelaar, 2019), this is unlikely to be sufficient to make night trains in Europe competitive and viable. Night-train services that have continued to operate (such as Austria's OBB Nightjet network) benefit from the fact that many of the cities they serve have air links that are infrequent or inconvenient. Another factor that affects the viability of night passenger trains is the higher priority that freight trains generally receive on rail infrastructure during the night (DB International, 2013), which affects the speed and quality of passenger services. Finally, for travelling by rail to be an assured improvement from a climate perspective, the power supplied should stem from renewable energy sources.

The government could also subsidize rail to reduce fares, thus making rail more attractive versus air travel. Although travelling per se should not be subsidized in a market economy, compensating subsidies for "clean" alternatives can be justified when the "dirty" alternative cannot be made to cover all its external costs, with a view to levelling the "playing field".

6.3 Reduce air travel supply

The number of air travellers and the distances they fly does not depend on demand alone, but also on supply. Policy measures designed to make the price-service package offered by airline companies less attractive can also contribute to reducing passenger-kilometres travelled by air.

6.3.1 VOLUNTARY APPROACHES

Airlines and airports can reduce their capacity for a variety of reasons. KLM claimed environmental responsibility when it announced, in October 2019, its plan to replace one daily connecting flight from Brussels to Schiphol by reserved seat capacity aboard a Thalys high-speed train connecting the two destinations (KLM Newsroom, 2019). It acknowledged, however, that this would also free a slot at Schiphol that the company can put to more profitable use with a long-haul flight.

6.3.2 REGULATORY MEASURES

<u>Limit or ban short-haul flights on routes where good alternatives exist</u>

As discussed in Section 6.2.5, rail services generally supplant air travel on routes where they are competitive on speed, convenience and price. Price is an issue, with rail often being more expensive than air travel. Rather than correcting this through subsidies for the rail and taxes on air travel, limiting or banning all supply on routes where good ground alternatives exist could be considered. There seems to be some popular support for this. A survey conducted across the European Union by the European Investment Bank in October 2019 found that 62% of respondents favoured a ban on short-haul flights. Note, however, that in case of a large price differential between air and surface transportation, a ban would be unpopular with travellers.

Several countries in Europe have considered this, though none have actually instituted a ban thus far. In France, the National Assembly voted on April 10, 2021, to ban domestic flights that could be substituted by a train ride of less than two-and-a-half hours. The measure must be approved by the Senate before becoming law. It was already included as a condition for the government bail-out of Air France in April 2020. Note that this ban affects a very small share of the domestic routes in

France, possibly only five.[30] In January 2020, Barcelona's mayor said that she would ask the airport to terminate all flights to Spanish cities that are served by high-speed rail.

6.3.3 QUANTITY MEASURES

Restrict airport capacity with a cap on slot allocations

Another measure to constrain growth in air traffic would be to not expand Swiss airports further. This would be analogous to the case of Heathrow airport, where a ruling by Britain's Court of Appeal in February 2020 stopped the planned construction of a third runway because of its impact on carbon emissions.

In addition to a moratorium on runway and passenger terminal expansions, the slot allocation mechanism could be revised. The number of available slots could be auctioned and reduced progressively. Currently, the Swiss airport slots are allocated for free according to the "use-it-or-lose-it" rule. This rule may create a perverse incentive to operate flights even at low passenger occupancy rates in order to not lose the slot. The revenues from the auctions could flow into the new Climate fund, to be used for CO_2 compensation projects or to promote synthetic fuels.

However, heavily restricted slots could incentivize airlines to use aircraft with larger passenger capacity, which would hardly reduce absolute emissions. For instance, at Geneva airport, which has only one runway, the number of line and charter aircraft movements increased by 16% from 124,040 in 2009 to 143,970 in 2019 (Genève Aéroport, 2020). Over the same period, the number of passengers increased by 59%, from 11.2 million to 17.8 million. This is the result of larger aircraft being deployed, allowing the average number of passengers per aircraft movement to increase from 91 in 2009 to 124 in 2019.

Geneva airport expects the number of passengers to increase to 25 million in 2030 and is constructing a new East Wing to accommodate such an expansion. It is also considering replacing its main terminal with a much larger terminal in the next decade to cope with further increases in passenger numbers. To avoid the rebound in emissions when airlines start to use larger aircrafts, the slot allocation mechanisms could be coupled with specific minimum fuel efficiency requirements for eligible aircraft types. Electric, hybrid-electric or other low-carbon aircraft types could be given preferential treatment.

[30] The Citizens Convention for Climate had called for a ban on all routes that can be replaced by a train ride of less than 4 hours.

6.3.4 PRICE MEASURES

Extend the VAT to international air transport

As for any mode of transport, the domestic value added tax (VAT) is levied on domestic flights. Flights to a foreign destination are exempted, as well as goods and services sold to companies that operate in majority international flights. The argument underlying this exemption is the same as for any good or service: its consumer should bear the VAT of her place of consumption. As a corollary, the VAT is levied on imported goods and services. This does not apply to incoming flights, though.

International air transport is entirely exempt from VAT in Europe. The European Commission repeatedly considered changing this, particularly as international rail transport is subject to the VAT, which distorts the market in favour of aviation. In the case of ground transport, the locally applicable VAT rate is applied to each segment of the international journey, a complicated solution that would hardly be applicable for air transport. Hence the proposal to levy the local VAT on the entire ticket price at the point of departure. Given that the Swiss VAT rate is significantly lower than the rates in European countries, were this regime to be adopted across Europe, it would favour Swiss airports.

Institute an airline fuel tax

A tax on all aviation fuels would be a particularly effective and efficient measure to abate emissions. An analysis by FÖS in Germany showed that the fuel tax exemption of kerosene is the most damageable subsidy for the climate (FÖS, 2020). A fuel tax would be easy to adopt for all types of aviation (freight, passenger and private). It would act as a strong incentive for airlines to improve fuel efficiency, as fuel costs represent typically 20-25% of an airline's total operating costs, without the rebound effect that past efficiency improvements induced.[31] A fuel tax would increase the competitiveness of alternatives such as rail travel. If the tax were related to the carbon content of jet fuels, it would become a carbon tax.

For domestic flights, a fuel tax already exists in Switzerland. The mineral oil tax is levied on fuels at a rate of CHF 0.74 per litre of aviation kerosene and CHF 0.70 per litre on aviation gasoline (FCA, 2020).

International flights are exempt from the mineral oil tax with reference to the Convention on International Civil Aviation. This agreement, also known as the Chicago Convention, was

[31] A direct rebound effect occurs when the reduced cost of using a more fuel-efficient equipment or vehicle leads to its increased use, which offsets part of the potential energy saving and emissions reduction. Miyoshi and Fukui (2018), for instance, estimated a long-run direct rebound effect of 19% for European airlines over the 2000-2013 period. Lower fuel costs also free income, which the users of the equipment or vehicle will direct to other spending, potentially using more energy and causing more emissions. This is the indirect rebound effect, which adds to the direct effect and may, in the worst case, more than offset the potential energy or emissions saving.

established in 1944 with the goal of furthering international aviation. In a response by the Swiss government to the demands of National Council members to introduce an aviation fuel tax, the Chicago Convention, as well as policy principles adopted by the ICAO Council, are mentioned as the main reasons for maintaining the fuel tax exemption (Schneider Schüttel, 2019). There are, however, legal debates regarding this interpretation. The European environmental NGO Transport & Environment argues that "it is a misconception that the Chicago Convention prohibits the taxation of aviation fuel; it disallows taxing fuel already onboard an arriving aircraft only, but it says nothing about taxing fuel taken onboard prior to departure" (Transport & Environment, 2019). The NGO argues that it is rather intergovernmental air services agreements that prohibit the taxation of kerosene, not the Chicago Convention. Following this interpretation, countries could start to tax aviation fuel bilaterally. Consequently, Switzerland could seek international partners for cooperation and establish a "coalition of the willing" to introduction an aviation fuel tax.

If Switzerland acted unilaterally, airline companies would at least partly choose to refill at foreign airports whenever possible for international flights. The incentive would be lost, in those cases, and the increased weight of airplanes would even result in somewhat higher emissions. This is clearly another measure that would be much more effective if it were implemented in a coordinated manner by many countries.

6.4 Improve passenger load factors

Emissions per passenger would be lower if fewer planes were used to transport a given number of passengers, that is, if the average load factor were higher. Of course, this does not mean attracting more passengers to fill the planes, but rather to better group passengers into flights and to adapt airplane seat configurations which accommodate more passengers.

6.4.1 REGULATORY MEASURES

Ban business and first class

In our simulations, the carbon footprint of a business class passenger is 1.5 times that of an economy class passenger on short-haul flights, and for long-haul flights we assume a factor of 3.06, average of business and first class. According to a World Bank report, the carbon footprint of business and first-class passengers could be even three times and nine times that of economy class passengers, respectively (Bofinger and Strand, 2013). In any case, banning the premium classes would reduce the per passenger carbon footprint of these flights.

In practice, however, this is likely to be very difficult to implement. These seats are particularly profitable for airlines. Furthermore, the vast majority of passenger traffic out of Geneva and Zurich is to international destinations. For example, flights to Zurich account for less than 4% of the total passenger traffic out of Geneva. To be able to execute a ban, the Swiss government would have to secure agreement from the European Union. This option has not been discussed or proposed by any EU government, so this is very unlikely in the short or medium term.

Allow "standing seats" on short-haul flights

Standing seats have been in the news for some time now. In 2010, an Italian seat manufacturer, Aviointeriors, came out with a design and Michael O'Leary, Ryanair's CEO, announced that the airline was considering introducing these on its flights. However, the design was not approved by the US Federal Aviation Administration. In 2018, Aviointeriors proposed a new design but faced a lack of interest from airline companies. Given the lack of market opportunities and the difficulties in getting a standing seat approved for use, it is unlikely that this will become a reality in the short to medium term.

Impose progressive fines on lower capacity utilization

Passenger load factors have increased worldwide from 75% in 2005 to 82% in 2019 (IATA). Airlines are obviously interested in increasing load factors. We can reasonably trust that they optimize within their own policy parameters. Nonetheless, imposing progressive fees on load factors could further incentivize airline policies which would improve load factors.

Currently, for example, airlines avoid transferring passengers to another airline. With sufficient incentive, airlines would increase and broaden their agreements on transferring passengers with other airlines flying the same route.

6.5 Reduce the global warming impact of airplanes

The global warming impact of a given number of airplane movements can be reduced when i) airplanes use less energy, and ii) they use energy that has a smaller climate impact. The first option amounts to increasing the fuel efficiency of airplanes. This has taken place (cf. section 2.5), but not to a sufficient extent to offset the increase in air travel. Part of this increase is, actually, due to the cost savings obtained through the fuel efficiency gains (rebound effect, see section 6.3.4). Hence, the emphasis shall be, here, on the second option, energy carriers with a smaller climate impact, from "well" to engine, than standard kerosene.[32]

One significant impediment in this respect is that, so far, jet engines and aviation infrastructure have been developed on the premise of petroleum-based fuel, resulting in a technological lock-in. Furthermore, on top of embodying a means of stocking energy, conventional kerosene holds a number of physical properties which are strictly regulated for safety reasons and may not always be easily replicated (Hileman and Stratton, 2014). Overcoming this lock-in would be prohibitively

[32] The two options are not independent. Alternative fuels may imply that more primary energy is used for the same transportation service.

expensive and time-consuming even if such a clean technology were readily available (which currently is not the case).[33] As a result, only “drop-in” fuels embody a realistic decarbonisation pathway for aviation in the medium term. Such fuels are defined as being fully compatible with current aircraft, infrastructure and fuel distribution networks. Despite this barrier, we also discuss whether electric planes constitute a potential long-term solution.

The main candidate low-carbon energy carriers we shall consider are:

1. Drop-in agrofuels:[34] fuels based on products or waste from agriculture or forestry
2. Drop-in synthetic fuels: fuels made from electricity, water and carbon dioxide
3. Renewable electricity for electric aircrafts

Among the first two options, agrofuels appear to be more promising in the short term, principally given their relatively lower cost, while synthetic fuels have more potential in the long run, mainly because they face fewer barriers in terms of feedstock availability (Scheelhaase et al., 2019; The Royal Society, 2019). It should be noted, that the potential for decreasing greenhouse gas emissions through agrofuels and synthetic fuels stems from their production and possibly transport, not their combustion. Nevertheless, from a lifecycle perspective,[35] such fuels may reduce the climate impact of flying by up to 80% according to ATAG (2020). Concerns relate to the scalability and cost of these novel types of kerosene, the sufficient availability of clean power, energy efficiency of the involved processes, water usage, as well as competition for resources with other sectors.

Agrofuels can start replacing fossil-based jet fuels to a significant scale in the late 2020s, synthetic fuels after 2030. Interestingly, up to the 2020 World Energy Outlook, the IEA counted essentially on fuel substitution and additional technology improvements to lead aviation on its sustainable development path. Now, it accepts that behaviour changes are also needed. Its new Net Zero Emissions scenario has a 50% reduction in CO_2 emissions from aviation after the technological improvement, with only a 12% reduction in flight numbers (Figure 21).

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[33] In 2018, the worldwide commercial fleet consisted of 23,100 aircraft, which at a lower estimate of USD 80m a piece, i.e. the average price of Airbus’ cheapest commercial aircraft – in comparison an A380 cost USD 445m (Airbus, 2018) – and with a delivery rate of 1,600 airplanes per year (Boeing, 2019), would require an investment upward of USD 1.8tn and over 14 years to be replaced, disregarding infrastructure costs and safety issues. Note that while the global fleet is expected to grow substantially, the delivery rate has increased over the years too; hence, this order of magnitude is expected to be representative irrespective of the reference year. Moreover, although official price tags might not be representative of actual deals between airline companies and manufacturers, which largely rely on leasing contracts, the figure remains informative.

[34] Agrofuels are still frequently called "biofuels" to suggest that they are more natural and sustainable than they really are.

[35] Which indeed is the relevant measure for climate policy.

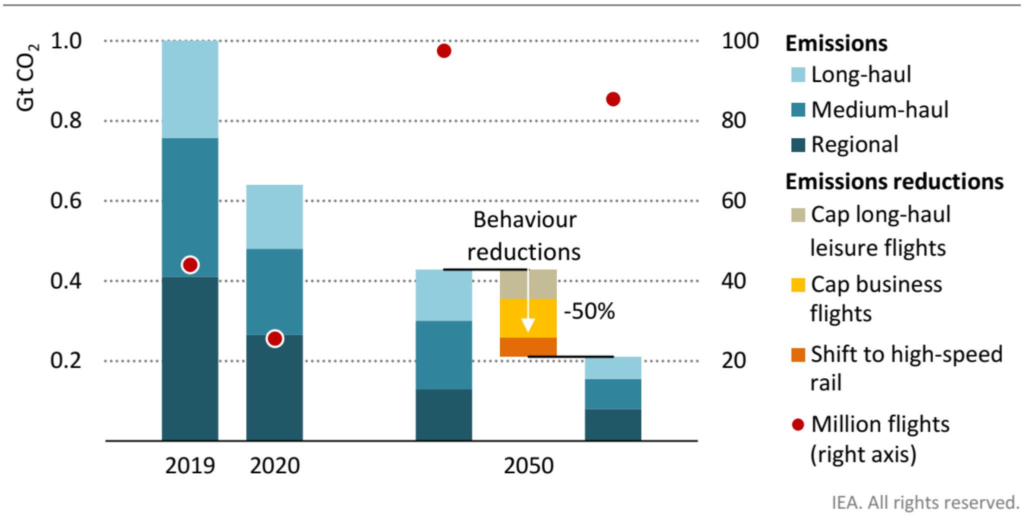

Figure 21: Global CO_2 emissions in aviation by abatement measure in the Net Zero Emissions scenario relative to the Stated Policies Scenario (IEA, 2021)

It will be paramount to ensure that the agrofuels used are indeed low carbon over their lifecycle and sustainable, especially with respect to forest and biodiversity conservation. Such fuels are conventionally called "advanced biofuels" or "Sustainable Aviation Fuel (SAF)". Any policy promoting agrofuel uptake will need to require strong certification to ensure low carbon intensity and sustainability. The worldwide potential of such agrofuels, which are ideally produced from organic waste, is limited however.

Synthetic kerosene, also called electrofuel, is a more promising alternative in the longer run. To obtain such fuels, electricity is used for splitting water into hydrogen and oxygen. Together with carbon dioxide collected from the atmosphere (or another carbon source), the hydrogen is converted to syngas and later, in a Fischer-Tropsch process, to hydrocarbon fuels like jet fuel. The combustion of these synthetic fuels would only emit as much CO_2 as was extracted from the atmosphere in order to produce them (Figure 22). There would remain, however, the climate impact of non-CO_2 emissions such as water vapour at high altitudes. This together with technological and economical scalability are described as being major challenges for synthetic fuels (Jönsson et al., 2019).

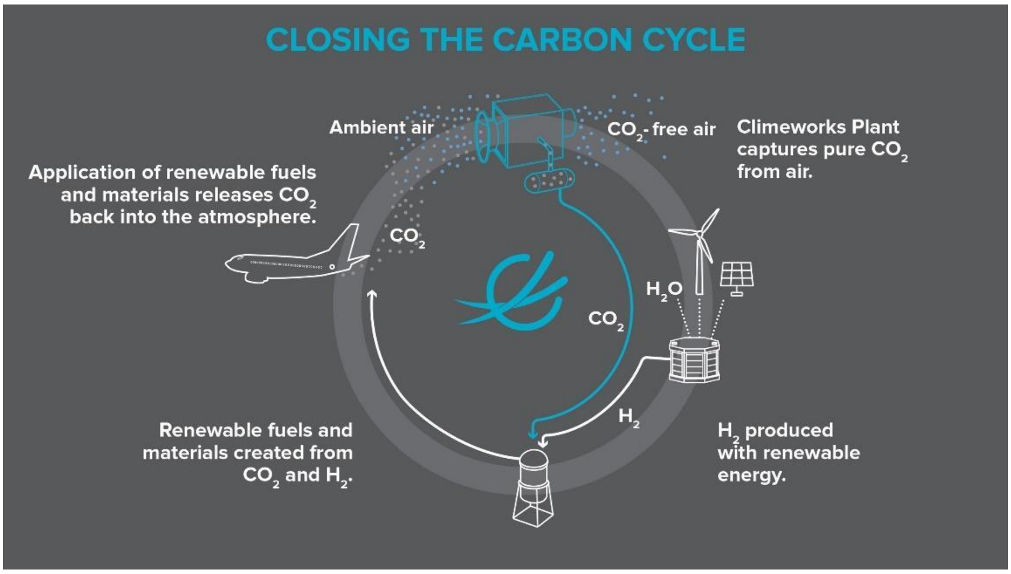

Figure 22: Idealized closed loop for synthetic kerosene production (Climeworks, 2019)

Obviously, a condition for synthetic fuels to be low-carbon fuels is that the electricity used to produce them is derived from renewable or low-carbon electricity that is not replaced by high-carbon generation for the remaining electricity demand. Alternatively, surplus generation from new renewables could be used for the production of synthetic fuels. As for the agrofuels, any policy promoting synthetic fuels will have to be accompanied by stringent certification mechanisms to guarantee sustainability. Promising projects include the partnership between Climeworks and Synhelion, two ETH Zurich spin-offs, which has attracted interest by the Lufthansa Group (Lufthansa Group, 2020).

The cost of synthetic liquid fuels is estimated to be at around 18 cents per kWh in 2022 if produced with electricity generated through solar photovoltaics and onshore wind, while it is 24 cents per kWh if produced with offshore wind in Europe (Agora Energiewende, 2017). This is equivalent to 3.6 and 4.8 times the price of fossil petrol. However, with further decreasing cost of renewable electricity generation, costs could drop down to 13 and 11 cents per kWh respectively by 2050, which would only be 2.6 and 2.2 times the price of fossil petrol (Figure 23).

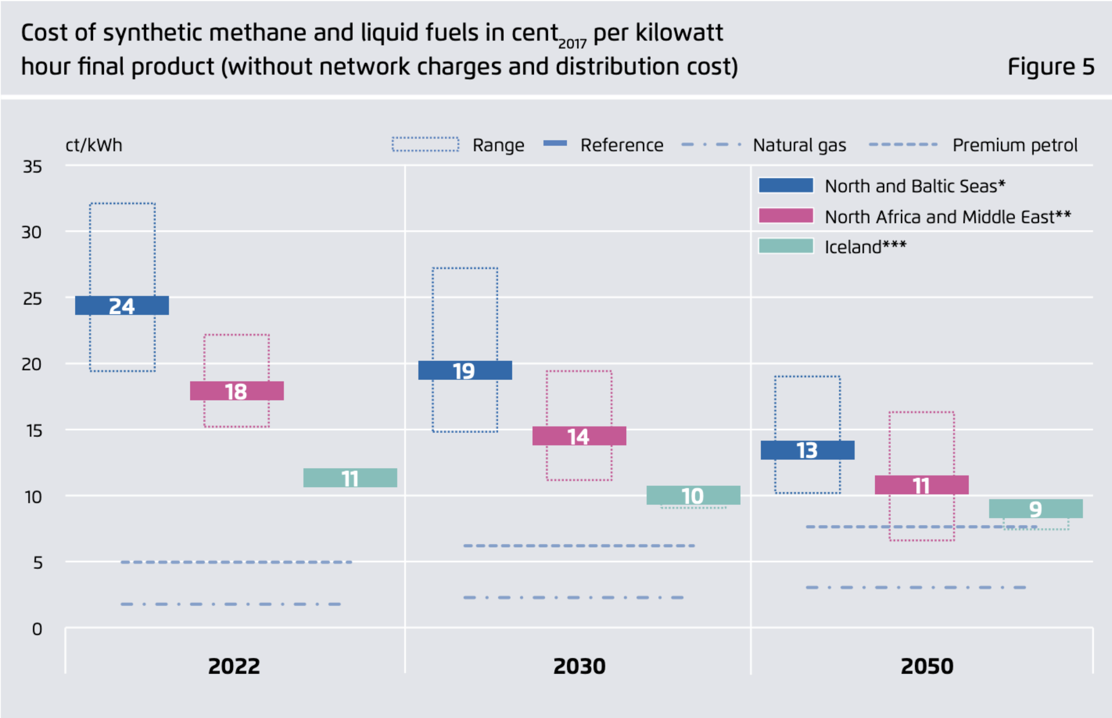

Figure 23: Production costs predictions for synthetic fuels derived from renewable electricity for 2022, 2030 and 2050 (Agora Energiewende, 2017)

While technically feasible, large amounts of renewable electricity generation, as well as water, are required if the whole aviation sector shall be powered entirely by synthetic fuels. For the European Union, that would require to use almost the whole EU renewable electricity generation in 2015 only for synthetic fuel production (Figure 24). Consequently, any climate policy focusing on synthetic fuels would need to be accompanied by a strong expansion of renewable energy generation.

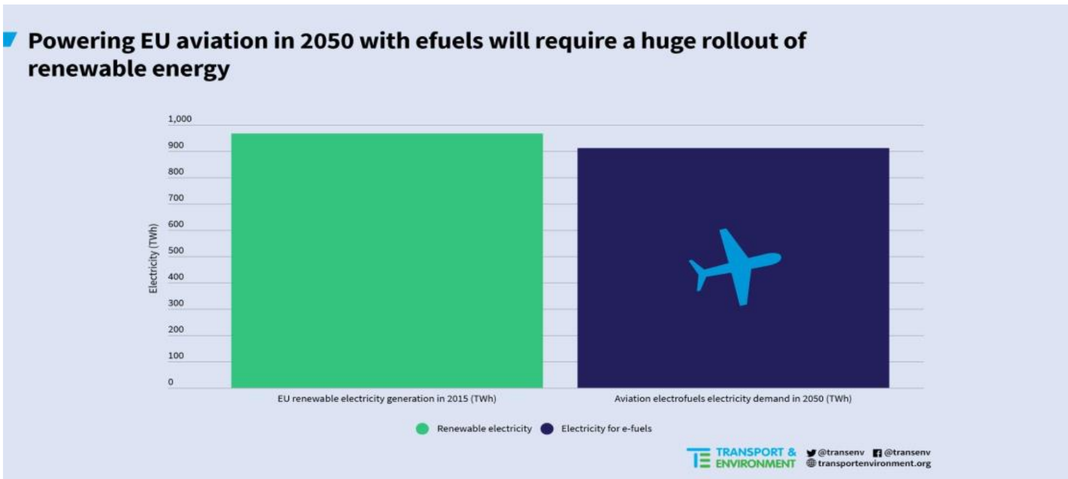

Figure 24: Amount of renewable electricity needed to produce synthetic fuels to power European aviation demand (Transport & Environment, 2020)

Nevertheless, contrary to sustainable agrofuels, the worldwide potential for synthetic fuels produced with renewable energy is vast.

It is estimated that there were around 215 electrically-propelled aircraft in development around the world in 2019 (Roland Berger, 2020). However, for large commercial aircraft mainly hybrid propulsion is being considered. Indeed, fully electric propulsion in commercial aviation faces both technological and physical barriers. To start with, the energy content of liquid jet fuels is higher than that of lithium-ion batteries by a factor of 45 at least in terms of mass and at by a factor of 14 at least in terms of volume.[36] Given the current state of technology, it is agreed that an aircraft aiming to perform a standard commercial flight in terms of distance covered and passengers transported would simply be too heavy to take off. Nevertheless, EasyJet, for instance, does plan on offering fully electric flights, thanks to a partnership with Wright Electric. The electric aircraft is expected to cover distances of up to 500km but won't be flown commercially before 2030 (Engineering & Technology, 2020), a "very ambitious" timeline according to some experts (BBC, 2020). However, long-haul flights, responsible for the bulk of emissions, are unlikely to rely on electric propulsion in the foreseeable future. Safety concerns also need to be addressed, given the risk of fire associated with lithium-ion batteries (Clean Energy Institute, 2020). Furthermore, as with trains, it should be noted that electric or hybrid aircraft only make sense if the power utilised stems from clean energy sources. Finally, this technological substitution only makes sense if the full lifecycle greenhouse gas emissions induced by the operation of such aircraft are lower.

Note that solar-powered electric planes, such as the famous Solar Impulse 2 project, do not hold large-scale commercial potential. Essentially, regardless of solar cell technology, the amount of sunlight available at any location is insufficient to supply the required energy for performing a typical commercial flight.[37]

6.5.1 VOLUNTARY APPROACHES

Offsetting

The possibility to offset carbon emissions on a voluntary basis (e.g. via myclimate or South Pole) by passengers or by airlines is relatively popular, However, it accounts for only a very small share of emissions and it rarely calculates the full impact of aviation (three times the CO_2 emissions, see section 2.1). Furthermore, it is not sustainable in the long run, as all sources of greenhouse gas emissions need to decline to near zero, including those from aviation.

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[36] The specific energy (i.e. expressed in terms of mass) of kerosene is around 43 MJ/kg, whereas its energy density (i.e. expressed in terms of volume) is close to 35 MJ/L, given that a litre of kerosene weighs approximately 0.8 kg. These figures correspond to 11'944 Wh/kg and 9'722 Wh/L respectively. In comparison, a lithium-ion (Li-ion) battery holds 100-265 Wh/kg and 250-670 Wh/L (Clean Energy Institute, 2020).

[37] On average, the radiant energy emitted by the sun during an hour arriving at the top of the atmosphere is 1'361 Wh/m2 (Coddington et al., 2016). Considering that an A320 has around (100m2 wings + 138m2 fuselage, top third; Airbus, 2020) 250m2 of horizontal top surface, the energy captured would be around 0.3mWh. In comparison, the same aircraft flying from Paris CDG to London LGW that lasts around an hour uses the equivalent of 28.9mWh (ICAO, 2016) of fossil energy. Again, increasing the plane's surface would face the obstacles of additional weight and drag.

6.5.2 Quantity measures

Impose a minimum share of low-carbon drop-in fuels

Setting a cap on the carbon content of airplane fuels would leave companies the choice of the most cost-efficient options. More constraining is a minimum share of a specific low-carbon fuel or compulsory blending share. An ETH Zurich professor, for instance, recommends imposing a minimum share of synthetic kerosene, starting at 1% in the immediate future, and progressively increasing the legal lower bound thereafter, so as to see production capacity grow by 20% per year and achieve 100% sustainable kerosene by 2050 (Patt, 2019). Specifying which low-carbon fuel is to be adopted would send a clear message to investors, who currently fear that increased production capacity would not translate into increased sales given the higher price of low-carbon fuels relative to conventional kerosene. The growth in production would drive down production costs through technological learning.

Quotas can be put in place by national governments today but would have an even higher impact if they were put in place in cooperation with the European Union, given that the vast majority of air traffic is international, not domestic. Norway has been among the first countries to institute such a requirement, with a 0.5% minimum share for advanced agrofuels in place since January 2020. Agrofuels derived from problematic feedstocks such as palm oil are ineligible. At the time of writing, only five airports have regular agrofuel distribution (Bergen, Brisbane, Los Angeles, Oslo and Stockholm). The European Commission is currently discussing synthetic fuel quotas as part of its hydrogen strategy. The German Minister for the Environment recently proposed a goal of 2 % synthetic fuels by 2030.

Rather than implementing minimum blending shares applied directly at the flight or airline level, Sheelhaase et al. (2019) recommend the use of green certificates. By letting airlines trade their obligations to use a given amount of low-carbon fuels, the additional cost of their use is separated from their actual use. Such a system would help overcome logistical issues, as it would be easier to supply all the available low-carbon fuels to a few airports only.

6.5.3 Price measures

Enhance fiscal incentives for fleet renewal

Airlines based in Switzerland (in particular Swiss International Airlines and EasyJet) have been investing in new, more fuel-efficient aircrafts that will reduce their emissions per passenger-kilometre. Airlines will continue to invest in newer, more fuel-efficient aircrafts, since this helps reduce their fuel costs. The Swiss government could consider enhancing fiscal incentives (for example, allowing accelerated depreciation) to encourage them to do this faster. It remains to be seen if this strategy makes sense from a lifecycle perspective, as the gains in fuel efficiency over the aircraft's lifetime could be (over-)compensated by the emissions generated during its construction.

Furthermore, these new aircrafts are usually larger, which tends to offset their greater efficiency, so it is not clear that this is a net positive from the perspective of reducing total emissions.

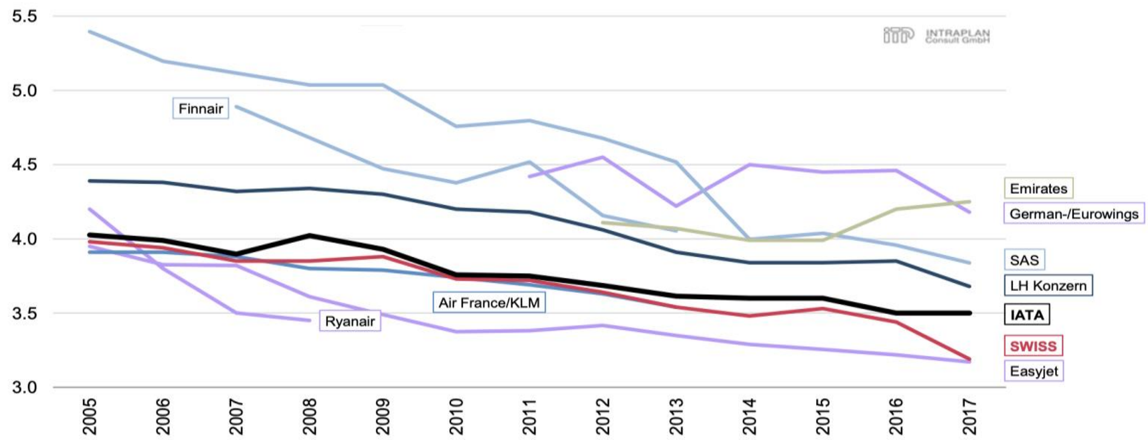

Figure 25: Fuel efficiency of different airlines operating in Switzerland in litre per 100 pkm (Intraplan Consult, 2018)

Temporarily subsidize low-carbon fuels

In a recent resolution, ICAO members stated that they recognize "that the technological feasibility of drop-in sustainable aviation fuels is proven and that the introduction of appropriate policies and incentives to create a long-term market perspective is required" (ICAO, 2019c). Indeed, since low-carbon fuels are more expensive than kerosene (Figure 26), direct subsidies to increase their competitiveness may be needed for companies to adopt them on a voluntary basis. Although airplane fuels per se should not be subsidized in a market economy, compensating subsidies for "clean" alternatives can be justified until the "dirty" alternative can be made to cover all its external costs, with a view to levelling the "playing field". The more efficient solution would be, of course, for the kerosene price to reflect all of its external costs. Fiscal incentives for low-carbon fuels could then be provided as exemptions from a kerosene tax or carbon tax on kerosene that would have to be introduced first (Sect. 6.3.4).

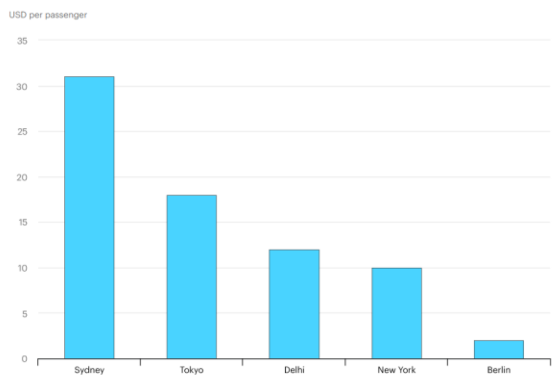

Figure 26: Cost premium of a 15% blend of commercial aviation agrofuels per passenger from London to selected cities (IEA, 2019a)

6.5.4 OTHER MEASURES

Support R&D for revolutionary aircraft propulsion systems and designs

In addition to switching to alternative fuels, aircraft fuel efficiency needs to be increased considerably each year. However, evolutionary technologies will not be enough to keep a similar CO_2 emissions reduction rate as today, which makes it necessary to develop revolutionary technologies in the long-term (IATA, 2019a)

By supporting aviation R&D, future technology options such as hybrid-electric propulsion systems and blended wing body designs (Figure 27) might be enabled, which could drastically improve fuel efficiency with up to 40 % when combined, according to Airbus. This would mitigate the challenge of producing large amounts of synthetic fuel with renewable electricity but faces a number of other important limits as discussed above.

Figure 27: MAVERIC, the airbus blended wing aircraft demonstrator could reduce fuel burn by 20 % on its own (Photo: Airbus)

Consider co-investing in agrofuel and synthetic fuel manufacturing facilities

A key challenge in the initial stages of the switch to agrofuel and synthetic fuels for aviation will be the lack of production capacity. Producers may be unwilling to put additional capacity in place given the uncertainty around levels of demand. This may require governments to step in and shoulder some of the investment risk in the initial stage by co-investing in production facilities.

6.6 Conclusions concerning additional measures to reduce the climate impact of aviation

The proposed ticket tax would be a step toward Swiss climate goals, but is not sufficient to offset long-term *growth* trends, let alone push down absolute emissions. Therefore, additional measures would be necessary. This chapter provided a landscape view of such potential additional measures.

Relatively quick implementation and impact could be achieved through the following options:

- Night and high-speed trains are a promising alternative to air travel for the busiest destinations such as London, Berlin and Amsterdam. Multiple means to achieve this, including outright bans on short-haul flights, subsidies, and the development of the railroad offer, could support shifts in mode of transport.
- Establishing social norms through limiting advertising and good role models can prove successful directly through decreased demand and social acceptance of other policies
- Policies to increase passenger loads through, for example, disincentives or bans on business seats in short- and medium-haul flights, and progressive fines on airlines for lower capacity flights.

In the medium- and long-term, a greater use of synthetic fuels will be necessary if the airline industry is to get close to carbon neutrality without the use of offsets. Given the scales required, synthetics are likely a better longer-term bet than bio-fuels. Legal incentives could be established quickly – such as drop-in requirements, subsidies on R&D, and offsets for first-mover disadvantages. Early legislative signalling to industry would be useful; and scaling up of production would be required.

In the longer-term, major technological shifts, such as battery-powered aircraft for short-haul flights are conceivable. While R&D in battery technology is growing rapidly, even the fastest-case scenario of retrofitting existing planes with battery-power, this is at best a longer-term solution.

7 Conclusion

When including the non-CO_2 effects from aircraft emissions, aviation is the economic sector with the largest contribution to the global warming impact of Swiss domestic greenhouse gas emissions. While all other sectors are reducing their climate impact, no improvement was observed in aviation before the COVID-19 pandemic. Without any additional climate policy, the number of flights departing from Switzerland is expected to grow by 2.1% and passenger demand by 3.2% per year until 2030. Even under an optimistic scenario with a 2.5% annual growth in passenger demand and a 1.5% annual improvement in aircraft fuel consumption, the global warming potential of Swiss aviation is expected to grow by 36% until 2050. Hence, the curtailment of air passenger growth is a crucial part of climate policy to reach carbon-neutrality by 2050. Policy tools for demand curtailment include an air ticket tax, a frequent flyer tax, fuel taxes, tradable individual flight quotas as well as softer policies based on voluntary approaches.

The frequency of air travel is strongly dependent on income (FSO and ARE, 2017). On average, Swiss citizens living in households with an income below CHF 4,000 per month only take 0.3 flights per year. On the other hand, Swiss citizens living in high-income households with earnings exceeding CHF 12,000 per month take 1.7 flights per year, which is 5.7 times the travel frequency of the lowest income class. Consequently, air ticket taxes with per-capita revenue redistribution lead to financial benefits for low-income households. As 77% of Swiss air passengers travel to European countries, a modal shift to night- and high-speed trains is a viable alternative to air travel where such rail infrastructure exists.

To determine the impact of air ticket taxes, a literature review of national price elasticities of demand was performed. Considerably lower elasticity values were found for premium than economy class travel. Slightly lower values were also found for long-haul than for short-haul flights. Elasticity estimates for short-haul economy class demand were found to be around 1.2, and slightly lower at 1 for long-haul economy flights. For the premium class, the elasticity estimates were found to be substantially lower: 0.5 for short-haul and 0.25 for long-haul flights.

For the scope of this white paper, it was assumed that short-haul economy tickets would be taxed with CHF 30 and premium tickets with CHF 60. Long-haul economy tickets would be taxed with CHF 90 and premium tickets with the maximum rate of CHF 120. As a result of these taxation rates, passenger demand could be reduced by up to 21% and CO_2 emissions by 16% relative to a baseline without air ticket tax. In order to provide a more thorough assessment, we simulated further air ticket tax schedules: a schedule that has the tax rise by 4.7% every year until 2050, a schedule equivalent to the UK Air Passenger Duty of 2021, and a schedule that charges CHF 74 per ton CO_2eq of flight-related climate impact. These schedules differ in some respects but end up affecting passenger numbers and emissions in relatively similar magnitudes.

Future research should focus on estimating the supply curve of Swiss air tickets, as well as providing updated elasticity estimates for Swiss air travel demand differentiated by household income. Finally, a better understanding of air ticket pricing mechanisms should be established, in order to consider the internal pricing strategies of airlines aiming to moderate passenger demand reductions.

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Appendix: Terminology

Business flight	Plane trip performed for professional reasons, within the context of work.
Charter flight	Non-scheduled air route, typically a flight bought by a tour operator and included in a holiday package.
Flight	Journey by plane.
General aviation	Civil aviation other than commercial air transport or aerial work operation. Or all private and commercial flights other than scheduled flights and charter flights.
Great circle distance (GCD)	The shortest distance between two points on the surface of a sphere, measured along the surface of the sphere, as opposed to a straight line through the sphere's interior.
Local passenger	Passenger departing from a Swiss airport who is neither in transfer nor transit.
Long-haul flight	Commonly defined as a flight of more than 4,500 km or more than 6 hours, but these limits vary. For the Swiss air ticket tax, a long-haul destination lies east of the Ural, south of the Mediterranean border countries or beyond the Atlantic. For our simulations, it is defined as a flight from a Swiss airport to any destination outside of Europe.
Passenger	Person who uses a given mode of transport to travel.
Passenger-kilometre (pkm)	Unit of measurement corresponding to the transport of one passenger over one kilometre. For a given flight, this implies [pkm] = [number of passengers on flight] * [flight distance in km]. Closely related to revenue passenger kilometre (RPK).
Personal flight	Plane trip performed for personal reasons, such as a leisure, visiting relatives, etc.
Radiative Forcing Index	Multiplier applied to the CO_2 emissions of aircrafts to account for the net warming effect of all emissions from kerosene combustion at high altitude.
Resident local passenger	Local passenger whose place of residence is in Switzerland.
Route	Given combination of departure and arrival locations. E.g. Paris-London route.
Scheduled flight	Commercial flight with a regular and frequent pattern to transport goods or passengers.

Short-haul flight	Commonly defined as a flight of less than 1,500 km or less than 3 hours, but these limits vary. For the Swiss air ticket tax, a short-haul destination is in Europe except for some destinations on the edge of Europe considered as medium-haul. For our simulations, it is defined as a flight from a Swiss airport to any destination in Europe.
Short-long-haul flight	Long-haul flight with a transfer after a short-haul flight. For our simulations, it is defined as a flight from a Swiss airport to any destination in Europe, but with a final destination located outside of Europe.
Transfer passenger	Passenger who has not arrived at her/his final destination and changes aircraft at the airport under consideration within 24 hours. This type of passenger is counted twice in general passenger statistics, once at arrival, once at departure.
Transit passenger	Like a transfer passenger, except that he/she departs again with the same flight number (usually the same airplane).

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About E4S

Enterprise for Society (E4S) is a joint venture of the University of Lausanne through HEC Lausanne, IMD and EPFL, under the stewardship of its College of Management of Technology, with the mission of spearheading the transition towards a more resilient, sustainable, and inclusive economy. E4S is dedicated to train the next generation of leaders, inspire economic and social transformation, and activate change by strengthening start-ups and boosting innovation.

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