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Citation for the original published paper (version of record):
Larsson, J., Elofsson, A., Sterner, T. et al (2019). International and national climate policies for aviation: a review. Climate Policy, 19(6): 787-799.
http://dx.doi.org/10.1080/14693062.2018.1562871

Climate Policy

ISSN: 1469-3062 (Print) 1752-7457 (Online) Journal homepage: https://www.tandfonline.com/loi/tcpo20

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To cite this article: Jörgen Larsson, Anna Elofsson, Thomas Sterner & Jonas Åkerman (2019) International and national climate policies for aviation: a review, Climate Policy, 19:6, 787-799, DOI: 10.1080/14693062.2018.1562871

To link to this article: https://doi.org/10.1080/14693062.2018.1562871

Published online: 11 Jan 2019.

CLIMATE POLICY
2019, VOL. 19, NO. 6, 787–799
https://doi.org/10.1080/14693062.2018.1562871

Taylor & Francis
Taylor & Francis Group

SYNTHESIS ARTICLE

International and national climate policies for aviation: a review

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ABSTRACT

Aviation constitutes about 2.5% of all energy-related CO_2 emissions and in addition there are non-CO_2 effects. In 2016, the ICAO decided to implement a Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and in 2017 the EU decided on faster emission reductions in its Emissions Trading System (EU ETS), which since 2012 includes the aviation sector. The effects of these policies on the expected development of air travel emissions from 2017 to 2030 have been analyzed. For the sample country Sweden, the analysis shows that when emissions reductions in other sectors are attributed to the aviation sector as a result of the EU ETS and CORSIA, carbon emissions are expected to reduce by −0.8% per year (however if non-CO_2 emissions are included in the analysis, then emissions will increase). This is much less than what is needed to achieve the 2°C target. Our analysis of potential national aviation policy instruments shows that there are legally feasible options that could mitigate emissions in addition to the EU ETS and CORSIA. Distance-based air passenger taxes are common among EU Member States and through increased ticket prices these taxes can reduce demand for air travel and thus reduce emissions. Tax on jet fuel is an option for domestic aviation and for international aviation if bilateral agreements are concluded. A quota obligation for biofuels is a third option.

Key policy insights

- Existing international climate policies for aviation will not deliver any major emission reductions.
- Policymakers who want to significantly push the aviation sector to contribute to meeting the 2°C target need to work towards putting in place tougher international policy instruments in the long term, and simultaneously implement temporary national policy instruments in the near-term.
- Distance-based air passenger taxes, carbon taxes on jet fuel and quota obligations for biofuels are available national policy options; if they are gradually increased, and harmonized with other countries, they can help to significantly reduce emissions.

ARTICLE HISTORY
Received 8 August 2018
Accepted 13 December 2018

KEYWORDS
Aviation emissions; biofuels; carbon credits; carbon tax; policy instruments

1. Introduction

To achieve the 2°C target under the 2015 Paris Agreement, climate polices are needed in basically all sectors in all countries. Global civil aviation accounts for 2.5% of all energy-related CO_2 emissions (IATA, 2017). In addition to this, there are non-CO_2-effects from civil aviation, principally emissions of nitrogen oxides, contrails, and aviation-induced cirrus clouds. These effects are estimated to be almost as significant as aviation's CO_2 emissions themselves in terms of their 100 year global warming potential (GWP) (Azar & Johansson, 2012; Lee et al.,

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2010). There is uncertainty about exactly how large these non-CO_2-effects are, but when best scientific estimates are used, total greenhouse gas (GHG) emissions from aviation amount to about 4–5% of total global emissions (Lee et al., 2010). GHG emissions from aviation typically constitute a larger share of total GHG emissions in high-income countries. One study found that the GHG emissions from Swedish residents' air travel across the globe is on a par with emissions from private automobiles in Sweden (Larsson, Kamb, Nässén, & Åkerman, 2018).

Mitigation strategies for the aviation sector include (1) technological improvements, (2) use of low carbon fuels (including biofuels), (3) optimized air traffic management for minimizing aviation's CO_2 and non-CO_2-effects, and (4) reduced air travel volumes compared to business-as-usual. Since 2012, CO_2 emissions from flights with both take-off and landing points within the EU[1] have been included in the EU Emissions Trading System (EU ETS) (European Commission, 2014). In 2016, the International Civil Aviation Organization (ICAO), a UN body, made the decision to implement a Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) with the aim of achieving 'carbon neutral growth' from 2020 (ICAO, 2016a). In addition to this, some countries have implemented national climate policies for aviation, e.g. air passenger taxes in several European countries.

A great deal of information has been gathered about climate policies in general (e.g. carbon taxes) and there has been some research into individual policies for the aviation sector, but a comprehensive analysis of international and national climate policies for aviation is lacking. The aim of this paper is to provide such an analysis, and in doing so, to provide decision support for policy-makers at the national and international levels who are concerned about rising GHG emissions from aviation. This paper aims to clarify two questions. What is the expected effect of current and planned international policies (EU ETS and CORSIA) regarding reductions in carbon emissions from aviation up to 2030, and how does this relate to the 2°C target? Are there legally feasible policy instruments that can be decided nationally and that would result in additional emissions reductions from both domestic and international air travel? This analysis, which is both qualitative and quantitative, is based on policy papers from the relevant organizations (mainly the EU and ICAO) as well as on a literature review of academic journal publications.

2. International aviation climate policies

The preferred choice for regulating international activities like aviation is international policy instruments, of which a global carbon tax on jet fuel would probably be the most efficient. However, jet fuel for international aviation is exempt from taxes. The Chicago Convention on International Civil Aviation from 1944 is often incorrectly stated as generally forbidding the taxation of jet fuel, but in fact it only prohibits taxing the fuel in the tanks of arriving aircraft. However, a resolution from ICAO (1993) states that '… the fuel, lubricants and other consumable technical supplies taken on board for consumption during the flight shall be furnished exempt from all customs and other duties …'. This can theoretically be changed but there is no support for this among most of the member states, and ICAO has instead taken a decision to implement a global scheme for carbon offsetting (CORSIA).

The EU ETS started in 2005 and aims to achieve overall emissions reductions in a cost-effective manner by using tradeable emissions allowances as a mechanism to steer emissions reductions to sectors and businesses where they can be implemented at the lowest cost. The system covers over 12,000 energy and manufacturing plants in the EU. Since 2012, parts of the aviation sector are included in the EU ETS, which means that airlines affected must have emission allowances covering their annual emissions. The aviation part of the EU ETS covers flights where both take-off and landing are within the EU. Initially, the EU planned to include all flights even if the take-off or landing point was outside the EU (this is referred to as full-scope). But after protests from mainly the United States and China, the system was modified to a 'reduced scope' (Evans, 2016). This 'stop-the-clock' approach is temporary and if no new decision is made, 'full scope' will start in 2024. The allowances specifically for airlines are called European Union Aviation Allowances (EUAA). If airlines need additional allowances, they can purchase 'regular' European Union Allowances (EUA). The allowances issued for 2013–2020 correspond to 95% of the emissions of 2008–2012. From 2021 onwards, there is to be a linear annual reduction until 2064, when no additional EUAA allowances will be issued (the last EUA will be issued in 2057) (EU, 2017).

The possibility of applying the 'full scope' of the EU ETS has put pressure on ICAO, and in 2016 a decision was made by its 192 countries[2] to introduce CORSIA, which aims to facilitate 'carbon neutral growth' for international aviation from 2020 (ICAO, 2016b; Scheelhaase, Maertens, Grimme, & Jung, 2018). The agreement under this scheme stipulates that airlines are obliged to offset their increase in emissions after 2020 by purchasing credits from emissions mitigation projects outside the aviation sector. Between 2020 and 2027[3] the system is voluntary, but after that it becomes mandatory for all countries (ICAO, 2018; ICCT, 2017). There are several exemptions. For example, countries whose share of global air traffic (Revenue Tonne Kilometres or RTK, which is sold capacity multiplied by distance) is less than 0.5% are exempt; and Least Developed Countries (LDCs), Small Island Developing States (SIDS) and Landlocked Developing Countries (LLDCs) are also exempt. The European Commission (2017) has estimated that 80% of the increase in emissions will be covered by CORSIA, while another estimate is 73% (ICCT, 2017). This leaves a major gap in relation to the goal of achieving carbon-neutral growth. When looking at both domestic and international flights, and at total emissions, not just the increase, it has been estimated that 12% of aviation emissions will be offset due to CORSIA in 2030 (Scheelhaase et al., 2018).

It should be noted that it is unprecedented for almost all the world's nations to have agreed to implement a global policy instrument that will entail out-of-pocket expenses for companies. On the other hand, CORSIA has a major shortcoming since it will not achieve absolute emissions reductions. Also, neither the EU ETS nor CORSIA covers the non-CO_2-effects of aviation. Another criticism is that it will not reduce emissions at their source, only through carbon offsetting around which there are many uncertainties (see Section 3.2). There is also a risk that it will weaken national climate ambitions in developing countries. The basis of the Paris Agreement is that nations make commitments through what are termed nationally determined contributions (NDCs). The CORSIA document stipulates that 'double counting' must be avoided (ICAO, 2016b), e.g. that the emissions credits from a wind farm in India cannot be sold to an airline and also counted as a contribution from India. However, it might be tempting for countries to sell credits to airlines instead of using emissions reductions to achieve their own NDC since the former provides additional income. On the other hand, the increased demand for carbon credits in developing countries caused by CORSIA may contribute to some degree by keeping up interest in the climate issue in those countries until more effective global measures can be implemented.

An important issue is whether CORSIA will be applied for intra-EU flights despite the fact that the more ambitious EU ETS is already applied to these flights. There are no exceptions for intra-EU flights either in the decisions by ICAO (2016b) or the EU (2017). However, airlines argue that it is unreasonable that they should have to pay for carbon credits under CORSIA, since they have already surrendered carbon allowances under the EU ETS for the same emissions. The first payment under CORSIA is due in 2025 and to date it remains unclear how intra-EU flights will be handled (Sjöberg, 2018). Several options exist and the best one, according to Scheelhaase et al. (2018), is to keep aviation in the EU ETS for intra-EU flights (termed 'reduced scope') and for CORSIA to cover flights from the EU to non-EU destinations. This is what we assume in the analysis below.

In order to assess the need for national aviation policies, it is relevant to look at what these international policies mean for a specific country. Table 1 shows an analysis of what effects CORSIA and the EU ETS will have on GHG emission levels from air travel by 2030. An adequate accounting system for emissions from air travel is important for decision-makers assessing the need for new instruments. The existing voluntary reporting system for international aviation is problematic since it allocates very large shares of emissions to countries with major transit hubs and very little to other countries. To avoid this problem, a residency-based approach has been developed. So far, this has only been applied to Sweden (Larsson et al., 2018). Therefore, Sweden

Table 1. Forecast for carbon emissions from Swedish residents' air travel in relation to international policies, in Mt CO_2.

	A Emissions 2017	B Forecast 2030 Direct emissions	C Emissions reductions in other sectors	D Forecast 2030 Net emissions (B minus C)
Flights within the EU (including domestic)	3.2	3.7	−1.3 (EU ETS)	2.5
Flights to destinations outside the EU	2.3	2.7	−0.3 (CORSIA)	2.5
Total	5.5	6.5	−1.6	4.9

has been chosen as an example based on access to data. However, the structure of the analysis is relevant for all EU Member States. The columns in Table 1 can be described as follows:

A. The baseline for Sweden is the carbon emissions from all air travel anywhere in the world by Swedish residents in 2017, which has been estimated at 5.5 Mt of CO_2 (Kamb & Larsson, 2018; Larsson et al., 2018).
B. The forecast for direct emissions is based on the passenger volume increase minus the decrease in emissions per passenger kilometre. The forecast for passenger volume increase is 3.3% per year and it is based on the average of a forecast to 2024 by the Swedish Transport Agency (2018) and a forecast to 2040 by the Swedish Transport Administration (2016). The assumption regarding emissions per passenger kilometre is that the historical rate will continue, i.e. −1.9% per year (where about half is due to higher passenger load factors) (Larsson et al., 2018).
C. Emission reductions on top of 1.9% per passenger-km (see B above) is not assumed to be achieved in the aviation sector since the abatement cost is expected to be lower in other sectors, e.g. the power sector (Cui, Wei, Yu, & Li, 2016; Vespermann & Wald, 2011). In column C the emissions reductions in other sectors, which are attributed to the aviation sector as a result of purchases of carbon credits, are estimated. EU ETS: The quantity of allowances issued for the aviation sector will be reduced by 22% between 2017 and 2030 (EU, 2017). In addition, airlines will need allowances for their projected emissions increases between 2017 and 2030 of 0.5 Mt.[4] CORSIA: Here it is assumed that 80% of the emissions increase between 2021 and 2030 will be offset through CORSIA (European Commission, 2017).

The forecast above indicates that the direct carbon emissions from aviation caused by Swedish residents' air travel will increase by about 1.3% per year between 2017 and 2030. When emissions reductions in other sectors are attributed to the aviation sector as a result of the EU ETS and CORSIA, carbon emissions are expected to reduce by −0.8% per year (if non-CO_2 emissions are included in the analysis, then emissions will increase). However, at least minus 2% per year is needed in order to have a decent chance of meeting the 2°C target (UNEP, 2017).

In theory, one option could be that new international aviation policies are put in place before 2030. However, this is unlikely. The only new international policy instrument in the pipeline is a CO_2 emissions standard for new aircraft (ICAO, 2016a). It can be described as a performance standard with a maximum emissions level for all new aircraft sold. The emissions reductions that are being negotiated in new emissions standards are quite modest and will likely not contribute any emissions reductions on top of what can be anticipated from incremental efficiency improvements.

3. National aviation climate policy options

For the sample country of Sweden, the previous section has shown that the direct carbon emissions from aviation caused by Swedish residents' global air travel will increase substantially in the future. However, when emissions reductions in other sectors are attributed to the aviation sector, due to the EU ETS and CORSIA, then carbon emissions are expected to be reduced by 0.8% per year.

International climate policies have many advantages in comparison with national aviation policies. Emission reductions can be achieved at lower costs if the economic policy instrument covers many countries and many sectors, because then the reductions can be made where the cost is the lowest. Another advantage is that the risk of avoidance strategies by airlines or consumers based on policy differences between countries would be minimized. However, to increase the chance of meeting the 2°C target, national aviation policies could be considered. National policies can be easier to implement than international policies, and they can also inspire stronger international policies in the future. National policy instruments could be viewed as 'temporary' and should be discontinued if more efficient, and sufficiently powerful, international policy instruments are implemented.

In this section, different aviation policies that can be decided at the national level are analyzed. Based on how urgent it is to limit GHG emissions, the focus is on policy instruments that can be implemented, and lead to emission reductions, in the near term. The selected policy instruments are a tax on jet fuel, a distance-based air passenger tax, and a quota obligation for biofuels. Policies that are not feasible with regard to current international agreements, such as carbon-related landing charges and per-plane taxes, are only briefly described. Policies that would lead to emissions reductions in the longer term, such as policies for accelerating technological innovation, are not included in the analysis. Some unorthodox policy ideas are also excluded from the analysis. Examples are a 'frequent flyer levy' whereby the tax level would increase for every additional flight a person takes per year (www.afreeride.org), refunding emissions payments schemes where taxes would be redistributed to all citizens on an equal basis (www.citizensclimatelobby.org), and tradeable personal carbon allowances which are a form of individualized cap-and-trade policy (Jagers, Löfgren, & Stripple, 2010). These policies are still immature and the latter two have not even been proposed for air travel specifically. However, we find these policies interesting, and worthy of development and analysis, in terms of practical design, emissions control systems, efficiency, integrity, etc. Nonetheless, in this paper we excluded them, since they are not sufficiently developed for implementation in the near term. The focus is thus on the following taxes and regulations.

Tax on jet fuel

Almost all countries have taxes on fossil fuels for road transport and this is an effective instrument for decreasing emissions as well as financing the public sector (Sterner & Coria, 2011). Few countries have a tax on jet fuel: Norway and Japan are two exceptions (Cairns & Newson, 2006; González & Hosoda, 2016; Norway, 2016).

Distance based air passenger tax

An alternative to using fuel as the tax base is to tax tickets. The UK was an early adopter and implemented an Air Passenger Duty in 1994. Today, many countries have implemented similar taxes, including Germany, Sweden, France, Norway, Austria and South Africa (Faber & Huigen, 2018). These taxes are for both domestic and international air traffic, and the rates are usually differentiated based on distance.

Quota obligation for biofuels

For the road sector, many countries in the EU have biofuel quota obligations, sometimes called a biofuel mandate, in order to meet the EU target that 10% of fuels for road transport must be renewable by 2020 (Energimyndigheten, 2014; European Commission, 2018). These instruments are designed to ensure that fuel suppliers for road transport have to sell an increasing proportion of low carbon fuels. More refined systems involving fuel carbon-intensity standards, accounting for differences in performance based on the resources base, and production method, are an alternative used by Germany (Res Legal, 2018) and California (Yeh, Witcover, Lade, & Sperling, 2016). Biofuel quota obligations for aviation will be implemented in Norway starting in 2020 (Norwegian Environment Agency, 2018a).

The policy options described above are analyzed in terms of their legal feasibility and environmental benefits. The starting point is an analysis of whether the policy instrument is legally feasible under ICAO conventions and EU regulations. The next step is to assess its environmental benefits. First, we examine whether the different national policy options would contribute additional reductions on top of what the EU ETS and CORSIA can deliver. After that each policy is briefly described in terms of whether it gives incentives for emissions reductions for airlines and/or for consumers (Table 2).

Table 2. Assessment of national aviation climate policies.

	Legal feasibility for		Additionality in relation to the EU ETS and CORSIA	Incentives for emissions reductions for	
	Domestic flights	International flights		Airlines	Consumers
Tax on jet fuel	✓	Only with bilateral agreements	✓	✓	✓
Distance-based air passenger tax	✓	✓	✓	–	✓
Quota obligation for biofuels	✓	✓	✓	✓	✓

3.1. Legal feasibility

Regarding legal feasibility, it is essential to distinguish between domestic and international aviation. Each country can implement any of the climate policy instruments described above for domestic aviation. However, for international aviation, ICAO conventions and EU regulations impose restrictions.

As described in the previous section, a *tax on jet fuel* for international aviation is not permitted under current international agreements (ICAO, 1993). The EU Energy Tax Directive also prohibits EU Member States from imposing a general tax on jet fuel for all international aviation (2003/96/EC, Article 14.1). These regulations have not only hindered a tax on jet fuel but even 'next best' options, such as per-plane taxes and carbon-related landing charges. The UK Government announced in 2010 that it wanted to replace the per-passenger tax with a per-plane tax based on the weight of the aircraft, which would give airlines stronger incentives to fly with full aircraft. But in 2011, the UK Minister of Finance announced; 'We have tried every possible option, but have reluctantly had to accept that all are currently illegal under international law', this has however not been challenged in court of law (Faber & Huigin, 2018).

Despite the description above, it is possible to introduce a tax on jet fuel for international flights between two, or more, countries. The EU Energy Tax Directive (2003/96/EC, Article 14.2) allows taxation for flights between two countries if this is agreed upon in their bilateral Aviation Service Agreement, and if the countries have reserved the right to tax jet fuel in relation to the relevant ICAO resolution (1993). By extending these Aviation Service Agreements, a carbon tax on jet fuel could be introduced for a sub-group of European countries or for all EU Member States (Cairns & Newson, 2006; Krenek & Schratzenstaller, 2016). The implementation of a tax on jet fuel might, however, be slow, since these bilateral agreements are dependent on decisions in both countries. In addition, a very large number of agreements would be needed.

Distance-based air passenger taxes are a legally feasible alternative to taxes on jet fuel. There are no restrictions on implementing this tax on international aviation. For countries within the EU however, the taxes must be the same for all flights within the European Union (Faber & Huigen, 2018).

Quota obligation for biofuels for aviation is being implemented in Norway. The restricted parties in policies involving quota obligations are usually the companies selling fuels. From 2020, 0.5% of all fuel sold in Norway must be advanced biofuels (for both domestic and international aviation), with the aim of reaching 30% in 2030 (Norwegian Ministry of Climate and Environment, 2018, p. 172) and a similar scheme is being investigated in Sweden (Swedish Government, 2018). The Norwegian government's analysis is that since this is a regulation of suppliers of jet fuel, and not of airlines, it does not violate bilateral agreements, ICAO resolutions or CORSIA rules (Norwegian Environment Agency, 2018b, p. 37).

3.2. Additionality in relation to the EU ETS and CORSIA

After identifying several legally feasible policy options, the next step is to investigate their environmental benefits. The first aspect of this is whether these policies will result in lower global GHG emissions compared to a country relying on the EU ETS and CORSIA alone. Our analysis reveals that national climate policies for aviation can decrease global emissions, for several reasons.

In contrast to CORSIA, national policy instruments can deliver direct emissions reductions in the aviation sector, instead of relying on carbon credits from off-setting projects with questionable additionality. Carbon offsetting has the potential to be economically efficient since mitigation can be implemented in sectors and geographical regions where abatement costs are the lowest. On the other hand, carbon offsetting must be additional, meaning that the reduction would not have happened if there were no investments from offsetting (Hyams & Fawcett, 2013). Critics argue that the bulk of offsetting projects would have occurred regardless of investments stemming from offsetting (Anderson & Bernauer, 2016). A study commissioned by the European Commission found that 87% of 5,500 evaluated offsetting projects were not additional and were not delivering the CO_2 reductions that they were certified for (Cames et al., 2016). Since carbon offsetting can thus be expected to have an efficiency well below 100%, national policy instruments may be added to achieve significant emission reductions.

Regarding the EU ETS, the recently decided annulment scheme within the trading system gives some additionality to national initiatives. Previously, this scheme was organized in such a way that decreased aviation emissions would allow increased emissions in other sectors, thus not resulting in net absolute emissions reductions. This has partly changed due to a new annulment mechanism (European Council, 2018).[5] The mechanism means that if national policy instruments for aviation lead to lower carbon emissions, then larger quantities of EU ETS allowances can be annulled. Emission reductions through national policy instruments might also improve the chances that the EU ETS will survive politically by reducing the risk that very high prices for carbon allowances would cause protests by industry and consumers. Efficient national policy instruments can also increase the chances of an EU-decision implying a higher reduction rate in the EU ETS after 2030.

Finally, neither the EU ETS nor CORSIA covers non-CO_2 emissions. As described in Table 1 direct carbon emissions from aviation will likely continue to increase and consequently non-CO_2 emissions will grow as well. If nationally decided policies like a tax on jet fuel or tickets were to be passed onto consumers, and if this led to a decrease in air travel volumes, then both CO_2 and non-CO_2 emissions would be reduced accordingly.

3.3. Incentives for emission reductions

After assessing legal feasibility and additionality in relation to international policies, each policy is analyzed regarding which mechanisms might be involved in delivering environmental benefits. One mechanism is whether the policy gives airlines incentives for reducing fuel consumption, e.g. through air traffic management or through replacing the fleet with more energy efficient aircraft. Another mechanism functions by incentivizing consumers to, for example, choose other transport modes.

3.3.1. Tax on jet fuel

As mentioned, a tax on jet fuel is legally feasible for domestic aviation which accounts for about 40% of global aviation emissions (IPCC, 1999). For small countries, this percentage is much lower. Less than 10% of the emissions from Swedish residents' air travel are from domestic aviation (Kamb & Larsson, 2018). Consequently, the scope for reducing emissions from a tax on jet fuel is limited. In the long run, a fuel tax for international aviation might be possible, in which case the potential would be greater.

In theory, a carbon tax on fuel is an efficient means of decreasing emissions through price signals to airlines (through higher fuel costs) and/or consumers (through higher ticket prices). A study of the charge on jet fuel for domestic flights in Japan found it to be an effective instrument for reducing emissions (González & Hosoda, 2016). However, similar results could not be found in the analysis of the tax on jet fuel that Australia had between 2012 and 2014 (Markham, Young, Reis, & Higham, 2018). The latter study only analyzed the effect on consumer behaviour and not on airlines. Its conclusion was that the carbon price was far too low to cause any measurable change in consumer behaviour.

3.3.2. Distance-based air passenger tax

An air passenger tax is a way to avoid the legal problems related to taxing jet fuel for international air traffic. However, air passenger taxes do not give airlines any incentives to reduce their emissions and are less effective than a tax on jet fuel (Mayor & Tol, 2007). Instead, they operate by altering the price relationship between air travel and other transport modes, along with other categories of consumption. If the air passenger tax is distance-based, it also incentivizes consumers to choose less remote holiday destinations that require shorter flights.

If a tax is going to influence consumer behaviour, it must be passed on to them through higher ticket prices, and it is claimed that this is usually the case (Cairns & Newson, 2006). However, the study of the Australian jet fuel tax mentioned above (Markham et al., 2018) found that it was unclear whether it was passed on to consumers. The study also found that this might be due to the fact that it was relatively low (the tax was roughly EUR 15 per tonne of CO_2 which is about one tenth of the Swedish carbon tax on road fuels, Åkerman, Larsson, & Elofsson, 2016), and that the price of jet fuel was very volatile.

These factors might be different for passenger taxes. The tax might be higher; the British Air Passenger Duty for flights within Europe is EUR 15 per trip (UK Government, 2018) which is much higher than the Australian jet fuel tax at roughly EUR 2–4 per trip (Surgenor, 2014). A passenger tax is also stable and predictable, which makes it more likely to be fully passed on to the consumer. If the tax is not passed on to the consumer, and is instead borne by the airline, it can still decrease emissions since the business case for each route will be less favourable, resulting in fewer flights per week.

Air passenger taxes reduce demand and their effect depends on the tax level and price elasticity (Macintosh & Wallace, 2009; Sterner & Coria, 2011). The airlines' international cooperation organization IATA commissioned a report that looked into price elasticities based on previous scholarly studies and new econometric estimates (InterVISTAS, 2007). Their results showed a price elasticity of −0.8 as the global average. Price elasticity is lower for business trips and higher for private trips, and lower for longer flights and higher for shorter flights. A study based on marginal price changes for air tickets from the UK to 10 different destinations between 1994 and 2010 described average price elasticities of −0.4 for longer flights, and −0.9 for shorter flights (Seetaram, Song, & Page, 2014).

The UK Air Passenger Duty is the equivalent of EUR 15 for flights under 2,000 miles in economy class, while the tax for flights over 2,000 miles is the equivalent of EUR 88 (UK Government, 2018). The tax levels in Germany, Austria and France are less than half of this. Their relatively low tax levels minimize the risk that passengers will choose to fly from airports in their non-taxing neighbouring countries (Leicester & O'Dea, 2008). In order to achieve more substantial effects however, much higher tax levels than those that exist today are needed. Tax avoidance strategies may then become a problem, but can be minimized if more countries introduce air passenger taxes and if tax levels are harmonized (SOU, 2016:83).

3.3.3. Quota obligation for biofuels

In a situation when a sufficiently high price on GHG emissions is hard to achieve, policy instruments that target specific technological solutions are an alternative. A number of biofuels are approved for up to 50% blends by the standardization body ASTM (www.astm.org). Many airlines have made occasional flights with biofuels and the low carbon scenarios produced by the aviation industry depend heavily on biofuels (IATA, 2009, 2015). The aviation industry in Sweden has committed to achieving 100% biofuels for domestic aviation by 2030, and has a similar vision for all international flights leaving Sweden by 2045 (Swedish Air Transport Society, 2018).

Today, very small volumes of biofuels are produced, and the prices are high. The long-term prices of biofuels are hard to predict. Economies of scale can reduce prices but greater competition for bio-based resources and stricter sustainability criteria could increase prices. Biofuels for the road transport sector is a larger market where the prices are about 80% higher than for fossil fuels when compared minus taxes (Åkerman et al., 2016). Biofuels for the aviation sector can be slightly more expensive to produce than biofuels for the road transport sector. If biofuels were to cost twice as much as fossil fuels in the future, it would imply that using 50% biofuel would increase the costs for airlines by about 20%.[6] General policy instruments, such as the current one that certified biofuels are counted as zero emissions in the EU ETS, would need a much higher carbon cost in order to trigger the introduction of biofuel into the aviation industry. Due to the additional costs, strong policies, such as a quota obligation for low-carbon fuels, would be needed.

However, since the potential volumes of biofuels with good climate performance are limited, biofuels are only one measure among several that will be needed to reduce the climate impact of aviation. Advanced biofuels produced from waste and residues typically score well, with up to 80% lower climate impact than fossil fuels (IATA, 2015). For jet fuel, recent research has also indicated that some biofuels result in lower emissions of particles and thus probably entail a lower non-CO_2 effect (Moore et al., 2017) compared to fossil fuels. But the available volumes of biofuels based on waste and residues are limited, and it has been estimated that within the EU they can cover only about 2.5% of the projected energy demand for land-based transport in 2030 (El Takriti, Pavlenko, & Searle, 2017; Searle & Malins, 2016). What remains is biofuel based on feedstock. When indirect land use changes (ILUC) are included, the total carbon emissions for biofuels based on feedstock in some cases can be even higher than for fossil-based fuels (e.g. Ahlgren & Di Lucia, 2014). A recent study found that the climate impact was higher from biofuels produced from cane, maize, wheat, rapeseed, palm-oil and soybean than from regular gasoline and diesel (Searchinger, Wirsenius, Beringer, & Dumas, 2018). The feasible global supply of bioenergy is also highly uncertain, but has been estimated to lie somewhere in the region of 100–300 EJ by 2050 (Creutzig et al., 2015), which can be compared to the total global consumption of fossil fuels, which in 2015 amounted to 470 EJ (IEA, 2017). Much of the bioenergy potential is based on feedstock, which has questionable climate performance. In addition, there is the issue of biofuel production competing with food production, resulting in higher food prices, which could be problematic in poor countries. Our conclusion is that biofuels can only be part of a solution to the climate issue for aviation.

4. Discussion and conclusion

For the sample country Sweden, our analysis shows that the direct carbon emissions from aviation caused by Swedish residents' air travel across the globe will increase substantially in the future. But when emissions reductions in other sectors are attributed to the aviation sector as a result of the EU ETS and CORSIA, then carbon emissions are expected to fall by up to 0.8% per year. This is much less than what is needed for having a good chance of meeting the 2°C target (UNEP, 2017). Policymakers who want to significantly push the aviation sector to contribute to meeting the 2°C target need to work towards putting in place tougher international policy instruments in the long term, and simultaneously implement temporary national policy instruments in the near term. If this is not done, other sectors such as the road transport sector, will be forced to accept significantly higher reduction levels and policy pressure.

Regarding international policy instruments, there is substantial and valid criticism of CORSIA. One option could be to push for a strengthening of CORSIA (Becken & Mackey, 2017; ICCT, 2017; Scheelhaase et al., 2018; Zanin et al., 2016). An important major improvement to this international framework would be to push for only allowing 'real' off-setting in terms of trustworthy carbon dioxide removal. A key option for achieving negative emissions on a large scale is through Bio-Energy with Carbon Capture and Storage (BECCS). Many scenarios include BECCS as a cost-effective road towards meeting climate targets (Azar et al., 2010; Fuss et al., 2018; Solano Rodriguez, Drummond, & Ekins, 2017). If the airlines were to finance the market introduction of carbon dioxide removal through BECCS for example, it could transform the aviation sector from part of the problem to being part of the solution. Another means of strengthening CORSIA would be to include mandatory off-setting for all aviation emissions, not just the increase after 2020. A further important part of an international aviation climate agenda is to address the sector's non-CO_2 emissions. Climate-optimized air traffic routing, aiming to minimize flying in air space with high humidity which causes non-CO_2 emissions, is an interesting option (Grewe et al., 2017; Niklaß et al., 2017).

In the EU ETS, yearly releases of emission allowances are set to decrease linearly, and no new allowances will be released after 2064 according to current decisions (EU, 2017). This end-point may well trigger substantial increases in the price of emission allowances, which in turn could make more mitigation measures economically viable. A further potential consequence, if the EU ETS and CORSIA are going to continue to co-exist, is that aviation biofuel will be used primarily for intra-European flights.

Under the EU ETS and climate targets in general, strong technological development is needed in parallel with constraining travel volumes. Electric aircraft have been much discussed lately (e.g. The Guardian, 2018), but expectations are often set too high. Currently, the weight of the batteries needed to fuel an aircraft is roughly 30 times higher than the weight of jet fuel, even when taking into consideration the higher efficiency of an electric engine. According to Reimers (2018), if/when battery energy density triples from the present 170 Wh/kg, it might be possible to introduce all-electric aircraft for trips up to 500 km. This segment still only represents less than 5% of all GHG emissions due to air travel. Furthermore, since it typically takes 40–65 years from the start of the development of a new technology until the total fleet is renewed (IPCC, 1999; Schäfer, Evans, Reynolds, & Dray, 2016), all-electric aircraft will play scarcely more than a marginal role in mitigating emissions before 2050.

Hydrogen-fuelled aircraft is another option. These would not have the range limitations of battery-driven electric aircraft and if hydrogen is produced using renewable electricity, carbon emissions could be eliminated. However, emissions of water vapour are more than twice as high (Dincer & Acar, 2016) which necessitates a lowering of the flight altitude to avoid contrail and cirrus cloud formation. Since switching to hydrogen would require a totally renewed aircraft fleet as well as new hydrogen production facilities and a new distribution system, it would take several decades until such a transformation could be complete.

Electrofuels could also be a more sustainable option compared to biofuels made from feedstock. These fuels are produced using electricity, water and captured CO_2. If low-carbon electricity is used, then these fuels could have a very low carbon intensity. Production technology for electrofuels exists, but the costs are currently many times higher than for fossil-based fuels (Brynolf, Taljegard, Grahn, & Hansson, 2017).

Since the radical technological transformations mentioned above will not deliver significant emissions reductions in the near future and strong global agreements on pricing measures seem exceptionally hard to achieve, there is a need for more immediate action if global warming is to be limited to 2°C.

The second part of a progressive aviation climate policy agenda would thus be to implement temporary national policy instruments. Our analysis of potential national aviation policy instruments shows that there are legally feasible options that could mitigate emissions in addition to the EU ETS and CORSIA.

Many countries already have distance-based air passenger taxes. In the EU, the populations of countries having an air passenger tax amount to 235 million people, that is, almost half of the EU population. Certainly, such taxes do not stimulate technological change, but they can reduce demand for air travel and thus emissions (InterVISTAS, 2007; Seetaram et al., 2014). Air passenger taxes can also be motivated by the desire to create a more level playing field between different modes of transport (where road transport is paying fuel taxes while air transport is not), and as a way of compensating for the VAT exemption on international flight tickets (Keen, Parry, & Strand, 2013; Krenek & Schratzenstaller, 2016). The existing levels in most countries are low and national strategies could be to increase the tax level over time, initially to harmonize with the UK, which currently has the highest tax level. If tax levels are relatively harmonized between countries, they can be increased substantially. Such taxes might, however, meet with opposition from the aviation industry and the general public. Therefore, it is relevant to work on alternative tax arrangements with the potential for higher general acceptance, such as where the tax level would increase for every additional flight a person takes per year (http://afreeride.org).

A tax on jet fuel between two or more countries is a possible alternative to a tax on tickets which would give incentives for both airlines and consumers to reduce emissions. However, implementation is likely to be difficult, since many bilateral agreements would need to be renegotiated, but if this were achieved, it could replace air passenger taxes in the future.

In addition, a quota obligation for biofuels is an option. However, there are several problematic aspects here. One aspect is the limited global supply of bioenergy, which will hardly suffice to replace fossil fuels in all sectors globally. Another is that the climate performance of feedstock-based biofuels, according to some sources, may in fact be worse than fossil fuels (Searchinger et al., 2018). What remains are biofuels from waste and residues, and the available resources for these are relatively low in volume. Yet another problem relates to the possibility of what is termed tankering, which would mean that for short to medium distances, airlines might include fuel for the return trip and thus avoid filling up with the more expensive fuel in a country with a quota obligation. This would in turn increase emissions due to heavier aircraft on average. For intra-European flights, tankering could pose a problem even with rather modest quotas, e.g. below 10%, if biofuel is 2–3 times more expensive than fossil fuel for aviation. In theory, a way to avoid the tankering problem could be to use landing charges at airports differentiated according to the proportion of biofuel used. The Norwegian parliament decided in 2015 that aircraft using 25% biofuel would get a 25% reduction in landing fees. However, an analysis by the Norwegian Ministry of Transport found that it was not legally feasible, since ICAO policy (2009) stipulates that landing fees must be based on actual costs for services (Samferdselsdepartementet, 2017, p. 255). In view of this, starting up a quota obligation scheme with relatively low blending levels might still be an option.

A supplementary policy could be compulsory climate declarations on advertisements for air travel (Åkerman et al., 2016). Information policy measures usually have only a marginal direct effect, but as part of a policy package they can contribute to raising public awareness and acceptance of other policy instruments (Givoni, Macmillen, Banister, & Feitelson, 2013).

In Section 2 we estimated the impact that the EU ETS and CORSIA will have on emissions from Swedish residents' air travel. Even when we included indirect emissions reductions through the EU ETS and CORSIA (as a result of the aviation sector's purchases of emission allowances from other sectors), the resulting emissions reductions were expected to be rather modest, around 0.8% per year. Nor will radical technological innovations like all-electric aircraft or hydrogen-fuelled aircraft result in any significant emissions reductions in the coming decades. From this, we draw the conclusion that, given the urgency of mitigating climate change, there is a need for supplementary policies that have a faster impact. In this paper, we have identified and analyzed three such measures that are legally feasible and which may have an impact on emissions in addition to what the EU ETS and CORSIA may achieve. The suitability of each of these measures and the levels to choose depend on the circumstances of the country in question.

Notes

1. The EU ETS covers countries within the European Economic Area (EEA), which consists of all EU Member States as well as Iceland, Liechtenstein, and Norway. Since the acronym EEA is less well-known, EU is used instead in this paper.
2. Countries here refer to members in ICAO.
3. As of July 2018, 73 states, representing 88% of international aviation activity, have pledged their participation in the pilot phase starting in 2020, leaving only 7 states (including Russia, India and Brazil) on the list of mandatory states that would be added to the scheme in 2027. https://www.icao.int/environmental-protection/Pages/market-based-measures.aspx
4. The aviation emissions for the period 2008–2012 were 221,542,935 tonnes per year. For 2013–2020, 210,465,788 allowances will be issued per year (one EUAA gives the right to emit 1 tonne of CO2). From 2021 the number of issued allowances per year will decrease by 2.2% of the base year allowances ($221{,}542{,}935 \times 0.022 = 4{,}873{,}945$ per year). The allowances issued in 2030 will subsequently be 22% lower than in 2017 (no change being made between 2017 and 2020).
5. From 2019 the supply of ETS allowances is regulated by the Market Stability Reserve. Unused allowances exceeding 833 million tons of CO2 will be transferred to this reserve, but when the amount exceeds a certain cap these allowances will be permanently annulled. The cap will equal the amount of allowances that was issued during the previous year.
6. Based on the assumption that about 40% of the airlines' costs today come from fuel.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by Stiftelsen för Miljöstrategisk Forskning: [Grant no. 2016/3]; VINNOVA: [Grant no. 2016-01743].

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