THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Economic incentives for fuel efficiency under a U.S. aircraft CO_2 standard

Authors: Anastasia Kharina and Dan Rutherford

Date: October 2019

Keywords: aviation; ICAO; aircraft; fuel efficiency; CO_2 standard

Introduction

Globally, aircraft emissions are the most rapidly growing, yet most unregulated, transportation source of carbon dioxide (CO_2). CO_2 emissions from U.S. domestic aviation increased by 7% from 2014 to 2016, due to low fuel prices and increased activity (Olmer & Rutherford, 2017b), and they hit a post-9/11 peak in 2017 (Graver & Rutherford, 2018b). Globally, commercial aviation emitted 905 million metric tons (Mt) of CO_2 in 2018, an increase of 27% over the previous five years (International Air Transport Association [IATA], 2019).

Following a 2016 finding that greenhouse gas (GHG) emissions from aircraft endanger public health and welfare, the U.S. Environmental Protection Agency (EPA) is set to propose an aircraft CO_2 emissions standard under the Clean Air Act (Office of Management and Budget, 2019). The EPA may adopt an international aircraft CO_2 standard developed in 2016 by the UN International Civil Aviation Organization (ICAO). The standard would apply to all new aircraft starting in 2028, and noncompliant models could not operate internationally or in countries that enforce the standard. The ICAO standard was designed to be anti-backsliding (i.e., to prevent less fuel-efficient models in the future), so it will not require additional improvements in fuel efficiency from manufacturers if implemented as written.

ICAO's approach contrasts with the United States' traditional regulatory approach, which promotes the development and deployment of new technologies to reduce GHG emissions. ICAO member states are free to adopt domestic regulations that go beyond the standards set by ICAO. The EPA under the Obama Administration stated that it anticipated setting a standard "at least as stringent" as ICAO's (U.S. EPA, 2016). Options to strengthen the standard include adopting a stricter standard on manufacturers, applying the standard to in-service aircraft or airlines (Graver & Rutherford, 2018b), and complementary policies that create market pull for new, more efficient aircraft.

This paper surveys current economic incentives applied to the aviation sector and then explores additional ways to leverage the fuel-efficiency benchmark provided by the ICAO CO_2 standard to promote more fuel-efficient aircraft. Adoption and implementation of these incentives could help the United States reach its goal of carbon neutral growth for its airlines from 2020 (U.S. Government, 2015). Revenue-neutral or revenue-positive incentives are most likely to avoid socially regressive incentives for additional flying.

A brief review of the ICAO CO_2 standard is presented in the following section to familiarize readers with the standard and the ways in which it is relevant in identifying complementary initiatives. A review of existing economic measures affecting aircraft in the United States is then presented. We follow that with a brief survey of potential new approaches to economic incentives for more fuel-efficient aircraft, including labeling, airport-specific incentives, purchase incentive and feebate systems, and requirements attached to aircraft financing.[1] We close by comparing the advantages and disadvantages of each potential new approach, and assess the expected implementation difficulty.

1 A feebate system is an incentive system in which more efficient vehicles receive rebates and less efficient vehicles are assessed fees.

Acknowledgments: The authors thank Clare Lakewood, Andrew Murphy, and Jennifer Callahan for their comments on an earlier draft.

ICAO CO_2 standard

It is important to review the ICAO CO_2 standard and understand how it can interface with the economic incentives discussed in this document. Independent of the standard's possible effect on emissions, it has established an internationally agreed-upon way of comparing aircraft fuel efficiency, which in turn could support economic incentives for more efficient aircraft.

Every flight consists of six stages: taxi, takeoff, climb, cruise, descent, and landing. The ICAO CO_2 standard assesses aircraft fuel-efficiency performance in the cruise stage, known as the specific air range (SAR). The fuel efficiency of each aircraft and engine combination is assessed via a metric value (MV) calculated as 1/SAR divided by a proxy of aircraft floor area raised to an exponent of 0.24. The SAR value itself is an average of three equally weighted values, evaluated at test points that approximate real aircraft weights at the top of climb, mid-cruise, and start of descent of a flight.

To assign different regulatory targets to a wide range of aircraft sizes, ICAO chose aircraft maximum takeoff mass (MTOM) as the scaling factor. MTOM designates the maximum combined mass of aircraft empty weight, payload, and fuel at which an aircraft can operate. This scaling factor helps distinguish smaller aircraft—business jets, turboprops, and regional jets—from larger commercial aircraft that have more technologies available to improve fuel efficiency. Larger aircraft types that are more than 60 metric tons MTOM are assigned relatively stricter requirements than smaller aircraft.

As it is a pass or fail requirement, the effect of the ICAO standard will depend upon the improvements required from individual aircraft models. Table 1 compares the expected CO_2 intensity of select aircraft types anticipated to

Table 1. Estimated CO_2 intensity relative to the ICAO standard by manufacturer and aircraft type

Manufacturer	Aircraft type	Exceedance
Airbus	A220-100	-20% to -16%
	A220-300	-15% to -11%
	A350-800	-15% to -11%
	A350-900	-14% to -10%
	A350-1000	-13% to -8%
	A319neo	-11% to -6%
	A320neo	-13% to -9%
	A321neo	-7% to -3%
	A330-800neo	-16% to -11%
	A330-900neo	-15% to -11%
Antonov	An-158	-3% to 2%
Boeing	B787-8	-14% to -10%
	B787-9	-17% to -12%
	B787-10	-17% to -13%
	B737 MAX 8	-10% to -5%
	B737 MAX 9	-7% to -2%
	B777-8	-13% to -9%
	B777-9	-16% to -12%

Manufacturer	Aircraft type	Exceedance
Bombardier	Global 5000	-4% to 4%
	Global Express 6000	-7% to 1%
	Global 7000	-20% to -16%
	Global 8000	-18% to -14%
Cessna	Citation X	-15% to -11%
	CitationJet CJ3	-9% to -3%
	E175-E2	-19% to -15%
	E190-E2	-16% to -12%
	E195-E2	-18% to -14%
Gulfstream	Gulfstream 550	-17% to -10%
	Gulfstream 650	-21% to -14%
Irkut	MC-21-200	-10% to -6%
	MC-21-300	-10% to -5%
Mitsubishi	SpaceJet	-22% to -18%

Note: Negative values indicate meeting the standard, and larger negative values correspond to lower CO_2 intensity and better fuel efficiency.

be in production in 2023 with what is required under the ICAO standard.[2] Negative values indicate that the aircraft would pass the standard by that margin, while positive values indicate that the aircraft would fail the standard.

As seen in Table 1, virtually every aircraft type predicted to be delivered by the time the ICAO CO_2 standard is fully implemented in 2028 will pass the standard, many by a large margin.[3] This means that the standard, as written, will not promote aircraft fuel efficiency improvement beyond business-as-usual improvements. Therefore, additional supportive measures are needed to further reduce emissions from the aviation sector.

An analysis by Graver and Rutherford (2018b) suggests that the in-use fleet average of all U.S. jets will comply with the ICAO standard by 2024, four years before the standard will be fully enforced in 2028. To achieve additional reductions in emissions, the analysis recommends applying the standard to in-service, rather than new, aircraft beginning in 2028, with additional tightening over time. This paper explores other measures that the United States could apply to strengthen the effect of the ICAO CO_2 standard, and it focuses on economic instruments to promote the production and sale of more fuel-efficient aircraft.

Existing economic measures

There are already a few economic measures in place that may influence the fuel efficiency of commercial aircraft, either directly or indirectly, via fuel prices. In this section, we survey these at the federal, regional, and airport level in the United States.

FEDERAL JET FUEL TAXES

The U.S. federal government imposes a tax of 4.3 cents per gallon on domestic jet fuel. This is directly correlated with airline operational costs. Because fuel consumption is directly correlated with CO_2 emissions, a change in the commercial jet fuel tax level may impact airline behavior. According to airline financial reporting data (Form 41) accessed through Airline Data Inc., the 4.3 cents per gallon tax corresponds to about 3% of the average cost paid by U.S. airlines for jet fuel in the United States in 2017.[4]

In a global ranking of fuel taxation policies, the United States falls roughly in the middle. On one end of the spectrum are countries with no tax at all. For example, European Union member states do not impose any jet fuel tax, nor do they impose a value-added tax on jet fuel purchases (Transport & Environment, 2013). On the other end of the spectrum, Japan imposes an ¥18 per liter fuel tax, or about 60 cents per gallon in U.S. dollar terms (Japanese Ministry of Environment, 2012). Australia, which is also in the middle, imposes a tax of AUD 3.56 cents per liter, or about 17.6 cents per gallon in U.S. dollar terms (Australian Taxation Office, n.d.).

Japan's fuel tax in particular has been found to influence aviation demand. In April 2011, it was reduced 30% from ¥26 per liter, or about 86 cents per gallon in U.S. dollar terms. This abrupt change in tax rates made it possible to analyze the real-life effect of jet fuel taxes on aviation fuel consumption and CO_2 emissions in the country. González and Hosoda (2016) found that jet fuel demand in Japan increased by 10% after 2011 and concluded that the reduction in fuel taxes unequivocally increased CO_2 emissions from aircraft.

Fuel taxes change the ownership cost of aircraft, as an example will show. We modeled four matching aircraft pairs at different technology levels and price points: for single aisle, we used Boeing 737-800, Boeing 737 MAX8, Airbus A320-200, and Airbus A320neo; and for twin aisle we used Boeing 777-300ER, Boeing 777-8, Airbus A330-200, and Airbus A330-800neo. Piano 5, a commercial aircraft performance modeling tool developed by Lyssis, Ltd., was used to estimate fuel burn. Each aircraft was "flown" on a set of typical missions for each of the two aircraft types within their payload-range envelope.[5] More details on the precise fuel burn modeling methodology applied can be found in Kharina, Rutherford, and Zeinali (2016).

To calculate the fuel cost over an appropriate operational period, we assume a jet fuel price of $1.80/gallon with a 2.2% annual increase based on the 2015 EIA Annual Energy Outlook jet fuel price projection up

2 ICAO's environmental standards recognize three types of new aircraft: new types, derivative designs, and other in-production aircraft. The CO_2 standard will apply to these commercial aircraft being delivered from approximately 2024, 2023, and 2028, respectively. See Rutherford and Kharina (2017) for further details. Additionally, predicted production status is based upon an analysis of the year of last delivery, assuming that aircraft without firm orders for delivery after 2019 in the Ascend database will be out of production in 2023. The analysis was based on Ascend Online Fleets Database as of May 2017.

3 Table 1, a partial reprint from Rutherford and Kharina (2017), has been updated for several aircraft types. The most commercially important aircraft type that would have failed the CO_2 standard if still in production in 2028, the Airbus A380, was discontinued from production in February 2019 due in part to its poor fuel efficiency (Katz, Kammel, & Bloomberg, 2019). The Boeing 737-800W, which had only nine deliveries pending out of almost 5,000 orders as of June 2019 (Boeing, 2019), is also unlikely to be produced in 2023 and so has been removed from Table 1.

4 http://www.airlinedata.com/

5 A payload-range envelope is defined by the aircraft capability of carrying the maximum amount of payload authorized under its airworthiness certification over a certain range.

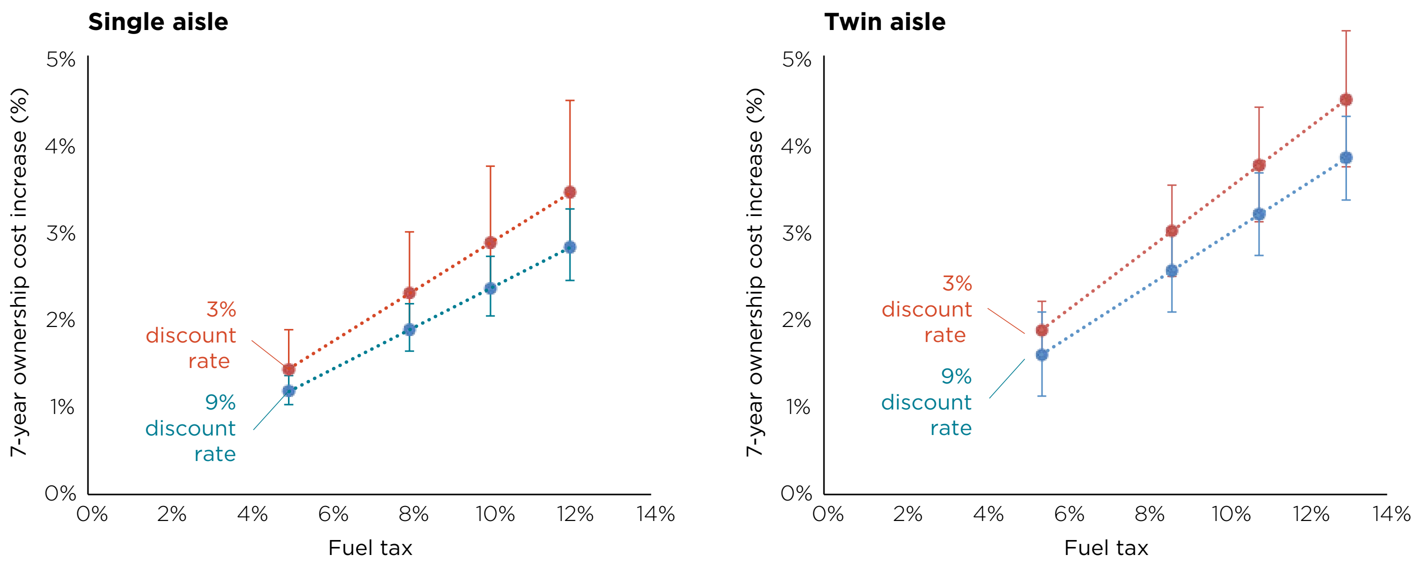

Figure 1. Effect of jet fuel tax increase on 7-year ownership cost

to year 2040 (U.S. Energy Information Administration, 2018).[6] The total cost is calculated as estimated aircraft price and (discounted) fuel cost during the first seven years of the aircraft's operation, excluding maintenance and other operational costs.[7] A 9% discount rate approximates the private cost of capital for airlines, while the lower 3% discount rate is often used by policymakers to assess the benefits and costs of public policies.

Figure 1 shows that a higher fuel tax would increase the cost of operating the aircraft through a typical break-even period for an aircraft, in this case seven years. For example, increasing the fuel tax by 10% could increase the cost of aircraft ownership by 2% to 5%, depending on the discount rate and aircraft type. Accordingly, increasing the fuel tax may support the market for more fuel-efficient aircraft.

While an increase in the fuel tax may be an effective way to promote fuel efficiency, tax code revisions in the United States can only happen through statutory change. Every federal tax code change has to be voted on by Congress and put into law, and this makes it difficult to implement. However, because fuel tax is a component of the Airport and Airway Trust Fund that funds major parts of FAA spending (Federal Aviation Administration [FAA], 2018), increasing the fuel tax may have a co-benefit of more funding for aviation programs run by the FAA.

STATE OR LOCAL SALES AND USE TAX FOR AIRCRAFT

A sales tax based on fuel efficiency could promote fuel-efficient aircraft. However, aircraft sales taxes are set by states, and many states in the United States award exemptions for aircraft used by airlines. Unless all states revoke the exemptions unanimously, this option would not be effective because an aircraft could avoid the tax in one state by domiciling in a neighboring state that provides the exemption.

STATE OR LOCAL JET FUEL TAX

Jet fuel taxes vary among states, but airlines are exempt in the majority of U.S. states. According to data collected by Stone and Borean (2014), only 15 states impose sales tax on commercial jet fuel. Sixteen states tax private jet fuel purchases but exempt commercial airlines, while 19 states do not impose jet fuel sales taxes at all. The same report shows that 28 states apply fuel excise taxes, while three states—New Jersey, New York, and Washington—only tax fuel estimated to be burned within their state borders.[8]

The FAA imposes limitations on the use of aviation fuel tax revenues (FAA, 2013). The tax revenue may be used for any purpose for which other airport revenues may be used, to support a state aviation program, and on or off

6 12-month average from September 24, 2017, to September 23, 2018. Source: U.S. Energy Information Administration (2018).

7 See Tecolote Research, Inc. (2015).

8 Excise taxes are indirect taxes levied by a government on a producer or vendor, in contrast to taxes paid directly by the consumer of a good or service.

airport for noise mitigation purposes. Most U.S. states are airport sponsors, and the majority of airports in the United States are subject to an Airport Improvement Program (AIP) grant agreement. As a condition of receiving a grant, these airports are bound by the agreement that fuel tax revenue be used as described above. Furthermore, this federal limit on the use of aviation fuel tax proceeds applies to an airport that is the recipient of federal assistance, whether or not the airport is currently subject to the terms of an AIP grant agreement and regardless of whether the state or local jurisdiction is imposing the tax.

FUEL FEES AT AIRPORTS

Some commercial airports in the United States apply fuel charges in the form of fuel flowage fees, fuel farm fees, or both. A few airports in the United States, for example Dallas Fort Worth Airport (DFW), have a fuel flowage fee levied on all fuel delivered to the airport. It ranges from 14 cents per gallon for fixed-based operators to 26 cents per gallon for self-fueling (Fort Worth Aviation, 2017). This fee is waived for operators paying landing fees. Other airports, like Hartsfield–Jackson Atlanta International (ATL), charge fuel farm fees by the gallon. Similar to applying fuel tax, higher fuel fees at airports may prod operators to procure more fuel-efficient aircraft to reduce costs.

However, because many fuel farms at airports are owned and/or operated by an airline consortium, airports typically have little discretion to modify the fuel fees. In addition, raising the fuel flowage fee at one airport could incentivize airlines to load excess fuel at a lower-cost airport, and this might result in higher fuel consumption overall (Ryerson, Hanson, Hao, & Seelhorst, 2015). In the United States, rates and charges for fuel at airports are somewhat regulated by the Department of Transportation and the FAA, and they require that rates and charges at airports be related to cost, and that they are fair and reasonable (FAA, 2013).

Table 2. Landing fees as a percentage of total operating costs in 2016

Source: BTS (2017).

Airline	Landing fees as percentage of operating expenses
Federal Express	1%
Delta Air Lines	2%
American Airlines	2%
Hawaiian Airlines	2%
Alaska Airlines	2%
Sun Country Airlines	2%
United Airlines	2%
Virgin America	3%
Southwest Airlines	3%
JetBlue Airways	3%
Frontier Airlines	4%
Spirit Airlines	4%
United Parcel Service	4%
Allegiant Air	5%

LANDING CHARGES

Space rentals and landing fees at airports make up a significant part of an airline's total operating costs. Although reports vary as to how much airlines pay for airport rental and landing costs, Doganis (2002) estimated landing fees and en-route fees at between 4% and 9% of direct operating costs, and Rexaline (2017) placed rental and landing expenses at between 4% and 6% of revenues.

The U.S. Bureau of Transportation Statistics (BTS, 2017) provides data on the contribution of landing fees to airline expenses. BTS Data Form 41 Schedule P7 was analyzed for major commercial airlines in the United States (Table 2). In BTS data, landing fees are marked as part of indirect operating expenses, and they equate to 1% to 5% of total operating costs for major U.S. airlines. These shares of total costs vary across carriers and depend on the aircraft type, airports and routes served, and factors including the amount spent on passenger service (which amounts to zero for freight carriers), marketing expenses, and others.

Currently, all airports in the United States apply MTOM-based fees only, with fee values determined by each airport or airport authority. Airports in other countries including the United Kingdom, Sweden, France, Germany, Switzerland, and Italy base landing charges on MTOM, noise profile, and/or the NO_x intensity of the aircraft.

We compared fees and charges imposed by different airports in the United States with airports in two European countries—the United Kingdom and France—to see how differentiating landing charges by noise and/or NO_x emissions might impact different aircraft types in the United States.

Table 3 compares fees imposed on seven aircraft types at four airports: Los Angeles International Airport (LAX) and ATL in the United States, and London Heathrow Airport (LHR) and Charles de Gaulle Airport (CDG) in Europe. The total fee includes landing fee and parking for two daytime hours. All fees are in U.S. dollars, at the October 2017 exchange rate.

For LAX, ATL, and CDG, overall charges are fairly linear to aircraft size (MTOM). LAX and ATL charge only as a function of MTOM. Although CDG charges on the basis of noise, the noise coefficient is a percentage of MTOM and is relatively small for daytime hours. In contrast, LHR has a semi-fixed noise charge that is based on aircraft margin to the ICAO noise standard; this causes overall charges to deviate significantly from an aircraft's MTOM. Under this pricing structure, operators of very large aircraft such as the Boeing 747-8I and the Airbus A380 actually pay less than those flying regional jets and single-aisle aircraft.

Differentiating landing fees based on emissions performance could promote the use of more fuel-efficient aircraft. The ICAO CO_2 standard establishes a globally accepted benchmark for setting differential charging for aircraft based on fuel efficiency. However, the current U.S. airport fee structure is difficult to change to allow CO_2-based differential charging; this is because airports are subject to Department of Transportation and FAA rates and charges policies.

Airports in Europe already have noise- and NO_x-based emissions charging systems. Furthermore, some European airports have taken steps to promote low-carbon air transport. For example, Norway's state-operated airport network, Avinor, set an ambitious target to use electric aircraft for all short-haul flights by 2040 (Dowling, 2018). London's Heathrow has announced that the first electric-hybrid aircraft flying regular services out of the airport will not have to pay landing charges for an entire year.

DOMESTIC CARBON MARKET

Another way to promote more fuel-efficient aircraft is to price carbon emissions. The European Union has adopted a CO_2 cap-and-trade market under the European Union Emission Trading System (EU ETS). A limit is set on the total CO_2 emissions that can be emitted by the system. Companies are allowed to emit up to their individual allocation, and to purchase or sell excess credits as needed. In this way, the market determines the price of carbon. The overall limit is reduced over time so that total emissions go down.

The EU ETS was the first system to include all flights to and from EU countries, and they have been included since 2012. However, the application to flights outside of Europe was postponed to allow ICAO to negotiate its Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). In October 2017, European member states, the European Commission, and the European Parliament reached an agreement that limits the exemption of flights to and from

Table 3. Airport fees by aircraft type (in U.S. dollars, at October 2017 exchange rate)

Airport	EMB 170	A320-214	B737-800	B787-8	B777-200	B747-8I	A380-800
Los Angeles International	$346	$700	$709	$2,045	$2,177	$4,017	$5,159
London Heathrow	$3,225	$3,266	$3,258	$1,206	$2,140	$1,364	$1,491
Hartsfield-Jackson Atlanta International	$64	$129	$130	$376	$400	$738	$948
Charles de Gaulle	$723	$1,011	$1,127	$2,403	$2,539	$4,442	$5,624

Calculated from: Los Angeles World Airports (n.d.); Heathrow Airport Ltd (2014); Hartsfield-Jackson Atlanta International Airport (2017); Aeroports de Paris (n.d.).

Europe to the end of 2023, three years after CORSIA is scheduled to start (Transport & Environment, 2017). This time limit is meant as a backstop in case Europe determines that CORSIA's rules, which are still under refinement, are too weak. The agreement also includes a provision to progressively reduce the limit on allowances from 2021, which puts aviation in line with other sectors covered by the EU ETS.

Other countries are also moving to incorporate aviation into their emission trading systems. Swiss and European Union governments have agreed to link their respective aviation trading schemes and integrate flights between Switzerland and the European Economic Area (i.e., the European Union, Iceland, Norway, and Liechtenstein) countries into the EU ETS (Swiss Federal Council, 2017). Following in Europe's footsteps, China launched its own nationwide domestic carbon market in late 2017, starting with the power sector only. It plans to add other sectors in the future, including aviation. As China has the world's fastest growing aviation sector, this would contribute to its emerging leadership in fighting global climate change.

For a carbon market to successfully pressure companies to lower their carbon emissions, the price has to be right. Currently, carbon prices worldwide are well below both the estimated social cost of carbon and prices expected to influence airline behavior. According to an auction platform for emission allowances in the EU ETS European Energy Exchange, the mean EU aviation allowance price between September 2017 and September 2018 was €11.7 per metric ton CO_2-equivalent ($13 U.S./metric ton). Current prices (July 2019) are higher, in the range of €27/metric ton, or about $30 U.S./metric ton (European Energy Exchange, 2019). IATA, in a paper to ICAO (2016), suggests carbon costs ranging from $15 to $35 in 2025 and $20 to $40 in 2035. As quoted by King (2016), Jonathan Counsell of British Airways said that carbon prices should be around $40 a metric ton to send a "strong signal" to the sector. This is still less than the EPA's estimate of the social cost of carbon of $51 in 2020.[9]

A separate carbon market for international aviation will soon be implemented under CORSIA. Agreed upon at ICAO's 39th Assembly in 2016 in Montreal, Canada, CORSIA marks the first time a market-based measure covers an entire international sector. CORSIA will first be implemented as a voluntary system from 2021 to 2026 and will be mandatory from 2027 to 2035, when it will apply to all ICAO member countries, with the exception of some developing countries and small markets (Olmer & Rutherford, 2017a).

The impact of CORSIA on airline efficiency and emissions is expected to be limited at best, for three main reasons. First, while it covers about three-quarters of industry growth between 2020 and 2035, CORSIA will affect only about 5% of international aviation emissions through mid-century (International Coalition for Sustainable Aviation, 2018). Second, the overall carbon price imposed will be low, as the offsetting system is likely to be reliant upon certified emission reduction (CER) credits with an average price of less than €1 per metric ton ($1.11 U.S.; Fearnehough, Day, Warnecke, & Schneider, 2018; Winchester, 2019).[10] Third, the carbon price experienced by airlines will be reduced because offsetting obligations are established in large part as a function of the industry's overall emissions, not those of individual airlines. Accordingly, previous ICCT work (Olmer & Rutherford, 2017a) suggests that the average direct cost of the CORSIA requirements imposed on airlines will be negligible before 2030 and reach only 0.9% of total operating costs in 2035.

ICAO's CORSIA will only apply to international flights. However, the United States could build its own domestic carbon market, either exclusively for aviation or in conjunction with other sectors. The Low Carbon Fuel Standard in California and Renewable Fuel Program in Oregon are two examples of successful carbon markets in the United States. Paired with the developing alternative jet fuel industry, a domestic carbon market may be a part of efforts that promote fuel-efficient aircraft and low-carbon flights.

Other options to promote aircraft fuel efficiency

This section presents new ideas for potential measures to promote aircraft fuel efficiency, including labeling, airport facility priority, feebates, and "green" financing support. Some of these incentives are lessons from other sectors that could be applied to promoting new, more fuel-efficient aircraft. The first two measures presented in this section—labeling and airport facility priority for fuel-efficient aircraft—offer non-economic benefits. The latter three—direct purchase incentive, a feebate system, and financing through the Export-Import Bank of the United States (EXIM)—offer favorable conditions for purchasing more fuel-efficient aircraft.

9 Adjusted for inflation using the Consumer Price Index to 2018 U.S. dollars. See EPA (2016).

10 As implied by this low price, the environmental integrity of these offsets may be quite low. A separate study, by Cames et al. (2016), estimates that only 2% of the projects and 7% of potential CER supply have a high likelihood of being additional and without overestimated emission benefits. Proposals to improve the effectiveness of the CORSIA system can be found here: https://icsa-aviation.org/wp-content/uploads/2018/02/ICSA_Understanding_the_CORSIA_Package_summary_en.pdf

LABELING PROGRAM

In many countries, vehicle fuel efficiency labeling is used as a complementary measure to improve the fuel efficiency of the on-road transport fleet. Labeling is meant to address market failures for fuel efficiency, namely excessive discounting of future fuel efficiency savings, and it helps consumers identify and purchase more fuel-efficient vehicles. In addition, better recognition of fuel-efficient vehicles sets better performing vehicles and manufacturers apart from the competition. Labeling programs are often implemented in conjunction with, or prior to, a fuel economy standard.

For aviation, the direct purchasers of aircraft are not passengers or shippers, but rather airlines, lessors, and financial institutions. Assuming that these purchasers already have access to information about the fuel efficiency of products, an effective labeling system would need to be adapted to target passengers and shippers. Unlike passenger vehicles, where the consumer directly controls equipment acquisition, aircraft end consumers do not directly influence the type of aircraft airlines procure. However, a better-informed flying public could reward carriers that integrate more fuel-efficient aircraft into their fleets.

Research shows significant differences in the carbon intensity of carriers and flights. Among airlines providing transatlantic flights to and from the United States in 2017, the worst performing airline, British Airways, burned 63% more fuel per passenger kilometer than Norwegian, the best performing airline (Graver & Rutherford, 2018a). Analysis performed on air travel in the United States and Canada arrived at a similar conclusion; the gap between the most- and least-efficient carriers ranged from 9% to 87% on domestic routes (Zeinali, Rutherford, Kwan, & Kharina, 2013), and between 6% and 36% on direct transborder routes (Liu & Kharina, 2017). This indicates that airlines can improve their fuel efficiency and that the flying public has options to choose more fuel-efficient flights.

Beyond labeling the aircraft itself, disclosing information about the fuel consumption or CO_2 emissions could be required for individual flights. The United States could require that airlines serving flights departing or arriving at U.S. airports provide information regarding the fuel consumption by itinerary, including seating class (i.e., economy vs. business). This information could be made directly available to passengers, for example through ticket brokers or online flight search engines. If per-flight emission labeling is implemented in conjunction with carbon offsetting, passengers will have more visibility regarding the climate impact of their flight, and could choose lower-emission flights based on the route, aircraft type, seat class, etc.

AIRPORT FACILITY PRIORITY FOR FUEL-EFFICIENT AIRCRAFT

Airport facility priority could be offered to fuel-efficient aircraft at airports. When landing slots become open at priority airports, for example through mergers (Jones, 2014), airlines operating more efficient aircraft to that airport could be prioritized. Alternatively, priority access to more desirable apron locations, or a bump in the takeoff queue, may be given to airlines with more fuel-efficient fleets.

The latter would require the use of a ground management program (GMP) to replace the currently common first-come-first-served takeoff queue. With a GMP, instead of queuing on the tarmac to preserve their relative takeoff position, departing aircraft may be held at the gate or another holding location, and released to the runway in time to join a short departure queue before taking off. John F. Kennedy International Airport in New York started using a departure metering program in 2010 during a construction project. The program not only significantly reduced departure queues and taxi-out times, it also produced the co-benefit of major reductions in fuel burn and emissions (Stroiney, Levy, Khadilkar, & Balakrishnan, 2013).

PURCHASE INCENTIVES

When acquiring an aircraft, airlines can buy or lease, just like when people acquire a car. Also, similar to cars, the upfront cost of new, fuel-efficient aircraft designs is usually higher than the older, less efficient ones (see Table 4).

Table 4 presents the estimated purchase price of four predecessor-successor aircraft pairs, calculated by discounting their publicly listed price from the respective manufacturer website by 40%. This is a conservative assumption when compared with discount values cited by Fontevecchia (2013), Lamigeon (2013), Zhang (2016), and Michaels (2012), among others, and it accounts for the deep discounts that aircraft manufacturers generally provide airlines against the public "sticker price." The successor aircraft are estimated to be 13% to 17% more fuel efficient per passenger-kilometer transported than their predecessors. This is roughly proportional to their incremental costs, as the successors are about 9% to 15% more expensive.

Incentives provided as a function of fuel efficiency could be used to close this gap. Examples could be drawn from road transport, specifically incentives for electric passenger cars. Despite their higher sticker price compared with conventional fuel vehicles, electric vehicle sales in the United States and elsewhere have been steadily increasing. Market growth has been driven by a combination of financial incentives, benefits such as

Table 4. Estimated price of predecessor and successor aircraft pairs (in USD)

Source: Boeing (n.d.) and Airbus (2018)

Predecessor aircraft type		Successor aircraft type			
Name	**Estimated price (million $)**[a]	**Name**	**Estimated price (million $)**	**Price premium (million $)**	**Price premium (%)**
737-800	61	737 MAX 8	70	9	15%
A320	61	A320neo	66	6	10%
777-300ER	217	777-8	237	20	9%
A330-200	143	A330-800neo	156	13	9%

[a] Calculated by discounting official list prices by 40%

cheap or free parking and lane access, charging infrastructure, and education and outreach activities (Lutsey, Searle, Chambliss, & Bandivadekar, 2015).

U.S. government support for electric vehicles is significant. The federal government provides an income tax credit of up to $7,500 for electric vehicle purchases. Many states also provide rebates that directly reduce the upfront cost of an electric vehicle. Table 5 compares total incentive amounts (federal plus state) as percentage of manufacturer's suggested retail price (MSRP) for some electric vehicle models in select U.S. states in 2018. These figures were calculated from public vehicle MSRPs and data on incentives compiled in Slowik and Lutsey (2019).

As shown in Table 5, BEVs, which run exclusively on electricity provided by on-board batteries, generally receive higher incentives than PHEVs, which have both an electric motor and an internal combustion engine. Notably, incentives provided for electric passenger vehicles as a percentage of MSRP are typically larger than the price differentials between new generation aircraft and their legacy replacements shown in Table 4.

Government incentives in the form of either rebates or tax credits could increase the competitiveness of more fuel-efficient aircraft by helping to reduce their upfront costs. Studies such as one performed by the National Research Council (2013) suggest that the estimated benefits of fuel savings and reduced emissions from the policy-induced transition to electric vehicles outweigh the costs in the long term. This strategy may be especially important during transition periods when manufacturers are offering both existing and advanced designs for sale (e.g., the A320ceo and neo options). To avoid indirect subsidies for air travel, purchase incentives could be linked to increases in the aviation taxes, fees, or carbon pricing policies highlighted above.

FEEBATES

Compared with direct purchase incentives paid for by governments, revenue-neutral feebate systems (Jenn & Sperling, 2017) may be more economically attractive for governments. Feebate systems, which get their name from fee and rebate, impose a fee on vehicles with high CO_2 emissions or fuel consumption (i.e., low fuel economy), and then provide a rebate to vehicles with low CO_2 emissions or fuel consumption (i.e., high fuel economy) (German & Mezler, 2010). If applied to aircraft, this would help close the cost gap between more and less fuel-efficient planes by promoting the former.

The average new single-aisle and twin-aisle aircraft delivered in 2018 is expected to exceed the ICAO CO_2 standard taking full effect in 2028 by approximately 5% (Rutherford & Kharina, 2017). Using this as a pivot point, a revenue-neutral feebate system could be developed to promote more fuel-efficient aircraft. For example, an aircraft with a CO_2 metric value (CO2MV) score complying with ICAO's CO_2 standard by more than 5% could be assigned a rebate, while an aircraft that complies by less than 5% could be assigned a fee. In this example, we added a 1% fee to the aircraft's discounted sticker price for every percentage point it performs worse than the pivot point (-5%) and assigned a rebate of 1% to an aircraft for every point it performs better than the pivot point. Thus, an aircraft that passes the ICAO CO_2 standard by 10% would get a 5% rebate, while another

Table 5. Combined federal- and state-level electric vehicle incentives, as a percentage of MSRP, 2018

Make model	Type	Price	Purchase incentive as percent of vehicle price			
			California	Colorado	Massachusetts	New York
Tesla Model S	BEV	$78,000	13%	16%	13%	12%
Chevrolet Bolt	BEV	$36,620	27%	34%	27%	26%
Nissan Leaf	BEV	$29,990	33%	42%	33%	32%
Toyota Prius Prime	PHEV	$27,300	22%	35%	22%	23%
Chevrolet Volt	PHEV	$33,220	27%	38%	27%	28%

BEV = battery electric vehicle; PHEV = plug-in hybrid electric vehicle.

that fails the standard by 10% would face a 15% fee.

Using this system, we compared the prices of older, less fuel-efficient aircraft with newer, more fuel-efficient aircraft in the same family. Specifically, we used the four aircraft pairs introduced earlier in the paper to see how the fuel savings of more fuel-efficient aircraft affect the total cost of owning the vehicle, and how a feebate scheme could tip the balance. The results are summarized in Figure 2. Figure 2 compares the costs of procuring and operating the four pairs of predecessor-successor aircraft introduced in Table 4. Data for older aircraft models are shown in the left bar of each pair; data for the successor models are shown on the right.

The purchase price of the predecessor aircraft, which is calculated as the list price discounted by 40%, is assigned a value of 100% as a benchmark. Figure 2 shows that the estimated purchase price for a successor aircraft is always higher than its predecessor. However, because the successor aircraft are more fuel-efficient, that price gap narrows significantly when fuel savings over seven years of operation are considered.[11] Furthermore, when the fee and rebate are applied to the aircraft based on their performance against the ICAO CO_2 standard, it tips the balance so that the successor is cheaper over a seven-year payback period.[12] Although these results are case specific, they are an indication of how feebate systems could improve the relative economics of more fuel-efficient aircraft.

EXIM BANK SUPPORT

Apart from any purchase incentives, procuring an aircraft usually involves financing. A financing scheme that favors fuel-efficient aircraft could provide an economic boost for such aircraft. The EXIM Bank is a U.S. government-owned trade agency that provides financing and guarantees on loans taken abroad to help foster exports. In theory, to promote more fuel-efficient aircraft production, the EXIM Bank could adopt a fuel-efficiency threshold for aircraft purchase financing requests.

Having received more than $8 billion in assistance during fiscal year 2013, Boeing was the biggest beneficiary of EXIM Bank's activity that year. This came mostly in the form of loan guarantees, and the assistance earned it the nickname "Boeing's Bank" (De Rugy, 2014). When provided with a government guarantee from the bank, Boeing's foreign customers can obtain good credit terms and lower borrowing costs. This, in turn, helps Boeing sell its products overseas.

At the time of writing, and since July 2015, the EXIM Bank is unable to authorize new commitments for transactions in excess of $10 million due to lack of quorum on its board of directors. This limit nixes the bank's ability to approve financing assistance for commercial aircraft. But export sales of Boeing's products in recent years suggest that the company is not entirely dependent on EXIM Bank. One good example is the Kacific case, where the Singapore-based company successfully secured alternative funding to purchase

11 Fuel savings over 17 years, the average period of first ownership of an aircraft by U.S. airlines, more than offsets the incremental capital costs of more fuel-efficient aircraft.

12 Payback period indicates the period of time after which extra capital costs of purchasing a more fuel-efficient vehicle are fully offset by lower fuel costs. Airlines are believed to target a seven-year payback period when purchasing aircraft (Tecolote Research, Inc., 2015).

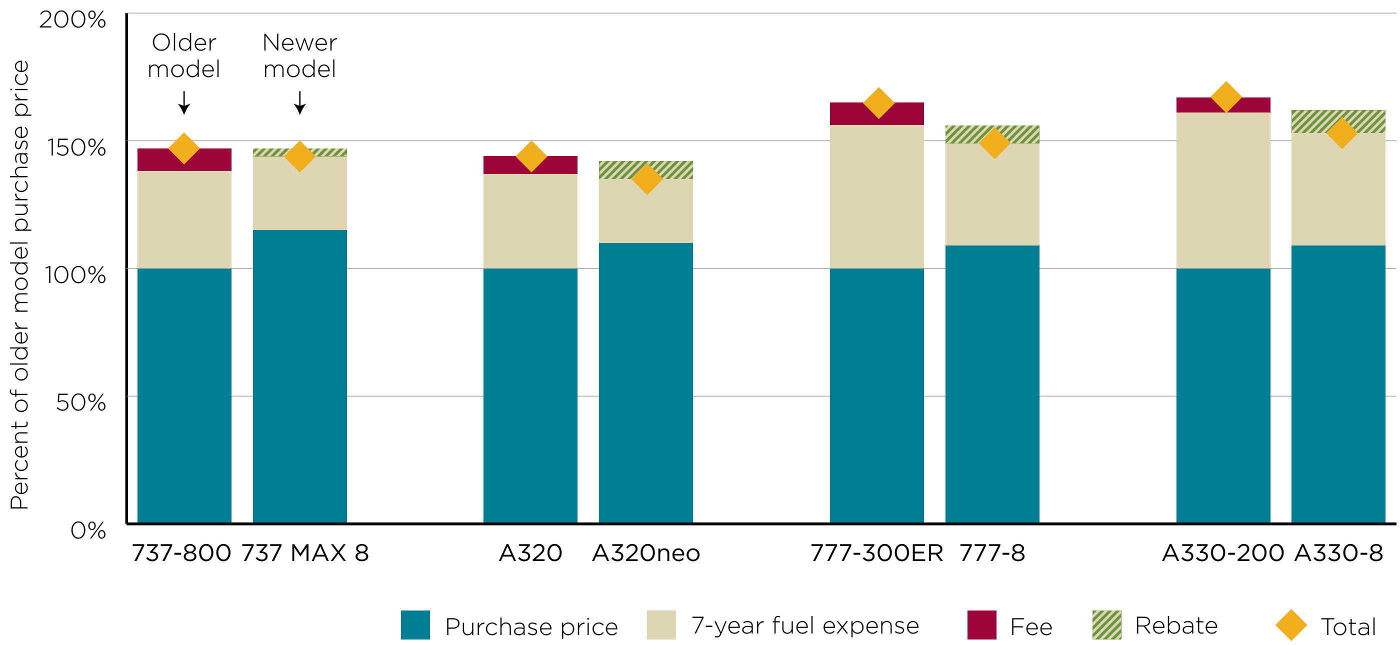

Figure 2. Price increment with feebate applied by aircraft pair. Fuel savings are calculated based on 7-year operations and a 9% discount rate.

Boeing's satellite after EXIM Bank's reauthorization lapse in 2015 (Henry, 2017). In addition, the lapse has not stopped foreign airlines from adding to Boeing's commercial order book in the past few years.

If and when the EXIM Bank's ability to provide financing for aircraft is restored, it could incorporate a fuel-efficiency requirement to promote more fuel-efficient aircraft production and sales. While such a tightening of requirements for loan guarantees would not promote fuel-efficient U.S. fleets, it might still be effective in promoting the sale of fuel-efficient aircraft abroad. About one-third of commercial air traffic in the United States is international (FAA, 2017). Ensuring export of less-polluting aircraft means a higher probability of more fuel-efficient aircraft from abroad flying in U.S. airspace.

Comparing the new options

The ICAO CO_2 standard opens a possibility for governments such as the United States to develop new incentives for aircraft fuel efficiency. Table 6 qualitatively compares the reduction potential and implementation difficulty of the new economic incentives discussed above. The more direct influence the measure has on the promotion of fuel-efficient aircraft, the higher the score granted. For example, incentives that directly lower the cost of ownership of more fuel-efficient aircraft score higher than labeling, which would require additional action from the flying public to affect airline behavior.

Implementation difficulty scoring was based on the effort it would take for the incentive to reach its maximum potential in the United States. For example, the development and implementation of a feebate system would likely require congressional authorization because it is a form of taxation.

Table 6 suggests that, with a few exceptions, the higher an initiative ranks on its potential to promote fuel-efficient aircraft, the more challenging it would be to implement. However, no single incentive is a silver bullet. Instead, the strategies could complement one another and provide a collective stimulus for more fuel-efficient aircraft. A concerted effort aimed at targeting different actors and implemented by different agents in the aviation sector is necessary to achieve maximum emission reductions.

A labeling mandate would inform the flying public about the aircraft on which they fly. It is assumed that public preference would, in turn, pressure airlines to purchase more fuel-efficient aircraft. Either a direct purchase incentive or a feebate system would directly incentivize airlines to buy or lease more fuel-efficient aircraft. The deal may be sweetened by favorable landing fees or airport facilities for more fuel-efficient aircraft.

When demand for fuel-efficient aircraft increases, it would make sense that manufacturers would not only produce more such aircraft, but they would also design even more fuel-efficient aircraft.

Different agencies could adopt and implement different initiatives within their jurisdictions. For example, an airport, or a local government that owns an airport, could support fuel-efficient aircraft operating in the form of a favorable airport facility or a fee waiver. A state government could start a labeling mandate for aircraft operating in its state, or for flights in or out of its cities. The federal government could set up a revenue-neutral feebate system based on an aircraft's performance against the CO_2 standard.

The case for revenue neutrality, or even revenue-generating economic incentives, is strong for aviation. According to Airlines for America (Heimlich, 2016), the top 10% of fliers in 2015 were responsible for approximately two-thirds of all flights taken by American adults, and half of all trips were taken by the top 6% of frequent fliers. Thus, the benefits of revenue-negative aviation incentives could accrue disproportionately to higher-income individuals who travel frequently. Thus, economic policies like taxes, carbon markets, or a revenue-neutral or revenue-positive feebate system may be more appropriate than direct purchase incentives in promoting aircraft fuel efficiency. They would also be more consistent with the Polluter Pays Principle, which posits that actors responsible for environmental pollution should pay for its mitigation.

Conclusions

ICAO's CO_2 standard is not expected to require additional efficiency improvements beyond what is expected without the standard's implementation. Therefore, if the United States seeks to reduce CO_2 emissions from aircraft operating in the country beyond a business-as-usual scenario, it needs to either adopt a stricter standard or implement additional measures. Because the ICAO standard provides a new way to compare aircraft fuel efficiency, it could support additional incentives to reduce emissions.

This paper discussed economic measures at the federal, regional, and airport levels that could promote the use of more fuel-efficient aircraft and help the United States reach its goal of reducing CO_2 emissions from aviation. Some challenges in adopting these measures were also discussed. For example, measures that involve taxation and spending, such as direct commercial incentives in the form of a rebate or a feebate system, may need congressional authorization to implement. Other measures, such as

Table 6. Instruments and relevant characteristics

Instrument	Target	CO_2 Reduction Potential	Implementation Difficulty	Note
Labeling	Ticket purchasers	Low to medium	Low	Not a direct economic action, but may change public behavior over time
Landing fees based on aircraft fuel efficiency	Airlines	Medium	Low	U.S. airports are subject to the Department of Transportation and FAA rates and charges policies
Airport facility priority for fuel-efficient aircraft	Airlines	Low to medium	Medium	Requires a departure management system that may also save fuel
Direct commercial incentive for aircraft purchase	Airlines	High	High	Indirect subsidy for flying and overall program cost could be substantial
Feebate system	Airlines, Manufacturers	High	Medium	May be designed to be revenue neutral. A form of taxation/spending policy and may need congressional authorization.
EXIM Bank support	Manufacturers, Foreign airlines	Low	Low	Will not affect U.S. domestic market, but may indirectly affect international flights in the United States

differentiating landing fees based on fuel efficiency and providing favorable airport facilities for fuel-efficient aircraft, need the active participation of airports and regional governments.

Many of the economic measures included in this report are best practices that have been proven to promote the purchase of more fuel-efficient cars, trucks, and buses. The efforts to reduce carbon emissions from the road sector faced many challenges that required different government agencies and the private sector to work together. The same will apply to the aviation sector. The EPA, the agency with the authority to regulate aircraft emissions under the Clean Air Act, cannot do it alone. It needs the political will from the FAA and other national agencies to support CO_2 reductions from aircraft.

References

Aeroports de Paris. (n.d.). *Fee Schedule for Services Rendered*. Retrieved from http://www.parisaeroport.fr/docs/default-source/professionnel-fichiers/services-aux-compagnies-aeriennes/adp-tarif-2017_eng.pdf?sfvrsn=1111ebd_2

Airbus. (2018, January 15). *Airbus 2018 price list press release* [Press release]. Retrieved from https://www.airbus.com/newsroom/press-releases/en/2018/01/airbus-2018-price-list-press-release.html

Austin-Bergstrom International Airport. (n.d.). Environmental initiatives. Retrieved January 9, 2018, from http://www.austintexas.gov/page/environmental-initiatives

Australian Taxation Office. (n.d.). *Excise rate for fuel*. Retrieved November 4, 2017, from https://www.ato.gov.au/Business/Excise-and-excise-equivalent-goods/Fuel-excise/Excise-rates-for-fuel/#FuelDef2

Boeing. (n.d.). *Prices*. Retrieved November 4, 2018, from http://www.boeing.com/company/about-bca/#/prices

Boeing (2019). Current products and services: Orders and deliveries. Retrieved from http://www.boeing.com/commercial/?cm_re=March_2015-_-Roadblock-_-Orders+%26+Deliveries/#/orders-deliveries

Bureau of Transportation Statistics, U.S. Department of Transportation (2017). Air Carrier Financial Reports (Form 41 Financial Data) Retrieved from https://www.transtats.bts.gov/Tables.asp?DB_ID=135&DB_Name=Air%20Carrier%20Financial%20Reports%20%28Form%2041%20Financial%20Data%29&DB_Short_Name=Air%20Carrier%20Financial

Cames, M., Harthan, R., Füssler, J., Lazarus, M., Lee, C., Erickson, P., & Spalding-Fecher, R. (2016). *How additional is the Clean Development Mechanism? Analysis of the application of current tools and proposed alternatives*. The Oeko-Institut. Retrieved from the European Commission, https://ec.europa.eu/clima/sites/clima/files/ets/docs/clean_dev_mechanism_en.pdf

De Rugy, V. (2014). *The biggest beneficiaries of the Ex-Im Bank*. Retrieved from the Mercatus Center, https://www.mercatus.org/publication/biggest-beneficiaries-ex-im-bank

Denver International Airport. (2013). *Sustainability management plan*. Retrieved from https://www.flydenver.com/sites/default/files/environmental/sustainReport2013.pdf

Doganis, R. (2002). *Flying off course: The economics of international airlines* (3rd ed.). London: Routledge.

Dowling, S. (2018, August 22). Norway's plan for a fleet of electric planes. *BBC*. Retrieved from http://www.bbc.com/future/story/20180814-norways-plan-for-a-fleet-of-electric-planes

European Energy Exchange (2019). *European emission allowances*. Retrieved from https://www.eex.com/en/market-data/environmental-markets/spot-market/european-emission-allowances

Fearnehough, H., Day, T., Warnecke, C., & Schneider, L. (2018). Discussion paper: Marginal cost of CER supply and implications of demand sources. German Emissions Trading Authority (DEHSt). Retrieved from https://www.dehst.de/SharedDocs/downloads/EN/project-mechanisms/Marginal-cost-of-CER-supply.pdf?__blob=publicationFile&v=1

Federal Aviation Administration. (2018). *Airport and Airway Administration Trust Fund (AATF) Fact Sheet—Updated: March 2018*. Retrieved from https://www.faa.gov/about/budget/aatf/media/AATF_Fact_Sheet.pdf

Federal Aviation Administration. (2017). *Current aviation excise tax structure*. Retrieved from https://www.faa.gov/about/budget/aatf/media/excise_tax_structure_calendar_2017.pdf

Federal Aviation Administration. (2013). Policy regarding airport rates and charges. (Document No. 78 FR 55330). Retrieved from https://www.federalregister.gov/d/2013-21905

Fontevecchia, A. (2013, May 21). Boeing bleeding cash as 787 Dreamliners cost $200M but sell for $116M, but productivity is improving. *Forbes*. Retrieved from https://www.forbes.com/sites/afontevecchia/2013/05/21/boeing-bleeding-cash-as-787-dreamliners-cost-200m-but-sell-for-116m-but-productivity-is-improving/#4d448e315cb5

Fort Worth Aviation. (2017). *Airport rates and charges FY 2018*. Retrieved from http://fortworthtexas.gov/aviation/rates.pdf?v=2017

German, J. & Mezler, D. (2010). *Best Practices for Feebate Program Design and Implementation*. Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/best-practices-feebate-program-design-and-implementation

González, R., & Hosoda, E.B. (2016). Environmental impact of aircraft emissions and aviation fuel tax in Japan. *Journal of Air Transport Management.* Volume 57: 234-240. doi:10.1016/j.jairtraman.2016.08.006

Graver, B., & Rutherford, D. (2018a). *Transatlantic airline fuel efficiency ranking, 2017*. Retrieved from the International Council on Clean Transportation, https://www.theicct.org/publications/transatlantic-airline-fuel-efficiency-ranking-2017

Graver, B., & Rutherford, D. (2018b). *U.S. passenger jets under ICAO's CO2 standard, 2018-2038*. Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/us-passenger-jets-icao-co2-standard

Hartsfield-Jackson Atlanta International Airport. (2017). Airline rates and charges, effective October 1, 2017. Retrieved from http://www.atl.com/wp-content/uploads/2017/10/FY2018-Airline-Rates-Charges-Effective-10-1-2017.pdf

Heathrow Airport Ltd. (2018, October 16). *Heathrow offers free landing charges for a year to UK's first electric plane* [Press release]. Retrieved from https://www.heathrow.com/file_source/Company/Static/PDF/Partnersandsuppliers/Heathrow_%20Airport-2015_airport_charges_decision.pdf

Heathrow Airport Ltd. (2014, October 31). *Decision - 2015 Airport Charges* [Conditions of Use Letter]. Retrieved from http://mediacentre.heathrow.com/pressrelease/details/81/Corporate-operational-24/10194

Heimlich, J. (2016). *Status of air travel in the USA*. Ipsos Public Affairs. Retrieved from http://airlines.org/wp-content/uploads/2016/04/2016Survey.pdf

Henry, C. (2017, February 21). Kacific overcomes Ex-Im setback by teaming with JSAT on Boeing condosat order. *SpaceNews*. Retrieved from http://spacenews.com/kacific-overcomes-ex-im-setback-by-teaming-with-jsat-on-boeing-condosat-order/

International Air Transport Association (2019). Economic performance of the airline industry. Retrieved from https://www.iata.org/publications/economics/Reports/Industry-Econ-Performance/Airline-Industry-Economic-Performance-Jun19-Report.pdf

International Coalition for Sustainable Aviation. (2018). *ICSA views on a long-term climate goal for international aviation*. Retrieved from https://icsa-aviation.org/wp-content/uploads/2018/06/ICSA-views-LTG-June-2018.pdf

Japan Ministry of Environment. (2012). *Environment-related tax system in Japan*. Retrieved from http://www.env.go.jp/en/policy/tax/env-tax/20120814a_ertj.pdf

Jenn, A. Sperling, D. (2017). *A California Feebate Program can Support Transition to Zero Emission Vehicles at No Cost to Taxpayers.* UC Davis Institute of Transportation Studies Policy Brief 2017-06. Retrieved from https://escholarship.org/uc/item/3vs740q2

Jones, C. (2014, January 30). JetBlue, Southwest gain slots at Reagan Airport. *USA Today*. Retrieved from https://www.usatoday.com/story/travel/flights/2014/01/30/jetblue-reagan-national-airport--slots/5055035/

Katz, B., Kammel, B., & Bloomberg. (2019, February 14). Airbus ends production of A380 Superjumbo after Emirates rethinks order. *Fortune*. Retrieved from https://fortune.com/2019/02/14/airbus-ends-production-a380/

Kharina, A., Rutherford, D., & Zeinali, M. (2016). *Cost assessment of near- and mid-term technologies to improve new aircraft fuel efficiency*. Retrieved from the International Council on Clean Transportation, https://www.theicct.org/publications/cost-assessment-near-and-mid-term-technologies-improve-new-aircraft-fuel-efficiency

King, E. (2016, October 18). British Airways: UN aviation deal won't bite till 2030s. *Climate Home News*. Retrieved from http://www.climatechangenews.com/2016/10/18/british-airways-un-aviation-deal-wont-bite-till-2030s/

Lamigeon, V. (2013, June 13). Le vrai prix des avions d'Airbus et de Boeing. [The real price of Airbus and Boeing planes]. *Challenges*. Retrieved from https://www.challenges.fr/salon-du-bourget/le-vrai-prix-des-avions-d-airbus-et-de-boeing_10040

Liu, C., & Kharina, A. (2017). *Canada-U.S. transborder airline fuel-efficiency ranking*. Retrieved from the International Council on Clean Transportation, https://www.theicct.org/publications/transborder-airline-fuel-efficiency-ranking

Los Angeles World Airports (n.d.). *Rates and charges for the use of terminal facilities.* Retrieved from https://www.lawa.org/-/media/lawa-web/lawa-rules-and-reg/lax-passenger/rate-methodology_final.ashx?la=en&hash=7F4634930D75DD0D6076B845D2948B972280FD8D

Lutsey, N., Searle, S., Chambliss, S., & Bandivadekar, A. (2015). *Assessment of leading electric vehicle promotion activities in United States cities*. Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/assessment-leading-electric-vehicle-promotion-activities-united-states-cities-2015

Michaels, D. (2012, July 9). The secret price of a jet airliner. *The Wall Street Journal*. Retrieved from https://www.wsj.com/articles/SB10001424052702303649504577494862829051078

National Research Council. (2013). *Transitions to alternative vehicles and fuels.* National Academies Press. Retrieved from http://www.nap.edu/catalog/18264/transitions-to-alternative-vehicles-and-fuels

Office of Management and Budget. (2019). *Agency Rule List—Spring 2019. U.S. Environmental Protection Agency.* Retrieved July 25, 2019, from https://www.reginfo.gov/public/do/eAgendaMain?operation=OPERATION_GET_AGENCY_RULE_LIST&currentPub=true&agencyCode=&showStage=active&agencyCd=2000&Image58.x=27&Image58.y=19&Image58=Submit

Olmer, N., & Rutherford, D. (2017a). *International Civil Aviation Organization's Carbon Offset and Reduction Scheme for International Aviation (CORSIA)*. Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/ICAO-carbon-offset-and-reduction-scheme-international-aviation

Olmer, N., & Rutherford, D. (2017b). *U.S. domestic airline fuel efficiency ranking, 2015-2016*. Retrieved from the International Council on Clean Transportation, http://www.theicct.org/publications/us-domestic-airline-fuel-efficiency-ranking-2015-16

Organisation for Economic Co-operation and Development. (2011). *Sector understanding on export credits for civil aircraft*. Retrieved from https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=tad/asu(2011)1&doclanguage=en

Rexaline, S. (2017, July 13). What airport costs say about airlines' margins, competitiveness. *Benzinga*. Retrieved from https://www.benzinga.com/analyst-ratings/analyst-color/17/07/9768331/what-airport-costs-say-about-airlines-margins-competitiv

Rutherford, D. (2016). *Brother, can you spare three cents (for the climate)?* [Blog post]. Retrieved from the International Council on Clean Transportation website: http://www.theicct.org/blogs/staff/brother-can-you-spare-three-cents-climate

Rutherford, D., & Kharina, A. (2017). *International Civil Aviation Organization's CO2 Standard for New Aircraft*. Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/international-civil-aviation-organization-co2-standard-new-aircraft

Ryerson, M.S., Hansen, M., Hao, L., & Seelhorst, M. (2015). Landing on empty: Estimating the benefits from reducing fuel uplift in U.S. Civil Aviation. *Environmental Research Letters, 10*(2015), 094002. doi: 10.1088/1748-9326/10/9/094002

San Francisco International Airport. (2016). *2015 Climate Action Plan*. Retrieved from http://media.flysfo.com/media/sfo/community-environment/2015-sfo-climate-action-plan.pdf

Slowik, P., & Lutsey, N. (2019). *The surge of electric vehicles in United States cities*. Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/surge-EVs-US-cities-2019

Stone, L., & Borean, R. (2014). *Combined effective commercial jet fuel tax rates and fees by state*. Retrieved from https://web.archive.org/web/20180107062510/https://taxfoundation.org/combined-effective-commercial-jet-fuel-tax-rates-and-fees-state/

Stroiney, S., Levy, B., Khadilkar, H., & Balakrishnan, H. (2013). Assessing the impacts of the JFK ground management program. *32nd Digital Avionics Systems Conference*. Syracuse, New York. Retrieved from http://www.mit.edu/~hamsa/pubs/StroineyLevyKhadilkarBalakrishnanDASC2013.pdf

Swiss Federal Council. (2017). *Emissions trading scheme: Acquisition of aviation data in 2018* [Press release]. Retrieved from https://www.admin.ch/gov/en/start/documentation/media-releases.msg-id-66925.html

Tecolote Research, Inc. (2015). Aviation fuel efficiency technology assessment (AFETA). Consultant Report to the International Council on Clean Transportation. Retrieved from https://www.theicct.org/publications/aviation-fuel-efficiency-technology-assessment-afeta

Transport & Environment. (2017, October 30). *Europe refuses to give ICAO a blank cheque with aviation carbon scheme* [Press release]. Retrieved from https://www.transportenvironment.org/news/europe-refuses-give-icao-blank-cheque-aviation-carbon-scheme

Transport & Environment. (2013). *Does aviation pay its way?* [Briefing]. Retrieved from https://www.transportenvironment.org/sites/te/files/publications/2013_07_VAT%20Fuel%20Tax%20Loss%20One%20Pager_FINAL.pdf

U.S. Energy Information Administration. (2018). *U.S. Gulf Coast kerosene-type jet fuel spot price FOB* [Data set]. Retrieved from https://www.eia.gov/dnav/pet/hist/eer_epjk_pf4_rgc_dpgD.htm

U.S. Environmental Protection Agency. (2016). *EPA determines that aircraft emissions contribute to climate change endangering public health* [Press release]. Retrieved from https://19january2017snapshot.epa.gov/newsreleases/epa-determines-aircraft-emissions-contribute-climate-change-endangering-public-health_.html

U.S. Government. (2015). United States Aviation Greenhouse Gas Emissions Reduction Plan, submitted to the International Civil Aviation Organization. Retrieved from https://www.icao.int/environmental-protection/Lists/ActionPlan/Attachments/30/UnitedStates_Action_Plan-2015.pdf

Winchester, N. (2019). A Win-Win Solution to Abate Aviation CO_2 Emissions. *Journal of Air Transport Management*, 80, 101692. doi: 10.1016/j.jairtraman.2019.101692

Zeinali, M., Rutherford, D., Kwan, I., & Kharina, A. (2013). *U.S. domestic airline fuel efficiency ranking, 2010.* Retrieved from the International Council on Clean Transportation, https://www.theicct.org/publications/us-domestic-airline-fuel-efficiency-ranking-2010

Zhang, B. (2016, March 9). Boeing just gave United a massive discount. *Business Insider*. Retrieved from http://www.businessinsider.com/boeing-took-some-extraordinary-measures-to-crush-its-canadian-opposition-2016-3