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Regulating international aviation emissions without market distortion

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Summary

Commercial aviation currently accounts for about 2.4% of global carbon dioxide (CO_2) emissions. Projected growth in air traffic means this percentage could increase rapidly in the coming decades. Countries use different approaches to regulate aviation emissions; some only target emissions from flights operated by carriers registered in their country, while others aim to regulate emissions from all flights departing from their country.

This paper investigates the market effects of different regulatory methods by modeling regional carbon taxes on airfares with two approaches: accounting by country of operator registration and accounting by country of departure. Our analysis focuses on the 30 international routes with the most kilometers traveled by revenue-paying passengers (known as revenue passenger kilometers or RPKs) in three regions: China, Europe, and the United States. We applied regional carbon tax estimates to average ticket prices of these routes and compared resulting fare increases among different carriers based on regulatory approach.

Our findings show that competition is at risk of being distorted across carriers when emissions are regulated by an operator's country of registration. Distortion would occur if carriers were charged different carbon prices based on their country of registration despite operating the same routes and with similar carbon intensities. This effect could be amplified for flights between China and Europe because of the greater difference in assumed carbon prices between these regions. On average, the variance in fare increases for European carriers relative to Chinese carriers is 3.5 times greater when regulating emissions by the country of registration compared to country of departure. This outcome highlights the shortcomings of implementing emissions mitigation measures by country of registration; it provides a market advantage to operators registered in countries with fewer regulations in place, potentially deterring countries from taking swift action to decarbonize.

Background

In October 2022, the International Civil Aviation Organization (ICAO) adopted a Long-Term Aspirational Goal (LTAG) to reach net-zero emissions in international aviation by 2050 (ICAO, 2022). This agreement establishes ICAO's commitment to providing

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leadership and guidance in the regulation of international aviation emissions. Countries need to rapidly reduce their use of fossil fuels and improve the technical efficiency of their fleets to reach the net-zero goal. Carbon pricing and other market-based measures will be essential to funding the deployment of low-emissions technologies such as zero-emission planes (ZEPs) and alternative fuels (Graver et al., 2022). While the LTAG established a global target for ICAO and its member countries, it did not establish any country-level targets.

Some measures adopted by ICAO, called Standards and Recommended Practices (SARPs), are global in nature. They standardize safety, performance, and efficiency in international aviation. An example of a SARP is ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), which is a global market-based measure (MBM) designed to offset emissions that are difficult to reduce through operational and technical improvements. ICAO currently takes a route-based approach to implementing CORSIA guidelines (Olmer & Rutherford, 2016). Countries are included or exempted from CORSIA by aggregating the total CO_2 emissions from all international activity coming from flights departing their airports. Airline operators must purchase carbon credits to offset the impact of their emissions above 2020 levels on included routes, with their country of registration leading the monitoring, reporting, and verification of this process (ICAO, 2018). CORSIA will be implemented in phases to capture emissions from mature markets while allowing developing countries—which have contributed very little to historical aviation emissions—to continue their economic growth (ICAO, 2016).

Other mitigation measures are implemented on a country-by-country or regional basis. In 2010, ICAO created the SAP initiative to provide countries with resources and tools to develop national emissions mitigation plans. Within their SAPs, countries are encouraged to define policy measures they plan to implement, including deployment of sustainable aviation fuels (SAFs), introduction of ZEPs, improvements in operational and fuel efficiency, and out-of-sector measures (Mithal & Rutherford, 2023). ICAO recommends that countries regularly consult with their relevant national stakeholders and update their SAPs every 3 years to reflect actions taken. A crucial element of implementing and tracking these mitigation measures is defining a consistent emissions accounting methodology.

In its guidance on SAP development, ICAO defines two commonly used approaches in accounting for emissions (ICAO, 2019). The distinction in these approaches is key to defining the scope of SAP measures and the responsibilities of countries in the regulation of their respective aviation emissions. If they have registered operators, ICAO encourages countries to practice accounting by country of operator registration when implementing their SAPs. If they do not have registered operators or are already practicing emissions accounting by departure (for example, to align with the International Panel on Climate Change Reporting Guidelines), countries can continue following that convention.

Planned regulatory approaches vary for emissions accounting. Some countries, including the United States, plan to regulate only the emissions from their national carriers through the measures described in their State Action Plans (United States Federal Aviation Administration, 2021). Others look to regulate emissions from all flights departing from the country. This discrepancy in national policies creates the potential for market distortion and regulatory double counting of flights. ICAO emphasizes the importance of avoiding both market distortion and double counting in its key design principles within the LTAG resolution (ICAO, 2022). For example, an airline may be registered in a country that imposes certain regulations only on carriers registered in that country; these regulations would apply to that carrier on all of its routes worldwide. Another carrier flying the same international route may be registered in a country where similar regulations apply to all aircraft departing from that country's airports; these regulations would not apply to the carrier elsewhere in the world. Thus, the first carrier—with regulations already applied by its country of registration—could be faced with an additional burden in countries where all departing flights are regulated.

As countries act to implement their SAPs, national regulations covering international aviation will expand. Inconsistent approaches in country-level emissions mitigation strategies within SAPs could make it more challenging to both implement and evaluate those strategies. Accordingly, the results of this analysis are relevant to all forms of regulation reliant on emissions accounting, including emissions-trading systems like the European Union Emissions Trading System (EU ETS), and policies to promote SAFs. Clearer regulatory methodologies are needed to plan and achieve effective mitigation pathways to help reach the global net-zero target.

This paper is structured as follows. We first introduce the methods and assumptions behind our carbon price modeling of top international routes between China, Europe, and the United States. Then, we present our findings in each region-pair, explore the regulatory consequences of these findings, and discuss future development of this research.

Methods

Two emissions accounting options were assessed in this study: regulation by country of operator registration and regulation by country of departure. To analyze the market effects of these approaches in international aviation, we examined the changes in airfare if carbon pricing schemes of varying ambition were implemented under each scenario. A carbon price is a fixed cost charged per tonne of CO_2 emitted. Each kilogram of jet fuel burned results in 3.16 kg of CO_2 emissions. In the case of aviation, we assume that a carbon tax would be distributed among all passengers on a flight. The carbon intensity of a single passenger varies across seating classes but was assumed to be constant for all passengers in our calculations because of data limitations.[1]

We estimated potential regional carbon prices to conduct this analysis for international flights traveling between China, Europe, and the United States. Note that all prices are hypothetical as no governments have yet imposed a carbon cost on international aviation beyond intra-European Union (EU) flights. The United States has not yet introduced any carbon pricing, so the social cost of carbon—a regulatory metric used by the Biden administration—was treated as an estimate. At the time of this analysis, this metric was priced at $51.00 per tonne of CO_2 (Mindock, 2022). For Europe, the forecasted 2023 average EU ETS value of $86.40 per tonne of CO_2 was used (Twidale, 2023). China does not currently have regional carbon pricing in place, so we used the 2022 average of its national ETS value, which was $8.22 per tonne of CO_2 (International Carbon Action Partnership, 2022).[2]

ICAO's CORSIA Aeroplane to State Operator List (first, second, and third editions) (ICAO, n.d.) was used to identify the operators registered to each of these countries or regions. Relevant operators and their respective international routes were located within the ICCT Global Aviation Carbon Assessment (GACA) model 2019 database, which reports a global inventory for commercial aviation activity with carrier-level CO_2 emissions and fuel burn data (Graver et al., 2020). The top ten RPK routes departing from each of our three regions of interest were identified in the GACA 2019 dataset.

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[1] In our analysis, passengers were assigned the full carbon cost of a given flight. In practice, some of that cost would be accrued to belly freight carried on passenger flights. The relative belly freight volumes across different carriers are also likely to vary, but we expect the effects of this assumption on carrier-level carbon intensity to be small.

[2] International flights are not currently subject to regional carbon pricing schemes; in reality, they would only be charged for carbon offsetting based on CORSIA. Hong Kong SAR and the United Kingdom may maintain their own ETS for international aviation in the future, but the Chinese national ETS and EU ETS were used respectively in this study as a simplifying assumption.

Routes connecting to countries outside of these regions or operated by carriers registered to other governments were excluded from this study. Table 1 shows the top 30 routes; they cover 153.8 billion RPKs, or about 19% of the total international RPKs traveled between these regions. There are 16 carriers represented in our analysis, with a total of 235 aircraft operating these routes in 2019.

Table 1. Top 30 international RPK routes between China, Europe, and the United States in 2019.

Region pair	Departure airport	Arrival airport	Total RPKs (billions)	Number of operators	Number of distinct aircraft types
China–Europe	HKG	LHR	7.55	3	4
China–Europe	PVG	CDG	4.56	3	8
China–Europe	PVG	FRA	3.40	4	11
China-U.S.	TPE	SFO	5.28	3	3
China–U.S.	HKG	LAX	5.27	3	5
China–U.S.	PVG	LAX	4.49	4	9
China–U.S.	TPE	LAX	4.42	2	4
China–U.S.	HKG	SFO	5.78	2	7
China–U.S.	PEK	LAX	3.35	2	5
China–U.S.	HKG	JFK	3.26	1	2
U.S.–Europe	JFK	LHR	8.67	4	13
U.S.–Europe	LAX	LHR	6.89	4	10
U.S.–Europe	LAX	CDG	4.75	5	10
U.S.–Europe	JFK	CDG	4.61	5	15
U.S.–Europe	SFO	LHR	4.51	3	7
U.S.–China	SFO	HKG	5.48	3	7
U.S.–China	SFO	TPE	5.25	3	4
U.S.–China	LAX	HKG	4.98	3	3
U.S.–China	LAX	PVG	4.49	5	10
U.S.–China	LAX	TPE	4.38	2	6
Europe–U.S.	LHR	JFK	8.61	4	13
Europe–U.S.	LHR	LAX	6.85	4	10
Europe–U.S.	CDG	LAX	4.76	5	11
Europe–U.S.	CDG	JFK	4.59	5	15
Europe–U.S.	LHR	SFO	4.47	3	7
Europe–U.S.	LHR	ORD	4.01	3	7
Europe–U.S.	LHR	MIA	3.66	3	6
Europe–China	CDG	PVG	4.56	3	8
Europe–China	FRA	PVG	3.40	4	11
Europe–China	LHR	HKG	7.55	3	4

Sources: Graver et al., 2020; ICAO, n.d.

Of these 30 routes, we selected two routes departing from each region for detailed analysis. The average fares for these routes were identified using the International Bureau of Aviation (IBA) 2019 dataset, which contains route-level fares averaged across all seating classes and airline carriers. For routes with fares not available within this dataset, we used a regional average dollar per kilometer value—which was extrapolated from the IBA fare data for different flight distance ranges—to calculate the route-level fare. While there is variation in fares at the carrier level, the scope of this analysis was limited to route-level averages due to the availability of fare data.

Equation 1 was used to calculate the average CO_2 emissions per passenger as follows:

$$CO_2\ emissions\ (per\ passenger) = \frac{Total\ flight\ CO_2\ emissions}{Available\ seats \times Load\ factor} \qquad (1)$$

Average total flight CO_2 emissions were taken from the GACA 2019 data set which models flight emissions using PIANO 5 software and validates the results with real-world fuel burn data (Graver et al. 2020). GACA reports tank-to-wake (TTW) CO_2 emissions specific to the aircraft type, available seats, passenger load factor, and number of passengers. These per-passenger CO_2 emissions values were averaged at the carrier level for each route in our analysis.

Equation 2 was used to calculate the average increase in airfare as a product of CO_2 emissions per passenger, regional carbon price, and fuel cost pass-through rate. The fuel cost pass-through rate was assumed to be constant across all markets at 75%, with airlines absorbing a portion of cost increases to remain competitive (Dray et al., 2014; Koopmans & Lieshout, 2016; Wang et al., 2017).

$$\textit{Average increase in airfare (in USD)} = \\ \textit{CO}_2\textit{ emissions per passenger} \times \textit{Regional carbon price} \times \textit{Fuel cost pass-through rate} \quad (2)$$

For each route, we calculated the average airfare increase using both methods of regulation. When calculating the carbon tax (and subsequent fare increases) by country of registration, the carbon price of each operator's ICAO registration country was used. When calculating by country of departure, all operators were charged the carbon price of the departure country on a given route. The average carbon intensity of each carrier varies due to factors including aircraft type, payload, and seating arrangement. This variance was present regardless of the emissions attribution method and was considered in each case when assessing the source of fare disparity.

Results

In this section, we highlight the key findings of our analysis, presenting a route analysis of two top routes from each region followed by a discussion of the regional effects of allocation methods on fare increases and regulation.

Table 2 presents the average emissions per passenger, absolute fare increases in U.S. dollars, and percentage increases across all carriers from carbon pricing using both regulation approaches for six one-way routes. These increases are based on 2019 IBA fare data and the associated fuel efficiency, operational efficiency, and jet fuel costs.

Table 2. Changes in fare due to carbon pricing on top China, Europe, and U.S. routes.

Route	Carrier	Average CO_2 per passenger (tonnes)	Absolute fare increase in USD by		Percentage fare increase by	
			Country of departure	Country of operator registration	Country of departure	Country of operator registration
1. HKG–LHR (Hong Kong–London)	**British Airways**	1.01	$6.23	$65.50	1.18%	12.41%
	Cathay Pacific Airways	0.98	$6.07		1.15%	
	Virgin Atlantic Airways	0.90	$5.56	$58.44	1.05%	11.08%
2. HKG–SFO (Hong Kong– San Francisco)	**Cathay Pacific Airways**	0.98	$6.04		1.51%	
	Hong Kong Airlines	0.86	$5.30		1.33%	
	United Airlines	1.17	$7.21	$44.75	1.81%	11.22%
3. CDG–PVG (Paris–Shanghai)	**Air China**	0.86	$55.48	$5.28	13.84%	1.32%
	Air France	0.88	$56.76		14.16%	
	China Eastern Airlines	0.99	$64.30	$6.12	16.04%	1.53%
4. LHR–JFK (London–New York)	**American Airlines**	0.52	$33.75	$19.92	9.45%	5.58%
	British Airways	0.56	$36.06		10.10%	
	Delta Airlines	0.56	$36.06	$21.48	10.10%	6.02%
	Virgin Atlantic Airways	0.62	$40.24		11.27%	
5. LAX–HKG (Los Angeles–Hong Kong)	**American Airlines**	1.12	$42.57		7.31%	
	Cathay Pacific Airways	1.57	$60.19	$9.70	10.34%	1.67%
	Hong Kong Airlines	1.11	$42.48	$6.85	7.30%	1.18%
6. JFK–CDG (New York–Paris)	**Air France**	0.58	$22.19	$37.60	6.43%	10.90%
	American Airlines	0.59	$22.62		6.55%	
	Delta Airlines	0.58	$22.14		6.42%	
	Norwegian Air Shuttle	0.54	$20.59	$34.89	5.97%	10.11%
	XL Airways France	0.43	$16.50	$27.95	4.78%	8.10%

Among these, Route 1 (HKG–LHR) and Route 3 (CDG–PVG) are the most susceptible to fare distortion. For a flight from Hong Kong to London (Route 1, HKG–LHR), when regulating by country of registration, a British Airways passenger would be charged $65.50 (12.41% fare increase) in carbon taxes, while a Cathay Pacific Airways passenger would be charged $6.07 (1.15% fare increase). This discrepancy is eliminated when regulating by departure, as passengers of all carriers would be charged a common Chinese carbon price on their respective carbon intensities. This approach results in the British Airways airfare increasing by $6.23 (1.18% fare increase) and the Cathay Pacific Airways airfare increasing by $6.07 (1.15% fare increase).

Similarly, for a flight from Paris to Shanghai (Route 3, CDG–PVG), when regulating by country of registration, an Air China passenger would be charged only $5.28 in carbon tax (1.32% fare increase), while an Air France passenger would be charged $56.76 (14.16% fare increase). These flights are nearly equal in carbon intensity, so the fare difference comes almost entirely from the regulation method. On the other hand, when regulating by departure, the fare increase becomes $55.48 (13.84% fare increase) for the Air China flight and $56.76 (14.16% fare increase) for the Air France flight, with the 0.32% difference being attributable to the higher average carbon intensity of Air France aircraft.

Routes between the United States and Europe would not be affected as much by the regulation method, though there are still disparities among carriers. On a flight from London to New York (Route 4, LHR–JFK), when regulating by country of registration, a Delta Airlines passenger would be charged $21.48 (6.02% fare increase) in taxes, while a British Airways passenger would be charged $36.06 (10.10% fare increase). Given these two carriers are operating routes with equal carbon intensities (0.56 tonnes of CO_2 per passenger) and would have identical carbon taxes when regulating by departure, this regulation approach provides a market advantage to Delta Airlines.

Figure 1 illustrates the average fare increase from carbon pricing across the top 30 routes for carriers registered in each region. This average was calculated by summing the increases across the top 30 routes and weighting each route at the carrier level by its percentage of regional RPK coverage. As seen in Figure 1, when calculating the fare increase by departure, there is more consistency between operators. European carriers would have the greatest average fare increase across both regulation methods due to a higher carbon tax being imposed across a larger share of their operations.

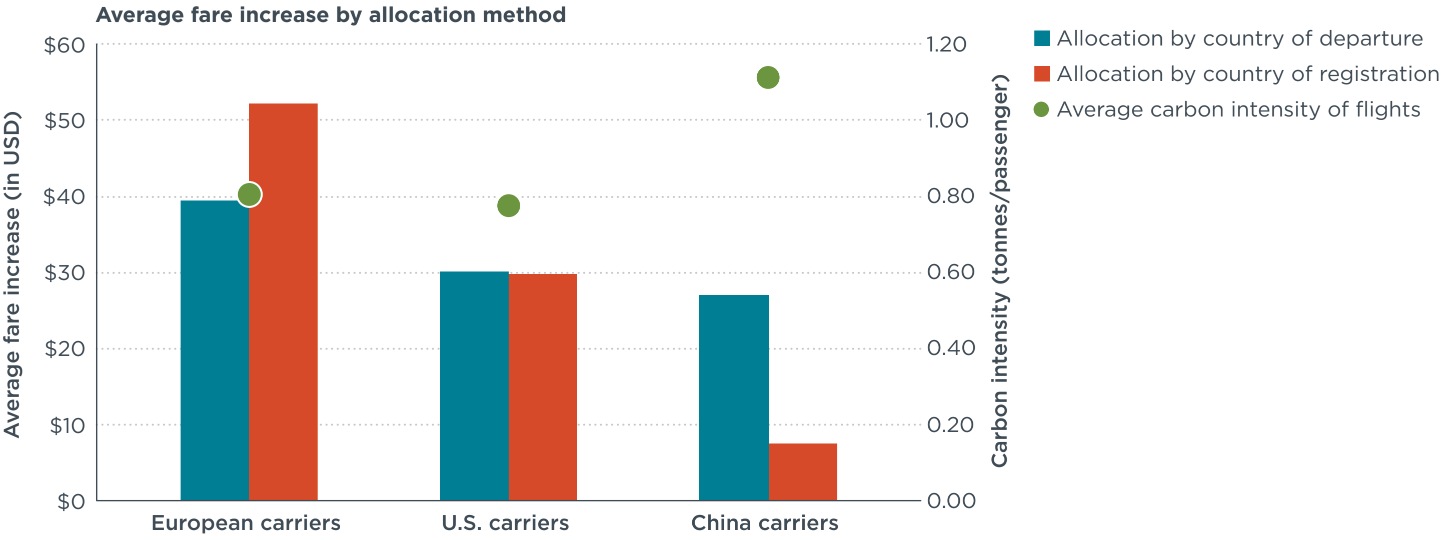

Figure 1. Average fare increase for 30 routes by carrier country of registration and allocation method, along with the average carbon intensity of routes by carrier country of registration.

The average fare increases for carriers registered in Europe, the United States, and China when regulating by departure would be $39.48, $30.11, and $26.96, respectively. Thus, the average passenger on a European carrier would experience a $13 larger fare increase than the average passenger on a Chinese carrier on representative international routes. When regulating emissions by country of registration, these averages shift to $52.13 for European carriers, $29.73 for U.S. carriers, and $7.52 for Chinese carriers. This represents a $45 difference in the average fare increase for European versus Chinese carriers, or 3.5 times larger than emissions charged based on country of departure. Given that Chinese carriers have the highest average carbon intensity per flight at 1.11 tonnes of CO_2 per passenger (largely due to the greater average stage-length of flights), this result shows a clear market advantage for carriers registered in countries with low carbon taxes.

Conclusions

Our analysis demonstrates the inconsistency of implementing regional market-based measures by country of operator registration. As consumer behavior is largely driven by ticket prices, carriers registered in countries with little-to-no carbon pricing in place would have a market advantage on common routes. Carriers would be incentivized to register their companies in countries with low carbon pricing to avoid losing customers; conversely, governments could give an advantage to carriers based in their countries by adopting the lowest possible carbon price. This would also potentially decrease the amount of revenue generated through carbon taxes to develop and deploy low-emissions technologies.

Based on this study's assumptions, carriers registered in China would be charged about 10% of the carbon tax charged to European carriers on the same routes. This, in turn, would result in lower prices for consumers purchasing tickets from Chinese carriers compared to European carriers. While the carbon prices used were estimates, this method of regulation adds an inherent dependency on a relatively arbitrary metric, location of registration, for flights that are otherwise identical. This would be the case for other regulations outlined in SAPs as well, like SAF policies. ICAO should encourage member countries, in its guidance for SAP development, to design regulations and mitigation strategies that apply to all flights departing from their respective airports. This guidance to regulate by departure country would then serve as a basis for accounting principles in carbon pricing and other areas of aviation climate policy. Additionally, adopting a unified accounting strategy across all markets ensures that international aviation emissions are covered by the relevant regional regulations with minimal leakage, further aligning country trajectories with the global net-zero goal.

Our results are particularly relevant for large, multinational passenger and freight airlines that operate flights in many regions. In these cases, the country of registration does not accurately capture the full geographic coverage of their operations and the resulting emissions, yet they would still be regulated in the context of that country.

When we applied a carbon price by country of departure, there was uniformity in the unit charge per tonne of carbon for each carrier on a route. The only external variable affecting the net fare increase was each individual flight's carbon intensity; the impact of carbon intensity on fares could help push airlines to invest in fuel efficiency improvements and low carbon fuels.

Future development of this area of research can explore domestic aviation markets and whether there needs to be a distinction in regulatory policy for carriers operating only domestic routes. Another area of study includes examining the monitoring, reporting, and verification (MRV) procedures used by different countries to measure and regulate fuel use. The results of this paper, demonstrating the benefits of emissions accounting by departure, can be used while assessing countries' progress towards net-zero emissions targets in the coming years.

References

Dray, L., Evans, A., Reynolds, T., Schäfer, A. W., Vera-Morales, M., & Bosbach, W. (2014). Airline fleet replacement funded by a carbon tax: An integrated assessment. *Transport Policy*, *34*, 75–84. https://doi.org/10.1016/j.tranpol.2014.02.021

Graver, B., Rutherford, D., & Zheng, S. (2020). *CO_2 emissions from commercial aviation: 2013, 2018, and 2019.* International Council on Clean Transportation. https://theicct.org/publication/co2-emissions-from-commercial-aviation-2013-2018-and-2019/

Graver, B., Zheng, S., Rutherford, D., Mukhopadhaya, J., & Pronk, E. (2022). *Vision 2050: Aligning aviation with the Paris Agreement*. International Council on Clean Transportation. https://theicct.org/publication/global-aviation-vision-2050-align-aviation-paris-jun22/

International Carbon Action Partnership. (2022). *China National ETS* [dataset]. https://icapcarbonaction.com/en/ets/china-national-ets

International Civil Aviation Organization. (2016). *Resolution A39-3: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Global market-based measure (MBM) scheme*. https://www.icao.int/environmental-protection/documents/resolution_a39_3.pdf

International Civil Aviation Organization. (2018). *Annex 16—Environmental Protection, Volume IV, Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA): Vol. IV* (1st ed.). https://www.icao.int/environmental-protection/CORSIA/Pages/SARPs-Annex-16-Volume-IV.aspx

International Civil Aviation Organization. (2019). *Guidance on the Development of States' Action Plans on CO_2 Emissions Reduction Activities* (Doc 9988) (3rd. ed) https://store.icao.int/en/guidance-on-the-development-of-states-action-plan-on-co2-emissions-reduction-activities-doc-9988

International Civil Aviation Organization. (2022). Resolution A41-21: Consolidated statement of continuing ICAO policies and practices related to environmental protection—climate change. In *Resolutions adopted by the Assembly*, (94–105). https://www.icao.int/Meetings/a41/Documents/Resolutions/a41_res_prov_en.pdf

International Civil Aviation Organization. (n.d.). *CORSIA Aeroplane Operator to State Attributions - previous versions*. https://www.icao.int/environmental-protection/CORSIA/Pages/Aeroplane-Operator-to-State.aspx

Koopmans, C. & Lieshout, R. (2016). Airline cost changes: To what extent are they passed through to the passenger? *Journal of Air Transport Management*, *53*, 1–11. https://doi.org/10.1016/j.jairtraman.2015.12.013

Mindock, C. (2022, October 21). *Biden "social cost of carbon" climate risk measure upheld by U.S. appeals court*. Reuters. https://www.reuters.com/markets/commodities/biden-social-cost-carbon-climate-risk-measure-upheld-by-us-appeals-court-2022-10-21/

Mithal, S., & Rutherford, D. (2023). *Towards net-zero aviation State Action Plans*. International Council on Clean Transportation. https://theicct.org/publication/state-action-plans-oct23/

Olmer, N., & Rutherford, D. (2016). *Is carbon neutral growth on the horizon for aviation? That depends on your definition* [Blog]. International Council on Clean Transportation. https://theicct.org/blogs/staff/MBM-carbon-neutral-growth-horizon-for-aviation

Twidale, S. (2023, January 25). *Analyst EU carbon price forecasts edge higher but risks remain*. Reuters. https://www.reuters.com/business/energy/analyst-eu-carbon-price-forecasts-edge-higher-risks-remain-2023-01-25/

United States Federal Aviation Administration. (2021). *United States 2021 aviation climate action plan*. https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf

Wang, B., O'Sullivan, A., Dray, L., Al Zayat, K., & Schäfer, A. (2017, July 5–8). *Modelling the pass-through of airline operating costs on average fares in the global aviation market*. [Conference session]. 21st ATRS (Air Transport Research Society) World Conference, Antwerp, Belgium. http://www.atslab.org/wp-content/uploads/2017/08/Wang_ATRS _248.pdf