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Variation in aviation emissions by itinerary: The case for emissions disclosure

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Summary

The environmental price tag of commercial air travel has become more visible to consumers and policymakers in recent years. Growth in travel demand continues to outstrip improvements in aircraft and operational fuel efficiency, leading to increased emissions of greenhouse gases (GHG). Carbon offsets may help assuage the concerns of environmentally conscious consumers, but offsetting does not directly reduce emissions from planes themselves. Other consumer options for reducing emissions include avoiding flying altogether or using alternative modes of transport. Still another option, largely unstudied but the focus of this paper, is to give consumers the ability to choose less-emitting flights, thereby rewarding emissions reductions by airlines.

This paper investigates the CO_2 intensities of different itineraries on 20 popular U.S. domestic routes in 2019 using ICCT's Global Aviation Carbon Assessment (GACA) model. On average, we find that the least-emitting itinerary on a route can emit 63% less CO_2 than the most-emitting option, and 22% less than the route average. The wide emissions gaps point to potentially significant climate benefits in encouraging consumers to choose the lowest-emitting flights. However, identifying lower-emitting itineraries is not straightforward. While nonstop flights and the use of fuel-efficient aircraft or airlines are likely to yield fewer emissions than alternatives on the same route, there are many exceptions depending on seating configuration, load factor, and other operational parameters.

The paper also investigates the relationship between flight emissions and ticket price. We find that consumers can secure lower-emitting itineraries even if they filter for cheaper tickets. In most cases, the least-emitting itinerary is relatively inexpensive, and the cheaper itineraries are likely to be lower-emitting than the average. The results suggest that choosing less-emitting itineraries likely should not increase costs for consumers.

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The analysis highlights the value to consumers of disclosing flight emissions at the point of purchase. Credible and standardized emissions disclosures will help meet consumer demand for low-emitting flights, but will require collaborative efforts from regulators, airlines, travel search engines, and environmental organizations. Once in place, climate-informed consumer choices could accelerate the decarbonization of air travel from the supply side as well, as airlines see a payoff in offering more low-emitting options.

Background

Carbon dioxide (CO_2) emissions from commercial aviation are growing rapidly and are on track to triple by 2050, under a pre-COVID business-as-usual scenario. At that point they could claim up to a quarter of the global 1.5°C carbon budget (IATA, 2013; Pidcock & Yeo, 2016). Of all CO_2 emitted from commercial aircraft in 2019, passenger air travel was responsible for about 85%, or 785 million tonnes (Graver, Rutherford, & Zheng, 2020).

Consumers are increasingly aware that air travel, whether for business or leisure, carries a significant environmental cost. Air travel can account for a large portion of an individual's carbon footprint, especially for frequent flyers (Rosenthal, 2013), yet the industry is only beginning to develop decarbonizing technologies that would lower emissions and appeal to consumers: sustainable aviation fuels are in early stages of commercialization, while electricity- or hydrogen-powered aircraft are still at the research and development stage. In the absence of mature technological solutions, the public increasingly considers the option of flying less to be a serious climate protection strategy, as evidenced by the emergence of the *flygskam* ("flying shame") movement in Europe. This is a concerning trend for airlines. Meanwhile, the COVID-19 pandemic is fueling more scrutiny of business air travel, with some analysts estimating that up to 36% of business travel may never return (McCartney, 2020).

However, Davison et al. (2014) identified a value-action gap between consumers' awareness of the climate impacts of air travel and their behaviors: not all climate-conscious consumers can or do cut back air travel. An alternative for these consumers could be to choose less-emitting flights based on emissions information available at the point of ticket purchase. Airlines would likely prefer a system of accurate climate disclosure to the unwelcome alternative: an end to flying for many travelers.

Currently, public information on flight emissions is scarce. U.S. carriers report their operations (T-100) and financial data including fuel burn (Form 41) quarterly to the Bureau of Transportation Statistics (BTS) of the U.S. Department of Transportation (DOT). The granularity of the data varies—it can be as coarse as by carrier and aircraft type—but is not precise enough to determine emissions by itinerary. Several online carbon calculators, including those from the International Civil Aviation Organization (ICAO), ClimateCare, and individual airlines, allow users to estimate CO_2 emissions for origin-destination airport pairs.[1] However, these online calculators do not provide specific information on carrier or aircraft type and cannot be used by consumers to choose less-emitting flights; they are mostly intended to assist in calculating the carbon offsets needed for a typical flight on a given route.

1 ICAO's carbon emissions calculator can be accessed at https://www.icao.int/environmental-protection/Carbonoffset/Pages/default.aspx. The carbon calculator developed by ClimateCare can be accessed at https://climatecare.org/calculator/. United Airlines' carbon offset calculator can be accessed at https://united.conservation.org/.

Through years of study of airline fuel efficiency, the International Council on Clean Transportation (ICCT) has analyzed and publicized the fuel efficiency gap among different carriers in the same market, as well as factors that affect fuel efficiency. Most recently, we found that the gap between the most and least fuel-efficient airlines on U.S. domestic operations was 26% in 2018 after controlling for differences in airlines' business models (Zheng, Graver, & Rutherford, 2019). This gap appeared to be wider for international flights on a passenger- kilometer basis. For instance, the fuel efficiency gap between the most and least fuel-efficient airlines was 64% for the transpacific market (in 2016) and 63% for the transatlantic market (in 2017) (Graver & Rutherford, 2018a, 2018b). Overall, when airlines deploy more fuel-efficient aircraft, include less premium seating, and load fuller planes (both passenger and belly freight), their average fuel efficiency beats that of their peers.

ICCT research has also identified a large gap in route-specific fuel efficiency—up to 90% on a passenger-mile per unit-of-fuel basis for popular U.S. domestic routes (Zeinali et al., 2013). An airline's overall fuel efficiency does not always translate into its route-specific performance. Aircraft type and layover location introduce variations in fuel efficiency[2] on specific itineraries. Similarly, aircraft type plays an important role in fuel efficiency on U.S.-Canada transborder routes (Liu & Kharina, 2017). Choosing single-aisle, mainline aircraft or turboprops over regional jets could likely lead to lower-emitting trips, although relative airline fuel efficiency performance varies across routes. Carrier performance metrics, while a useful general benchmark, do not supply all the information needed by consumers to make informed choices about specific flights.

Research is limited on the climate benefits of offering consumers information for choosing lower-emitting flights. Literature on consumer behavior change regarding air travel has typically focused on the willingness to pay for carbon offsets and on substituting flights with alternative transportation modes (Mair, 2011; van Birgelen et al., 2011; Sgouridis et al., 2011). In addition, Mayer et al. (2012) and Wittmer and Wegelin (2012) discussed consumer perceptions of the sustainability practices of airlines and how these might affect booking decisions.

The role of flight-level emissions disclosure in influencing consumer behavior has been studied by Baumeister (2017). The author estimated flight-specific fuel burn based on USDOT data, which revealed very different emissions profiles for flights on the same route. The analysis highlighted the limited usefulness of emissions calculators, which rely on average values of flight data. The study also evaluated environmental organizations' two most recommended strategies (see also Rutherford, 2019) for choosing less-emitting flights—flying on fuel-efficient aircraft and flying non-stop—and found clear exceptions to each, i.e., the recommendations do not always lead consumers to the most climate-friendly flights. These findings suggest a need for credible emissions disclosures at the time of booking.

Travel search engines like Google Flights, Kayak, and Skyscanner have introduced "eco-flight filters" into their platforms. These filters label flights with lower-than-average emissions among all search results, but the absolute CO_2 emissions for each itinerary are not currently shown. The emergence of these filters reflects growing consumer interest in climate disclosure at the time of purchase. They are an example

2 Sustainable aviation fuels (SAFs) generated from biofuels and renewable electricity (e-fuels) could one day influence the GHG intensity of airlines. But SAFs currently account for about 0.05% of global jet fuel use (IATA, 2020), and therefore do not materially impact airline emissions. For this reason, this work focuses on fuel efficiency alone.

of environmental labeling, a common tool applied to many consumer products to assess their sustainability. When deployed with integrity, labels can provide concise and easy-to-digest information for environmentally conscious consumers, but they are also susceptible to being over-simplified and misleading. In contrast, direct disclosure of emissions tends to be more objective and informative. Baumeister & Onkila (2017) have found that an eco-label for flights could be an effective way to inform consumers and nudge them toward lower-emitting flights.

Researchers at University of California, Davis surveyed university employees on their flight purchasing preferences when hypothetical price and emissions estimates were presented side by side (Amenta & Sanguinetti, 2020). The surveyed employees expressed willingness to pay more for a lower-emitting flight—about $200 per tonne of CO_2-equivalent of emissions saved, which is much higher than the carbon offset prices seen today. The emissions information also reportedly provided more incentives for the employees to choose direct flights from a non-preferred airport over flights with a layover leaving from a preferred airport. This study indicates that presenting emissions information at the time of booking can indeed affect consumer behavior and emissions.

This paper examines the emission intensities of different itineraries on the same route, based on airline- and aircraft-specific fuel burn modeling. The analyses highlight the gap of CO_2 emissions per passenger between most- and least-emitting itineraries on each studied route. We also explore the relationship between itinerary emissions and various itinerary characteristics, including number of stops, aircraft deployed, carrier, and ticket price.

Methods

This paper analyzed a total of 20 frequently traveled U.S. domestic routes. Sixteen of these routes were selected based on the high number of departures and total revenue passenger-miles (RPMs) in 2019. On the remaining four selected routes, low-cost carriers account for more than 60% of market share; these routes were selected based on number of departures in 2019 as well as on carrier diversity.[3]

For this analysis, the distinction between ***itineraries*** and ***routes*** is important. A route encompasses the entire set of itineraries a consumer might purchase between a pair of origin and destination airports. Itineraries may be direct, or broken into multiple legs, with one or more layover airports between legs[4] (Figure 1). For each route, itinerary data including origin airport, destination airport, distance, carrier and aircraft type for each leg, passenger count, and average fare were retrieved from Airline Data Inc. (2021). The platform provides processed data from Bureau of Transportation Statistics' (BTS) Airline Origin and Destination Survey (DB1B), which provides detailed information for a 10 percent sample of U.S. domestic travel itineraries.

3 U.S. low-cost carriers included Allegiant Air, Frontier Airlines, JetBlue Airways, Southwest Airlines, Spirit Airlines, and Sun Country Airlines. These carriers were identified based on a list published by the International Civil Aviation Organization (ICAO, 2017).

4 The generic term "flight," where used in this document, indicates aircraft operations generally; its use is not confined to routes, itineraries, or legs.

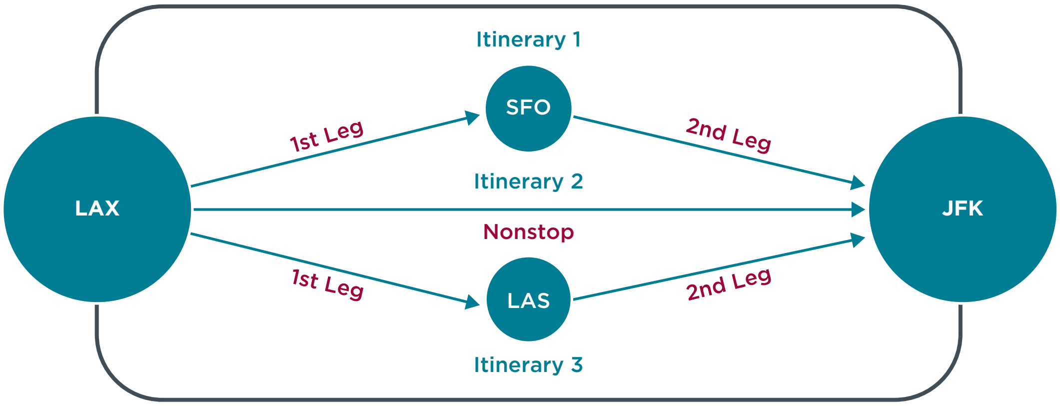

Figure 1. Relationship among routes, itineraries, and legs.

Summary statistics for the 20 selected routes are shown in Table 1, arranged in order of declining stage length (flight distance).

Table 1. Routes selected for analysis, one-way statistics, 2019

Origin	Destination	Passengers	Revenue Passenger Miles	Stage Length (mi)
Boston Logan International Airport (BOS)	San Francisco International Airport (SFO)	6,706,270	18,133,754,080	2,704
Los Angeles International Airport (LAX)	Boston Logan International Airport (BOS)	6,755,450	17,638,479,950	2,611
San Francisco International Airport (SFO)	John F. Kennedy International Airport (JFK)	9,118,780	23,581,165,080	2,586
Newark Liberty International Airport (EWR)	San Francisco International Airport (SFO)	8,701,530	22,319,424,450	2,565
Los Angeles International Airport (LAX)	Honolulu International Airport (HNL)	6,802,070	17,386,090,920	2,556
Los Angeles International Airport (LAX)	John F. Kennedy International Airport (JFK)	15,843,690	39,213,132,750	2,475
Los Angeles International Airport (LAX)	Newark Liberty International Airport (EWR)	7,883,580	19,346,305,320	2,454
Hartsfield–Jackson Atlanta International Airport (ATL)	Los Angeles International Airport (LAX)	6,434,330	12,526,152,249	1,947
O'Hare International Airport (ORD)	San Francisco International Airport (SFO)	6,500,980	12,000,809,080	1,846
Los Angeles International Airport (LAX)	O'Hare International Airport (ORD)	9,407,400	16,408,606,272	1,744
Orlando International Airport (MCO)	**Luis Muñoz Marín International Airport (SJU)**	**5,804,590**	**8,505,672,421**	**1,465**
Fort Lauderdale-Hollywood International Airport (FLL)	**LaGuardia Airport (LGA)**	**6,401,740**	**7,720,872,914**	**1,206**
Orlando International Airport (MCO)	**Philadelphia International Airport (PHL)**	**8,215,290**	**9,019,867,899**	**1,098**
Seattle-Tacoma International Airport (SEA)	Los Angeles International Airport (LAX)	8,612,110	8,215,952,940	954
Newark Liberty International Airport (EWR)	Orlando International Airport (MCO)	9,431,090	8,839,197,621	937
Hartsfield–Jackson Atlanta International Airport (ATL)	LaGuardia Airport (LGA)	8,939,690	6,810,220,977	762
LaGuardia Airport (LGA)	O'Hare International Airport (ORD)	12,725,710	9,327,945,430	733
Denver International Airport (DEN)	**McCarran International Airport (LAS)**	**6,478,810**	**4,575,492,463**	**706**
Los Angeles International Airport (LAX)	San Francisco International Airport (SFO)	11,846,390	3,992,233,430	337
Los Angeles International Airport (LAX)	McCarran International Airport (LAS)	9,040,230	2,133,494,280	236

Note: Low-cost carrier dominant routes indicated in red.

We estimated the full flight fuel burn of each leg in an itinerary using our Global Aviation Carbon Assessment (GACA) model (Graver, Rutherford, & Zheng, 2020). GACA models fuel burn using Piano 5 aircraft files, with adjusted distance, taxi time, and payload. Fuel burn estimates for U.S. domestic flights were validated against real-world fuel consumption based on various data sources described in Graver & Rutherford (2021). The resulting inventory provides data on fuel burn for each unique leg-airline-aircraft combination. Each leg in the DB1B database was matched with GACA based on origin-destination and airline; when more than one aircraft type was deployed in 2019, the most prevalent aircraft flown, defined by number of departures, was used for fuel burn estimates. The CO_2 emissions associated with burning one tonne of jet fuel were estimated using the internationally accepted constant of 3.16 tonnes (ICAO, 2020), assuming a density of 0.8 kilograms per liter of jet fuel (ICAO, 2019). For passenger flights with belly freight on board, full flight fuel burn was apportioned to passengers based on the passenger versus freight payload mass, taking into account the furnishings and service equipment used for passengers.

To compare the carbon intensities of different itineraries, CO_2 emissions per passenger was calculated for each leg and summed for the entire itinerary, based on 2019 operations. Route averages were weighted by the number of passengers on each itinerary; this helps account for the fact that a majority of passengers travel on the handful of direct flights on each route, while the remaining passengers spread out among various one-stop or two-stop itineraries. Infrequently traveled itineraries, defined as those with more than two stops or fewer than 100 passengers recorded in the survey, were excluded from the analysis. A small number of itineraries that were recorded in DB1B survey but not represented in T100 operations, accounting for about 2% of the frequently traveled itineraries, were also excluded. In total, 771 itineraries over the 20 routes are included in the analysis.

Fare information was analyzed to investigate the relationship between itinerary carbon intensity and ticket price. The fare data used represent an average of ticket price across cabin classes and for both fared and unfared ($0) passengers.[5] For consistency, total flight averages were used for both per passenger CO_2 emissions and fares rather than attempting to break these down by cabin class.[6]

Data Analysis

We present the highest, lowest, and passenger-weighted average CO_2 emissions per passenger[7] for all analyzed itineraries on each of the 20 routes in Table 2. The table also shows the percentage differences between (1) most- and least-emitting itineraries and (2) lowest versus average emissions per passenger on the route.

5 The fare data analyzed do not include ancillary fees charged by airlines. Ancillary fees make up a larger proportion of revenues for low-cost carriers than for legacy carriers (Olmer & Rutherford, 2017); therefore, ticket price only serves as a proxy of the total cost of an itinerary and may represent larger cost differentials among carriers.

6 Graver, Rutherford, & Zheng (2020) found that the, after accounting for the greater cabin space inhabited, first and business class seating emitted between 2.6 and 4.3 times as much CO_2 per passenger km as economy seating on commercial flights in 2019. Since flights analyzed here include varying amounts of premium seating, different results could be attained by analyzing emissions and fares by seating class. That is beyond the scope of this document.

7 The route average emissions is a weighted average of all analyzed itineraries on that route based on number of passengers on each itinerary, as opposed to a simple average of all itineraries. Passenger-weighting is important because passengers already tend to choose direct flights to reduce travel time, which has the co-benefit of reducing fuel use and emissions.

Table 2. Emissions per passenger on each analyzed route.

Origin	Destination	Number of itineraries	One-way Emissions per Passenger (kg CO_2/pax)			Low vs average difference	Low vs high difference
			Lowest	Average	Highest		
EWR	**SFO**	72	306	410	612	-25%	-50%
BOS	**SFO**	43	268	407	651	-34%	-59%
SFO	**JFK**	25	306	389	593	-21%	-48%
LAX	**BOS**	60	258	369	603	-30%	-57%
LAX	**EWR**	51	258	362	641	-29%	-60%
LAX	**JFK**	50	287	360	641	-20%	-55%
LAX	**HNL**	33	278	312	746	-11%	-63%
ORD	**SFO**	59	230	252	574	-9%	-60%
ATL	**LAX**	63	191	248	545	-23%	-65%
LAX	**ORD**	75	201	229	545	-12%	-63%
FLL	**LGA**	23	134	160	354	-16%	-62%
MCO	**SJU**	10	124	157	306	-21%	-59%
EWR	**MCO**	23	96	156	306	-39%	-69%
SEA	**LAX**	31	134	152	306	-12%	-56%
LGA	**ORD**	75	115	136	488	-16%	-76%
ATL	**LGA**	53	86	130	364	-34%	-76%
MCO	**PHL**	27	86	118	431	-27%	-80%
DEN	**LAS**	20	67	93	258	-28%	-74%
LAX	**SFO**	12	67	77	220	-13%	-70%
LAX	**LAS**	9	48	61	134	-21%	-64%
Average						-22%	-63%

Among the analyzed routes, the least-emitting itinerary on average emits 63% less CO_2 than the most-emitting itinerary on the same route, with a range from 48% to 80%. This emissions gap between most- and least-emitting itineraries is much wider than the airline-level fuel efficiency gap of 26%, reflecting the influence of layovers (direct vs. non-direct flights), aircraft used, and variations in operational parameters like load factors. When compared to the route averages, the least-emitting itineraries are on average 22% less carbon-intensive.

Number of stops and routing

The CO_2 emissions per passenger for the top 12 most traveled itineraries between Los Angeles International Airport (LAX) and John F. Kennedy Airport (JFK) in New York are shown in Figure 2. This was the most traveled U.S. domestic route in 2019 in terms of both number of passengers and total RPMs. The average itinerary on this route emitted 360 kg CO_2 per passenger in 2019.

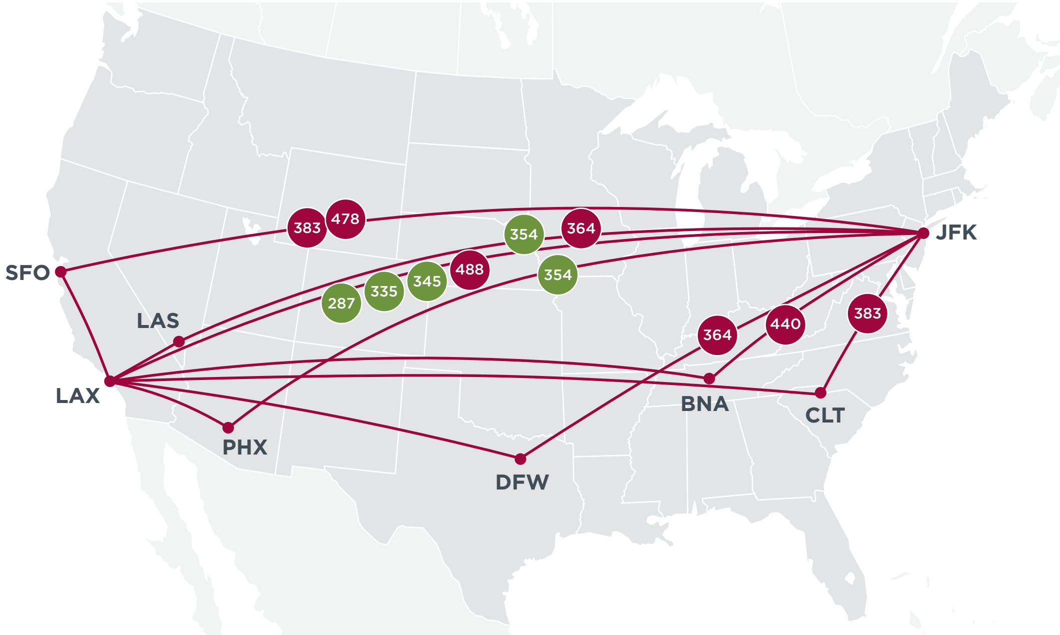

Figure 2. One-way CO_2 emissions per passenger (kg) from LAX to JFK itineraries. Green circles represent itineraries with below average per-passenger emissions, while red circles represent those above average.

Several observations can be made. First, among the four direct flights on this route, three are lower-emitting than the average, including one with the lowest per-passenger emissions of all itineraries on this route. The remaining direct flight, however, is among the highest-emitting itineraries on this route because of a premium-seating oriented aircraft configuration. Most one-stop itineraries emit more CO_2 per passenger than the route average, with the exception of less circuitous routes.[8] For instance, a layover in Las Vegas or Phoenix does not significantly increase the total stage length of the itinerary compared to a direct flight, and therefore emits less CO_2 per passenger than itineraries with more circuitous layovers (e.g., San Francisco and Nashville).

Table 3 breaks down the data for all 20 analyzed routes based on the number of stops for each itinerary. A 50th percentile value represents the median CO_2 emissions per passenger. Values lower than 50 are lower-emitting itineraries, while values higher than 50 represent higher-emitting options.

Table 3. Average emissions percentile value by number of layovers on each itinerary.

Itinerary Type	Number of Itineraries	Average Emissions Percentile Rank	Percentile Range
Nonstop	87	24th	1 - 99th
One-stop	600	53th	1 - 99th
Two-stop	84	66th	17 - 99th

In general, the data confirm that a nonstop flight is likely to emit less CO_2 per passenger than an itinerary with layovers. However, as seen in the LAX-JFK example above, there

8 At the airline level, circuity is defined as the total number of passenger miles traveled divided by the number of intended/productive passenger miles, as defined by the great circle distance linking an origin and destination airport. For a single passenger, a non-stop route would have a circuity of 1.00 while a layover that increased travel distance by 20% from great circle distance would have a circuity of 1.20. See Zeinali et al., (2013).

can be relatively fuel-inefficient nonstop flights that emit more than some one-stop itineraries on the same route. Across the analyzed routes, emissions percentiles for both nonstop and one-stop itineraries range from 1st (lowest emitting of the route) to 99th (highest emitting of the route), suggesting that the number of stops does not always identify lower-emitting itinerary options.

Aircraft

The correlation between itinerary emissions and aircraft deployed is also complicated. First, for itineraries with one or more layovers, more than one aircraft type is likely used. Comparing the combined fuel efficiencies of multiple aircraft based on their types alone (i.e., without estimating fuel burn based on stage length, seating configuration, and other factors) yields high uncertainties and is not easily done by an average consumer.

Even for nonstop flights, the relative emissions of different itineraries using the same aircraft type vary depending on operational factors and on the other types of aircraft flown on the route. As shown in Figure 3, itineraries on the same aircraft can be low-emitting on one route but high-emitting on another. The carrier that operates the aircraft also matters. An airline may carry more passengers on a given flight, either by operating at higher load factors or via single class service, leading to lower per-passenger emissions than other carriers flying the same aircraft on that route. Load factors, aircraft age, congestion at hub airport, and many other factors also contribute to the different emissions outcomes for the same aircraft type.

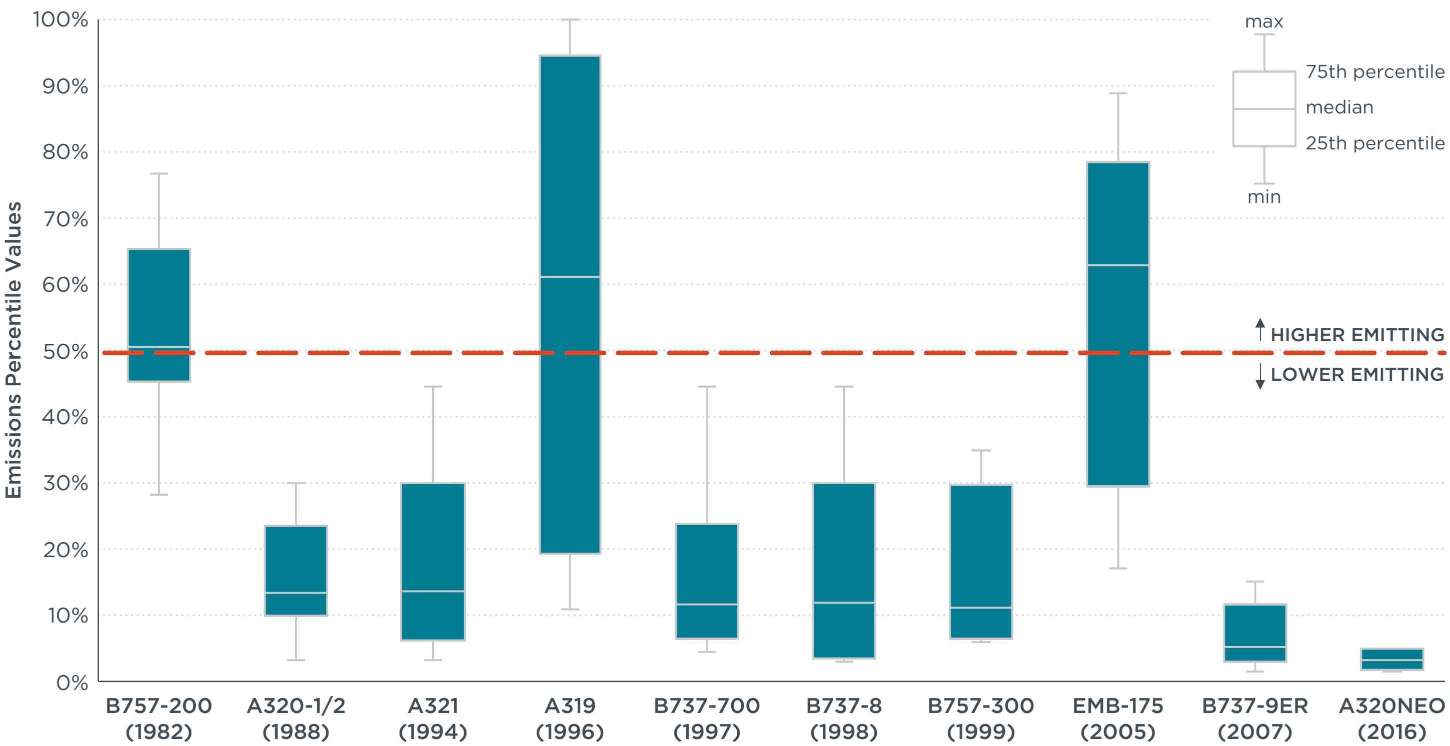

Figure 3. Emissions percentile values by aircraft type on nonstop flights, in the order of first entry-into-service year.

Despite the variation across routes, some aircraft types are on average more fuel-efficient than others. This is especially true for the newest generation of aircraft types, such as Airbus' A320neo series. These types are at least 15% more fuel-efficient than older aircraft; therefore, flights on these aircraft are likely to be less emitting regardless of other factors. On the other hand, flights on older aircraft types, such as Boeing 757-200, or small single-aisle jets, such as Airbus A319 and Embraer EMB-175, are likely to be higher emitting in general. But beyond these general patterns, the emissions outcomes of other aircraft types will depend on the route and the carrier.

Carrier choice

Table 4 presents emissions per passenger, rounded to the nearest 10 kg, of the least-emitting itinerary by airport pair and marketing carrier. For clarity, the 12 most competitive routes by carrier were selected and sorted by weighted average per passenger CO_2 emissions. The route average was weighted by number of passengers on each itinerary.

Carriers were ordered from left to right by the number of routes they operate on. Two U.S. carriers, Hawaiian Airlines and Allegiant Air, are not shown because of their limited presence on these routes. Cells marked in green represent the itineraries that emit no more than the route average, while red cells represent high-emitting itineraries. Asterisks denote the least emitting itinerary on a given route.

Table 4. Emissions per passenger (kg CO_2/passenger) of least-emitting itinerary by carrier and route.

Route	American	Delta	United	Southwest	Alaska	JetBlue	Spirit	Frontier	Sun Country	Weighted average
LAX-LAS	60	80	60	60	70	----	**50***	60	60	60
MCO-PHL	130	200	270	120	----	220	**90***	110	----	120
ATL-LGA	180	110	210	120	----	260	260	**90***	----	130
SEA-LAX	240	140	190	190	**130***	----	160	190	----	150
MCO-SJU	190	260	310	140	----	190	**120***	130	----	160
EWR-MCO	180	210	170	110	----	150	120	**100***	----	160
LAX-ORD	220	280	230	----	250	----	**200***	210	240	230
ATL-LAX	260	240	270	250	390	440	200	**190***	----	250
LAX-EWR	340	330	320	320	280	440	**260***	----	310	360
LAX-BOS	350	330	330	320	350	350	**260***	**260***	320	370
BOS-SFO	380	350	330	320	350	380	----	**270***	330	410
EWR-SFO	370	350	330	320	**310***	470	----	----	330	410

*Denotes least emitting itinerary on a given route.

While our past studies have shown that some airlines operate with higher average fuel efficiency than their peers, the relative emissions performance among carriers varies from route to route, as shown in Table 4. In many cases, the least-emitting itinerary operated by an airline is among the low-emitting options on that route. However, there are exceptions to this pattern; the lowest-emitting itinerary by a carrier sometimes emits more than the route average, indicating that loyalty to a single airline could lead a consumer to choose a higher-emitting itinerary than necessary.

The average performance of each airline generally aligns with the U.S. domestic airline fuel efficiency ranking presented in Zheng, Graver, & Rutherford (2019). However, there is no one carrier that operates only low-emitting itineraries (better than route average) across all the analyzed routes on which it operates. An airline can also emit much less than other airlines on one route but show the opposite emissions pattern on another route.

Most of the lowest-emitting itineraries across these 12 routes were operated by Frontier Airlines, Spirit Airlines, or Alaska Airlines. Meanwhile, the three big legacy carriers—American, Delta, and United—do not offer least-emitting itineraries on any of these routes. Therefore, while a consumer can generally reduce their emissions by choosing a better than average itinerary, it may be difficult for them to choose the absolutely least emitting itinerary if they want to stick with one airline for most of their travels, particularly if the airline in question is a full-service legacy carrier. Another factor to consider is that airlines offering more lower-emitting itineraries may not have a service network as extensive as the legacy carriers. Thus, selecting lower-emitting itineraries based on carrier would be a complicated task.

Ticket price

In addition to number of stops and carrier, ticket price is a key criterion for selecting itineraries. Consumers can be highly sensitive to price, especially for leisure trips. To explore any possible tradeoff between itinerary fare and emissions, we analyzed the carbon intensities of relatively cheap tickets only, and how they compare to the carbon intensities of all tickets sold on a route.

In Figure 4, we show the range of least- to most-emitting itineraries on a route with and without a fare filter. The full bar width (hatched plus yellow) represents the spread of CO_2 emissions per passenger for all itineraries on a given route, while the hatched bar represents the spread assuming that a passenger only considers the cheapest quarter of itineraries.

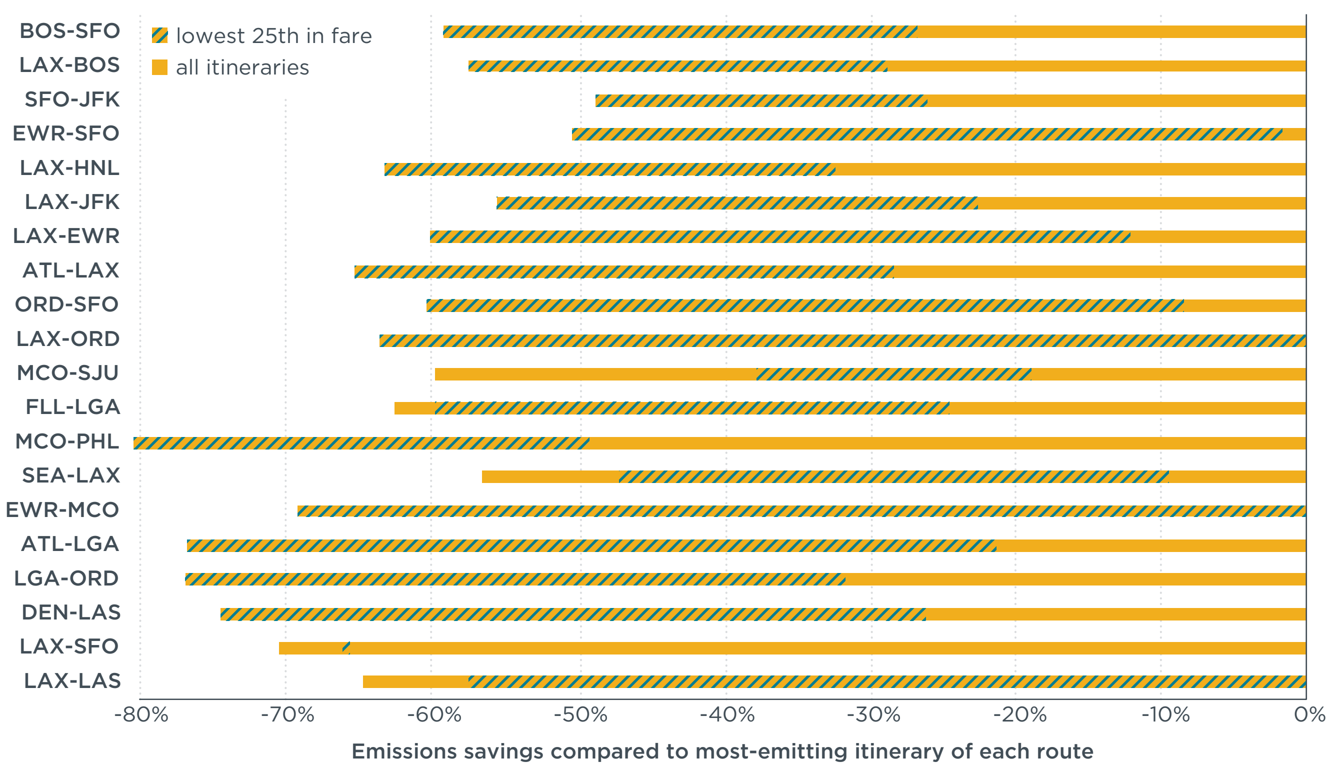

Figure 4. Emissions savings relative to most-emitting itinerary on each route, for all itineraries on the route (yellow plus hatched) and for the 25th percentile cheapest itineraries (hatched only).

As shown, the emissions gap of almost all analyzed routes narrows when only itineraries with lowest 25th percentile of fare were considered. For 15 out of the 20 analyzed routes, the lowest-emitting itinerary remains in range even if consumers filter for ticket price. Meanwhile, the higher-emitting itineraries on many routes also tend to be more expensive and thus are left out when a fare filter is applied. The LAX-SFO route is a special case, where only one itinerary meets the fare filter. On average, emissions can be reduced by 55% by choosing itineraries within the cheapest 25th percentile of cost and by 63% by choosing the single most fuel-efficient itinerary relative to the worst itinerary.

In most cases, the least-emitting itinerary is also relatively inexpensive compared to the others on the same route. A possible reason is that airlines pass along some of their fuel savings to consumers in the form of cheaper tickets. The fuel savings could come from flying newer planes, operating nonstop flights, having higher load factors, or including more seats. Specifically, for 17 out of the 20 analyzed routes, the average fare of the least-emitting itinerary is within the lowest 20th percentile. And for more than half of the routes, the least-emitting itinerary costs less than 90% of other itineraries.

Moreover, cheaper itineraries are likely to emit less than the route average. Figure 5 presents the spread of emissions percentile values of the 184 itineraries with average fare in the lowest 25th percentile of each analyzed route (blue bars) compared to all 771 itineraries (red line). More than one-third of these relatively low-cost itineraries are also lower emitting (within 20th percentile), while almost two-thirds emit less CO_2 per passenger compared to the route average. The remaining one-third of the lower-cost itineraries are higher emitting on a per passenger basis, suggesting that choosing cheaper tickets alone doesn't guarantee lower emissions.

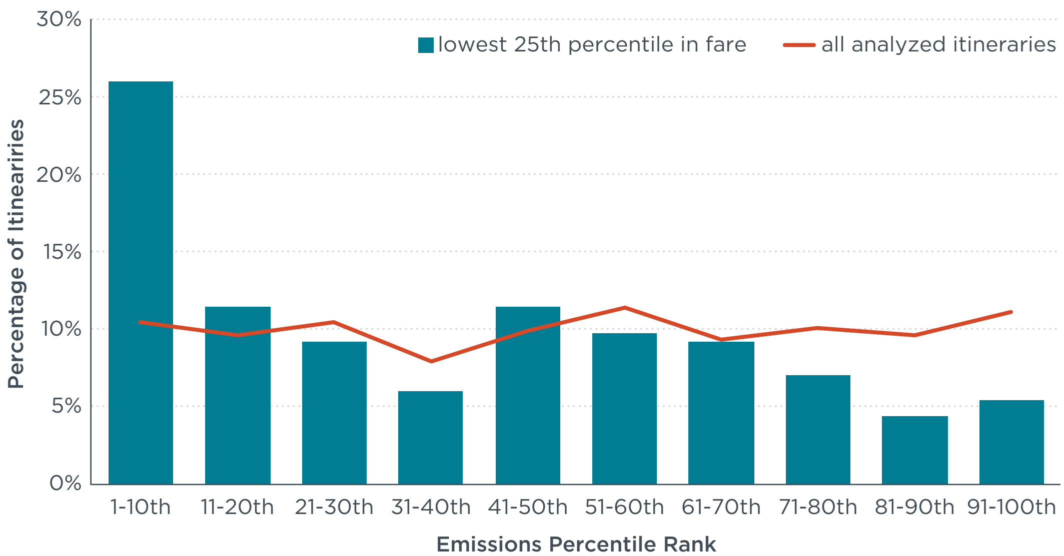

Figure 5. Emissions percentile rank of itineraries with 25% lowest fare on each analyzed route.

Conclusions and Next Steps

The large variation in itinerary emissions on each route clearly demonstrates the value of itinerary-level emissions disclosure by airlines at the point of purchase. Meanwhile, the analysis of ticket price suggests that greater efficiency tends to correlate with lower prices, which is a win-win for consumers and the environment.

In our analysis, the carbon footprint of different itineraries on the same route varies greatly in terms of CO_2 emissions per passenger. On average the most fuel-efficient itineraries emitted 63% less CO_2 per passenger than the highest-emitting itineraries. Selecting an itinerary from the cheapest 25 percent of fares could reduce a passenger's CO_2 emissions by 55% compared to the highest-emitting itinerary. While strategies such as flying direct and choosing more fuel-efficient aircraft offer some guidance to consumers, an emissions profile approach is more dynamic than these generalized rules and requires more detailed data on flight emissions. Some airlines have more fuel-efficient operations than others on average, but there is no one "greenest" airline when evaluated at the route and itinerary level. For brand-loyal customers, low-emitting options are generally available, but choosing the least emitting itinerary can be challenging for people who fly with a single carrier, particular a full-service legacy carrier.

Our analysis also showed that consumers have plenty of choices for lower-emitting flights even if they only consider relatively inexpensive flights on a given route. Therefore, selecting lower-emitting flights will likely not come with material costs for consumers. Moreover, the lowest-emitting flights of analyzed routes often fall on the inexpensive end of all itineraries on those routes. However, not all lower-cost itineraries are necessarily less-emitting, so itinerary-level disclosure is still key.

While emissions disclosure at the point of purchase aims to inform consumer choices, the resulting emissions reduction depends on both the number of consumers choosing a less-emitting flight and the consequential effect of these consumer choices on airline operations. If only a few passengers switched from a higher-emitting flight on a route to a lower-emitting one, both flights will still be operated, resulting in little real emissions reduction.

Nevertheless, emissions disclosure would raise consumer awareness of their carbon footprint and, more importantly, reward airlines that operate more fuel-efficient flights. Consumer preferences could reward airlines that lower emissions through strategies such as deploying newer, more fuel-efficient aircraft and improving load factors. Eventually, as technologies such as sustainable aviation fuels (SAFs) and zero emission planes fueled by electricity and/or hydrogen become mature, emission reductions due to fuel switching and cleaner aircraft could be rewarded as well. Overall, emissions disclosure can empower the consumers to vote for cleaner flying with their travel dollars.

While ticket price already nudges consumers toward more fuel-efficient flights, choosing the lowest-emitting itinerary on a route can still reduce emissions by 22% compared to the average. This is a large reduction potential for the aviation industry, where fleet upgrades bring in aircraft, generally operated for 25 to 30 years, that are on average 15% more fuel-efficient than those of the previous generation. Choosing lower-emitting flights, on the other hand, requires much less time and many fewer resources, making it a key near-term mitigation tool.

While airlines can, in principle, disclose the carbon intensity of their flights voluntarily on their own websites or other booking platforms, public policy would help to ensure accurate and standardized disclosure from all airlines. National governments and domestic flights are a natural place to start. U.S. carriers already collect operations and fuel burn data from all flights and report them at a high level to DOT. Policymakers could require carriers to disclose previous-year emissions by route and aircraft on their websites; third-party booking sites might also choose to display such information. Objective validation of carrier-reported data can help ensure the accuracy and integrity of the disclosed information. Travel search engines can leverage a combination of carrier-reported data and independently modelled emissions inventories to provide credible information to consumers. Labeling or other measures that help consumers process emissions information is useful but should not replace the disclosure of the absolute carbon intensity of a flight.

The flip side of voluntary behavior change by consumers is to internalize the environmental costs of flying into ticket prices through taxation policies or market-based emissions regulations. While effective, experience suggests that these policy instruments are politically difficult, and may take a long time, to craft and implement. Emissions disclosure, on the other hand, could conceivably be implemented in a shorter period with fewer resources because it is politically less fraught.

Future work can expand the analysis in this paper to international routes and distinguish between business and leisure travel, if relevant data are available. Detailed analysis by cabin class would help isolate differences in carbon intensities and fares associated with premium versus economy-class seating. The data analyzed in this paper can also feed into an actual low carbon travel search tool. Consumers' behavior change in response to inclusion of emissions data in itinerary descriptions is also a key area for future study.

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