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Aviation carbon emissions, route choice and tourist destinations: Are non-stop routes a remedy?

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ABSTRACT

Air travel emissions comprise 20% of tourism's global carbon footprint. The purpose of this study was to determine whether non-stop routes to tourist destinations can mitigate air travel carbon emissions relative to routes that connect through airline hubs. Based on International Civil Aviation Organization data, we analyzed carbon emissions for both direct and connecting routes between the ten most populated metropolitan areas located in the Northeastern United States and 13 different tourist destinations located in the Sunbelt and Western regions of the US. Direct routes generally outperformed connecting routes regarding carbon emissions, although there were several exceptions. On average, non-stop routes reduced carbon emissions by roughly 100 kg/person relative to the next best connecting option.

Introduction

According to the World Travel and Tourism Council (WTTC) (2018), global tourism is an $8.3 trillion industry (10.4% of the global Gross Domestic Product), that is forecast to grow 4% annually through 2028. International tourist arrivals grew 7% in 2017 – the eighth consecutive year of sustained growth – with more than 1.3 billion visitors worldwide, a rate that outpaced the growth of international trade (United Nations World Tourism Organization [UNWTO], 2018). Economic activity at this scale has significant impacts on the environment. Lenzen et al. (2018, p. 522) have recently suggested that global tourism accounts for 8% of all greenhouse gas emissions and that the rapid increase in tourism demand is “effectively outstripping the decarbonization of tourism-related technology.”

Particularly in high-income countries, air transportation is a key ingredient of travel and a highly energy- and carbon-intensive commodity. Although aviation only currently accounts for about 3% of CO_2 emissions worldwide (Rothengatter, 2010), air travel emissions comprise 20% of tourism's global carbon footprint (Lenzen et al., 2018). Furthermore, emissions from the aviation sector are projected to grow by nearly 50% in the near future, while the United States accounts for half of all carbon-dioxide emissions from airplanes around the world (New York Times, 2016). Lee et al. (2009 p. 3521) have argued the following when assessing the potential of aviation-related anthropogenic activities to affect climate:

> Aviation stands out as a unique sector since the largest fraction of its emissions are injected at aircraft cruise altitudes of 8–12 km. At these altitudes, the emissions have increased effectiveness to cause chemical, and aerosol effects relevant to climate forcing (e.g., cloud formation and O_3 production).

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Although it is now widely acknowledged that aviation is a major contributor to climate change (Dessens et al., 2014; Rothengatter, 2010 and Schafer & Waitz, 2014), Baumeister (2017, p. 2) recently observed that "only a few studies have discussed the issue of mitigating environmental impacts through behavioral change by air passengers actively selecting airlines or flights that are less polluting." Additionally, previous studies have challenged the conventional wisdom that flying non-stop is always the cleanest option (Schipper & Rietveld, 1997). For example, Loo et al., (2014) found that airline hubbing can enhance CO_2 emission efficiencies by bundling passenger streams through larger aircraft and higher passenger load factors, which reduces carbon emissions per passenger especially on long distance flights. The overarching purpose of this paper was to analyze the carbon emissions associated with tourist air travel in the United States. Specifically, the study aimed to address three research questions:

- Do non-stop routes to tourist destinations mitigate air travel carbon emissions when compared with routes that connect through airline hubs?
- Are any differences in carbon emissions between direct and connecting routes statistically significant?
- Can route choice decisions help keep emissions below an individual's critical annual mobility carbon budget threshold?

In this paper, we utilize an existing carbon calculator developed by the International Civil Aviation Organization (ICAO) to analyze carbon emissions for major direct and connecting route segments in the United States for several of the biggest tourist destinations in the country (e.g., Las Vegas, Orlando and New Orleans). It should be noted that this study primarily analyzed aggregate route choice dynamics (i.e. the average difference between direct and connecting options) rather than the individual differences between specific flights and aircraft types. We focused on route choice rather than flight or aircraft choice because several studies have indicated that routing (i.e. non-stop vs. connecting) is a more notable determinant of air passenger travel behavior than aircraft type (Zhang & Xie, 2005; Warburg et al., 2006; National Academy of Sciences, 2013). Route selection therefore provides an important pathway through which tourists can potentially mitigate the carbon emissions associated with their air travel. Overall, analyzing aggregate route choice dynamics was particularly suitable for this study since it produced robust yet actionable recommendations for tourists traveling by air that were not overly restricted by the specificities of individual flights.

The paper is structured as follows. We first outline current research on carbon emissions as it relates to the tourist industry and particularly air transportation. Next, we describe the carbon emissions calculator developed by the ICAO and the origin – destination database we utilize to analyze the geography of carbon emissions by route in the United States. Finally, we present our major findings followed by a conclusion with several policy recommendations.

Carbon emissions: Connections to tourism and aviation

A majority of tourism-related activities require energy directly in the form of fossil fuels (e.g., transportation) or indirectly in the form of electricity often generated from petroleum, coal or gas (e.g., accommodation). Much of this consumption leads to the emission of greenhouse gases, largely carbon dioxide. The analysis of the tourism carbon footprint and its contribution to the anthropogenic component of global warming has gained prominent attention in recent years.

Becken and Patterson (2006) provided one of the earliest efforts to develop a methodology for measuring carbon dioxide emissions from tourism at a national scale using New Zealand as a case study. Others have subsequently estimated the carbon footprint of Australian tourism (Dwyer et al., 2010), Antarctic tourism (Farreny et al., 2011), island destinations (Sun, 2014), religious pilgrimage tourism (Hanandeh, 2013), and ski resorts (Kelly & Williams, 2007). More recently, Zhang and Zhang (2018) were one of the first to attempt to simulate the impacts of different carbon taxes on tourism-related CO_2 emission levels based on an analysis of the tourism industry in China. They found that a carbon tax policy is likely to significantly affect core tourism industries like air transportation.

Scott et al., (2010) have questioned whether tourism can deliver its "aspirational" greenhouse gas emission targets set by the Intergovernmental Panel on Climate Change (IPCC), UNWTO, WTTC and others. They point out that success in achieving emission reductions in tourism will be heavily dependent on major policy initiatives focused on air travel, which they say is projected to grow to 53% of all CO_2 emissions attributable to tourism by 2035. In some locales, transportation is already a major contributor to tourism-generated carbon emissions, particularly in small island destinations that are highly dependent on international tourist arrivals by air. In the Seychelles, Gossling and Schumacher (2010) found that more than 85% of tourist carbon emissions were attributable to air travel. Kelly and Williams (2007) uncovered broadly similar trends for Whistler, British Columbia – one of North America's leading mountain resort destinations – where air transportation to/from Whistler accounted for 72% of the total energy consumption and 78% of the greenhouse gas emissions. At a national scale, Dwyer et al. (2010) found that domestic air transport accounted for 56.7% of tourism industry-based greenhouse gas emissions in Australia.

The UNWTO (2008) has recognized the global and rising significance of tourism-related emissions, especially those generated by air transportation, and proposed two major mitigation strategies: (1) encourage tourists to choose short-haul destinations with an increased use of public transportation and less aviation; and (2) to provide market-based incentives for tourism operators to improve their energy and carbon efficiency. According to Lenzen et al., (2018, p. 526), the rapidly increasing carbon footprint of global tourism provides "proof that so far these mitigation strategies have yielded limited success."

Despite these challenges, Baumeister (2017) has suggested that an alternative approach might be to first determine whether or not the actual flights air passengers select can make a substantive difference in terms of carbon impacts. Mayer et al., (2012) and Wittmer and Wegelin (2012) have made similar points although they mainly focused on how the environmental image of an airline shaped air passenger perceptions particularly as it related to an air passenger's choice of flight and route. Part of the problem, according to

Davison et al., (2014) is that a “value-action gap” exists where an individual's pro-environmental attitudes or values are not reflected in their actual air travel behavior. Although many consumers actively practice environmentally conscious behavior at home (e.g., recycling or using public transit), transferring these values to their flying behavior has been problematic. A lack of flying alternatives and an unwillingness to change travel behavior in many cases have constrained the potential for changing demand patterns.

To this end, some environmental organizations (e.g., Union of Concerned Scientists, Smart Travel, Ecolife, Ecology Center) have attempted to mitigate this cognitive dissonance by providing recommendations on how the general public can reduce the environmental impacts of air transport. Baumeister (2017) found that two of the most frequently mentioned measures suggested to the public were to fly on a fuel-efficient plane and/or to fly non-stop wherever possible. Although flying non-stop may be the least polluting option (e.g. Morrell & Lu, 2007), Moisander (2007 p. 406) has argued it still remains very difficult for tourists to make the most environmentally sustainable consumer decision because of what she coined a “perplexity of environmental information.” She argues that not all tourists have the necessary skills to search for and access information. Juvan and Dolnicar (2014) have similarly questioned whether or not tourists can easily choose a low carbon footprint vacation given the complex and frequently contradictory information available to consumers on the environmental impacts of tourist activities. Of course, it is also challenging for tourists to minimize their carbon emissions associated specifically with air travel due to the large array of structural factors over which they have minimal influence, such as air traffic management inefficiencies that unnecessarily increase carbon output (Efthymiou & Papatheodorou, 2018).

In recent years, carbon dioxide emissions have emerged as one of the most widely used measures of how tourism-related activities can impact global climate change. Furthermore, Juvan and Dolnicar (2014 p. 179) have suggested that carbon dioxide emissions have the advantage that many different tourist-related activities “can be converted into this common currency, thus making assessments of impact less subjective in terms of criteria and criteria weighting.” Fortunately, a number of carbon calculators have emerged that have made the environmental impact of tourism and flying more easily measurable.

Methodology

ICAO carbon emissions calculator

One of the most commonly used methods for estimating the amount of carbon emissions generated by air travel is that developed by the ICAO – a specialized UN agency charged with standardizing the set of rules and laws that govern aviation across the world with the goal of making the industry safer and more efficient. The ICAO carbon emissions calculator is widely recognized within the aviation industry and has been adopted by many previous studies (e.g., Farreny et al., 2011; Hanandeh, 2013; Lu & Shon, 2012; Yin et al., 2015). The calculator leverages several of the same databases used by other flight performance tools, such as BADA and Piano-X, and compares favorably with carbon emission reference values produced by the UK's Department for Environment, Food and Rural Affairs for certain routes (Filimonau, 2012). In this paper, the publicly available ICAO calculator and its related databases were utilized to determine the average carbon emissions for each route included in our origin-destination database.

The ICAO (2017) methodology calculates carbon emissions for specific city-pair markets based on the great circle distance between any two given airports that offer scheduled flights. While the great circle paths do not necessarily correspond to flown flight paths, a correction factor is applied by the ICAO to account for the emissions associated with additional flight distance due to air traffic and weather conditions. Using published flight itineraries, the ICAO calculator determines the aircraft types that service the route and then each aircraft is mapped to one of 312 equivalent aircraft types to calculate fuel consumption. An average fuel consumption rate for the route is estimated by the ICAO based on the variety and frequency of equivalent aircraft servicing the route. To calculate the average carbon dioxide emissions per passenger for a given route, the ICAO (Version 10 – June 2017) uses the following formula:

$$\mathrm{CO_2\ per\ passenger} = 3.16 * \frac{(\mathrm{Total\ Fuel} * \mathrm{Passenger} - \mathrm{to} - \mathrm{Freight\ Factor})}{(\mathrm{Number\ of\ Seats} * \mathrm{Passenger\ Load\ Factor})}$$

The constant of 3.16 represents the number of tons of CO_2 produced when burning one ton of aviation fuel (Dings et al., 2003; Sutkus et al., 2001). Total fuel is computed within the ICAO calculator as the weighted average of the fuel used by all flights between the specific origin and destination pair selected by the user. The weighting is based on the frequency of departure of each equivalent aircraft type for a given route. Fuel usage for the individual flights servicing a route is estimated according to the ICAO Fuel Consumption Formula, which considers block time to account for the influence of less direct routings and/or prevailing winds. Block time is the total amount of time a flight takes from pushing back from the departure gate (“off-blocks”) to arriving at the destination gate (“on blocks”). Passenger-to-freight and passenger load factors are both derived from the ICAO Traffic by Flight Stage database and allow the calculator to estimate how much of the total fuel used can be accounted for by the number of passengers carried. The higher the passenger-to-freight ratio then the higher the proportion of fuel burn attributable to passengers instead of freight. To calculate fuel burn per passenger, this is then divided by the total number of occupied passenger economy class seats. The ICAO calculates the maximum number of economy seats that can fit into each equivalent aircraft type.

The ICAO updates traffic data on an annual basis although aircraft fuel consumption rates are updated more frequently based on any new information made available by aircraft manufacturers and air carriers regarding new aircraft types or technology improvements adopted by the industry. In this paper, we accessed the ICAO carbon emissions database in August 2018. The reader is referred to the ICAO methodology documentation for complete details regarding the ICAO carbon emissions calculator used in this

Table 1
Tourist origins and destinations.

Air passenger origin	
Metropolitan statistical area and airport code[a]	Total population, 2017
New York – Newark – Jersey City (JFK)	20,320,876
Washington – Arlington – Alexandria (IAD)	6,216,589
Philadelphia – Camden – Wilmington (PHL)	6,096,120
Boston – Cambridge – Newton (BOS)	4,836,531
Detroit – Warren – Dearborn (DTW)	4,313,002
Pittsburgh (PIT)	2,333,367
Cincinnati (CVG)	2,179,082
Columbus, OH (CMH)	2,078,725
Cleveland – Elyria (CLE)	2,058,844
Indianapolis – Carmel – Anderson (IND)	2,028,614
Air passenger destination	
County and airport code	Accommodation employment, 2016[b]
Clark County, NV (Las Vegas – LAS)	172,916
Orange County, FL (Orlando – MCO)	52,277
Los Angeles County, CA (LAX)	49,335
San Diego County, CA (SAN)	37,910
Miami-Dade County, FL (MIA)	32,298
Maricopa County, AZ (Phoenix – PHX)	28,290
San Francisco County, CA (SFO)	19,175
King County, WA (Seattle – SEA)	16,346
Bexar County, TX (San Antonio – SAT)	13,711
Orleans Parish, LA (New Orleans – MSY)	12,638
Davison County, TN (Nashville – BNA)	9,748
Hillsborough County, FL (Tampa - TPA)	8,425
Charleston County, SC (CHS)	7,134

Source: U.S. Census Bureau.

[a] The sixth ranked Baltimore – Columbia – Towson MSA was excluded because it was part of the Washington CMSA. JFK and IAD (Dulles) were selected because JFK was the largest airport in the New York MSA in terms of passenger totals and IAD had a more comprehensive set of flight connections to the selected destinations relative to Reagan National in the Washington MSA.

[b] The accommodation employment data is based on U.S. Census Bureau NAICS 721 which includes lodging or short-term accommodations for travelers, vacationers and others. It also includes hotels, motels, bed-and-breakfast inns, recreational vehicle parks, and others.

study (ICAO, 2017).

Baumeister (2017) has pointed out that carbon calculators like that developed by the ICAO "still base their calculations on average data, providing users with only the CO_2 emissions of a so-called typical flight." He also argues that most carbon calculators fail to distinguish between different seat layouts even though "the carbon dioxide emissions of an air passenger flying in premium class can be up to eightfold higher than the emissions of a passenger flying in economy class due to the higher amount of space a premium class seat occupies" (Baumeister, 2017 p. 4).

Although these are legitimate points, the ICAO (2017 p. 3) has suggested that while their calculator is not able to offer flight-specific outcomes, it remains one of the more robust estimators of carbon emissions and plays a key role in "educating the public and the industry on how these factors affect an individual passengers' emission intensity." Additionally, the results in this paper should be viewed as conservative estimates given that the data is based exclusively on economy seat configurations – it is likely that the emissions reported in this study would be higher on many routes if premium seating was included in the analysis.

Tourist origin-hub-destination network

In this paper, we analyzed the geography of aviation-related carbon emissions in the United States – which accounted for 29% of all airline-based carbon emissions in the world in 2010 (Dray, 2014) – by developing a case study that focused on tourist air travel originating from the ten most populated metropolitan areas in the Northeast (Table 1; Fig. 1). These metropolitan areas have both significant propensities to fly and relatively robust airport operations.

The 13 tourist destinations were selected based on the level of county-based employment in the accommodation sector and the overall distance of each destination from the 10 northeastern origins or tourist-generating markets. We utilized accommodation employment in this paper as a proxy for capturing the size and diversity of the tourist sector and as a measure of the utility or attractiveness of each destination. Each of the selected destinations ranked in the top twenty for accommodation employment when excluding the northeast region, airport hub locations (e.g., Salt Lake City), and tourist counties with limited airport operations (e.g.,

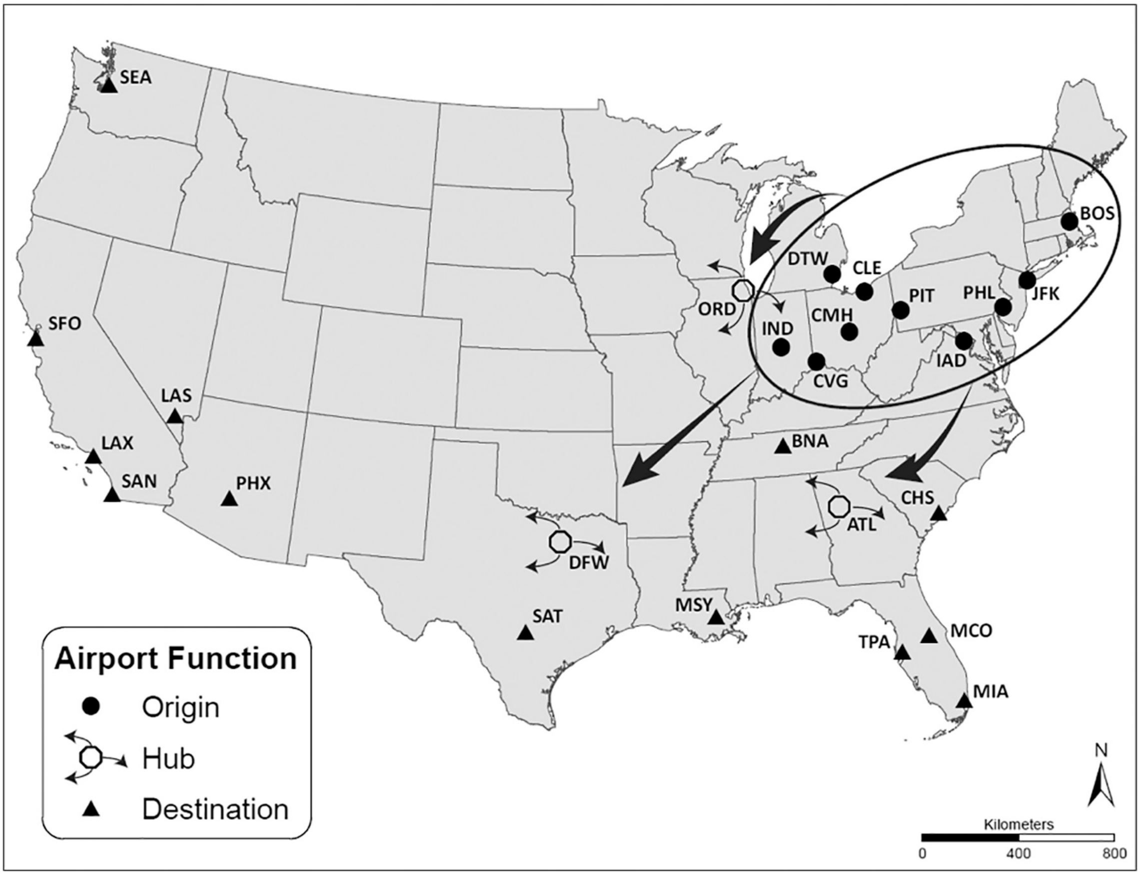

Fig. 1. Spatial distribution of airport origins, hubs and destinations.

Myrtle Beach). With the exception of Nashville, all of the destinations are located more than 500 miles from the 10 northeastern origins or starting points, thus, elevating the likelihood of traveling by air.

To analyze the differences in carbon emissions between direct and connecting routes, we included the three super hubs operated largely by the legacy carriers at Atlanta Hartsfield-Jackson Airport (Delta Airlines), Chicago O'Hare Airport (United Airlines and American Airlines) and Dallas-Fort Worth Airport (American Airlines) in the analysis. These three specific super hubs were selected primarily because of their large carrier shares, high traffic volumes, and notable levels of connectivity (Table 2). Each hub also provided relatively realistic connecting options given the geography of the tourist origins and destinations (Fig. 1). For each northeastern origin, we employed the ICAO carbon calculator to estimate the average emissions associated with the direct return route to each of the 13 different tourist destinations. Additionally, the ICAO calculator was used to estimate the average carbon emissions produced by the alternative connecting return routes, which travelled through each of the three super hub airports, for every origin – destination pair. We measured emissions based on CO_2 per passenger (CO_2 kg/p) as well as CO_2 per passenger per kilometer (CO_2 kg/p/km) to capture both total emissions output per passenger and to standardize for distance travelled. In effect, we examined four different routes from any one origin to any given destination based on two different carbon emission metrics. Table 3 provides an example of the database structure for one city-pair route. The end result was an analysis of tourist air travel carbon

Table 2
Super hub statistics.

Airport code	Carrier and share (%)[a]	Enplanements (rank)[b]	Connectivity (rank)[c]
ATL	Delta – 72.6%	50,251,964 (1st)	396 (2nd)
ORD	United & American – 58.0%	38,593,028 (3rd)	479 (1st)
DFW	American – 68.3%	31,816,933 (4th)	228 (4th)

[a] Carrier shares are based on enplaned passengers and were obtained from the Bureau of Transportation Statistics for December 2017–November 2018.

[b] Enplanements were obtained from the FAA for the 2017 calendar year.

[c] Connectivity values are based on the total number of all possible connections between inbound and outbound flights within a three-hour window and were obtained from the OAG for the 2018 calendar year.

Table 3
Example of the carbon emissions data for the New York – Las Vegas city-pair market (return routes), August 2018.

Origin	Hub	Destination	CO_2 kg/p	Distance km	CO_2 kg/p/km
JFK	Direct	LAS	520.8	7,216	0.072
JFK	ATL	LAS	668.2	8,046	0.083
JFK	ORD	LAS	675.2	7,236	0.093
JFK	DFW	LAS	694.6	7,854	0.088

emissions in the United States based on 520 origin – destination return routes (although 10 of these route segments lacked complete data).

Much like Baumeister (2017), we also utilized the carbon budgeting approach of the German Advisory Council on Global Change (2009) to contextualize the carbon emissions reported in the analysis. The Council suggested that to keep global warming below 2 °C, a threshold beyond which most scientists agree dangerous and irreversible change will occur, requires that each human not exceed an average annual carbon budget of 2,300 kg CO_2 of which only one-fourth (575 kg CO_2) is allotted to mobility or transportation (Atmosfair, 2017).

Statistical analysis

One of the key objectives of this paper was to evaluate the statistical significance of any differences in the average carbon emissions between various route options available to tourists traveling by air. Specifically, analysis of variance (ANOVA) tests were used to evaluate if direct routes significantly reduced carbon emissions relative to connecting alternatives. The ANOVA tests were performed for return routes within various distance categories to gain a better understanding of how the differences between direct and connecting options varied with route length. The return route distances were stratified based upon the 25th (3,766.5 km) and 75th (7,265.5 km) distance percentiles. Therefore, ANOVA tests were calculated that compared direct and connecting routes with distances below the 25th percentile ($n = 128$), between the 25th and 75th percentiles ($n = 254$), and greater than the 75th percentile ($n = 128$). Each ANOVA test produced an F-Statistic where larger F-values suggested that the two group means (i.e. connecting and direct) were less likely to be equal. The ANOVA results were visualized by constructing boxplots. The annual mobility carbon budget was also included on the boxplot for carbon emissions per person. By utilizing the 575 kg CO_2 cap on mobility, we vividly illustrate the stark choices facing each tourist when they commit to traveling by air to a destination.

Findings

The "dirtiest" and "cleanest" routes

The origin – destination database derived from the ICAO carbon emissions calculator included routes that varied in length from a maximum of 10,348 km for the BOS-DFW-SEA return journey to a minimum of 738 km for the relatively, short-haul direct return between Cincinnati (CVG) and Nashville (BNA). Overall, the average return route distance was 5,591 km for the 510 city-pair markets included in the analysis, so a large proportion of the route segments were relatively long-haul journeys.

The top five "dirtiest" return routes, which produced the most CO_2 emissions in kilograms per passenger (CO_2 kg/p), tended to prominently feature very long-haul and connecting city-pair markets (Table 4). The average distance travelled for the top five "dirtiest" return routes was 9,664.4 km and four of the five routes originated in either New York or Boston and connected through the Dallas-Fort Worth Airport while all five routes terminated in either Seattle or San Francisco. Three of the five "dirtiest" route segments were also three of the five longest city-pair markets in terms of distance travelled. The only direct route to feature in the top 200 "dirtiest" routes was Pittsburgh to San Francisco which ranked 195th at 593.4 CO_2 kg/p.

Many larger network carriers produce a large part of their CO_2 emissions on long-haul connecting routes. According to *Aviation Week and Space Technology* (2019, p. 82), "eighty percent of aviation CO_2 emissions come from flights over 1,800km." Much of this can be attributed to long-haul aircraft having to carry additional fuel leading to higher relative fuel consumption rates and significant carbon emissions. These effects can be exacerbated on long-haul connecting routes where the additional stopovers can increase the distance travelled and also lead to additional landing and take-off cycles where fuel burn is disproportionately high. According to

Table 4
Top five "dirtiest" and "cleanest" return route segments based on carbon dioxide emissions per kg per person (CO_2 kg/p), August 2018.

"Dirtiest" return routes	"Cleanest" return routes
JFK-DFW-SEA: 816.1	CMH-BNA direct: 144.7
IAD-DFW-SEA: 810.1	CVG-BNA direct: 151.5
BOS-DFW-SEA: 803.6	CLE-BNA direct: 177.1
JFK-DFW-SFO: 798.5	PIT-BNA direct: 177.5
BOS-ATL-SFO: 792.7	CVG-CHS direct: 179

Table 5
Top five "least efficient" and "most efficient" return route segments based on carbon dioxide emissions per kg per person per km, August 2018.

"Least efficient" return routes	"Most efficient" return routes
CVG-BNA direct: 0.205 CO_2 kg/p/km	BOS-SAN direct: 0.066 CO_2 kg/p/km
IND-ORD-BNA: 0.186 CO_2 kg/p/km	BOS-SFO direct: 0.067 CO_2 kg/p/km
CVG-ORD-BNA: 0.182 CO_2 kg/p/km	JFK-SAN direct: 0.068 CO_2 kg/p/km
DTW-ORD-BNA: 0.180 CO_2 kg/p/km	BOS-LAS direct: 0.068 CO_2 kg/p/km
CLE-CHS direct: 0.179 CO_2 kg/p/km	BOS-LAX direct: 0.069 CO_2 kg/p/km

Jamin et al. (2004) and Baumeister (2017 p. 8), "an average of 10% in fuel burn and CO_2 emissions reduction could be achieved when substituting a connecting flight with a direct flight on U.S. domestic routes, with 4% accounting for the shorter flight distance and 6% for the additional landing and take-off cycle."

Partly because of this dynamic, the "cleanest" routes, which produced the lowest CO_2 emissions in kilograms per passenger (CO_2 kg/p), tended to be short-haul, direct routes (Table 4). However, most of these routes only generated low CO_2 kg/p because of the relatively short distances travelled. For example, the top five "cleanest" return routes were five of the seven shortest route segments in the database, averaging just 1,269.6 km travelled.

The "least efficient" and "most efficient" routes

When analyzing routes based on CO_2 emissions in kilograms per passenger per kilometer (CO_2 kg/p/km) to account for the variation in distances travelled, many of the "cleanest" routes listed in Table 4 in terms of total CO_2 emissions per passenger become some of the "least efficient" routes in terms of airline operations per kilometer. For example, the second "cleanest" route in terms of CO_2 kg/p (i.e., CVG-BNA direct in Table 4) becomes the "least efficient" in terms of CO_2 kg/p/km in Table 5. Most of the "least efficient" return routes listed in Table 5 are largely short-haul "hop" city-pair markets that comprise a mix of direct and connecting routes. Many of these same route segments are relatively "thin" passenger markets where lower passenger load factors, the proliferation of gas-guzzling regional jets, and the disproportionate amount of time spent in a landing and take-off cycle given the shorter distances travelled all contributed to higher CO_2 emissions per seat-kilometer.

By contrast, the "most efficient" routes listed in Table 5 tended to be long-haul, direct routes where the time spent in a landing and take-off cycle is a much smaller proportion of total time travelled, and the more efficient fuel burn with distance is triggered by the proliferation of larger aircraft on "thicker" passenger markets with relatively high passenger load factors. Morrell (2009) has suggested that "fuel efficiency is positively related to aircraft seating capacity, and for every 1% increase in seat capacity a 0.83% reduction in fuel might be obtained." In Table 5, the top five "most-efficient" routes tended to predominately feature A320's and Boeing 757's. Both aircraft are mid-to-large size, narrow-body, twin-engine airliners with good-to-excellent fuel efficiencies per seat. Furthermore, Egelhofer et al. (2008) has suggested that the most efficient fuel consumption rates tend to occur on routes that most closely approximate a stage length of 4,300 km where the "trade-off" between the high fuel burn of the takeoff procedure on short routes and the need to carry large quantities of fuel on long-haul routes is optimized. In Table 5, the average stage length for the top five "most-efficient" routes was 4,086 km, which was only marginally below the optimal stage length identified by Egelhofer et al. (2008). This suggests that the ICAO carbon calculator has captured some of these important aspects of flight physics.

The box-plot analysis of CO_2 kg/p/km by route length revealed that a statistically significant difference existed between direct and connecting segments for the short, medium and long distance categories (Fig. 2). Specifically, direct routes were more efficient than connecting routes across all three distance categories, although these discrepancies were most pronounced for route lengths greater than the 75th percentile as indicated by the larger F-value. In Fig. 2, the length of the actual boxplots indicates the difference between the 25th and 75th percentiles for CO_2 kg/p/km. Larger boxes are indicative of more variability and the line inside the box represents the median. The median is frequently closer to the bottom of the box in Fig. 2, suggesting that there was a general tendency towards larger values or positive skew. The most notable example of this positive skew was the CVG-BNA direct route in the less than 25th percentile distance category. It was both the least efficient route and a clear outlier in the boxplot largely because it was by far the shortest return route included in the dataset at only 738 km. The next shortest return route was 1,084 km. Despite the CVG-BNA exception, the boxplots and ANOVA analysis did suggest that direct routes were typically more efficient for all distance categories.

Carbon emissions per passenger and the annual carbon mobility budget

Although it seems clear that direct routes are preferential to connecting options in terms of CO_2 kg/p/km and that these efficiencies can be enhanced with distance travelled, such a metric is simply an assessment of the efficiency of airline operations with respect to carbon emissions rather than a measure of the total amount of carbon being emitted into the atmosphere. In reality, no matter how efficient a route may be in terms of CO_2 kg/p/km, most forms of air travel can be a tourist's most serious environmental sin particularly as it relates to carbon (New York Times, 2013). For example, the carbon emissions average for all 510 origin – destination pairs included in this analysis was 526.3 CO_2 kg/p, which is just short of the *annual* mobility budget (i.e., 575 CO_2 kg/p) recommended for individuals by Atmosfair (2017) for *all* forms of transportation (including *daily commuting*) if global warming is to

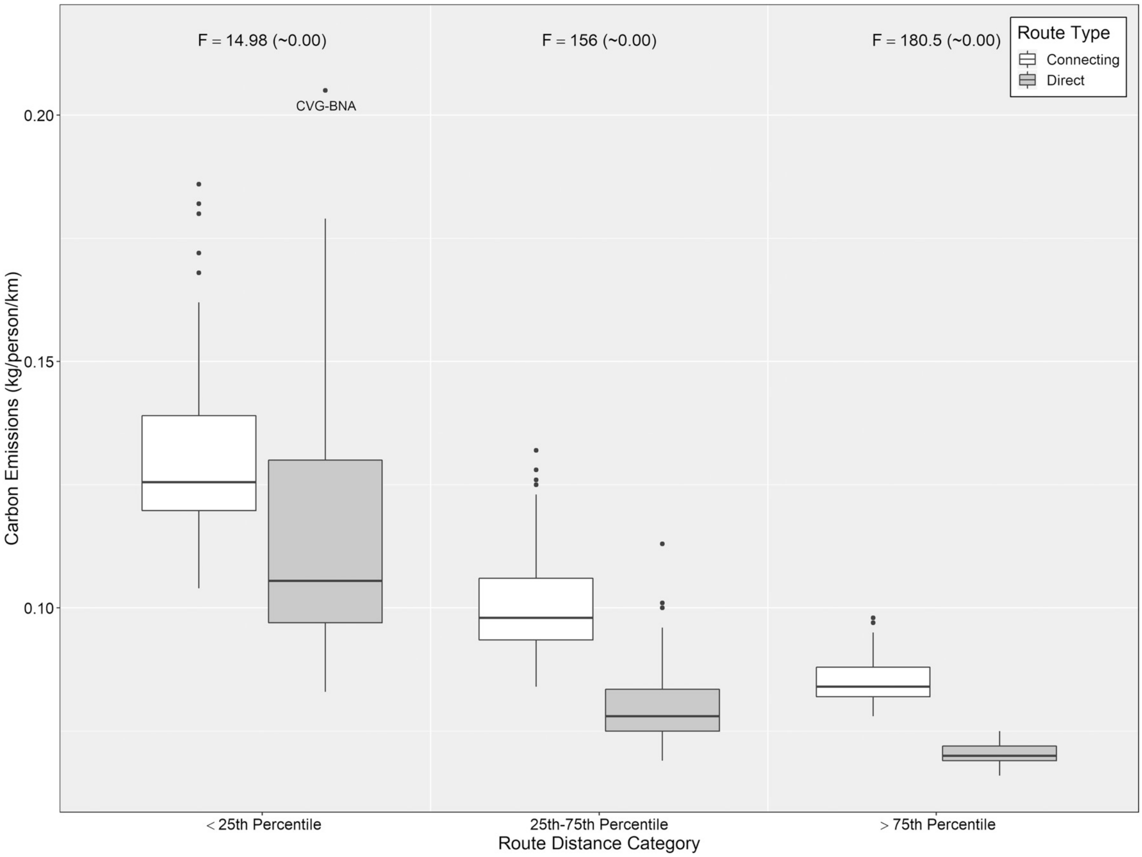

Fig. 2. Box plot analysis of CO_2 kg/p/km for direct and connecting route segments by distance with ANOVA F-Statistic and associated p-value in parentheses.

remain below the 2 °C threshold.

The magnitude of the carbon problem facing both the airline industry and tourists traveling by air is highlighted by the fact that 231 (45.3%) of the 510 route segments in our database exceeded the goal of 575 CO_2 kg/p. With nearly half of all routes in this database exceeding the annual mobility cap, it appears that with respect to air travel in the United States, tourist behavior can be characterized by the phrase coined by Juvan and Dolnicar (2014 p. 177) – "plenty of good intentions, few good behaviors".

Left unanswered is whether or not direct routes can help mitigate the likelihood of exceeding the annual mobility cap. The answer appears to be yes since 115 (95.8%) of the 120 direct routes analyzed in our database generated less than 575 CO_2 kg/p. The absence of a stopover and multiple landing and take-off cycles likely contributed to a more efficient fuel-burn in many of these direct city- pair markets. Only 5 of the 231 route segments that exceeded the 575 CO_2 kg/p cap were direct and these included:

- PIT – SFO: 593.4 CO_2 kg/p
- PHL – SFO: 587.3 CO_2 kg/p
- BOS – SFO: 585.2 CO_2 kg/p
- BOS – LAX: 577.6 CO_2 kg/p
- JFK – SFO: 575.8 CO_2 kg/p

All five direct segments barely exceeded the cap and were long-haul routes averaging 8,138 km return with 4 of the 5 routes terminating in San Francisco. The longer distances travelled (4 of the 5 were the longest direct routes included in the database) and the related heavier fuel loads likely contributed to the higher CO_2 kg/p on these direct routes. Ironically, four of these five routes also ranked in the top twenty for airline efficiencies in terms of CO_2 kg/p/km.

Another key question posed in this paper is whether or not direct routes provide a better option than connecting alternatives regarding carbon emissions per passenger, and also by what order of magnitude. A box-plot analysis of CO_2 kg/p revealed that a statistically significant difference existed between connecting and direct route segments for each distance category (Fig. 3). Specifically, the ANOVA results indicated that direct routes emitted significantly lower quantities of CO_2 kg/p for all three distances. The F-Values suggested that the differences between connecting and direct routes were most pronounced for routes with distances greater than the 75th percentile. Additionally, the decision to select direct or connecting options was particularly important for routes above

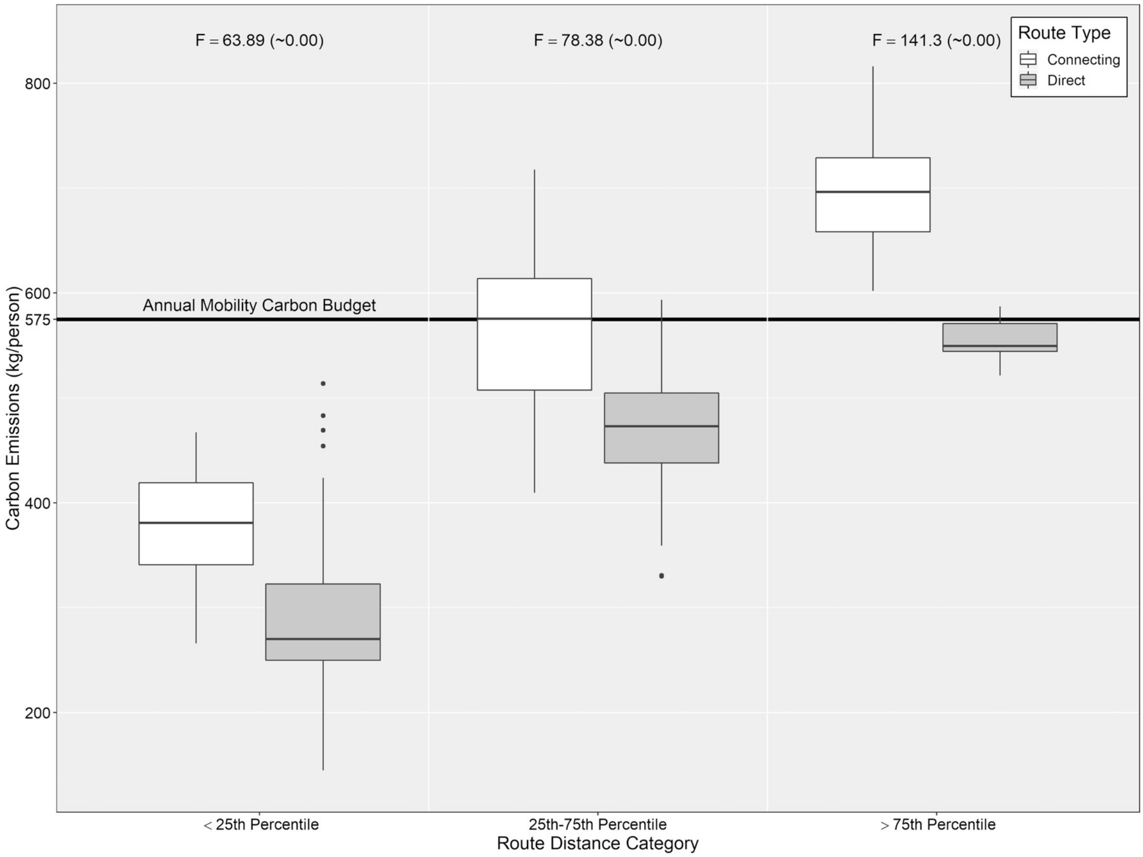

Fig. 3. Box plot analysis of CO_2 kg/p for direct and connecting route segments by distance with ANOVA F-Statistic and associated p-value in parentheses.

the 75th distance percentile since direct routes most often resulted in emissions below the 575 kg/p annual carbon budget while connecting routes greatly exceeded this threshold. Interestingly, the median value for these long-haul direct return routes was lower than that for the connecting routes in the middle distance category. This again highlights the potential benefits of direct routes in terms of total carbon emissions. Finally, the shortest routes remained well below the carbon budget threshold regardless of if they were direct or connecting. This illustrates that more localized tourism could also help reduce airline related carbon emissions.

Direct routes and the "next best" connecting route

Overall, 113 (94.2%) of the 120 direct routes analyzed in this paper generated lower CO_2 kg/p than the "next best" stopover option (through either Atlanta, Chicago or Dallas) by an average margin of 101.9 CO_2 kg/p – the equivalent to operating a refrigerator for one year according to Atmosfair (2017). Direct routes were nearly always the most environmentally responsible alternative when considering carbon emissions.

The top ten direct return routes ranked by the largest CO_2 kg/p decrease relative to the "next best" connecting route generated an average difference of 172.7 CO_2 kg/p with the most notable difference being in the Philadelphia – Miami city-pair market (Table 6). The direct return route between PHL – MIA generated 270.3 CO_2 kg/p compared to 487.5 when connecting through ATL – a 217.2 kg per person decrease in emissions. By contrast, connecting through ORD (544 CO_2 kg/p) and DFW (627.4) generated much higher emissions. Part of the explanation for the differences in carbon performance for the ten routes listed in Table 6 is largely linked to the type of aircraft operating on the respective routes. The PHL – MIA direct route is served by larger aircraft with much better fuel efficiencies relative to the connecting route through ATL. The direct route included Airbus 320/321's and Boeing 757's with fuel efficiencies per seat between 88 and 107 miles per gallon. By contrast, the connecting route through ATL included smaller, short-to-medium range aircraft like gas guzzling McDonnell Douglas 88's and the Embraer 175/190 series with much lower fuel efficiencies per seat between 60 and 70 miles per gallon. Similar logic can be applied to many of the other top ten connecting routes listed in Table 6 although the additional landing and take-off cycle was likely the main contributing factor on some of the longer-haul connecting routes.

That said, additional research is needed to more fully understand the network effects across the system, particularly regarding those routes **not** featured in Table 6. In many cases, it is possible that larger aircraft may be operating as hub feeders while smaller

Table 6
Top ten direct return routes ranked by the largest CO_2 kg/p decrease relative to the "next best" connecting route option.

Direct route	Connecting route	CO_2 kg/p decrease
PHL – MIA: 270.3	PHL – ATL – MIA: 487.5	217.2
JFK – SEA: 545.4	JFK – ORD – SEA: 726.9	181.5
JFK – MIA: 293.8	JFK – ATL – MIA: 473.9	180.1
IAD – MIA: 291.2	IAD – ATL – MIA: 467.1	175.9
PIT – SEA: 473.8	PIT – ORD – SEA: 645.8	172.0
BOS – MIA: 329.9	BOS – ATL – MIA: 500.9	171.0
JFK – SFO: 575.8	JFK – ORD – SFO: 737.7	161.9
JFK – SAN: 535.8	JFK – ATL – SAN: 694.6	158.8
CMH – BNA: 144.7	CMH – ATL – BNA: 299.3	154.6
JFK – LAX: 548.6	JFK – ATL – LAX: 703.0	154.4

ones may be operating direct services particularly in "thin" passenger markets. Further research that disaggregates by effects is also needed to quantitatively identify the degree to which individual mechanisms (e.g. aircraft technology, aircraft scale effects, load factors, and detour factors) are responsible for the differences in carbon emissions between direct and connecting routes.

It should also be noted that it was not always the case that the direct route was the best option with respect to CO_2 kg/p. We found 7 direct routes based on the ICAO carbon emissions calculator that "under-performed" relative to the "next best" connecting route (Table 7), although the average difference between these routes was slight at just 35.5 CO_2 kg/p. In each of these 7 anomalies, the direct route was mainly serviced by fuel-inefficient regional jets operated by a commuter airline affiliate of a major carrier. Most of these direct city-pairs were largely "thin" passenger markets featuring at least one smaller to medium-sized origin and/or destination. For example, the CVG – MIA direct route was largely operated by Envoy Air as part of the American Eagle network utilizing an Embraer RJ145 with just 50 seats and much lower fuel efficiencies per seat relative to the connecting route. For tourists traveling by air, the irony here is that the advice of several prominent environmental organizations to select a direct route whenever possible, in order to minimize your carbon footprint, may be substantively flawed in the cases where inefficient regional jets are used like the routes listed in Table 7.

Conclusion

This study provides one of the first efforts to quantify the carbon emissions associated with tourist air travel in the continental United States. The research also helps clarify the apparent contradictions in the literature regarding the mitigative potential of direct routes relative to connecting alternatives. The findings indicated that statistically significant differences existed between direct and connecting options, as both CO_2 kg/p and CO_2 kg/p/km were generally lower for direct routes. Additionally, the ANOVA analysis revealed that these differences were magnified for longer routes.

When viewed from the broader perspective of climate change, we found that nearly half the routes included in our database exceeded an individual's annual mobility carbon budget of 575 CO_2 kg/p. It was hard not to conclude that most forms of air travel – no matter whether they are direct or connecting – are a tourist's most serious environmental sin, at least as it relates to an individual's carbon footprint. By contextualizing the carbon emissions associated with tourist air travel within this broader carbon budget, it becomes possible to elevate an individual's awareness and understanding of how air travel choices can shape climate change and carbon emissions. More theoretically, it can help contribute to a closing of the "value-action gap" – the idea that an individual's pro-environmental attitudes and values are often not reflected in their actions particularly with respect to air transportation.

Clearly, the most obvious solution to reduce the carbon emissions associated with tourist air travel is to simply not fly to tourist destinations. Even within academia, there is a burgeoning movement questioning the need for air travel to academic conferences (i.e. business tourism) due to the carbon emissions produced (e.g. Nevins, 2014; Wynes et al., 2019). If flying is deemed unavoidable, one potential tactic to mitigate the carbon footprint associated with tourist air travel is to select non-stop routes whenever possible (even

Table 7
Direct return routes ranked by the largest CO_2 kg/p increases relative to the "next best" connecting route.

Direct route	Connecting route	CO_2 kg/p increase
CVG – MIA: 469.2	CVG – ATL – MIA: 381.2	88
CLE – MIA: 513.6	CLE – ATL – MIA: 428.3[a]	85.3
CMH – MIA: 483.1	CMH – ATL – MIA: 414.5	68.6
PIT – MIA: 454.1	PIT – ATL – MIA: 445.9	8.2
CLE – CHS: 343	CLE – ATL – CHS: 336.8	6.2
JFK – BNA: 361.7	JFK – ATL – BNA: 358.7	3.0
IND – MIA: 423.8	IND – ATL – MIA: 422.7	1.1

[a] It should be noted that the CLE-ORD-MIA connecting route (490.1) also generated lower CO_2 kg/p relative to the CLE-MIA direct route (513.6).

though it is frequently a more expensive option) because the vast majority of direct routes in the database generated carbon emissions below the 575 CO_2 kg/p mobility cap. Direct routes also generally out-performed the "next best" stopover option with respect to CO_2 kg/p although a few caveats to this rule were uncovered when direct routes were serviced by fuel-inefficient regional jets. On average, the difference between direct and connecting routes was equivalent to operating a refrigerator for an entire year (or roughly 100 CO_2 kg/p). If flying direct is not possible, tourists should consider purchasing carbon offsets in most cases to stay within their annual mobility carbon budget and mitigate the environmental impacts of their air travel.

Of course, these findings are sensitive to the configuration of the case study network. Further research is needed to better understand the complex geography of aviation carbon emissions by examining in more depth the dynamics of individual airline route networks, aircraft types, and other origin – destination data flows (Miyoshi & Mason, 2009). Additionally, the data utilized in this paper does not allow air passengers to compare between actual flight and aircraft options because the ICAO carbon emissions calculator captures data for the typical or average flight on any given route segment. The statistical and spatial differences in carbon emissions are also likely understated in this paper regarding their full impact on climate change. Only economy seating was analyzed, and we know that premium seating generates a much more notable carbon footprint because of the additional space needed to accommodate first-class seating and/or cabins. The carbon emission estimates are also conservative since we only considered domestic tourism within the contiguous United States – the emissions would almost certainly be magnified if we included international flights.

Ultimately, to realize more meaningful reductions in carbon emissions linked to tourist air travel, broader structural shifts and more substantive policy initiatives than merely advising tourists to fly direct whenever possible are clearly needed. In our database, even the average CO_2 kg/p on direct routes was remarkably high such that one direct return trip would consume more than two-thirds (68.7% or 395 CO_2 kg/p) of an individual's annual mobility budget. Additionally, Higham et al. (2019) have highlighted the potential futility of relying upon individualized behavioral shifts to minimize the emissions associated with tourist air travel and the need instead for broader collective action. Important remedies will likely include policy initiatives that accelerate technological innovations regarding aircraft fuselage, jet engines, and jet fuel. By some estimates, if all the commercial aircraft were replaced by the best available technology then carbon emissions would decline by up to 10% (Dray, 2014; Schafer & Waitz, 2014). However, due to the technological challenges surrounding such advancements, carbon removal/capture strategies will likely be necessary at least in the near-term. The carbon emissions associated with tourist air travel could also be mitigated by further minimizing air traffic management inefficiencies (e.g. Efthymiou & Papatheodorou, 2018). From an airline manager's perspective, these results indicate that a shift away from the traditional hub and spoke network would help reduce carbon emissions, although such a transition would clearly have additional implications for airlines. Of course, the most impactful remedy will likely be the introduction of realistic carbon pricing for air travel on a global scale. Although politically this will be very challenging, several nations such as Canada have already implemented modest carbon pricing initiatives via the direct taxation of fossil fuels and/or through cap and trade programs (New York Times, 2019).

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References

Atmosfair (2017). *Atmosfair airline index 2017.* Bonn: Atmosfair.
Aviation Week and Space Technology (2019). *Editorial: Don't scapegoat aviation in climate change battle February 25–March 10.* 82.
Baumeister, S. (2017). 'Each Flight is Different': Carbon emissions of selected flights in three geographical markets. *Transportation Research Part D, 57*, 1–9.
Becken, S., & Patterson, M. (2006). Measuring national carbon dioxide emissions from tourism as a key step towards achieving sustainable tourism. *Journal of Sustainable Tourism, 14*(4), 323–338.
Davison, L., Littleford, C., & Ryley, T. (2014). Air travel attitudes and behaviors: The development of environment-based segments. *Journal of Air Transport Management, 36*, 13–22.
Dessens, O., Kohler, M. O., Rogers, H. L., Jones, R. L., & Pyle, J. A. (2014). Aviation and climate change. *Transport Policy, 34*, 14–20.
Dings, J., Wit, R., Leurs, B., Davidson, M., & Fransen, W. (2003). *External costs of aviation.* Berlin: German Federal Environmental Agency.
Dray, L. (2014). Time constants in aviation infrastructure. *Transport Policy, 34*, 29–35.
Dwyer, L., Forsyth, P., Spurr, R., & Hoque, S. (2010). Estimating the carbon footprint of Australian tourism. *Journal of Sustainable Tourism, 18*(3), 355–376.
Efthymiou, M., & Papatheodorou, A. (2018). Environmental considerations in the Single European Sky: A Delphi approach. *Transportation Research Part A, 118*, 556–566.
Egelhofer, R., Marizy, C., & Bickerstaff, C. (2008). On how to consider climate change in aircraft design. *Meteorologische Zeitschrift, 17*(2), 173–179.
Farreny, R., Oliver-Sola, J., Lamers, M., Amelung, B., Gabarrell, X., Rieradevall, J., Boada, M., & Benayas, J. (2011). Carbon dioxide emissions of Antarctic tourism. *Antarctic Science, 23*(6), 556–566.
Filimonau, V. (2012). Carbon calculators as a tool for carbon impact appraisal of holiday travel: A critical review. *Worldwide Hospitality and Tourism Themes, 4*(4), 302–331.
German Advisory Council on Global Change (2009). *Solving the climate dilemma.* Berlin: The Budget Approach WBGU.
Gossling, S., & Schumacher, K. P. (2010). Implementing carbon neutral destination policies: Issues from the Seychelles. *Journal of Sustainable Tourism, 18*(3), 377–391.
Hanandeh, A. E. (2013). Quantifying the carbon footprint of religious tourism: The case of Hajj. *Journal of Cleaner Production, 52*, 53–60.
Higham, J., Ellis, E., & Maclaurin, J. (2019). Tourist aviation emissions: A problem of collective action. *Journal of Travel Research, 58*(4), 535–548.
International Civil Aviation Organisation (2017). *ICAO carbon emissions calculator methodology version 10.* Montreal: ICAO.
Jamin, S., Schafer, A., Ben-Akiva, M. E., & Waitz, I. A. (2004). Aviation emissions and abatement policies in the United States: A city-pair analysis. *Transportation Research Part D, 9*, 295–317.
Juvan, E., & Dolnicar, S. (2014). Can tourists easily choose a low carbon footprint vacation? *Journal of Sustainable Tourism, 22*(2), 175–194.
Kelly, J., & Williams, P. W. (2007). Modelling tourism destination energy consumption and greenhouse gas emissions: Whistler, British Columbia, Canada. *Journal of*

Sustainable Tourism, 15(1), 67–90.
Lee, D. S., Fahey, D. W., Forster, P. M., Newton, P. J., Wit, R. C. N., Lim, L. L., Owen, B., & Sausen, R. (2009). Aviation and global change in the 21st century. *Atmospheric Environment, 43*, 3520–3537.
Lenzen, M., Sun, Y. Y., Faturay, F., Ting, Y. P., Geschke, A., & Malik, A. (2018). The carbon footprint of global tourism. *Nature: Climate Change, 8*, 522–528.
Loo, B., Li, L., Psaraki, V., & Pagoni, I. (2014). CO_2 emissions associated with hubbing activities in air transport: An international comparison. *Journal of Transport Geography, 34*, 185–193.
Lu, J. L., & Shon, Z. Y. (2012). Exploring airline passengers' willingness to pay for carbon offsets. *Journal of Transportation Research Part D, 17*, 124–128.
Mayer, R., Ryley, T., & Gillingwater, D. (2012). Passenger perceptions of the green image associated with airlines. *Journal of Transport Geography, 22*, 179–186.
Miyoshi, C., & Mason, K. J. (2009). The carbon emissions of selected airlines and aircraft types in three geographic markets. *Journal of Air Transport Management, 15*, 138–147.
Moisander, J. (2007). Motivational complexity of green consumerism. *International Journal of Consumer Studies, 31*(4), 404–409.
Morrell, P. (2009). The potential for European aviation CO_2 emissions reduction through the use of larger jet aircraft. *Journal of Air Transport Management, 15*, 151–157.
Morrell, P., & Lu, C. (2007). The environmental cost implication of hub-hub versus hub by-pass flight networks. *Transportation Research Part D, 12*, 143–157.
National Academy of Sciences (2013). *Understanding airline and passenger choice in multi-airport regions.* Washington DC: The National Academies Press.
Nevins, J. (2014). Academic jet-setting in a time of climate destabilization: Ecological privilege and professional geographic travel. *The Professional Geographer, 66*(2), 298–310.
New York Times (2013). *Your biggest carbon sin may be air travel January 23rd*.
New York Times (2016). *Global deal on curbing emissions by airlines February 9th*.
New York Times (2019). *These countries have prices on carbon. Are they working April 2nd*.
Rothengatter, W. (2010). Climate change and the contribution of transport: Basic facts and the role of aviation. *Transportation Research: Part D, 15*, 5–13.
Schafer, A. W., & Waitz, I. A. (2014). Air transportation and the environment. *Transport Policy, 34*, 1–4.
Schipper, Y., & Rietveld, P. (1997). *Economic and environmental effects of airline deregulation.* Amsterdam: Tinbergen Institute.
Scott, D., Peeters, P., & Gossling, S. (2010). Can tourism deliver its "Aspirational" greenhouse gas emission reduction targets? *Journal of Sustainable Tourism, 18*(3), 393–408.
Sun, Y. Y. (2014). A framework to account for the tourism carbon footprint at island destinations. *Tourism Management, 45*, 16–27.
Sutkus, D., Baugcum, S., & Dubois, D. (2001). *Scheduled civil aircraft emissions inventories for 1999.* Washington D.C.: Database Development and Analysis NASA/CR-2001-211216.
United Nations World Tourism Organization (2008). *Climate change and tourism – Responding to global challenges.* Madrid: UNWTTO.
United Nations World Tourism Organization (2018). *UNWTO tourism highlights 2018 edition.* Madrid: UNWTTO.
Warburg, Valdemar, Bhat, Chandra, & Adler, Thomas (2006). Modeling Demographic and Unobserved Heterogeneity in Air Passengers' Sensitivity to Service Attributes in Itinerary Choice, Transportation Research Record: Journal of the Transportation Research Board, No. 1951. *Transportation Research Board of the National Academies, Washington, D.C,* 7–16.
Wittmer, A., & Wegelin, L. (2012). Influence of airlines' environmental activities on passengers. *Journal of Air Transport Studies, 3*, 73–99.
World Travel and Tourism Council (2018). *Economic Impact 2018.* London: WTTC.
Wynes, S., Donner, S. D., Tannason, S., & Nabors, N. (2019). Academic air travel has a limited influence on professional success. *Journal of Cleaner Production, 226*, 959–967.
Yin, K., Dargusch, P., & Halog, A. (2015). An analysis of the greenhouse gas emissions profile of airlines flying the Australian international market. *Journal of Air Transport Management, 47*, 218–229.
Zhang, J., & Zhang, Y. (2018). Carbon tax, tourism CO_2 emissions and economic welfare. *Annals of Tourism Research, 69*, 18–30.
Zhang, Y., & Xie, Y. (2005). Small community airport choice behavior analysis: A case study of GTR. *Journal of Transport Management, 11*, 442–447.

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