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‘Each flight is different’: Carbon emissions of selected flights in three geographical markets

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Abstract

Air travel is considered the biggest individual climate sin. Avoiding flying, however, seems impossible. In this paper we argue that the flight a passenger chooses can be significant. For this purpose we compared the carbon emissions of selected flights in three geographical markets. We found tremendous differences in the environmental performance of individual flights. Furthermore, we also found that flying with the most modern aircraft or flying non-stop represents, in many cases, the least polluting option. Nevertheless, we were able to show that there are exceptions to this rule. Based on our results, we provide recommendations to the industry and for further research.

Keywords: Carbon calculators; climate change; flight choice; modern aircraft; non-stop flight.

1. Introduction

According to an article in the New York Times, air travel is considered the biggest individual climate sin (Rosenthal, 2013). Ironically, it is the middle-class that is the most environmentally aware (Alibeli and Johnson, 2009) but also the group who flies the most (Randles and Mander, 2009). Even though several studies found that consumers do identify air traveling as a cause of climate change (Bonini and Oppenheim, 2008; Brouwer et al., 2008) still there is little willingness to change the flying behavior or to sacrifice vacations for the environment's sake (Cohen and Higham, 2011; Lassen, 2010). For many, such changes would be considered a restriction of the personal freedom to travel (Becken, 2007). As Rosenthal (2010) argues, air passengers are caught in a "flying dilemma" where one's individual self-concept as an environmentally responsible consumer conflicts with the environmental impacts of frequent air travel. Though some consumers might act in environmentally conscious ways in everyday situations (e.g. by using public transport, recycling or going paperless), transferring these values to their flying behavior is considered to be difficult (Barr et al., 2009). Davison et al. (2014) clearly see a value-action gap when it comes to consumers' knowledge about the environmental impacts of air travel and their actual behavior. However, when looking at the barriers that prevent consumers from changing their behavior, as presented by Hares et al. (2010), it becomes obvious why the gap still exists: There is (a) a lack of alternatives to flying, (b) an unwillingness to change travel behavior and, (c) the contribution of one individual to climate change through air travel is seen as being insignificant.

While not to fly does not seem to be a feasible option, the question becomes whether there is a possibility to mitigate the environmental impacts by the way in which we fly. Miyoshi and Mason (2009) indicate that there is a difference between the environmental performances of individual airlines. Based on that, we argue that choosing the right flight could have an impact on the environmental outcome of our flying behavior. In order to support this argument we have conducted carbon dioxide emissions calculations for selected flights in three geographic markets. We then compared these figures with the often stated goal of keeping global warming below 2 degrees Celsius, based on pre-industrial levels. According to the German Advisory Council on Global Change (2009), to achieve the climate goal, each human would only be allowed an annual climate budget of 2,300 kg CO_2. Nevertheless, only one-fourth (575 kg CO_2) could be spent on mobility. The first objective of this paper is to show that there are differences between flight options and that, from an environmental point of view, these differences are indeed significant. Making those differences visible to the consumer could have great potential for mitigating the environmental impacts of flying, because the consumer could actively choose flights that are less polluting. Although a fair amount of air passengers are able to differentiate between the environmental friendliness of airlines (Mayer et al., 2012), Gössling et al. (2009) also found that it would require expert knowledge in order to be able to compare the environmental performance of airlines or individual flights. All that an average air passenger can currently rely on are some general environmental measures, such as flying on modern and fuel-efficient aircraft or flying non-stop. The second objective of this paper is therefore to analyze the effectiveness of these environmental measures, with the help of carbon emissions calculations. This paper is structured as follows. We first discuss environmental measures in more detail. Next, we examine emissions calculations by discussing different approaches and the limitations of existing methods. We then present our calculation method. After that we proceed with the results of our study, followed by a conclusion with recommendations to the industry as well as for further research.

2. Environmental measures for air passengers

Previous literature investigating the mitigation of environmental impacts of air travel through behavioral change has mainly examined air passengers' motivation and willingness to pay for carbon offset (e.g. Mair, 2011; van Birgelen et al., 2011; Gössling et al., 2009) or discussed changes of travel behavior in terms of using alternative transportation modes or avoiding holidays overseas (e.g. Davison et al., 2014; Sgouridis et al., 2011; Higham and Cohen, 2011). 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 (Mayer et al., 2012; Wittmer and Wegelin, 2012). However, those studies have mainly focused on the environmental image of airlines and how this might affect an air passenger's booking decision. Concrete environmental measures and their effectiveness in reducing carbon dioxide emissions have not yet been investigated. Because the current literature lacks examples of environmental measures, we turned our attention to commonly shared knowledge and recommendations on how to choose an airline or flight that is less polluting. Table 1 illustrates recommendations provided by various environmental organizations for how the general public can reduce the environmental impacts of air transport. These recommendations range from choosing eco-friendly airlines all the way to the total avoidance of flights in general. When focusing on the measures relevant for air passengers in terms of choosing a flight that has fewer environmental impacts, two measures were mentioned the most often and by almost all the environmental organizations: flying on a modern and fuel-efficient aircraft and flying non-stop. Because these two environmental measures are seen as the most crucial for making environmentally conscious flight choices, we will focus our further investigation on them.

Table 1. Environmental measures provided by environmental organization regarding less polluting flights.

Environmental Organization	Environmental Measures
Brighter Planet	**Fly direct**, avoid business or first class, **fly on modern aircraft** with high load factor and freight share, pack light, find alternatives to flying
Union of Concerned Scientists	Fly economy class, use aircraft with economy class seating only, **fly non-stop**, **choose fuel-efficient airplanes**, avoid airports with long delays
Treehugger	**Use modern aircraft**, choose flights with very few or no premium seats and high load factors, avoid low cost carriers, use turbo prop aircraft
WWF	Choose flights with high load factors, **fly on more efficient aircraft**, buy carbon offset, avoid short-haul flights, take vacations closer to home
Smart Travel	**Fly non-stop**, **choose efficient airplanes**, choose airports with fewer delays, buy carbon offset, use airlines testing biofuels
Friends of the Earth	Fly less frequently, avoid short-haul flights, search for alternative transportation modes, spend vacations closer to your home
Ecolife	Avoid business or first class, **fly non-stop**, use e-ticketing, reduce baggage weight, recycle onboard waste in the airport, use restroom before boarding, pay for carbon offset
Greenpeace	Avoid flying, search for alternative transportation options, don't use short-haul flights
Ecology Center	**Fly non-stop**, avoid short-haul flights, search for alternatives transportation, spend vacations closer to home
Sustainable Travel	**Avoid stopovers**, look for alternative travel modes, pack lightly, use restroom before getting on board, purchase carbon offset, recycle during the flight, avoid long-haul short-stay trips

Source: Environmental organization websites (accessed January 2015).

3. Carbon calculators

In recent years, a number of carbon calculators have become available, which made the environmental impact of flying more easily measurable. Unfortunately, there is a lack of consistency and different calculators produce different outcomes for the same journey (Miyoshi and Mason, 2009) as is shown in Table 2. So far no consensus exists on how to calculate the carbon emissions produced from air transportation. Nevertheless, as Jardine (2009) found, all aviation carbon calculators broadly utilize the same methodology.

Table 2. Results of different carbon calculators for a New York (JFK) to Helsinki (HEL) flight.

JFK-HEL (Economy)	ICAO	Climate Care	Atmosfair	Finnair	Our approach
Distance	6,603 km	6,607 km	6,653km	6,962km	6,750 km
CO_2 (kg)/p	426.49 kg	920.00 kg	640.00 kg	379.44 kg	395.99 kg

Sources: ICAO, 2015; Climate Care, 2015; Atmosfair, 2015; Finnair, 2015.

However, while the methodologies applied in the carbon calculators are similar, there are huge differences in the data they use. These differences can range from the use of simplified data indicating only short-, medium- and long-haul aircraft, as in the case of the UK Department for Environment, Food & Rural Affairs (DEFRA) calculator (DEFRA, 2012), to the use of actual fuel data, as in the case of Finnair's Emissions Calculator (Finnair, 2015). Table 3 illustrates the range of inputs different carbon calculators utilize. In addition, the data itself can be acquired from various sources, including both publically available sources and private ones. While data regarding distance, aircraft type, freight factor, passenger load factor and seating configuration is to a certain extend publically available, the actual fuel consumption is not. To our knowledge, only the Finnair Emissions Calculator utilizes actual fuel data, while all other carbon calculators have to rely on average data. However, software exists (e.g. Piano-X or FAA's AEDT) that is able to precisely model the fuel consumption of individual airplanes by also taking critical parameters into account such as weight, speed and flight level (Piano-X, 2008). Unfortunately, these programs are not freely available. Therefore most of the carbon calculators rely on data that come from publicly available emissions inventory guidebooks. A widely used guidebook is EMEP/Corinair, published by the European Environment Agency (EEA, 2007), which provides fuel consumption data of 44 aircraft types over 16 stage lengths. Fuel data is provided for the entire flight, including taxiing, take-off, climb, cruise, approach and landing. This method also accounts for the fact that short-haul flights burn more fuel per kilometer due to the energy intense take-off and rather short cruise. The same applies to ultra-long haul flights because of the additional weight of the fuel that needs to be carried to fly the longer distance. Nevertheless, EMEP/Corinair does not provide any information on fuel consumption based on different weights, speeds and flight levels, all of which certainly have an influence on the fuel consumption as well (Filippone, 2008).

Table 3. Key features of different carbon calculators.

Parameter	ICAO	DEFRA	Finnair	Our approach
Great circle distance correction	Up to 11%	9%	5% + 20km	Up to 11%
Plane type	50 aircraft types, some represen-tative	3 aircraft types, short, medium and long-haul	Actual aircraft	75 aircraft types, no represen-tatives
Fuel burn data	EMEP/ Corinair	EMEP/ Corinair	Real data	EMEP/EEA
Freight factor	Wide body: 72.9%–90.3% Narrow body: 91.7%–99.6%	Domestic: 99.8% Short-haul: 99.4% Long-haul: 88.1%	Real data	Real data
Load factor	Wide body: 64.5%–83.6% Narrow body: 67.3%–81.8%	Domestic: 66.4% Short-haul: 83.4% Long-haul: 81.9%	Real data	Real data
Seat configuration	Number of economy seats that fit into the aircraft	Represen-tative from CAA data	Real data	Real data

Sources: ICAO, 2014; DEFRA, 2012; Finnair, 2015.

In addition to many of the commonly used carbon calculators, numerous studies (e.g. Loo et al., 2014; Givoni and Rietveld, 2010; Winther et al., 2006; Romano et al., 1999) have based their calculations on the EMEP/Corinair database. A major drawback of the EMEP/Corinair inventory guidebook is that it does not distinguish between the different types within aircraft families (e.g. Airbus A319, A320) and has no data on newer aircraft models, such as the Airbus A380. In 2013, the EEA (2013) therefore published a revised version, the EMEP/EEA inventory guidebook, that contains 75 aircraft types featuring different types within the aircraft families and also includes newer aircraft models. We have based our calculations on this revised guidebook being now able to calculate with more accurate data by distinguish between different types within aircraft families.

The high relevancy of the EMEP/EEA fuel burn data was also confirmed by Park and O'Kelly (2014), who performed validation analysis by comparing the data with more sophisticated fuel burn data, determining a relationship of R^2 at 0.92. But even with the availability of detailed fuel data and actual flight data – such as distance, aircraft type, freight factor, passenger load factor and seating configuration – many carbon calculators still base their calculations on average data, providing users with only the CO_2 emissions of a so-called typical flight. As Miyoshi and Mason (2009) found, currently available carbon calculators treat all flights in the same manner, without distinguishing between the different environmental performances of individual airlines or flights. This problematic approach often starts with the aircraft type. Some carbon calculators use only a few generic types of aircraft instead of the specific aircraft that is operating the actual flight. This of course has consequences for the fuel burn and the amount of seats or passengers. Another common way of simplifying the calculations is the use of average passenger and freight load factors which, according to Miyoshi and Mason (2009), are often unrealistically high. Finally, most of the carbon calculators fail to distinguish between different seat layouts, which can differ tremendously between airlines and can certainly play an important role in terms of per passenger carbon emissions (Park and O'Kelly, 2014; Bofinger and Strand, 2013). While information on a typical flight might provide some estimation of how many CO_2 emissions a flight might produce, it does not allow air passengers to compare different flight options in the cases when there is more than one available. We argue that in order to make informed choices the carbon emissions of each and every flight needs to be calculated individually, which requires the utilization of all the actual and flight-specific data available. Once air passengers can compare individual flights based on their carbon dioxide emissions, they will be able to make environmentally conscious choices based on facts and not just on assumptions as discussed above.

Additionally, previous literature has not focused on the carbon emissions of individual flights but has instead looked on the CO_2 emissions of routes (Loo et al., 2014; Miyoshi, 2014; Hanandeh, 2013; Givoni and Rietveld, 2010; Miyoshi and Mason, 2009; Jamin et al., 2004) or airlines (Miyoshi, 2014; Miyoshi and Mason, 2009; Romano et al., 1999), mainly utilizing average data in terms of aircraft (Smith and Rodger, 2009), load factors (Miyoshi and Mason, 2009; Smith and Rodger, 2009; Gössling et al., 2005), seat configurations (Miyoshi and Mason, 2009; Smith and Rodger, 2009) or fuel burn per passenger-kilometer (Smith and Rodger, 2009; Peeters et al., 2007; Gössling et al., 2005; Jamin et al., 2004). With this study we want to go beyond average figures and show that significant differences exist between the environmental performance of individual flights even when operated by the same aircraft or the same airline on the same route.

4. Methods

Carbon dioxide emissions were calculated following the methodology provided by ICAO (2014). This methodology is most widely recognized within the aviation industry and has been adopted by many carbon calculators. Furthermore, in the existing literature many studies (e.g. Hanandeh, 2013; Lu and Shon, 2012) have utilized the ICAO method. However, as discussed earlier, the ICAO Carbon Emissions Calculator relies mainly on average data, while we wanted to base our calculations on actual data. Our approach therefore differs from the ICAO methodology because we acquired real traffic data from the United States Department of Transportation (USDOT) in order to calculate load factors, passenger-to-freight factors and the number of seats supplied on each flight. USDOT traffic data was available on a monthly basis and flight-specific data was collected by using the flight number as an indicator. The data used in this study was from April 2014.

The fuel data was calculated by interpolation, using a linear regression method. This was considered to be reasonable because the fuel consumption curve approaches a linear relationship to distance on medium- and long-haul flights. For short-haul flights, we applied the same method, which we considered to be appropriate because we had more accurate data available due to the smaller distance steps in the fuel database (125 nm, 250 nm, 500 nm, 750 nm). We are, however, aware that only real fuel data would result in accurate consumption figures. Nevertheless, comparing our results with that of Finnair's Emissions Calculator (see Table 2) gave us confidence in the accuracy of our calculation method. The Great Circle Distance (GCD) between the origin and destination was also acquired from the USDOT database. We used a correction factor in order to account for stacking, traffic and weather-driven diversion from the GCD. We hereby added 50 km to flights less than 550 km, 100 km to flights between 550 km and 5,500 km and 125 km to all flights longer than 5,500 km. To calculate carbon dioxide emissions per passenger, we used the following formula 1, as stated in the ICAO Carbon Emissions Calculator manual Version 7 (June 2014):

$$CO2\ per\ passenger = 3.157 * \frac{(total\ fuel * passenger\ to\ freight\ factor)}{(number\ of\ seats * passenger\ load\ factor)} \quad (1)$$

The constant of 3.157 represents hereby the number of tons of CO_2 produced when burning one ton of aviation fuel (Dings et al., 2003; Sutkus et al., 2001). The passenger-to-freight factor allocates how much of the total payload carried by the aircraft accounts for carrying the passengers. It is calculated by deducting freight and mail from the payload divided by the payload. The higher the passenger-to-freight factor is, the less freight and mail is carried by the aircraft which means more of the total emissions produced by the flight have to be allocated to the passengers. The flight connection data was acquired from the Official Aviation Guide (OAG) Flight Schedule, which provided information on departure and arrival times, flight numbers, aircraft type and cabin classes. All CO_2 emissions were calculated on a per passenger or per passenger-kilometer basis. All calculations of emissions per passenger were made regardless of cabin class. We did this while also being aware that 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 (Bofinger and Strand, 2013). In addition to using actual data, we also performed some maximum efficiency calculations where all factors were maximized in order to show the potentials of efficiency improvements based on currently employed aircraft technology. In these calculations, load factors were set up to 100%, while the passenger-to-freight factor was decreased to 75.73% (wide body) or 83.92% (narrow body), which equals the lowest factors that could be found within the ICAO Carbon Emissions Calculator's manual, and the maximum amount of seats aircraft were designed for were applied. In order to compare the aircraft's seat configuration with the designed maximum seating capacity, we determined a so-called seat ratio. Cabin seat charts helped to map the seat configuration of various aircraft and the amount of seats in each cabin class. This information was obtained from Seat Guru, which features one of the largest collections of aircraft seat maps online. The maximum seating capacity of each aircraft used in the study was acquired from the aircraft manufacturers directly. Based on these data, the seat ratio was calculated using the following formula 2:

$$Seat\ Ratio = \frac{Actual\ amount\ of\ seats\ the\ aircraft\ is\ currently\ equipped\ with}{Maximum\ amount\ of\ seats\ the\ aircraft\ was\ designed\ for} \tag{2}$$

While previous studies have built their emissions calculations on a large amount of routes (e.g. Loo et al., 2014; Hanandeh, 2013; Miyoshi and Mason, 2009), we decided to focus on selected flights of three routes and to instead analyze these in-depth. Nevertheless, our routes cover three geographical markets of short-, medium- and long-haul flights. For the short-haul market, we chose the busiest domestic route in the United States, Los Angeles (LAX) to San Francisco (SFO). This route was of special interest for us because the variety of aircraft used on this route is large. Still, the route is not so short that it would be operated as non-stop only, providing the chance to compare non-stop flights with connecting flights on a short-haul route. For the medium-haul route we chose the second busiest medium-haul route in the United States, Los Angeles (LAX) to New York (JFK). This route was chosen over Miami (MIA) to New York (NYC) because of the much greater diversity of operators and aircraft used on the LAX to JFK route. For the long-haul route we chose Los Angeles (LAX) to London (LHR), which is the third busiest U.S. international route after New York (JFK) to London (LHR) and Honolulu (HNL) to Tokyo (NRT). We chose this route over the others because it offers more connecting flights than the other two routes. In addition, the diversity of operators and aircraft was higher, giving more opportunities to compare different operators and aircraft. On the short- and medium-haul routes we did not analyze all flights but chose instead a time frame for departures that allowed us to include all major operators and the most common aircraft used on these particular routes. For the Los Angeles to San Francisco route we analyzed all departures between 10 a.m. and 12 p.m. and on the Los Angeles to New York (JFK) route we chose all departures between 6 a.m. and 7 a.m. On the long-haul route we considered all late afternoon departures that took place between 5 p.m. and midnight. On all three routes, all direct flights and all connecting flights that were listed on the OAG Flight Schedule were taken into consideration. Even flight connections that required longer detours were taken into account because they might be appealing to some air passengers due to lower airfares or loyalty to an airline that does not offer a non-stop flight. However, only flights were considered that operated at least five times a week. We calculated carbon emissions for each and every individual flight. Altogether, 68 flight connections operated by 118 different flights, connecting our three chosen city pairs, were included in this study.

5. Results & discussion

Figure 1 shows the total CO_2 emissions in kilograms per passenger for all 68 connections analyzed in this study. The figure illustrates clearly that which flight option passengers choose can make a huge difference because the emissions per passenger between the most efficient flight and the least efficient flight differ significantly. In the case of the short-haul route from Los Angeles to San Francisco, emissions range from 71 kg of CO_2 per passenger for a direct flight up to more than five times or 374 kg for a connecting flight via Dallas/Fort Worth. On the medium-haul route from Los Angeles to New York JFK, emissions range from 277 kg on a direct flight up to 659 kg on a connecting flight via San Francisco. In the case of a long-haul flight from Los Angeles to London Heathrow, emissions range from 594 kg for a non-stop flight up to 1,207 kg of CO_2 with a transfer through Istanbul. When these figures are brought into perspective with the often stated goal of keeping global warming below 2 degrees Celsius, the differences in emissions become even more significant. All one-way flights from Los Angeles to London exceed the goal of 575 kg of CO_2 and even some of the most inefficient one-way flights from Los Angeles to New York are close to doing so. In Figure 1, it is also of interest to note that some medium-haul flights from Los Angeles to New York nearly reach and in some cases even exceed the per passenger emissions of a long-haul flight from Los Angeles to London. This is remarkable because the distance between those two city pairs is more than twice as long.

[Figure 1]

Fig. 1. CO_2 emissions (kg)/passenger of selected flights in three geographical markets.

5.1. Flying the most modern aircraft

As shown above it certainly matters which flight passengers take, especially when we look at it from a broader perspective such as climate change. One option to reduce carbon dioxide emissions often discussed in the literature (e.g. Davison et al., 2014; Mayer et al., 2012; Cowper-Smith and de Grosbois, 2011) is to fly on a modern and fuel-efficient airplane. With every new aircraft generation, the fuel efficiency increases, which results in a lower carbon dioxide emission per passenger.

Figure 2 shows the maximum efficiency carbon dioxide emissions per passenger-kilometer of all intra-North American flights used in this study (blue bar). It then compares these emissions with the actual emissions these flights produced based on the actual data (blue + red bar). In this way, all relevant parameters for the emissions calculations, such as fuel consumption, load factor, passenger-to-freight factor and seat ratio are added, through which the differences in performance can be explained. When we first look at the maximum efficiency (blue bar), we can certainly see that the most modern aircraft just recently introduced by American Airlines, the Airbus A321ER Transcontinental, would outperform all the older aircraft emitting only 42 g of CO_2 per passenger-kilometer. The oldest aircraft, in this case the McDonnell Douglas MD-88, doubles this value by almost 74 g. Were all flights to be operated in the most efficient manner, flying on the most modern aircraft would be the best choice.

However, as the actual numbers (blue + red bar) show, the reality looks different. The brand new American A321ER emits 138 g of CO_2 per passenger-kilometer, 22 g more than the Delta McDonnell Douglas MD-88, designed in the 1980s. While the load factor and the passenger-to-freight factor of both flights are almost equal, the A321ER shows a much lower seat ratio than the MD-88. The A321ER seats only 102 passengers in a three-class configuration, which is less than half of the 240 seats the aircraft was designed for. The MD-88 instead has quite dense seating, with

149 out of 172 possible seats in a two-class configuration. Among the most efficient flights are the ones operated on the Airbus A321 by JetBlue Airways and US Airways. All three flights show relatively high load factors, high seat ratios and low passenger-to-freight factors. The Delta 757-300 also displayed good performance due to its high load factor of 96%. Figure 2 reveals a clear trend for low performing flights, which either have a low load factor or a low seat ratio. The only exception is the MD-88. In this case, the passenger-to-freight factor does not play a large role, because narrow body aircraft in general do not carry much freight or mail. The only exception seen in Figure 2 is the Delta Boeing 767-300, which shows a low passenger-to-freight factor that helps compensate for the low seat ratio of only 64%.

[Figure 2]

Fig. 2. CO_2 emissions (g)/pkm on selected U.S. medium-haul flights.

Figure 3 shows similar results. For long-haul flights when comparing the different flights in the maximum efficiency scenario (blue bar), we can see that twin-engine aircraft (B777, B767 and A330) certainly outperform the larger four-engine jets (A340, B747 and A380). The only exception is the Turkish Boeing 777-300ER. However, the higher CO_2 emissions per passenger-kilometer can be explained by the fact that this flight is significantly longer than the others and therefore has to carry additional fuel, which makes the aircraft heavier. Even though the differences between the flights displayed are not that large, a clear trend can be detected towards more modern aircraft performing better than older ones, for example when comparing the A380 with the Boeing 747. However, the picture changes completely once we examine actual performance (blue + red bar).

Now the Boeing 747-400 actually produces fewer carbon dioxide emissions per passenger-kilometer than the next generation A380, both operated by British Airways on the very same route. This result is because the 747 operates with a higher load factor and carries more freight than the A380. But also flights operated with the same aircraft can differ tremendously, as we can see in the example of two British Airways flights both operated by Boeing 777-200. While the first flight emits 134 g of CO_2 per passenger-kilometer, the second flight emits only 72 g of carbon dioxide. This gap is because the second flight has 50 seats more due to the absence of a first class and a smaller business class section. In addition, it is also much better occupied and carries more freight and mail than the first flight.

[Figure 3]

Fig. 3. CO_2 emissions (g)/pkm on selected North Atlantic flights.

Figure 4 compares the total carbon dioxide emissions per passenger on three short-haul routes. In contrast to medium- and long-haul flights where CO_2 emissions are almost linear to distance, this is not the case for short-haul flights where the take-off is rather energy intense compared to the much shorter cruise. We were therefore unable to compare short-haul flights of various lengths on a passenger-kilometer base. Once again, when looking at the maximum efficiency scenario (blue bar), modern aircraft lead the way. For example, on the Los Angeles to San Francisco route the modern Boeing 737-800 shows the best performance while its predecessor the 737-300 emits 28% more carbon dioxide per passenger. The two other routes in Figure 4 reveal another interesting phenomenon: in both cases regional jets show much higher carbon dioxide emissions per passenger than other aircraft even though the regional jets in this comparison are fairly modern.

[Figure 4]

Fig. 4. CO_2 emissions (kg)/passenger on selected short- and medium-haul flights in the U.S.

This confirms earlier studies by Babikian, Lukachko and Waitz (2002), who found that regional jets are 40–60% less fuel efficient than larger narrow- and wide-body jet aircraft and 10–60% less efficient than turboprop planes. On the Los Angeles to Phoenix route, the Airbus A321 emits only 77 kg of CO_2 per passenger while the Canadair Regional Jet 700 accounts for 123 kg. On the Los Angeles to San Diego route, the turboprop Embraer 120 outperforms the Canadair Regional Jet 200 by 25% even with a 4% lower load factor. Unfortunately, turboprop aircraft are often considered to be old-fashioned while regional jets are perceived to be more modern, making them appear more efficient although they are not.

5.2. Flying non-stop

A second option to reduce carbon emissions often discussed is to avoid stopovers because they increase the distance travelled and require additional landing and take-off (LTO) cycles. Jamin et al. (2004), for example, found that 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 LTO cycle. When the most efficient flights in all three markets are considered, as displayed in Figure 1, it confirms that the most efficient flights are non-stop, consisting of only one leg (only blue bar). Especially in the short-haul market, connecting flights cannot compete with non-stop flights in terms of carbon dioxide emissions. In the case of the medium-haul market, however, the picture looks different. Here even flights with three legs (blue + red + green bar), meaning two stopovers, perform better than some of the non-stop flights, which is certainly an unexpected finding. In fact, two of the four non-stop flights were outperformed by many flights with two stopovers as well as by flights with large detours of more than 1,500 kilometers, such as the Alaska Airlines flight via Seattle. Similar results can also be reported from the long-haul market. Even though several non-stop flights lead the market, some of the non-stop flights were outperformed by connecting flights. However, the vast majority of connecting flights did show higher carbon dioxide emissions. An interesting observation was also made among the two North Atlantic Airbus A380 flights operated by British Airways and Air France. Even with a stopover in Paris that requires a 742 km long detour and an additional LTO cycle, the Air France flight still emits 12 kg of CO_2 per passenger less than the non-stop British Airways service. The answer to this surprising result can be found in Figure 3 in which both flights are directly compared to each other on the basis of carbon dioxide emissions per passenger-kilometer. Not only does the Air France flight have a higher load factor of 91% versus 86%, but it also shows a higher seat ratio with altogether 516 seats while British Airways only has 469 seats on board its A380. Even though the difference between these two flights does not appear to be large, it certainly ranges on the level of an additional short-haul flight from Paris to London. This finding confirms what Loo et al. (2014) found, namely, that applying a hub-and-spoke operation can indeed reduce environmental impacts due to the fact that bundling passenger streams can lead to the use of larger aircraft and higher load factors. Flying non-stop does not always represent the cleanest option.

6. Conclusion

This study set out to investigate whether the flights air passengers select really can make a difference in terms of environmental impacts. It further examined whether general environmental measures such as flying on modern, fuel-efficient aircraft and flying non-stop are really effective in mitigating the environmental impacts of individual air passengers.

The study found that there are clear differences between flights, because the carbon emissions per passenger can vary tremendously. The relevancy of this finding becomes especially obvious when the calculated emissions are observed from the broader perspective of climate change. Unfortunately, there are currently no carbon calculators available that allow air passengers to compare individual flight options. The current calculators rely too heavily on average data in terms of fuel burn, load factors, passenger-to-freight factors and seat layouts. The results clearly indicated that only when calculating with real data can the differences in the environmental performance of flights be made visible. This clearly shows the limitation of existing carbon calculators as tools for air passengers to make informed choices about which flight to choose. To date, air passengers who want to mitigate their environmental impact of flying have to rely on some environmental measures, such as using modern and fuel efficient aircraft or flying non-stop. However, the results suggested that sometimes these measures do not correctly indicate the true environmental impact of individual flights because there are exceptions to this rule. Therefore, it can be concluded that these two measures do not necessarily provide the full picture to the environmentally concerned air passenger.

The problem remains that air passengers are currently not able to choose flights that generate lower carbon dioxide emissions per passenger. We therefore see a clear need for more credible information to be provided to air passengers in an easy-to-understand way at the time of booking. Sometimes just choosing one flight over another, while both having similar departure and arrival times or ticket prices, can make a real difference in terms of an air passenger's individual carbon footprint. At the same time, this choice can also send a strong signal to airlines operating flights that emit more carbon dioxide per passenger, making them alter their operations because demand might otherwise shift to more eco-friendly airlines. An eco-label, as proposed by Baumeister and Onkila (2017), providing information on the environmental performance could be one way to provide information to air passengers at the time of booking. Such an eco-label would give them the opportunity to make better informed choices and actively select cleaner flight options if they want to do so. Further research should examine ways to better inform air passengers about the environmental impacts of individual flights as well as methods to address the environmental impacts of aviation through a market-driven approach.

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References

Alibeli, M.A., Johnson, C., 2009. Environmental Concern: A Cross National Analysis. Journal of International and Cross-Cultural Studies 3, 1–10.

Atmosfair, 2015. Calculate Emissions. https://www.atmosfair.de/en/kompensieren/flug

Babikian, R., Lukachko, S.P., Waitz, I.A., 2002. The historical fuel efficiency characteristics of regional aircraft from technological, operational, and cost perspectives. Journal of Air Transport Management 8, 389–400.

Barr, S., Shaw, G., Coles, T., Prillwitz, J., 2009. ’A holiday is a holiday’: practicing sustainability, home and away. Journal of Transport Geography 18, 474–481.

Baumeister, S., Onkila, T., 2017. An eco-label for the airline industry? Journal of Cleaner Production 142, 1368-1376.

Becken, S., 2007. Tourists’ Perception of International Air Travel’s Impact on the Global Climate and Potential Climate Change Policies. Journal of Sustainable Tourism 15, 351–368.

Bofinger, H., Strand, J., 2013. Calculating the Carbon Footprint from Different Classes of Air Travel. The World Bank, Development Research Group Environment and Energy Team.

Bonini, S., Oppenheim, J., 2008. Cultivating the Green Consume. Stanford Social Innovation Review Fall 2008, 56–61.

Brighter Planet, 2010. Flying Greener: Understanding and reducing the climate impact of business air travel. http://www.etctravel.com/fly_green.pdf

Brouwer, R., Brander, L., Van Beukering, P., 2008. „A convenient truth“: air travel passengers’ willingness to pay to offset their CO_2 emissions. Climatic Change 90, 299–313.

Climate Care, 2015. Carbon Calculator. http://www.climatecare.org/home.aspx

Cohen, S., Higham, E., 2011. Eyes wide shut? UK consumer perception of aviation climate impacts and travel decisions to New Zealand. Current Issues in Tourism 14, 323–335.

Cowper-Smith, A. and de Grosbois, D., 2011. The adoption of corporate social responsibility practices in the airline industry. Journal of Sustainable Tourism 19, 59–77.

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.

DEFRA [Department for Environment, Food & Rural Affairs], 2012. 2012 Guidelines to Defra / DECC’s GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors, July 2012.

Dings, J., Wit, R., Leurs, B., Davidson, M., Fransen, W., 2003. External Costs of Aviation, German Federal Environmental Agency, Berlin, 2003.

Eco Life, 2015. Book your Air Travel with a Green Airline. http://www.ecolife.com/travel/air-travel/choosing-a-green-airline.html

Ecology Center, 2015. Tips for Eco-friendlier travel. http://ecologycenter.org/factsheets/travel_tips/

EEA [European Environment Agency], 2007. EMEP/CORINAIR Emissions Inventory Guidebook - 2007, EEA, Brussels, 2007.

EEA [European Environment Agency], 2013. EMEP/EEA Air Pollutant Emissions Inventory Guidebook - 2013, EEA, Brussels, 2013.

Filippone, A., 2008. Analysis of Carbon-Dioxide Emissions from Transport Aircraft. Journal of Aircraft 45, 185–197.

Finnair, 2015. Emissions Calculator. http://www.finnair.com/FI/FI/emissions-calculator

Friends of the Earth, 2015. Aviation and global climate change. http://www.foe.co.uk/sites/default/files/downloads/aviation_climate_change.pdf

German Advisory Council on Global Change, 2009. Solving the climate dilemma: The budget approach, WBGU, Berlin, 2009.

Givoni, M., Rietveld, P., 2010. The environmental implications of airlines' choice of aircraft size. Journal of Air Transport Management 16, 159–167.

Greenpeace, 2015. Aviation: Frequently Asked Questions. http://www.greenpeace.org.uk/climate/aviation/faq

Gössling, S., Peeters, P., Ceron, J-P., Dubois, G., Patterson, T., Richardson, R., 2005. The eco-efficiency of tourism. Ecological Economics 54, 417–434.

Gössling, S., Haglund, L., Kallgren, H., Revahl, M., Hultman, J., 2009. Swedish air travellers and voluntary carbon offsets: towards the co-creation of environmental value? Current Issues in Tourism 12, 1–9.

Hanandeh, A.E., 2013. Quantifying the carbon footprint of religious tourism: the case of Hajj. Journal of Cleaner Production 52, 53–60.

Hares, A., Dickinson, J., Wilkes, K., 2010. Climate change and the air travel decision of UK tourists. Journal of Transport Geography18, 466–473.

Higham, J., Cohen, S., 2011. Canary in the coalmine: Norwegian attitudes towards climate change and extreme long-haul air travel to Aotearoal/New Zealand. Tourism Management 32, 98–105.

ICAO [International Civil Aviation Organization], 2014. Carbon Emissions Calculator Methodology Version 7, June 2014.

ICAO [International Civil Aviation Organization], 2015. Carbon Emissions Calculator. http://www.icao.int/environmental-protection/CarbonOffset/Pages/default.aspx

Jardine, C.N., 2009. Calculating the carbon dioxide emissions of flights, Environmental Change Institute, Oxford University Centre of the Environment, Oxford, 2009.

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: Transport and Environment 9, 295–317.

Lassen, C., 2010. Environmentalist in Business Class: An Analysis of Air Travel and Environmental Attitude. Transport Review 30, 733–751.

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.

Mair, J., 2011. Exploring air travellers' voluntary carbon-offsetting behavior. Journal of Sustainable Tourism 19, 215–230.

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., 2014. Assessing the equity of the European Union Emission Trading Scheme on an African airline. Transport Policy 33, 56–64.

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.

Park, Y., O'Kelly, M.E., 2014. Fuel burn rates of commercial passenger aircraft: variations by seat configuration and stage distance. Journal of Transport Geography 41, 137–147.

Peeters, P., Szimba, E., Dujinisveld, M., 2007. Major environmental impacts of European tourist transport. Journal of Transport Geography 15, 83–93.

Piano-X., 2008. User's guide. http://www.piano.aero/

Randles, S., Mander, S., 2009. "Practice(s) and ratchet(s): A sociological examination of frequent flying", in: Gössling, S. and Upham, P. (Eds.) Earthscan, London, pp. 245–271.

Romano, D., Gaudioso, D., De Lauretis, R., 1999. Aircraft emissions: a comparison of methodologies based on different data availability. Environmental Monitoring and Assessment 56, 51–74.

Rosenthal, E., 2010. Can we kick our addiction to flying? The Guardian (24. May, 2010). http://www.theguardian.com/environment/2010/may/24/kick-addiction-flying

Rosenthal, E., 2013. Your Biggest Carbon Sin May Be Air Travel. New York Times (26. January, 2013). http://www.nytimes.com/2013/01/27/sunday-review/the-biggest-carbon-sin-air-travel.html?_r=0

Smart Travel, 2015. Easy Ways to Fly Green. http://www.smartertravel.com/blogs/today-in-travel/infographic-easy-ways-to-fly-greener.html?id=18258346

Smith, I.J., Rodger, C.J., 2009. Carbon emission offsets for aviation-generated emissions due to international travel to and from New Zealand. Energy Policy 37, 3438–3447.

Sgouridis, S., Bonnefoy, P.A., Hansman, R.J., 2011. Air transportation in a carbon constrained world: Long-term dynamics of policies and strategies for mitigating the carbon footprint of commercial aviation. Transport Research Part A 45, 1077–1091.

Sustainable Travel, 2015. To fly or not to fly. http://www.responsibletravelreport.com/component/content/article/2647-to-fly-or-not-to-fly

Sutkus, D., Baugcum, S., DuBois, D., 2001. Scheduled Civil Aircraft Emissions Inventories for 1999: Database Development and Analysis, NASA/CR-2001-211216, Washington DC, 2001.

Treehugger, 2015. Greener Flying: Not all flights are created equal. http://www.treehugger.com/aviation/greener-flying-not-all-flights-are-created-equal-part-1-of3.html

Union of Concerned Scientists, 2008. Getting There Greener: The Guide to Your Lower-Carbon Vacation, Cambridge, 2008.

van Birgelen, M., Semeijn, J., Behrens, P., 2011. Explaining pro-environmental consumer behavior in air travel. Journal of Air Transport Management 17, 125–128.

Winther, M., Kousgaard, U., Oxbol, A., 2006. Calculation of odour emissions from aircraft engines at Copenhagen Airport. Science of the Total Environment 366, 218–232.

Wittmer, A., Wegelin, L., 2012. Influence of Airlines' Environmental Activities on Passengers. Journal of Air Transport Studies 3, 73–99.

WWF [World Wide Fund], 2015. Travel light. http://wwf.panda.org/how_you_can_help/live_green/travel/

Figure 1

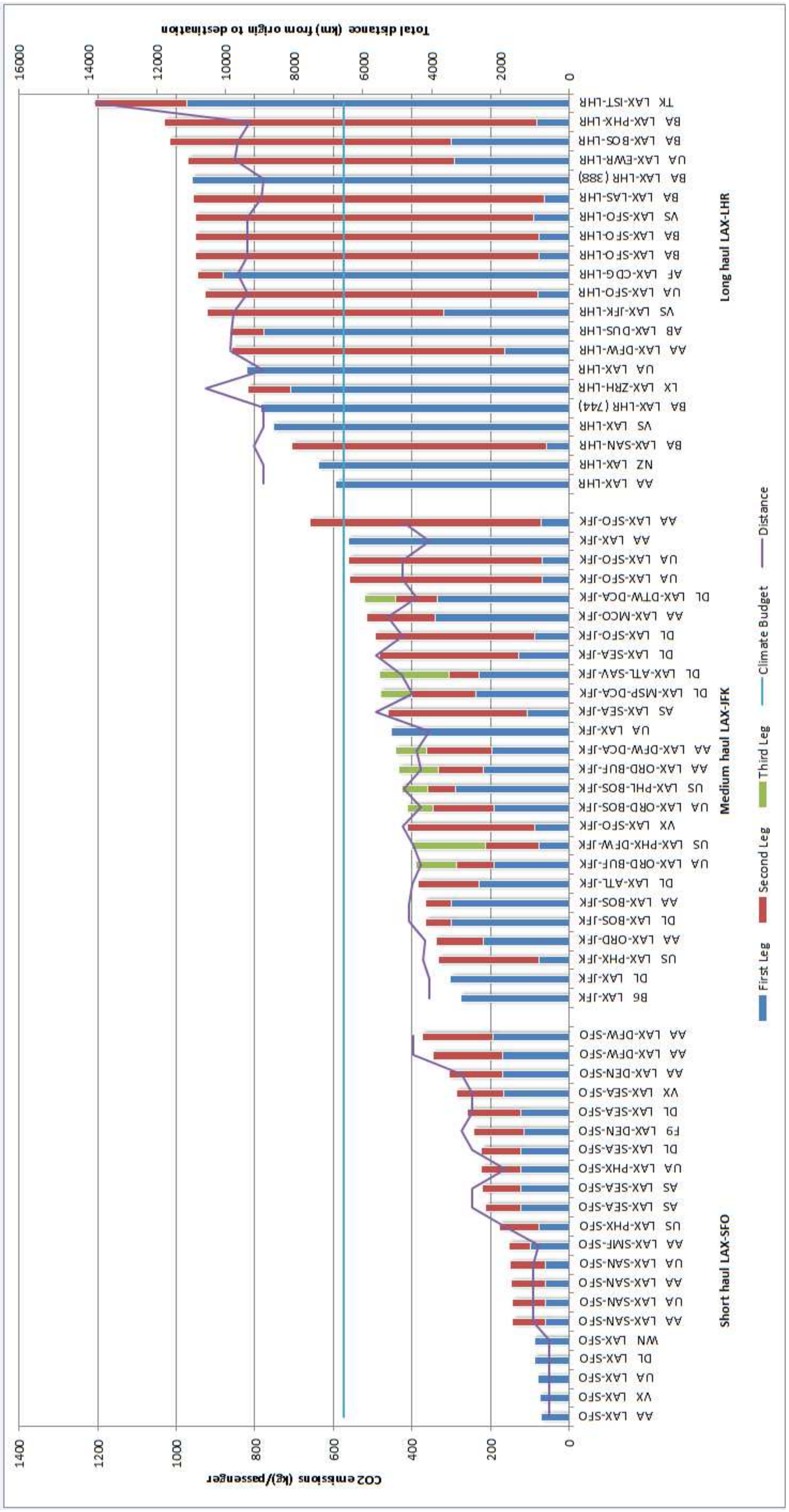
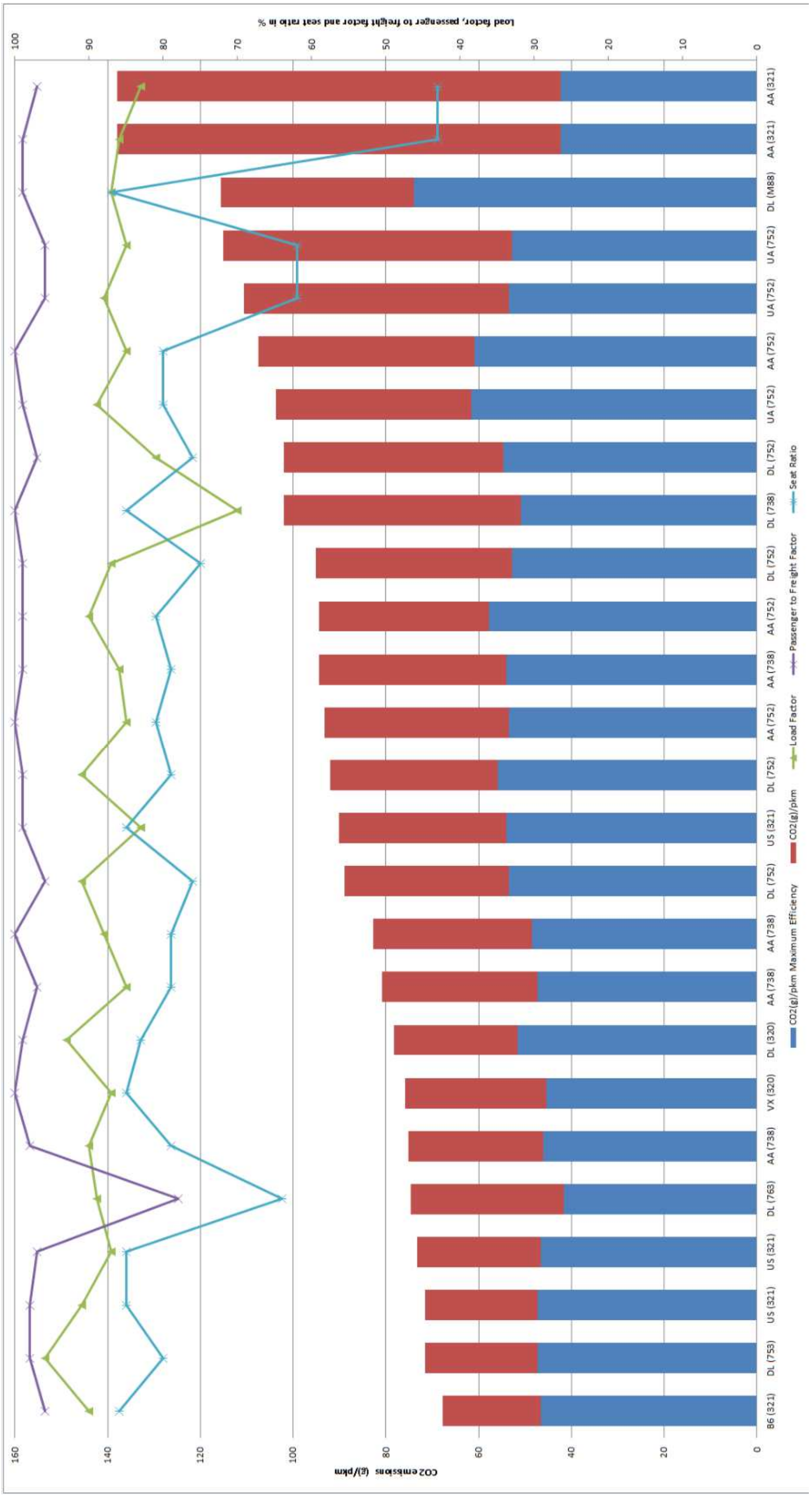
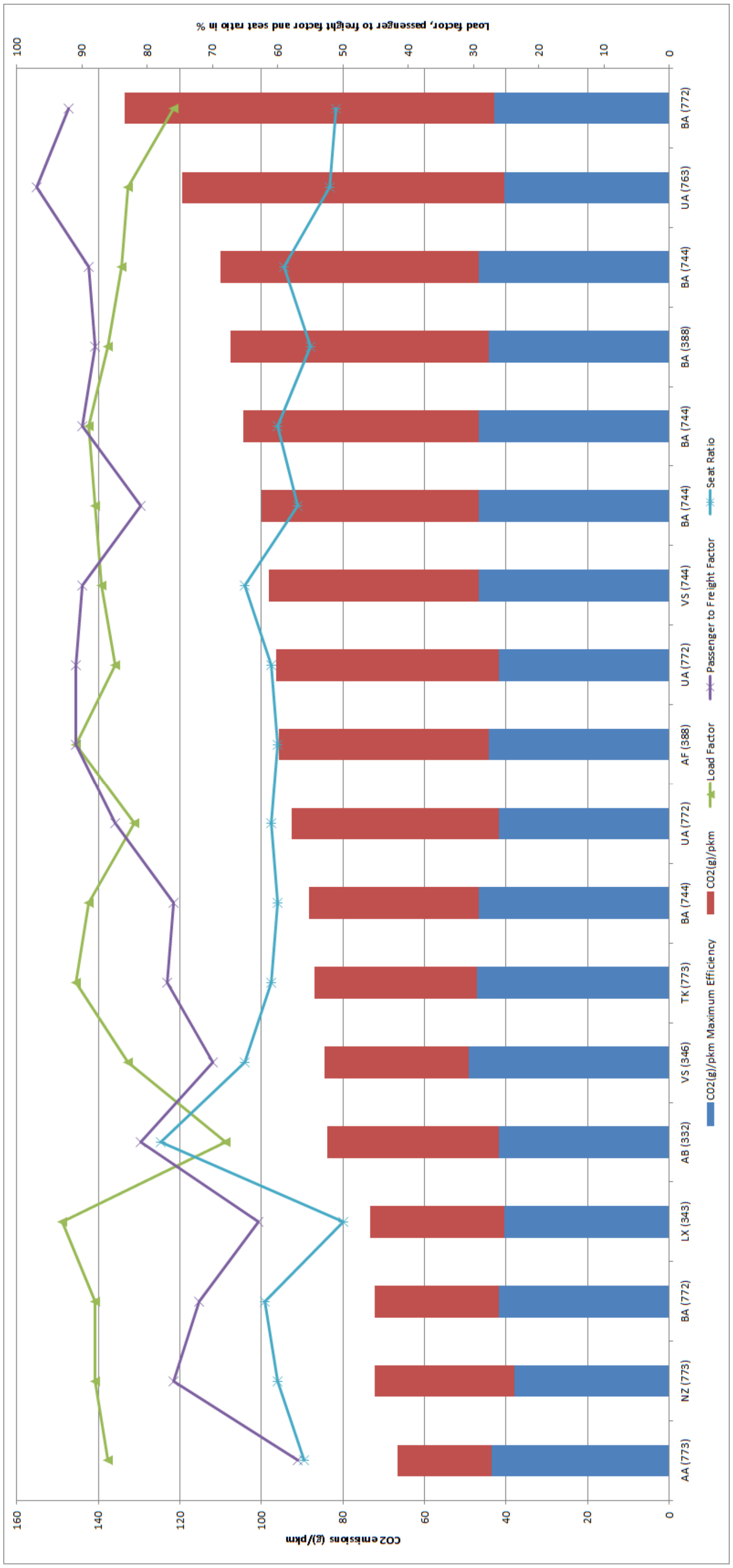

Total distance (km) from origin to destination
CO2 emissions (kg)/passenger
Long haul LAX-LHR
Medium haul LAX-JFK
Short haul LAX-SFO
First Leg
Second Leg
Third Leg
Climate Budget
Distance

Figure 2



Load factor, passenger to freight factor and seat ratio in %
CO2 emissions (g)/pkm
AA (321)
AA (321)
DL (M88)
UA (752)
UA (752)
AA (752)
UA (752)
DL (752)
DL (738)
DL (752)
AA (752)
AA (738)
AA (752)
DL (752)
US (321)
DL (752)
AA (738)
AA (738)
DL (320)
VX (320)
AA (738)
DL (763)
US (321)
US (321)
DL (753)
B6 (321)
CO2(g)/pkm Maximum Efficiency
CO2(g)/pkm
Load Factor
Passenger to Freight Factor
Seat Ratio

Figure 3



Load factor, passenger to freight factor and seat ratio in %
CO2 emissions (g)/pkm
BA (772)
UA (763)
BA (744)
BA (388)
BA (744)
BA (744)
VS (744)
UA (772)
AF (388)
UA (772)
BA (744)
TK (773)
VS (346)
AB (332)
LX (343)
BA (772)
NZ (773)
AA (773)
CO2(g)/pkm Maximum Efficiency
CO2(g)/pkm
Load Factor
Passenger to Freight Factor
Seat Ratio