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Carbon Offsetting & Air Travel

Part 1: CO₂-Emissions Calculations

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Introduction

Aviation activities currently account for about 2-5% of total anthropogenic Greenhouse Gas (GHG) emissions. Civil aviation is growing rapidly at 5.9% per year (IPCC, 2007, p. 334) and the sector's contribution to global warming will continue to grow. Companies and individuals are increasingly interested in purchasing carbon offsets as a way to reduce their climate impact from air travel. Yet calculating air travel emissions is not simple and the current available air travel calculator estimates can vary by up to a factor of three (Kollmuss, 2007).

The following paper is the first of two which examine the key factors that have to be taken into account when calculating air travel emissions for the purpose of carbon offsetting. This paper first gives a brief overview of three emissions calculators which were chosen because they are among the most comprehensive currently available:

- Atmosfair (<http://www.atmosfair.com>)
- TRX Travel Analytics (<http://carbon.trx.com>)
- Virgin Atlantic (<https://virginatlantic.myclimate.org>)

The paper then examines the aircraft parameters that are needed to calculate emissions on a per person basis and describes how each of the three calculators accounts for these parameters. The parameters discussed are:

1. Aircraft Model
2. Flight Profile and Flight Distance
3. Cargo on Passenger Flights
4. Seat Occupancy Rate (Load Factor)
5. Seat Class

The final section of the paper analyzes emissions calculations for flights between three city pairs, and compares the results of the three emissions calculators to each other as well as to the UK's Department for Environment, Food and Rural Affairs (DEFRA) multiplier for air travel emissions calculations. The DEFRA multiplier was included in the comparison because it is widely used by government agencies and private entities to calculate air travel emissions.

This paper does not discuss GHG emissions associated with other airport-related sources or ground travel transportation to and from airports. Greenhouse gas inventories prepared by airport operators indicate that when considering all emissions sources operating at an airport, aircraft represent 80% or more of GHG emissions (Vigilante, personal communication).

This paper does not discuss the user-friendliness of the evaluated calculators but instead focuses solely on the data sources and calculations used to account for the above listed parameters.

This paper does not include a discussion of how to account for non-CO₂ emissions from air-travel (i.e. RFI multipliers). This topic is the focus of the second paper.

1. Evaluated Air Travel Calculators

Atmosfair's Calculator

(<http://www.atmosfair.org>)

Atmosfair is a German carbon offset retailer that has developed its own carbon calculator. Detailed background information on its calculator assumptions and references are available on the Atmosfair website (Atmosfair, 2007).

There are two versions of the calculator:

- The public version is accessible for free on the Atmosfair website. This version has been designed for consumers that do not know many details about their flight, and who seek to calculate their emissions with minimum input (cities visited and number of passengers are sufficient). Details like aircraft type or seat class can also be specified by the user but are not required.
- The business version of the calculator is a more detailed reporting tool available for a fee and currently used by several international business travel agencies. The tool can be used for *ex-post* or *point-of-sale* analysis. In the ex-post reporting version, the impact of all travel activity (flight, car, rail, hotel) is analyzed. The level of aggregation and analytical depth are customized. The point-of-sale version feeds internet booking engines.

In our analysis, we looked at the public version.

TRX Travel Analytics' Calculator

(<http://carbon.trx.com>)

TRX Travel Analytics provides large businesses with data analyses to increase efficiency and reduce costs associated with business-related air travel. It draws upon a wide range of air travel industry data. Increasingly, its clients request information on air travel offsets and their calculation, and so in 2006 it developed its own air travel calculator.

There are two versions of the calculator:

- The public version is accessible for free on the TRX Travel Analytics website. This fully documented public version uses all the essential elements of its corporate calculator (see below) such as current airline schedule data, airline fleet data, fuel burn rates, allocation of emissions between passengers and cargo, allocation of emissions for each cabin, adjustment of emissions for passenger load factors, and optional adjustments for RFI and cost of CO₂ emissions.
- The corporate version, available for a fee, offers two types of reports - the *Enterprise Report* and the *Standard Report*. The Enterprise Report is an analysis of a client's recent airline emissions inventory. Quantitative options to reduce CO₂ emissions are also provided: effects of decreasing travel, using greener carriers, and avoiding unnecessary connections. The Standard Report is optimized for establishing a client's baseline emissions and to monitor progress after a baseline has been established.

In our analysis, we looked at the public version.

Virgin Atlantic's Calculator

(<https://virginatlantic.myclimate.org>)

Virgin Atlantic is an air travel carrier. Virgin Atlantic's founder, Sir Richard Branson, is well known for his bold statements concerning Virgin Atlantic's commitment to climate protection¹. Virgin Atlantic's passengers can offset their emissions with *myclimate*, a Swiss-based carbon offset retailer. Virgin Atlantic has also developed its own air travel emissions calculator for which it uses proprietary information of its own fleet.

2. Review of Parameters

There are a number of factors related to aircraft type, flight profile, flight distance, number of seats, occupancy rate, cargo, and seat class that air travel offset calculators should take into account when determining an individual traveler's impact on climate change. The most important of these parameters are explained below, together with a discussion of how each of the three calculators accounts for them.

2.1 Aircraft Type

The aircraft fleets of most countries are dominated by aircraft produced by two major manufacturers: Boeing and Airbus². Fuel consumption varies by aircraft model and engine type. To illustrate how the weight of an airplane and its payload are distributed, the fuel burn rates of three aircraft flying between New York (JFK) and Los Angeles (LAX) were compared by TRX Travel Analytics and presented in the table below. The table also shows the typical numbers of seats (three class configuration³) and fuel burn rate per passenger. Fuel burn rate per passenger is calculated as total fuel burned divided by total number of seats. In this example, it does not take into account different seat classes or the occupancy rate of an individual flight, which is not always 100%.⁴ To illustrate differences among airplane models, the table below shows that the fuel burn rate per passenger is a third higher for the B747 than it is for the A320. The example does not take engine type into account. Engine type can also influence efficiency considerably⁵.

Table1: Examples of Different Aircraft Types' Fuel Burn Rate

Aircraft	Fuel burned (kg of fuel)	Number of seats	Fuel burn per passenger (kg of fuel)
A320	11,608	150	77.4
B767-300ER	21,445	218	98.4
B747-400	42,920	416	102.4

(Source: Gillespie, 2007)

¹ “**Sir Richard Branson to Invest \$3BN (£1.6BN) to Fight Global Warming**”

“The Virgin boss said he would commit all profits from his travel firms, such as airline Virgin Atlantic and Virgin Trains, over the next 10 years.

“‘We must rapidly wean ourselves off our dependence on coal and fossil fuels,’ Sir Richard said. The funds will be invested in schemes to develop new renewable energy technologies, through an investment unit called Virgin Fuels.” (<http://www.virgin-atlantic.com/en/gb/allaboutus/environment/bransonpledge.jsp>)

See also: <http://www.virgin-atlantic.com/en/gb/allaboutus/environment/index.jsp>

² Detailed technical information about each airplane type can be found on their websites: www.airbus.com and www.boeing.com

³ Seat information taken from www.boeing.com/commercial/ and www.airbus.com/en/aircraftfamilies/a320/a320/specifications.html

⁴ Bureau of Transportation Statistics indicates that the current average load factor of flights in the US is about 80%, and has been increasing in recent years (see section on occupancy rates).

⁵ The data was taken from the EMEP EIG document, which does not specify engine type.

Aircraft fuel efficiency, through weight reduction and progress in aerodynamic and engine design has steadily improved over the last few decades. Yet there is considerable lag time between technology development and implementation. The total time span between preliminary technology development and the retirement of an aircraft averages 45 to 65 years (IPCC, 1999). Fuel consumption considerations are a priority for the airlines because profit margins are narrow and the price of fuel has steadily increased at a time when airfares have been decreasing in response to competition. While many airlines are moving to acquire newer, more fuel-efficient aircraft or to modify their aircraft to increase fuel efficiency, due to the long service lives of passenger aircraft (approx. 30 years), a substantial number of older, less fuel-efficient aircraft remain in service.

The more accurate calculators reflect fuel burn and efficiencies associated with specific aircraft models⁶. However, in circumstances when a passenger does not know the aircraft type, the more flexible calculators identify the aircraft for the user (as is done by TRX Travel Analytics) or clearly note that they are relying on average fuel burn.

Calculator Profiles for Aircraft Type

Atmosfair

Atmosfair's aircraft database is based on the German Aerospace Center (DLR) emissions calculations for the most common jet aircraft types as a function of altitude and distance⁷. According to Atmosfair's documentation, this database contains fuel consumption figures for 43 aircraft models and covers an estimated 95% of the total worldwide air traffic (Atmosfair, 2007). When the aircraft type is unknown, the offset customer has the option to enter "aircraft type unknown." The emissions calculator then assumes a virtual "hybrid aircraft," based on the frequency with which a certain aircraft type is flown a given distance in the flight region requested by the customer. The calculation of the "hybrid aircraft" is based on a database from 2004 that includes more than 500,000 flight control records.

Atmosfair applies a factor of 3.16 kg CO₂/kg fuel based on IPCC, 1999.

TRX Travel Analytics

TRX Travel Analytics' calculator requires the user to enter the city of departure and the destination city. It then identifies all the different carriers and their flight schedules on that route. This enables the user to identify the exact flight they have traveled. Also, the calculator can be consulted before the air travel is purchased to allow the traveler to select the flight with the lowest emissions.

For determining scheduled passenger flights, TRX Travel Analytics uses information obtained from the Airline Schedule database from OAG Back Aviation Solutions⁸. According to OAG Back Aviation Solutions, this database covers 100% of all carriers that distribute their schedules worldwide except for a few of the newer international low-cost carriers who do not distribute their schedules to anyone. The data is updated monthly. Fuel burn rate information is obtained from the latest version of the

⁶ Airlines sometimes change aircrafts for a particular flight. In that case the scheduled aircraft might not match the one which is actually used on that particular flight. Yet according to industry experts such changes do not happen very frequently.

⁷ Furthermore, atmosfair commissioned a study by QuinetiQ, a UK-based institute that carries out fuel calculation and simulation for research projects and the aviation industry (Brockhagen, personal communication).

⁸ OAG© - Official Airline Guides' BACK Airline Schedules and Capacity database contains information on every scheduled passenger and cargo carrier in the world filing with OAG. Its Airline Schedules database includes weekly updates on all schedule changes, additions and cancellations made by the carriers. Data access to OAG has to be purchased (<http://www.backaviation.com>).

EMEP/CORINAIR Emission Inventory Guidebook (EIG)⁹ which provides fuel burn rates for 44 aircraft. Using an EIG equivalence chart of ICAO¹⁰ and IATA¹¹ data, the fuel burn rates for the 44 aircraft can be applied to an additional 136 aircraft, for a total of 180 aircraft for which TRX Travel Analytics has specific fuel burn rate data.

For those aircraft not covered in this data set, the TRX Travel Analytics calculator makes the closest match based on equipment class (wide-body jet, narrow-body jet, regional jet, turboprop), manufacturer, and number of seats.

TRX Travel Analytics applies a factor of 3.15 kg of CO₂/kg of fuel based on EMEP/CORINAIR.

Virgin Atlantic

Virgin does not apply specific aircraft types to its calculations- see the section below on how Virgin calculates fuel use.

Virgin Atlantic applies a factor of 3.16 kg of CO₂/kg of fuel.

2.2 Flight Profile and Flight Distance

The civil aircraft fleet average for speed and cruise altitude is 575 miles/hour and 8 miles, respectively (IPCC, 1999). Just as a car experiences different fuel efficiencies at different speeds and under different conditions, aircraft experience different burn rates in various flight profiles: taxi, takeoff, climb, cruise, landing approach, and landing. The rate of fuel burned is proportional to the drag, the force that resists motion and which therefore has to be balanced by the thrust of the engine. The take off phase requires full engine thrust, and thus the most fuel. As the aircraft ascends to higher altitudes, the drag decreases and so does the rate of fuel use. Offset calculators have to take into account the variety of flight profiles encountered throughout a given flight.

Flight distance is an essential factor as well as aircraft fuel consumption depends on distance flown. Generally speaking, the farther the route, the more fuel burned. However, since takeoff and landing demand higher fuel burn rates than level flight, shorter routes where takeoff and landing comprise a larger portion of the overall flight tend to be less efficient (i.e. require more fuel per mile). Takeoff and landing are smaller portions of the overall flight for medium range routes, so they are generally more efficient. In addition, over very long distances the fuel use per mile increases because of the greater amount of fuel that has to be carried during the early stages of flight.

Offset calculators use different methods for calculating total flight distance. Some use only the great circle distance (the shortest distance between two points on the globe) between two airports. Some account for routing and delays. Since an aircraft's route is normally not an exact great circle due to flight path routing, detours around weather and delays due to traffic, some calculators add an extra amount to the overall distance.

⁹ The Cooperative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe/Core Inventory of Air (EMEP/CORINAIR) EIG is published by the European Environment Agency (EEA) and may be found at <http://reports.eea.europa.eu/EMEP-CORINAIR4/en/page002.html>. Data access is free.

¹⁰ The International Civil Aviation Organization (ICAO) is the international version of the FAA (the Federal Aviation Administration). It is responsible for the safety and air traffic management of civil aviation.

¹¹ The International Air Transport Association (IATA) is the international airline industry trade group.

Two studies calculated the excess distances of flights as the difference between the actual flight path length and the direct route length (great circle distance). Their results indicate that intra-European flights fly around 10 percent excess distance compared to direct routes. In the US, the inefficiency was found to be around 6- 8 percent. The studies further determined that about 70 percent of the total excess distance flown takes place within terminal airspace (Kettunen et al, 2005).

Yet these studies do not address regional differences. Some airports are heavily congested and experience regular delays, such as those in New England corridor (Boston to DC), the Chicago/Great Lakes area, or the Southern California corridor. Also, these delays can vary significantly depending on the time of day, the season and the weather. Congestion is a serious problem that airports and the communities they serve typically seek to address for social, environmental, and economic reasons. This congestion also leads to increased GHG emissions. Yet calculators cannot realistically incorporate these differences or use real time data. Rather, entities that would prepare a greenhouse gas inventory for a specific airport or aviation in general would capture these conditions. It therefore makes sense for carbon offset calculators to use an average multiplier to account for routing and delays.

The most accurate air travel calculators use specific information about total fuel consumption and flight distance. This calculation can be performed in a few different ways.

Calculator Profiles for Flight Profiles and Flight Distance

Atmosfair

Atmosfair's emissions calculator accounts for both flight profile and flight distance. The emissions calculator first calculates the flight distance as the great circle route. Detour estimates are based on German data showing an average of 31 extra miles flown per flight. Atmosfair therefore adds 31 miles to the great circle distance to determine total flight distance. It then calculates fuel consumption as a function of distance based on fuel consumed during three simplified altitude profiles: climb, cruise, and descent:

The Emissions Calculator has stored these standardized altitude profiles and the associated fuel consumptions during the three flight phases for the commonest aircraft types (DLR 2002, QinetiQ 2005). These profiles and the associated fuel consumptions are available for each aircraft for standard distances of 250, 500, 750, 1,000, 2,000, 4,000, 7,000 and 10,000 kilometers (provided the aircraft has this range (Atmosfair, 2007).

In addition, Atmosfair adds 2.2 lbs of extra fuel per passenger for holding delays and detours based on the Lufthansa Environmental Report 2002, and accounts for taxiing based on the average taxi time of 15 minutes by adding 5.5 lbs of extra fuel per passenger (Atmosfair, 2007).

TRX Travel Analytics

TRX Travel Analytics obtains fuel burn rate information from the most current version of the EMEP/CORINAIR Emission Inventory Guidebook (EIG). This dataset provides fuel consumption data for different aircraft from a range of total journey lengths for each of the different fuel-consumption stages: Taxi-out, Takeoff, Climb-out, Climb/Cruise/Descent, Approach/Landing, and Taxi-in. It therefore calculates the anticipated full fuel burn rate over the entire trip. The EIG's fuel burn rates are given for a range of distance buckets (in nautical miles) and TRX Travel Analytics interpolates from there:

Fuel burn rates are given for some or all of the following distance buckets (in nm): 125, 250, 500, 750, 1,000 ...and every 500 miles up to 6,500 for long-range aircraft.

The fuel burn rate, in kg per nm, for a particular flight is interpolated using the distance buckets above and below the city pair mileage. For example, the amount of fuel burned on a flight on a Boeing 777 between ORD-LHR, a distance of 3,423 nm, would be determined by interpolating the fuel burn rates of the 3,000 and 3,500 nm distance buckets for a Boeing 777. (Gillespie, 2007)

TRX Travel Analytics accounts for holding patterns and detours due to weather and congestion using the numbers from Kettunen et al.(2005) and applies a multiplier of 1.07 for US domestic flights and 1.10 for intra- European flights. For all other domestic and short haul city pairs, they apply the midpoint multiplier of 1.085. For long haul flights, TRX Travel Analytics decreases the multiplier from 1.07 to 1.01, dropping 0.01 for every 1,000 miles. In this manner, some correction is made for excess distance. TRX Travel Analytics states that these correction factors will be adjusted as more precise data become available (Tomosky, personal communication).

Virgin Atlantic

Virgin Atlantic is in a unique position for developing an emissions calculator since it can directly apply its own information from actual flight data. Instead of calculating total fuel burned based on average fuel burn rates and estimated distances flown, Virgin uses actual fuel use data taken from its 2006 fuel uplift figures, i.e. the amount of fuel actually put into its planes for each individual flight. This data is then averaged for the particular route over one year. The total fuel amount on a flight is multiplied by the IATA standard multiple of 3.16 to provide the total CO₂ emissions for that particular flight. Virgin explains that it uses its fuel uplift figures

because they offer the most accurate record of fuel use for the flight, as we are able to take it from the fuel pump figures when the planes are filled up, which our pilots sign off and then we receive the invoices for. This is more accurate than taking the records from what is left in the tanks, as different reading may result from different factors such as the warmth of the engine or any uneven surface underneath the plane. We then compare it with fuel burn data recorded by our pilots during the flights to ensure against any discrepancies. (Virgin Atlantic Airlines, n.d.)

The authors were not able to get more detailed information on how Virgin Atlantic calculates actual fuel used from their fuel uplift figures, e.g. how it accounts for rest fuel, over what time frame the fuel use data is averaged, and which flights were used in the sample.

This approach does not account for a specific aircraft, rather it takes the average fuel burned across all aircraft flown on a given route, and reflects actual flight distances and delays that were experienced.

2.3 Cargo on Passenger Flights

Once total emissions for a flight are known, emissions per passenger can be calculated. It is important to note that calculators differ in how they take into account the factors discussed in the following sections: cargo versus passenger load, seat occupancy rate, and seat class.

The majority of a flight's total weight is the aircraft itself and the fuel it carries. Flight crew, crew luggage, steward's supplies, etc. are all considered part of aircraft weight. 'Payload' is defined as the

weight of the people and items that are being transported, including passengers, their luggage, and cargo. An industry-wide standard of 220 lbs is assumed for each passenger and their luggage¹².

Table 2: Two Examples of Aircraft, Fuel and Payload Weight

Airplane type:	A 300-600 (in metric tons)	Percentage of max. takeoff weight	A320 (in metric tons)	Percentage of max. takeoff weight
Maximum takeoff weight	171.7	100%	73.5	100%
Maximum zero fuel weight	130	75.7%	61	83%
Maximum fuel capacity	55	32.2%	19	26.3%
Typical operating weight empty	90.9	52.9%	42.4	57.7%
Maximum payload	34.9	20.3%	16.6	22.6%
Estimated total maximum passenger weight in single class configuration	298 passengers * 100kg = 29.8	17.4%	164 passengers * 100kg = 16.4	22.3%

(Source: [Airbus](#))

Passenger airplanes usually also carry additional cargo. Cargo consists of freight and mail. Thus, cargo should be allocated some of the GHG emissions associated with the flight. There are several ways that this cargo can be accounted for in an air travel emissions calculator. Two such approaches are described below:

1. The responsibility for the airplane travel lies with the passengers. This approach assumes that the airplane flies because of the passengers and not because of the freight. The calculator therefore only subtracts the emissions associated with marginal increase in fuel consumption caused by the weight of the cargo: The increase in fuel burn due to the extra cargo is divided by the number of passengers and subtracted from each traveler's carbon footprint. Note that this increase in fuel burn is low because most of the weight of the airplane is its airframe and the fuel it transports.

2. The responsibility for the air travel lies proportionally with the passengers and with the cargo. The total emissions are assigned to cargo and to passengers based on their percentage of total cargo weight. For example, if 80% of the payload weight is passengers and luggage and 20% is cargo, then 20% of total flight emissions are subtracted from the passengers' carbon footprint.

Both of these approaches are valid, although the authors argue that if the cargo cannot be shipped with a particular passenger flight, it would be shipped in another passenger flight or in a cargo flight. Also, revenues from cargo are a significant source of income for most large passenger carriers. Because of this, the authors find the second approach more appropriate.

¹² According to industry experts, this estimate might be lower than the actual average weight of a passenger and his/her luggage (Tomosky, personal communication).

Calculator Profiles for Cargo versus Passengers

Atmosfair

Atmosfair's calculator uses the first approach and assumes an average cargo load of 8% of total payload on all flights. This number was calculated from data from the 2003 report of the *Arbeitsgemeinschaft deutscher Verkehrsflughäfen (ADV)*¹³. Atmosfair also uses the industry standard of 220 lbs per passenger, including their luggage. Atmosfair estimates the resulting increase in fuel burn due to cargo to be 2%. The calculator then subtracts 2% of total emissions to account for increased fuel burn due to cargo (Atmosfair Emissions Calculator, 2007).

TRX Travel Analytics

The TRX Travel Analytics calculator applies the second approach with the following data and assumptions. Cargo and passenger data are gathered for US carriers from the US Dept. of Transportation, Bureau of Transportation Statistics¹⁴. Both domestic and international flights are included. To avoid seasonality issues, data from the most recent calendar year is used and is updated annually.

TRX Travel Analytics applies the industry-wide standard of an average weight per passenger and their luggage of 220 lbs. Cargo estimates are based on aircraft type: TRX Travel Analytics allocates emissions between cargo and passengers for narrow-body and wide-body jets only. The amount of cargo weight relative to passenger weight is assumed to be negligible for regional jets and turboprops, because they are so small that there is not enough space for much additional cargo. Because of space constraints in Low Cost Carriers, these are also not allocated any cargo weight. If specific data is available for a flight, then the cargo proportion is calculated using that data. Otherwise, the following averages are used:

- Narrow-body jets: 1.7% cargo, 98.3% passengers
 - Wide-body-jets: 19.9% cargo, 80.1% passengers
- (Gillespie, 2007)

Virgin Atlantic

Virgin Atlantic uses the second approach. According to Virgin Atlantic, precise figures of actual flown cargo gross weight are used. The authors were unable to obtain more specific information on how Virgin Atlantic calculates and accounts for cargo.

2.4 Seat Occupancy Rate (Load Factor)

Not all flights take off fully occupied. Seat occupancy rate (also called *passenger load factor*) is the ratio of passengers to available seats on board a given flight.

The overall weight of a passenger aircraft is determined primarily by the airframe and amount of fuel carried. Therefore the number of passengers on board has a smaller impact on total fuel consumption (see Table 3 for examples of aircraft weights). Aircraft use less fuel per passenger the more passengers there are on board. The Royal Commission on Environmental Protection uses the following example to illustrate this: with an occupancy rate of 51%, the fuel burned per passenger-km is 0.176 lb. In

¹³ Cooperation of German Airports, ADV; see http://www.adv-net.org/de/gfx/daten_nat.php

¹⁴ <http://www.transtats.bts.gov>, BTS, Air Carrier Statistics: Form 41 Traffic (All Carriers), T-100 Segment (All Carriers)

comparison, a load factor of 100% corresponds to fuel burned per passenger-km of only 0.112 lb (RCEP, 2003).

Occupancy rates have fluctuated significantly over the last two decades. In the 1990s, the average load factor was around 65%¹⁵. Based on the Bureau of Transportation Statistics web site, the average load factor was 77.2% in 2005, increased to 79.2% in 2006 and further rose to 80.3% by Nov 2007¹⁶. These fluctuating occupancy rates show the need for regularly updated figures to increase the accuracy of air travel carbon emissions calculators.

The most accurate air travel calculators take occupancy rates into account. Ideally occupancy data would be available by route and not just by air carrier. Such data is to our knowledge not available to date.

Calculator Profiles for Occupancy Rates

Atmosfair

Atmosfair applies seat occupancy rates for scheduled flights based on German aircraft data from 2002 according to flight region: Germany 60%, EU 62%, and intercontinental traffic 75%. As these rates are lower than the average US load factor rates, this calculator would likely slightly overstate US-based flight emissions (Atmosfair, 2007).

Atmosfair makes a further distinction between scheduled and charter flights. Based on a study from 2004, Atmosfair states that chartered flights normally have higher occupancy rates than scheduled flights due to the longer booking period of charter flights. Atmosfair emissions calculator therefore applies a common average of 80% occupancy for chartered flights. If the flight type is not known, an average of 75% is applied (Atmosfair, 2007).

TRX Travel Analytics

TRX Travel Analytics currently uses the 2006 annual data from ICAO, which contains load factor data from 274 passenger-carrying airlines: 33 from the US, and 241 non-US. The values are updated annually and data from the calendar year is used to avoid seasonality issues. For carriers not among the 274 carriers, TRX Travel Analytics uses either a US average (75.93%) or a non-US average (67.35%), depending on the country of the airline¹⁷.

To evaluate the percentage of flights for which they have specific occupancy data available, TRX Travel Analytics analyzed all flights from December 2007 (a total of 178,804 flights) with the following result:

- For 70.8% of all flights they had specific occupancy rate data available
- For 3.1% of all flights they used the US average value of 75.93%.
- For 26.1% of all flights they used the non-US average value of 67.35%.

Virgin Atlantic

Virgin's calculator does not account for occupancy rates. No further information was available.

¹⁵ www.pata.org/patasite/fileadmin/docs/general/MORRISPeterApr15PAC03.ppt

¹⁶ http://www.bts.gov/press_releases/2008/bts008_08/html/bts008_08.html

¹⁷ The discrepancy between the occupancy rates quoted by the US Bureau of Transportation Statistics (BTS, quoted above) and the numbers used by TRX Travel Analytics can be explained as follows: TRX Travel Analytics uses data from ICAO, which includes non-US carriers. BTS only has data for non-US carriers when the origin or destination of the flight is in the US. This leads to biased data since these are long-haul flights only. For US carriers only, BTS data and ICAO data are in general agreement.

2.5 Seat Class

Seat class is another key factor in determining the emissions an individual is accountable for on a given flight. Seating area is limited in an aircraft. A plane that is configured with all economy-class seats accommodates the highest number of passengers. First- and business-class seats take up more space and fit fewer passengers. Weight is another consideration: the seats and entertainment systems for business- and first-class are larger and heavier than for economy seats. On the other hand, anecdotal evidence indicates that families traveling in economy often have more luggage. It might be possible to generalize that vacation and pleasure travelers tend to travel economy class and with more luggage, whereas upper-class seats are usually occupied by business travelers who aim to minimize their luggage.

Some calculators consider weight to be the primary determinant with regards to seat class. However, since an aircraft's weight is determined largely by the airframe and fuel on board, the weight of passengers on board has a small impact on the marginal increase in fuel consumption. What is true for occupancy rates applies to seat class also: more passengers means lower per person emissions. Since higher class passengers de-facto replace more economy passengers, emissions should be allocated by space (i.e. each upper-class passenger is allocated the emissions of the number of economy passengers that could have been seated in the same space).

To illustrate this with an example: A Boeing 767-300ER accommodates 350 passengers if it is configured as an all economy-class flight. The same airplane only accommodates 269/218 passengers in a two/three-class configuration¹⁸. In other words, in a three-class setup there are 132 fewer passengers (38% less) and the emissions therefore have to be divided among fewer people. To do so fairly, business and first class passengers should be allocated the emissions in proportion to the space they occupy relative to economy passengers they displace. In the table below, for example, an international first class passenger takes up an average of 3.13 economy seats and is therefore responsible for 3.13 times the emissions of an economy traveler. The most accurate air travel emissions calculators take seat class into account.

Table 3: Average Seat Room Based on Seat Class*

Seat Class	Average Seat Pitch (inches)	Average Seat Width (inches)	Smallest Seat Area (square inches)	Largest Seat Area (square inches)	Average Area (square inches)	Average Area as Percentage of Economy Class
U.S. Domestic Economy	31.8	17.4	520	648	554	100%
International Economy	32.2	17.3	512	630	555	100%
Premium Economy	38.5	18.9	677	1029	729	131%
U.S. Domestic First/ Business Class	40.0	20.4	663	1462	816	147%
International or Long-Haul Business Class**	57.6	20.4	684	2054	1163	210%
International First Class	77.9	22.3	1160	2485	1735	313%

* calculations based on information from <http://www.seatguru.com/>

** does not include suites (mini-cabins that include flat bed, work station, and TV)

¹⁸ Information taken from www.boeing.com/commercial

Calculator Profiles for Seat Class

Atmosfair

Atmosfair's calculator offers three seat options: economy, business, and first class. Atmosfair's emissions calculator assumes an average number of seats for a particular aircraft (calculated with data from the main German airlines in 2002). For airlines that are not representative of flights with German airlines, but also operate to and from Germany, an average is used based on manufacturers' standard seating configurations according to *Jane's 1990-2003: All the World's Aircraft* and *JP Airline-Fleets International 2007* (Atmosfair, 2007). The seat pitch and widths of equipment from various carriers is calculated from data available online at www.SeatGuru.com. Atmosfair then applies the following multipliers:

- Economy Class = 0.8
- Business Class = 1.5
- First Class = 2

If a customer does not indicate seat class, a factor of 1 is used, representing the average space requirements of a passenger in a generic three class flight (Atmosfair, 2007).

TRX Travel Analytics

TRX Travel Analytics uses the OAG Schedules database to determine the number of seats on a flight, and the OAG Fleet database to determine the distribution of seats among the various cabins (OAG Back Aviation Solutions, 2007). The seat pitch and widths of equipment from various carriers is calculated from data available online at www.SeatGuru.com. TRX Travel Analytics breaks seat class down into four types. If there are multiple seating configurations for an aircraft, TRX Travel Analytics uses an average - weighted by the number of aircraft - of the different configurations. When no specific data for a flight is available, average values based on the class of equipment are used. Where equipment class is unknown, overall averages for cabins of narrow-bodied jets are used:

- Economy Class = 1.00
- Premium Economy Class = 1.13
- Business Class = 2.04
- First Class = 2.69

Virgin Atlantic

Virgin bases its calculations on weight rather than seat space, arguing that seat classes other than economy include a higher baggage limit¹⁹ and involve larger seats that weigh more and include more sophisticated (and therefore heavier) entertainment systems. Virgin uses the number of seats in each seat class for a given route and multiplies it by seat weight, then adds that total to the 100kg (220 lbs) standard amount for each passenger's weight plus luggage. The authors were unable to obtain details on how Virgin Atlantic calculates seat class emissions or to find out why Virgin Atlantic chose to distinguish seat class by weight.

¹⁹ As mentioned above, despite the higher baggage limit in upper class, it is unclear if upper-class passengers bring more luggage on board. Anecdotal evidence would suggest the opposite.

3. Calculator Comparison & Conclusions

This last chapter examines and compares the three calculators. Table 4 summarizes the different parameters that each calculator is based on. Table 5 summarizes the input and output parameters of each calculator. The input parameters refer to the variables that a user can enter into an emissions calculator. The output parameters refer to the information that is conveyed to the user once the emissions have been calculated.

Three travel routes are then used to compare emissions calculation results for the three calculators and the UK’s Department for Environment, Food and Rural Affairs (DEFRA) multiplier for air travel emissions calculations. The DEFRA multiplier was included in the comparison because it is widely used by government agencies and private entities to calculate air travel emissions. DEFRA recommends the following multipliers for calculating emissions from air travel:

- 0.11 kg of CO₂ per person kilometer for long haul flights. This factor refers to a 5,000 km / 3,106 mile journey on a typical 450 seat capacity aircraft with a 70% occupancy rate.
- 0.15 kg of CO₂ per person kilometer for short haul flights. This factor refers to a 500 km / 310 mile journey on a typical 128 seat capacity aircraft with a 65% occupancy rate.

(DEFRA, 2005)

The last section includes the authors’ comments and opinions of each of the evaluated calculators and concludes with final remarks about the issues and the quality of air travel emissions calculators in general.

3.1 Input and Output Parameters of Offset Calculators

Table 4: Emissions Calculator Parameters

	atmosfair	TRX Travel Analytics	Virgin Atlantic	DEFRA
Non-CO₂ multiplier (RFI)²⁰	Yes: 1-3 for long haul ²¹ ; no multiplier for distances less than 500 km	Optional: 1 or 2.7	No	No
Aircraft model	Optional: Fuel burn rate data for 47 aircraft available.	Yes: Fuel burn rate data for 180 aircraft available. Data updated yearly.	Use of fuel consumption data of Virgin Atlantic fleet; unclear what data is used for non-Virgin Atlantic flights.	No
Routing and delays	Yes: adds 1kg of extra fuel per passenger for holding delays and 2.5 kg for taxiing, in addition adds 50 km to each trip for rerouting.	Yes: multiplier of 1.07 for US domestic flights; 1.10 for intra- European flights; Other short haul flights: 1.085. Long haul flights: decreases multiplier by 0.01 for every 1,000 miles, from 1.07 to 1.01	Not applicable since calculations are based on actual fuel use data.	No

²⁰ Radiative Forcing Index (RFI) is usually referred to as the multiplier that includes non-CO₂ warming effects. See second paper in this series (forthcoming, summer 2008). Strictly speaking, the RFI multiplier does not deliver CO₂ equivalent emissions, since it does not have Global Warming Potential. Atmosfair, for example, labels the emissions as “CO₂ emissions that would have a similar warming effect as the total aircraft emissions” (Brockhagen, e-mail April 6, 2008)

²¹ Atmosfair applies a multiplier of 3 for emissions above 9000 m altitude and a multiplier of 1 for all emissions below 9000m altitude. The factor is adjusted according to the actual altitude. Hence, the “average RFI” for a flight depends on the aircraft type and the flown distance, and varies from 1 -3 (Brockhagen, personal communication).

	atmosfair	TRX Travel Analytics	Virgin Atlantic	DEFRA
Cargo	Yes: 2% marginal fuel increase due to cargo subtracted	Yes: emissions assigned weight, flight specific data when available. Otherwise averages of narrow-body jets: 1.7% cargo; wide-body jets: 19.9% cargo.	Yes: emissions assigned weigh, exact calculations unknown	No
Seat Class	Optional: 3 classes calculated by space. Multipliers of: Economy = 0.8 Business = 1.5 First = 2.0 If no class is specified, multiplier =1	Yes: up to 4 classes calculated by space, flight specific data when available. Otherwise multipliers of: Economy = 1.00 Premium Econ Class = 1.13 Business = 2.04 First = 2.69	Yes: calculated by weight, 4 classes, exact calculations unknown	No
Occupancy Rate	Yes: averages used: Germany 60%, EU 62%, intercontinental traffic 75%, charter flights 80%	Yes: Airline specific data when available, otherwise averages used: US 75.93%, non-US 67.35%	No	Yes: Averages of 70% for long haul; 65% for short haul

Table 5: Emissions Calculator Input and Output Parameters

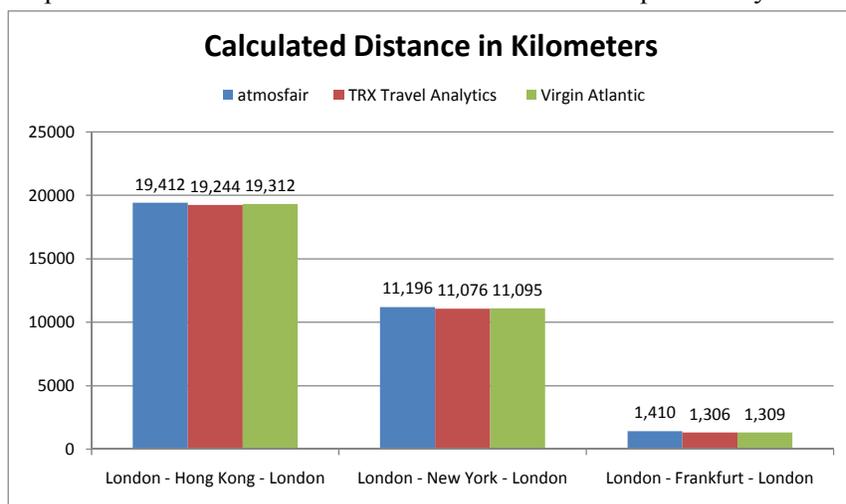
	atmosfair	TRX Travel Analytics	Virgin Atlantic	DEFRA
Inputs into calculator	<ul style="list-style-type: none"> • City pair • Seat class (optional) • Aircraft type (optional) • Scheduled or charter flight (optional) • Stop over (optional) • Round trip or one way • Number of trips • Number of travelers 	<ul style="list-style-type: none"> • City pair (for existing destinations; each stopover has to be calculated separately) • Airline (optional) • Multiplier for non-CO₂ impacts (2.7 or 1) • Round trip or one way • Price per ton of offset 	<ul style="list-style-type: none"> • City pair • Seat class • Round trip or one way • Number of travelers 	<ul style="list-style-type: none"> • Distance
Calculator Outputs	<ul style="list-style-type: none"> • Distance • Seat class, if specified • CO₂e (including multiplier) • Comparisons of emissions with other activities such as driving for a year, yearly emissions of average Indian. • Cost to offset through Atmosfair 	<ul style="list-style-type: none"> • Distance • All seat classes • CO₂e emissions (multiplier optional) • Flight schedule • Carrier airline • Operator airline • Equipment Code (aircraft type) • Cost to offset (based on chosen price) 	<ul style="list-style-type: none"> • Distance • Seat class • CO₂ • Cost to offset through myclimate 	<ul style="list-style-type: none"> • CO₂

3.2 Air Travel Examples²²

The following analysis focuses on CO₂ emissions calculations only. In other words, non-CO₂ effects (often referred to as *Radiative Forcing Index* (RFI) or *multiplier*), which are discussed in the second paper of this series, are not included. The discussion about the use of a multiplier is important. Our choice to remove it from this analysis does not imply that non-CO₂ warming effects from air travel should be ignored. Rather, it was removed to enable a comparison of how the parameters examined in this paper influence the results. Of the calculators discussed here, only the Atmosfair calculator automatically includes a multiplier. This multiplier has been removed from the examples below²³. TRX Travel Analytics offers an optional multiplier of 2.7, whereas Virgin Atlantic and DEFRA do not include a multiplier.

Graph 1: Calculated Distance

Graph 1 shows that the calculated distances of three trips are very similar for all three calculators.



Flight Example 1: London – Hong Kong – London

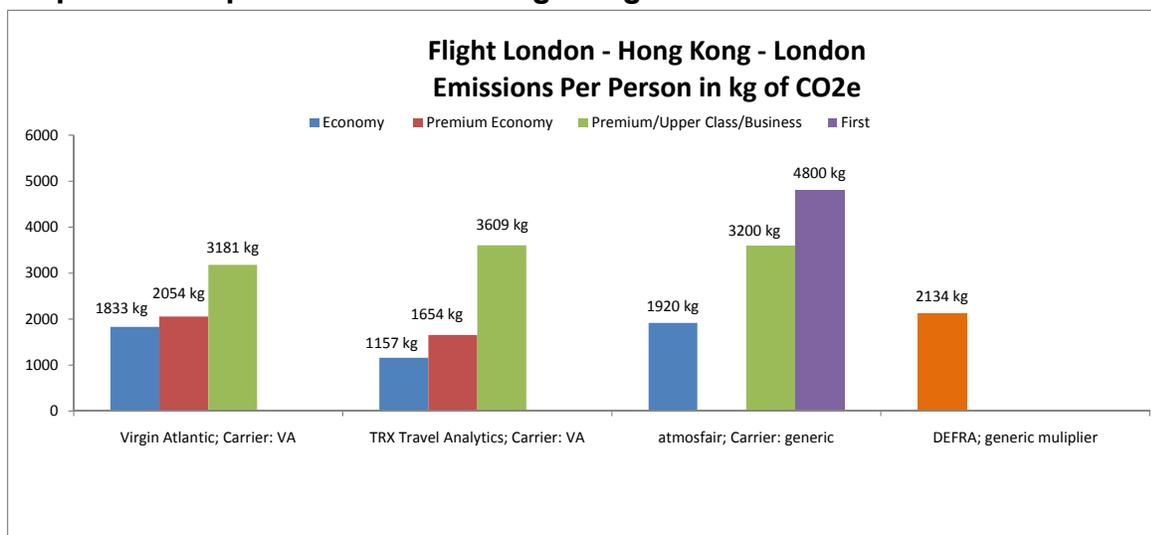
Flight Example 2: London – NYC – London

For the first two examples, it was assumed that the Virgin Atlantic calculations for this trip are based on Virgin Atlantic's fuel consumption data. To allow for comparisons, Virgin Atlantic flights were also used for the TRX Travel Analytics calculations. For Atmosfair, a generic carrier was chosen because Atmosfair does not allow for a particular airline carrier to be selected, and the type of aircraft for these Virgin Atlantic flights was unknown. DEFRA does not distinguish between seat classes.

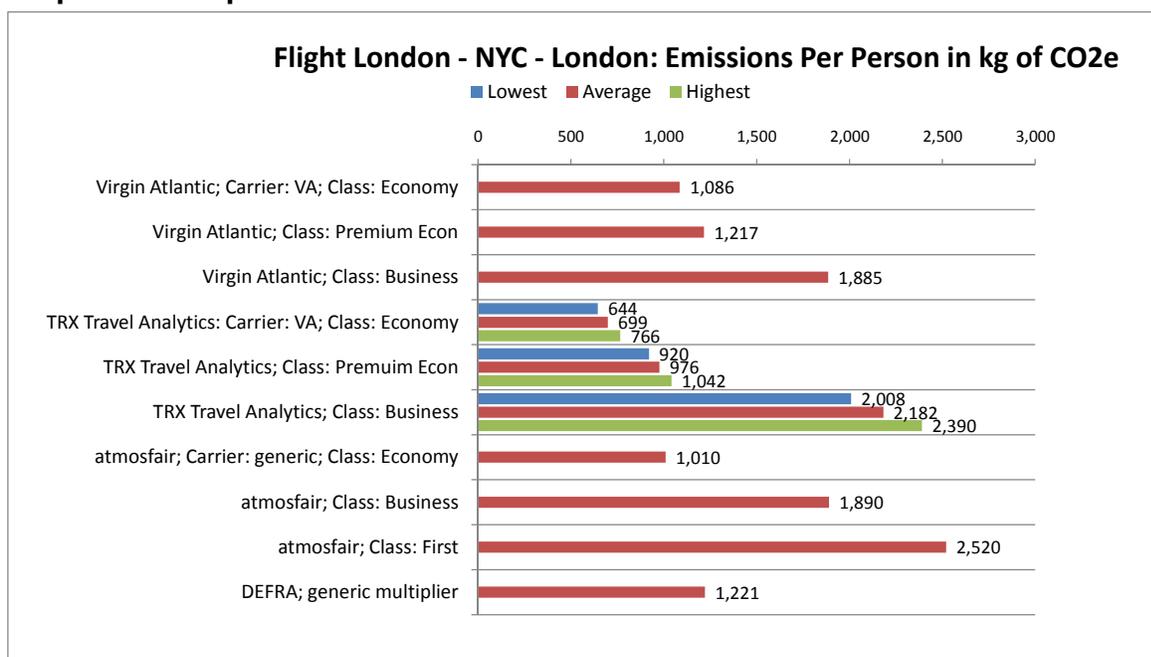
²² All examples were calculated on 2/21/2008, except for Atmosfair (see footnote 23).

²³ Atmosfair applies the multiplier to the emissions above 9 km altitude. Depending on the aircraft type, this multiplier is hence only applied to about 50% of the emissions for a flight of 500 km, and to about 90% for a flight of 10,000 km. For this reason, Atmosfair provided us with the numbers for the three examples used in these graphs (Brockhagen, personal communication).

Graph 2: Example 1: London – Hong Kong - London



Graph 3: Example 2: London – New York – London



Graph 3 shows emission averages from each the calculators in red. Virgin Atlantic uses two aircraft models on that route that have different emissions associated with them (see section on Aircraft Model). In its calculator, Virgin averages the emissions of these two aircraft models. TRX Travel Analytics, on the other hand, calculates the emissions for each of the two aircraft models. The blue bar shows the emissions of the more efficient model. The green bar shows the emissions of the less efficient model.

Discussion

The results vary considerably from calculator to calculator:

- In the first example, the results for an economy seat vary by a factor of 1.7; TRX Travel Analytics calculates 1157 kg, whereas Atmosfair calculates 1920 kg.

- In the second example, the results for an economy seat also vary by a factor of 1.7; TRX Travel Analytics calculates 644 kg, whereas Virgin Atlantic calculates 1086 kg.

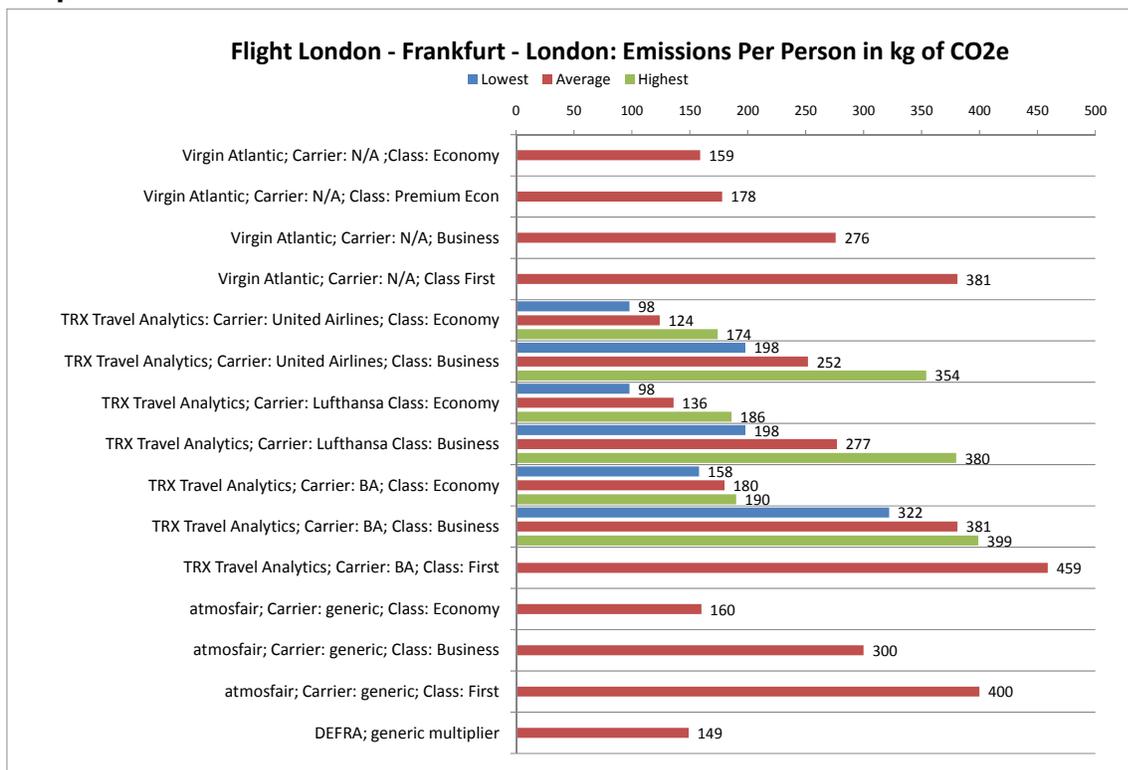
Seat class calculated by space requirement has a disproportionate impact on emissions:

- In both examples TRX Travel Analytics has the largest spread between seat classes (over 300%). The highest emissions (3609 kg/2390 kg TRX Travel Analytics, business class) are over three times as high as the lowest emissions (1157kg/644 kg TRX Travel Analytics, economy class).
- Virgin Atlantic’s results for a business class traveler are only 1.7 times larger than for an economy traveler. This can probably be explained by the fact that Virgin Atlantic bases its seat class distinctions on weight. The difference between economy and upper classes in both examples is therefore less pronounced than if the emissions were assigned by space requirement.

Example 3: London – Frankfurt – London

In this example, the TRX Travel Analytics calculator was used to compare emissions from the three different carriers that service this route (British Airlines, Lufthansa, and United Airlines). Because these carriers use different aircraft models and engine types, the emissions of the flights vary. The blue bars show the emissions of the most efficient aircraft model for each carrier, while the green bars show the emissions of the least efficient aircraft model for each carrier. The other calculators were also used: the red bars show averages.

Graph 4: London – Frankfurt – London



Discussion:

The results show significant differences between the aircrafts. According to the TRX Travel Analytics calculator, the emissions for the least efficient economy seat (190 kg, BA) are 194% higher than the most efficient economy seat (98 kg, UA). The emissions for the least efficient business seat (399 kg, BA) are 202% higher than the most efficient business seat (198 kg, UA).

3.2 Comments on the Evaluated Calculators

Atmosfair

Atmosfair developed one of the first air travel emissions calculators for offsets and provides in-depth background information. It also includes valuable information about other activities and their associated GHG emissions, which helps consumers put their air travel emissions in perspective. Although the authors approve of the transparency and level of detail included in the calculator, they conclude that the Atmosfair calculator could be improved in several ways:

- Atmosfair accounts for non-passenger cargo by subtracting the marginal increase in fuel use. It would be more correct to assume that cargo would be transported by air anyway and therefore emissions should be allocated proportionally to the weight of cargo and passengers with luggage.
- Atmosfair reports that it has updated its calculator twice since 2005. But many of Atmosfair's data sources seem to be a few years old and do not seem to be updated regularly. It is unclear how much this affects the accuracy of the calculations, but it certainly would be better if data sources were updated more frequently.

TRX Travel Analytics

TRX Travel Analytics developed its calculator in 2006. The website provides in-depth information about the data sources and metrics used for the calculator. For this and the following reasons, the authors rated the quality of the TRX Travel Analytics calculator as very high. It is the best of the three evaluated calculators and is likely the best currently available air travel CO₂ emissions calculator:

- The calculator is based on extensive data sets and accounts for the largest number of parameters.
- Data sets are updated regularly.
- Because the calculator distinguishes between different carriers, it enables travelers to choose the most efficient carrier ahead of time.

Virgin Atlantic

Virgin Atlantic is in the unique position of having access to actual fuel use, cargo, occupancy rate, etc. data. Virgin Atlantic is therefore in a great position to develop an accurate calculator. Yet the authors conclude that the Virgin Atlantic calculator could be improved in several ways:

- Virgin Atlantic calculates seat class emissions by weight. Allocation by space requirement would be a more accurate measure.
- Virgin Atlantic does not account for occupancy rates. This is a shortcoming of the calculator.
- Virgin Atlantic's calculator claims that it is based on actual company fuel use data. Yet the calculator also calculates non-Virgin Atlantic routes. It is unclear on what data Virgin Atlantic bases these calculations.
- Not much detail is available on the data and the underlying metrics that have been applied to develop the calculator. This makes it difficult to determine its accuracy.

3.3 Conclusions

The impact of air travel on climate change is often a topic of debate. There are several reasons why it is important that air travel calculators are as accurate as possible:

GHG emissions calculations and offsetting are complex and require well-educated policy makers and an informed general public. Having calculators that give widely disparate results is confusing to the public and can impact willingness to reduce or offset emissions. Perhaps even more significantly, inaccurate emissions estimates from air travel could potentially lead to poorly designed policies. There has been much criticism of carbon offsetting and the associated carbon calculators. If public confidence in climate mitigation policies in general and offsetting in particular is to be strengthened, accurate information needs to be available for all sectors of the economy, including air travel.

It is disproportionately the wealthy that travel by air. Since the impacts of climate change will be felt disproportionately by the poor, this raises equity concerns. To set policies that address climate and equity concerns,²⁴ it is necessary to know the full extent of climate impacts from aviation.

On an individual level, travelers who strive to minimize and/or offset their impacts need to be able to accurately calculate their emissions. For example, knowing how much greater the emissions from an upper-class seat are, a traveler might choose an economy seat instead.

This paper examined the aircraft parameters that are needed to calculate CO₂ emissions on a per person basis. Three air travel emissions calculators were analyzed in-depth. The travel example analysis revealed that results vary considerably among these calculators. It was impossible to pinpoint why the results varied so widely, yet the authors identified several areas where calculators could be improved.

The TRX Travel Analytics calculator was judged to be the best calculator currently available and known to the authors. Yet even the best calculators cannot be 100% accurate given the scientific uncertainties, lack of data availability, and unpredictability inherent in air travel. For example, as with cars, aircraft can be flown more or less efficiently. The slope an aircraft takes for its climb and landing approach affects its efficiency. Only if actual fuel use data is available can such behavioral strategies be quantified; otherwise calculators are unable to capture these effects.

Calculators should include disclosure statements about the precision of the calculations and the underlying assumptions and lists the data sources. In order to improve and maximize accuracy, calculators need to be updated regularly to keep up with the dynamics of the air travel industry and to integrate new research results and updated data sets.

Transparent and easy-to-use calculators that rely on the most current data are important tools that enable travelers to identify and compare their air travel emissions to other activities that contribute to their GHG footprint. They not only help consumers and companies to calculate how many carbon offsets they would have to purchase to compensate for their emissions, but more importantly can inform choices that reduce travel footprints, such as combining trips, avoiding upper-class seats, and opting for alternatives to travel such as video conferencing.

This paper is the first in a series of two reports which examine the key factors that must be taken into account when calculating per capita air travel emissions for the purpose of carbon offsetting. The second paper will focus on how to account for non-CO₂ emissions from air travel (i.e. RFI multipliers).

²⁴ For an in-depth analysis of a potential climate and equity framework, see the *Greenhouse Development Rights Framework* (Baer et al 2007)

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