atmosfair CO_2 - Event Report

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CLIMATE-FRIENDLY
EVENT

Event **2016 IUCN World Conservation Congress**
Organiser IUCN
Venue of the Event Hawai'i
Date of the Event 1st - 10th of December 2016

07.02.2017

	Position	Value	Unit	Emission	Unit
General					
	Duration of the event	10	days	-	
	Number of participants	8.634	people	-	
	Overnight stays	31.376	nights	1.081.807	kg CO_2
	Size of the venue	30.293	m²	-	
	Type of the event building	middle age		-	
	Electricity consumption	363.469	kWh	50.913	kg CO_2
	Heat consumption	0	kWh	0	kg CO_2
	Water consumption	2.358	m³	1.774	kg CO_2
	Amount of waste	19,5	t	20.282	kg CO_2
Catering					
	Number of meals	38.026	units	87.845	kg CO_2
	Organic	-		-	
	Local	62	%	-	
	Vegetarian	32	%	-	
	Transportation	6.020	km	3.110	kg CO_2
Arrival / Departure and local mobility					
	Flight	109.549.110	km	31.586.660	kg CO_2
	Train	0	km	0	kg CO_2
	Car	651.360	km	92.689	kg CO_2
	Airport Coach	64.168	km	4.813	kg CO_2
	Public transport	0	km	0	kg CO_2
	Taxi	64.194	km	9.135	kg CO_2
	Shuttle	63.729	km	4.780	kg CO_2
Goods transport					
	Distance	213.932	km	-	
	Weight of goods	34,8	t	510.907	kg CO_2

Total emission of the Event:	**33.454.713**	**kg CO_2**
Emission of the event without flights:	**1.868.053**	**kg CO_2**

Explanations concerning the atmosfair CO_2 – Event Report

Unless stated differently and explained in this document, the information in the atmosfair event report, was retrieved from and based on the input data atmosfair received from the IUCN.

1. Duration of the event

The duration of the event was calculated at 10 days using the start and end date, as provided by the IUCN.

2. Number of participants

This figure was provided by the IUCN as follows: 8634 participants in total, 3363 international, 1357 form the US mainland, 5271 from Oahu island and 526 from other Hawaiian islands.

3. Overnight stays

The figure for overnight stays was computed out of the hotel nights booked via the IUCN (provided by the IUCN), equalling 16 876 and 14 500 additional nights, which were not booked using the official housing centre of the IUCN. For the former, the respective hotel categories were provided. The total booked nights in the categories were then multiplied with the respective CO_2-emissions-factors, which are based on the VDR-Standard (https://www.atmosfair.de/portal/documents/10184/35898/VDR_Reportingstandard_Teil1_Methoden.pdf/c0de1c79-e2d9-4c2e-bb07-92012485f6c7). Based on the distribution of the centrally booked nights, weights were derived. Those weights were applied to the 14 500 additional nights. Afterwards, these weighted figures were multiplied with the VDR-Standard CO_2-equivalents per room night, which lie between 23,8 and 42,17 kg CO_2/night depending on the hotel category.

4. Size of the venue

This figure was provided by the IUCN at 30 293 m^2.

5. Type of the event building

Since no information was provided, the assumption was made that the venue was built between 1978 and 2002.

6. Electricity consumption

The kWh figure was provided by the IUCN at 363 469 kWh. It was multiplied with an average CO_2 equivalent of 0,587 kg CO_2/kWh for situations where the source of electricity generation is unknown.

7. Heat consumption

The kWh figure was provided by the IUCN at 0.

8. Water consumption

A number of 62 280 kgal was provided by the IUCN. It was converted into m^3 and multiplied with a CO_2-equivalent of 0,36 kg CO_2/ m^3 for water provision in cities.

9. Amount of waste

The initial figure of 19 516, 605 kg was provided by the IUCN. It was multiplied with a CO_2-equivalent of 139 kg CO_2/t from the Bavarian environmental ministry.

10. Catering

Number of meals and the share of local and vegetarian food was provided by the IUCN: 38 026 meals prepared, of which 32% were vegetarian. The CO_2-equivalent was based on numbers from the IFEU- institute for the different categories (from 2,6 kg CO_2/meal for conventional food, to 1,71 kg CO_2/meal for local, organic vegetarian food). The relevant numbers were multiplied. The transportation for the catering is based on numbers from previous events of a similar scope, which were taken from atmosfair's database.

11. Flights

Atmosfair received lists containing city and country of origin for all participants. Those, who came from anywhere but Oahu, were assumed to have used the airplane to get there. Based on those lists, atmosfair used the flight compensation calculator to determine the CO_2-emissions for the different flight routes to Honolulu, as well as the distances in km. Since atmosfair takes the "Radiative Forcing Index" (RFI) into account, when calculating the CO_2-emissions per flight, which is considered best practice, as it results in more accurate effects of flights on the atmosphere, the emissions are multiplied with a factor of 3 for km flown above an altitude of 9 km (for more information, please refer to https://www.atmosfair.de/portal/documents/10184/20102/Documentation_Calculator_EN_2008.pdf/21655b2c-d943-4f87-a1b5-ff8607542cda). Those "RFI-included" emissions and person km (pkm) were multiplied with the number of participants, using them.

12. Train

Does not apply on Oahu.

13. Car

It was assumed, that all Oahu residents arrived by car, travelling an average distance of 30 km in total per day. Those numbers were summed and multiplied with the CO_2-equivalent per pkm for cars from the German ministry for the environment (https://www.umweltbundesamt.de/sites/default/files/medien/publikation/long/4364.pdf , P. 32).

14. Airport Coach and Taxi

The IUCN provided atmosfair with an average of 13 km between Honolulu airport and the hotels. The number of participants who flew into Honolulu was equally distributed between using the airport coach and the taxi to get to the hotels, and back to the airport. Getting to the airport in the respective departure cities and countries was disregarded, since there were no reliable figures available. The CO_2-equivalent of 0,075 kg for busses and 0,142 kg per pkm came from the German ministry for the environment (https://www.umweltbundesamt.de/sites/default/files/medien/publikation/long/4364.pdf , P. 32).

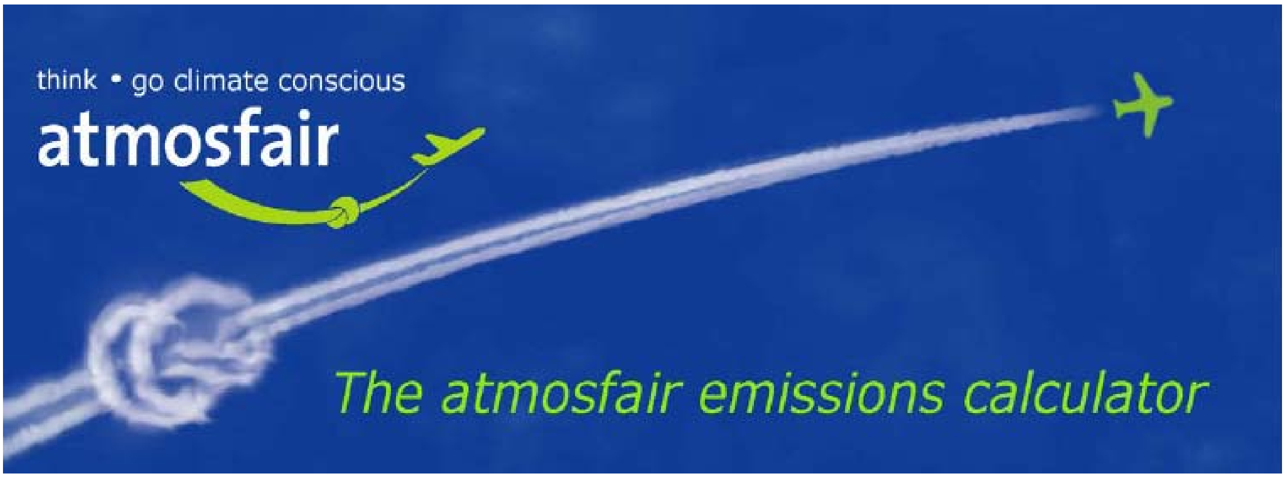
15. Shuttle

The IUCN provided a shuttle for the participants on the opening day of the event, for which the total distance travelled was provided at 6,3 km. By taking the number of participants (8634) and multiplying it with the provided distance travelled per shuttle, the total distance for the shuttle was approximated at 53 147 km. In addition, 3734 trolley passes were given out, for an estimated average of 2,5 km. The resulting 9335 km were added to the distance for shuttle. The respective result was multiplied with the CO_2-equivalent per pkm from the German ministry for the environment (see above).

16. Goods transport

The original figure of goods transported was provided by the IUCN, including the destinations of the individual items. For those goods transported by plane, the distances of their cities of origin to Honolulu were computed. The source for the emissions of air freight was the following http://www.sciencedirect.com/science/article/pii/S1352231011010144. However, the literature does not take the RFI into account. Therefore, the relevant CO_2-emissions per kilometre and tonne were multiplied by 2,7. Here we did not use 3, since not all km were flown above an altitude of 9 km. Therefore, 2,7 is used to consider take-off, climb, descent and landing. These factors were then multiplied with the weights and distances of the individual items. Afterwards, they were added together.

While it is likely that more goods were transported to Honolulu, neither the IUCN nor atmosfair did have or have any information on that. Therefore, the calculations are limited to the reliable figures, which were at our disposal.



This text documents the details of the public atmosfair Emissions Calculator program, accessible at www.atmosfair.org.

There is also a more sophisticated business version of the calculator (reporting tools for business travel agents). For enquiry, please mail to info@atmosfair.de

1. *Principles*
2. *What factors determine how climate-damaging my flight is and how are they captured by the Emissions Calculator?*
3. *On what data sources is the Emissions Calculator based?*
4. *How accurate are the methods and results?*
5. *Overview: aircraft types, seating, engines and standard distances*
6. *References*

1. Principles

The Emissions Calculator has been designed in accordance with the following principles:

- *Data independence*

The data sources come from independent scientific research projects.

- *Appropriate accuracy*

The accuracy of the calculations is appropriate to the nature of the subject. Those factors that a flight passenger can influence and that have the biggest impact on emissions are considered by the program in detail, whereas others, which are less important or cannot be influenced by the passengers are reflected through the application of average factors. Where the user is unable to provide the factors requested, average values are used.

- *Validation*

The Emissions Calculator's methodology and the data on which it is based have been checked by Germany's Federal Environmental Agency.

2. What factors determine how climate-damaging my flight is and how are they captured by the Emissions Calculator?

2.1 The different pollutants

Summary: Aircraft engines emit a range of pollutants which raise the temperature of the atmosphere directly or indirectly. Carbon dioxide (CO_2) is the easiest to describe in terms of its production and effect. It is produced during the combustion of kerosene in direct proportion to the consumption of kerosene. CO_2 is used as the basis for calculating climate damage. The various other pollutants and their effects can be summarised via an internationally recognised calculation method so that its warming effect can be converted into CO_2 emissions having the same warming effect. The Emissions Calculator first calculates the fuel consumption per passenger and, based on this, then determines the amount of CO_2 whose warming effect is comparable to that of all pollutants emitted by the flight together (effective CO_2 emissions). This is the amount of CO_2 output by the Calculator which is saved by atmosfair in climate protection projects.

Aircraft engines emit a range of pollutants which increase the atmospheric temperature. The most important are carbon dioxide (CO_2), nitrogen oxides (NOx) and various particles of soot or sulphur. The climate impact of these pollutants has been described in detail by the IPCC, the United Nations Intergovernmental Panel on Climate Change (IPCC 1999). The impact of these pollutants on the climate varies:

Carbon dioxide (CO_2)
is always generated during the combustion of fossil fuels (coal, gas, oil). The amount of carbon dioxide emitted is a direct function of fuel consumption: 3.16 kilograms CO_2 are produced per kilogram of kerosene on combustion in the aircraft engine with ambient air. Carbon dioxide is a greenhouse gas which, simplified somewhat, remains in the atmosphere for approx. 100 years after its emission. As a result is can spread over the entire globe, driving global warming throughout the world. CO_2 is regarded as a leading gas in climate science in climate science and is used as a reference variable for comparisons between the effectiveness of different greenhouse gases.

Nitrogen oxides (NOx ⇨ ozone)
Nitrogen oxides are produced in the aircraft engine at high temperatures and pressures by the reaction between oxygen and atmospheric nitrogen. Its production depends greatly on the engine load. It is estimated that approx. 8-15 grams nitrogen oxides are produced per kilogram kerosene consumed in passenger jet engines when cruising. Nitrogen oxides have two main impacts on the climate: firstly, they reduce the lifetime of the greenhouse gas methane, an effect that reduces global warming. Secondly, at cruising altitudes of about 10 kilometres they form the powerful greenhouse gas ozone which spreads out along the major air corridors, for example over the North Atlantic, where several hundred aircraft fly daily from Europe to the US and back.

Particles (condensation trails and ice clouds):
Particles in the engines' exhaust plume are produced by condensation from gaseous pollutants and consequent processes. Water, soot and sulphur are important starting materials for this. Ambient air saturated with moisture can condense on particles, resulting in condensation trails and high, hazy ice clouds (cirrus clouds). These clouds act like a glass roof over the earth and thus contribute to climate warming. The formation of these clouds depends less on the number of emitted particles than on the fact that the ambient atmosphere is sufficiently humid.

Further pollutants:
In addition to these pollutants there are others which are not discussed here because of their lesser importance than those mentioned above. More information on these substances can be found in IPCC 1999.

Calculating the impact of the pollutants using the RFI:
The climatic impacts of the different pollutants can be converted to those of carbon dioxide. This is done using the "Radiative Forcing Index" (RFI, see IPCC 1999). The result is a quantity of CO_2 that would have to be emitted to cause the same warming effect, when averaged globally, as the various pollutants together. The RFI is a numerical multiplier. Former estimates of the IPCC (1999) put the factor at approx. 2-4 with a best estimate of 2.7, see IPCC 1999). This means that the total climate impact of all the different pollutants from all flight could be approximately expressed by taking the emitted volume of CO_2 times 2,7. In 2007 the IPCC in its Fourth Assessment Report published new numbers on aviation and global warming. According to these numbers, the RFI has now a range of 1.9 to 4.7 (see Graßl et al., 2007). Atmosfair uses an RFI of 3, falling in the middle of this actual range. Since the RFI has been developed for effects like condensation trails, which only occur in high altitudes above 9 kilometres, atmosfair only applies the RFI to those emissions of a flight, that occur in these altitudes. This means that the RFI is not applied to the emission during climb out and landing approach and not to the cruise emissions, if cruise is below 9 kilometres (see section on flight profile).
Since carbon dioxide is a direct function of kerosene consumption (see above), all the Emissions Calculator needs is to calculate the kerosene consumption per passenger on a flight. The CO_2 and the effective CO_2 emissions are then calculated by simple multiplication by the above-specified factors (3.15 kg CO_2 per kilogram kerosene, and the RFI factor for those emissions above the 9 kilometre threshold). This is adequately accurate in light of the various uncertainties still existing.

RFI and differences between short haul and long haul flights:
When applying the RFI, one important distinction needs to be made: Some flights do not reach the critical altitudes above 9 kilometres, where most of the climate effects of pollutants other than CO_2 set in, such as the formation of contrails. Therefore, the RFI is only applied to emissions over this threshold altitude, which may not be reached by these flights, typically flights up to some 400 kilometres distance. Even on longer flights, no RFI applies to the emissions during the phases of climb and descent. This will be discussed in more detail in the following sections.

2.2 Flight altitude and state of the ambient air

Summary: The equivalent climate impact of the emissions and their effects depends on the flight altitude and the state of the atmosphere at the time when the aircraft flies through it and emits the pollutants. This is adequately addressed in that the Emissions Calculator treats the emissions at high cruising altitudes in excess of approx. 9 kilometres above sea level (these are usually reached in the cruise phase of flight distances of greater than approx. 400–500 km) as more harmful than those of short-haul flights. The equivalent climate impact of the nitrogen oxides and particles (see 2.1) is a function of the flight altitude and the state of the atmosphere at the time the aircraft flies through it and the pollutants are emitted.

Nitrogen oxides, ozone:
The generation of the greenhouse gas ozone from nitrogen oxides under the effect of insolation is a result of similar chemical smog reactions to the formation of nitrogen oxides from automotive emissions in cities during the summer months. At high flight altitudes above approx. 9 kilometres, however, the smog reaction is more effective than at ground level. The existing concentration of nitrogen oxides is crucial in this context: if there are few nitrogen oxides available, ozone is quickly formed; if, on the other hand, there is a very high concentration, further nitrogen oxides can even result in ozone being broken down again. It is therefore important to know whether a flight operates on a route which is frequently or rarely flown and whether the aircraft climbs to the critical heights.

Particles, ice clouds:
Long-lasting condensation trails and high hazy clouds of ice can only form if the air through which the aircraft is flying is sufficiently humid. Near the equator this is generally only the case at very high altitudes of about 12-16 kilometres above sea level. Since even modern civil jets rarely fly at such altitudes, the formation of condensation trails and ice clouds here is rarer than at more moderate latitudes and in the polar regions of the earth where these clouds can form at depths of as low as 5 kilometres. The humidity in the air is also generally a function of the season, as a result of which this too influences the likelihood of such aircraft-generated clouds being formed.

The Emissions Calculator cannot address these effects in detail since this would require an enormous amount of data which would be out of proportion to the accuracy thus achieved. Furthermore, neither the passenger nor the airline can influence the present state of the atmosphere on the route and at the time of a flight. It would therefore not be justified for some passengers to have to pay a higher surcharge than others. Consequently the Emissions Calculator only takes account of the most important systematic parameter, the flight altitude: for all emissions occurring above an altitude above 9 kilometres a RFI factor (see 2.1) of 3 is used in the calculation, meaning that average values are applied to simulate the impact of condensation trails, ice clouds and ozone from aviation-related nitrogen oxides. This approach means, that on a given flight the average RFI is always below 3, since all flights have an take off, climbing and descending phase below 9 kilometres altitude, for which emissions no RFI is applied.

2.3 Aircraft: aircraft type, seating, seat occupancy rate and transported cargo

Summary: The aircraft type, the number of seats on board, their seat occupancy rate and the transported cargo have a direct impact on the fuel consumption per passenger. The most important factors among these are seating and seat occupancy rate. The Emissions Calculator takes these factors into account by using the average figures for German airlines and aircraft manufacturers' standard configurations with regard to seating. As far as the seat occupancy rate is concerned, a distinction is drawn between the scheduled and charter market segments which have different average seat occupancy rates. In the case of scheduled flights these figures are also differentiated by flight region.

2.3.1 Individual Aircraft type

Fuel consumption depends on the aircraft type. A distinction is generally made between propeller-engined aircraft, which are generally used for short-haul flights, and jets, which operate on both short- and long-haul routes. Today's aircraft fleets in the industrialised countries are dominated by the various aircraft types of the two major manufacturers Boeing and Airbus. Since fuel consumption is an important criterion for the two manufacturers, modern (comparable) jets have similar fuel consumptions per passenger. However, because of jets' long service lives (approx. 30 years) many airlines are still using relatively old aircraft types today which often have significantly higher fuel consumption.

The Emissions Calculator has a database of detailed consumption figures of 47 aircraft types currently including their distance dependence, and these figures permit a largely realistic calculation of fuel consumption. These aircraft types come from different aviation engineering generations and cover an estimated 95% of the total worldwide air traffic. Propeller-engined aircraft are not yet included in the database since no data is yet available for these.

2.3.2 Hybrid aircraft, aircraft not specified by user

If the customer enters the option "Aircraft type unknown", the Emissions Calculator also operates with virtual "hybrid aircraft". These are virtual aircraft composed mathematically of defined proportions of the four real aircraft types which are operated mostly on the relation requested by the customer. So the system takes into account, for example, that different airlines and thus also different aircraft are used on flights to Eastern Europe than for domestic German flights or flights to Africa. The database for this composition of hybrid aircraft is more than 500.000 flight control records of real flights in the year 2004. In specific terms, air traffic is divided into 19 regions for "hybrid aircraft". Countries have been assigned as shown in table 1.

Table 1: Definition of the 19 atmosfair regions for hybrid aircraft

Region	Definition
Germany	Germany
EU_North	Norway, Finland, Sweden, Iceland
EU_South	Spain, Greece, Italy, Albania, Portugal, Bosnia, Croatia, Slovenia
EU_East	Hungary, Poland, Czech Republic, Bulgaria, Estonia, Latvia, Lithunia, Estonia, Romania, Slovak Republic, Ukraine, Belarus
EU_West	France, UK, Germany, Ireland, Netherlands, Belgium, Luxembourg, Denmark, Austria, Switzerland
Russia	Russia, Kazhakstan
Middle-East	Afghanistan, Turkey, Pakistan, Iran, Iraq, Israel, Syria, United Arab Emirates, Kuweit, Jordan, Lebanon, Quatar, Saudi Arabia
Asia	India, Bangladesh, China, Sri Lanka, Bhutan, Nepal, Mongolia, Myanmar
Japan	Japan
Indonesia	Phillipines, Indonesia, Malysia, Thailand, Vietnam, Papua, Laos, Cambodia, East Timor
Australasia	Australia, New Zealand
Africa_North	Algeria, Egypt, Maroc, Tunesie, Lybia
Africa_Central	Kamerun, Nigeria, Uganda, Kenya, Congo, Tanzania, Ethiopia, Somalia
Africa_South	South Africa, Namibia, Mozambique, Botswana, Sambia, Simbabwe
South_America_North	Brazil, Venezuela, Peru, Colombia, Suriname, Guyana, French Guyana,
South_America_South	Argentina, Chile, Paraguay, Uruguay, Bolivia
Latin America	Nicaragua, Mexico, Honduras, Guatemala, Costa Rica, Belize, Panama, El Salvador
Carribean	Bahamas, Costa Rica, Dominican Republic, Haiti, Jamaica, Cuba, Antigua and Barbuda, Aruba, Barbados, Dominica, Grenada, Saint Kitts, Saint Lucia, Saint Pierre, Saint Vincent, Trinidad and Tobago
USA	USA
Canada	Canada

Within these regions a distinction is made between different distance classes. A hybrid aircraft in the EU West region over a distance of 500 kilometres is thus made up of different real aircraft than in the case of a flight to the same region over 2,000 kilometres since different aircraft are actually used here.

Aircraft types available in the atmosfair database and data sources are shown in table 4.

2.3.3 *Number of seats*

A further important factor in fuel consumption is the number of seats on board. Today’s jets are fitted out with seating by the manufacturer in accordance with the airline’s specification. The seating can turn out very differently: the seats in Business class are larger and heavier than the Economy seats which generally constitute the major proportion of the seating in a jet. But the airlines also differ in the number of seats which fit in a row. Each airline attempts to configure the seating of its aircraft such that it best meets its customer profile in terms of willingness to pay and comfort requirement.

Since the weight of a jet is determined to a large extent by the airframe and fuel carried, whether there are many or few passengers on board has little impact on total fuel consumption. Calculations for an Airbus A310, for example, show that the total fuel consumption on a flight of 2,000 kilometres only increases by about 10% if the payload is increased from 60% to 100% (DLR 2000). Aircraft therefore use less fuel per passenger, the more passengers there are on board.

The Emissions Calculator assumes an average number of seats on board a particular aircraft configuration. The figures were determined as follows: the average weighted with the number of aircraft was determined for all the aircraft of a type operated by the main German airlines (Aero Lloyd, Hapag Lloyd, Air Berlin, DBA, Eurowings, Germania, Hamburg international, LTU, Lufthansa, Condor), based on the year 2006. This average is representative of flights with German airlines. For other airlines atmosfair uses an average over all airlines as published in the literature (Bucher (2007) and Janes (1990–2003).

2.3.4 *Service class*

There is only a limited area for seating in the body of an aircraft. But there is an almost direct correlation between seating and fuel consumption because the aircraft’s fuel consumption changes only slightly depending on whether there are many or few seats. Since, however, Business seats require more space than Economy seats, Business seats take space away from Economy seats where there is a fixed total space available. In an extreme case a Business seat can require more space than two Economy seats. Measured against the total number of seats available in the aircraft, therefore, the impact of Economy passengers on fuel consumption is below average and Business passengers above average. The deciding factor determining how marked this effect is the ratio of Business to Economy to First class seats and their respective space requirements. These vary from airline to airline and from aircraft type to aircraft type.

The Emissions Calculator uses an estimate based on the seating configurations of the worlds 40 largest airlines, as published in Bucher (2007). From this an average configuration of 74 : 20 : 6 for economy : business : first class is derived for a total of 100 seats. Applying now industry averages for the related space (Flight Guru), on average a relation of 1 : 1.9 : 2.6 emerges. If these spacings are applied to the class configuration, it turns out that on average, CO_2 emissions relate like 0.8 : 1.5 : 2.0 for the three classes, respectively. For fuel consumption this means that Economy passengers consume 20% less than the average for all seats, while Business passengers consume 50% more and first class passengers double the amount of the average.

2.3.5 Seat occupancy rate

The ratio of passengers on board to available seats is termed the seat occupancy rate. As shown above, the seat occupancy rate of passengers on board has a direct impact on fuel consumption per passenger. The seat occupancy rate achieved by the airlines depends on various factors, including ticket prices, the flight type and the flight region. The flight type is generally a distinction between charter and scheduled flights. Charter flights have a higher seat occupancy rate because they are usually chartered long before the flight by travel companies, with the result that the seats are often almost fully occupied. Scheduled flights, on the other hand, generally operate in accordance with a flight schedule. It is therefore possible for some aircraft to take off with few passengers on board if there is no demand at the particular time on the route in question.

The Emissions Calculator addresses these different seat occupancy rates by applying a common average of 80% for charter flights (Öko-Institut 2004). For scheduled flights the seat occupancy rates are also differentiated according to the flight region: for Germany 60%, EU 62%, intercontinental traffic 75% (AEA 2006). If the flight type is not known, an average of 75% is applied.

2.3.6 Transported cargo

Most airlines transport both passengers and cargo in passenger aircraft in order to make the most effective use of their aircraft. The additional cargo carried is generally handled flexibly, taking account of the seat occupancy rate by passengers.

The DLR emissions profiles, which are used to calculate the fuel consumption of the individual aircraft types, do not distinguish between the types of load (DLR 2000). Since, however, additional cargo is generally carried, the fuel consumption per passenger would turn out to be too high if the total fuel consumption were simply divided by the number of passengers. A certain proportion of the fuel must therefore be deducted to allow for the additional cargo. It can be calculated from information on the total cargo and passenger figures in Germany from the *Arbeitsgemeinschaft Deutscher Verkehrsflughäfen* [ADV – German Airports Association] that the ratio of cargo tonnes to passenger tonnes is around 16% in total (ADV 2006), where a total weight of 100 kg per passenger including baggage is assumed. It is known that approximately half of the cargo is additional cargo (Pompl 2002). The additional cargo proportion is therefore around 8%. In light of the weak correlation discussed above between payload and total fuel consumption this means that a proportion of almost 2% of the fuel consumption can be attributed to the additional cargo. The Emissions Calculator deducts 2% at the end from the consumption results without cargo to correct the systemic error for the additional cargo.

2.3.6 *Aircraft engine*

Different engines have different emissions figures, and even the same engines on different aircraft types can have quite different emissions figures if they are operated under different load conditions. Most aircraft types can be purchased with different engines from just a few major manufacturers.

Their fuel consumption is very similar for most engines within a class. However, the individual pollutant emissions can vary greatly depending on the manufacturer, e.g. for the nitrogen oxides that contribute to the formation of the greenhouse gas ozone.

The Emissions Calculator uses DLR databases (DLR 2000) in which a frequently used engine is assigned to particular aircraft. Other engines are not taken into consideration in the calculation.

2.4 *Flight distance and the ratio of take-off, cruising and landing of the aircraft*

Aircraft fuel consumption is highly dependent on the distance covered. In principle, the absolute consumption is higher in total, the greater the flight distance. On short-haul flights, however, the relative consumption per 100 kilometres covered is higher than on medium-haul flights. The reason for this is that the take-off and initial climb require a great deal of energy and play a greater role on short-haul flights. Long-haul flights also consume more fuel per 100 kilometres than medium-haul flights because for a large part of the flight the aircraft also has to carry the fuel which is only used at the end of the flight.

The Emissions Calculator calculates the distance of a flight as a great circle route (shortest distance between two points on the earth and adds surcharges for detours, holding patterns etc., see section 2.5) between the departure and destination airports and takes detailed account of the dependence of consumption on the climb, cruise and descent phases of a particular aircraft type.

Correlation between fuel consumption and distance
Fig. 1 below shows as an example the calculated fuel consumption of a fully occupied Airbus A340 with 271 seats as a function of the distance covered. The fuel consumption is given in litres kerosene per passenger per 100 kilometres. It is clearly apparent that consumption per 100 kilometres is at its lowest on medium-haul flights of around 2,000 kilometres in length, reaching figures of approx. 3.7 litres kerosene per passenger per 100 kilometres. On short- and long-haul flights, on the other hand, consumption is higher. The consumption figures can deviate widely from this example for other aircraft types, but the fundamental dependence of the consumption on the distance is characteristic of most modern jet aircraft.

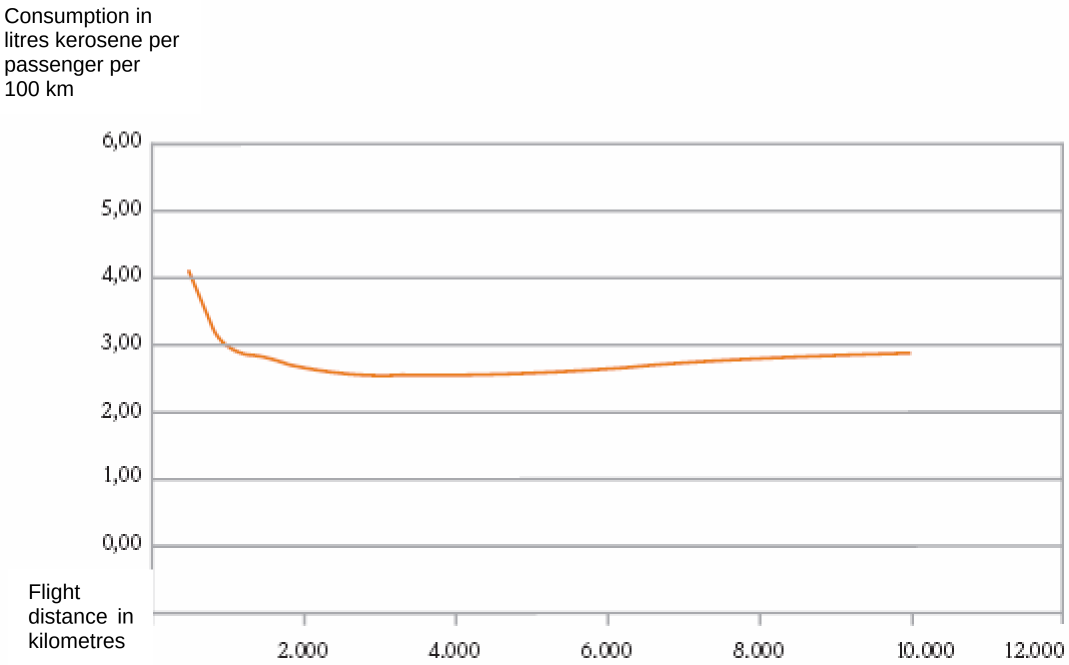


Fig. 1: Fuel consumption of a full Airbus A340 with 271 seats as a function of flight distance. Source: DLR 2000

2.4.1 *Taking account of the distance in the Emissions Calculator*

There are two stages to the Emissions Calculator: in the first stage it calculates the flight’s great circle distance (shortest distance between two points on the earth) from the geographic coordinates of the departure and destination airports. To this are added default values for detours, holding patterns etc. (see section. 2.5). In the second stage the Emissions Calculator calculates the fuel consumption of a particular aircraft as a function of the distance. Here the Calculator operates on the basis of altitude profiles. These indicate the flight altitude of a flight in comparison with the distance covered. Fig. 2 shows examples of typical simplified altitude profiles. It is apparent that each flight consists of three phases:

1. Climb phase, in which the aircraft climbs to its cruising altitude after take-off. This phase can be between about 50 kilometres and about 300 kilometres long.
2. Cruise phase, in which the aircraft covers a certain distance at a constant altitude. This phase can vary from one hundred to several thousand kilometres, depending on the total distance. The flight altitude of this phase varies: on short-haul flights it is in the range from about 5 to 7 kilometres, on long-haul flights it is frequently approx. 10.5 kilometres to about 13 kilometres.
3. Descent phase, in which the aircraft descends from its cruising altitude again until landing. It is often as long as or slightly longer than the climb phase.

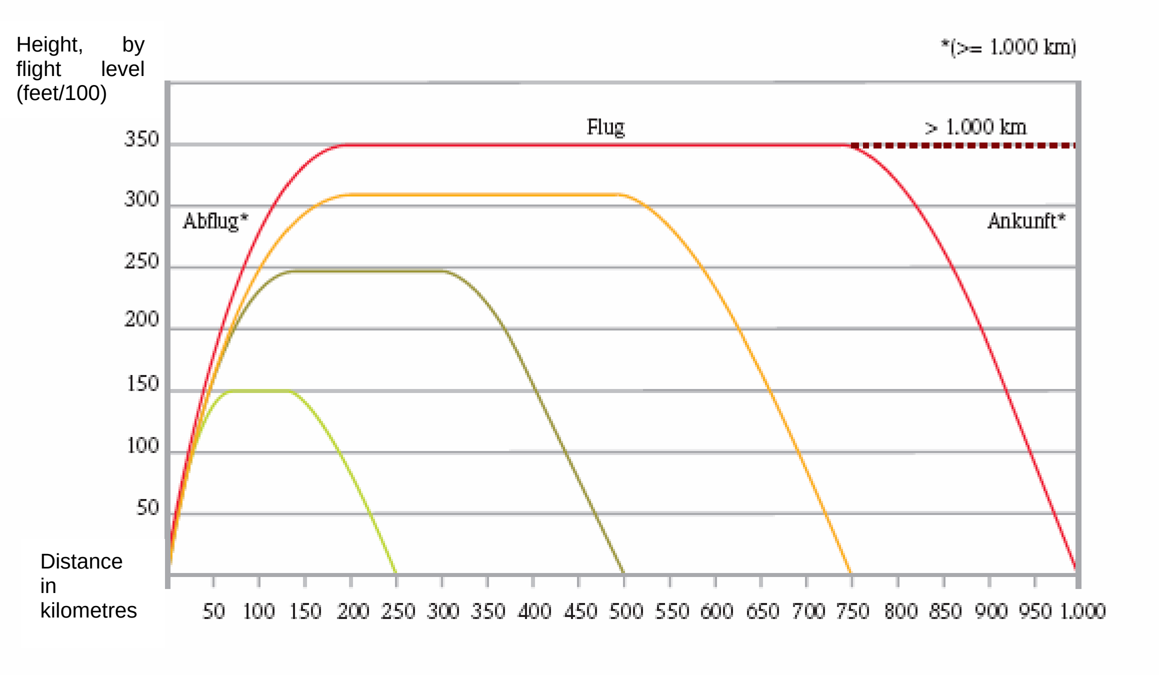


Fig. 2: Altitude profile of flights of different distance. On flights of 1,000 kilometres and more in length aircraft frequently climb to flight level 350 (approx. 10.7 kilometres altitude), on flights of 250 kilometres in length to flight level 150 (approx. 4.5 kilometres altitude). Further altitude profiles for flights up to 10,000 kilometres in length are not shown in the figure. Source: DLR 2000

The Emissions Calculator has stored these standardised 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 kilometres (provided the aircraft has this range).

In order to calculate the fuel consumption over a specified actual distance for a customer’s particular flight, the Emissions Calculator takes the consumptions on certain standard distances and interpolates for the precise result. Example: a passenger flies in a Boeing 737-400 from Frankfurt to Barcelona (distance approx. 1,140 kilometres). For this the Emissions Calculator uses the altitude profiles of the B 737-400 for the 1,000-kilometre and 2,000-kilomteres flights and interpolates between those two.

2.4.2 *Discussion of the method used*

The method used here represents a refinement of an existing method. The basic method was developed in 2000 in a study for the German Federal Environmental Agency by the German Technical Inspectorate (TÜV) and the German Aerospace Center (DLR) to calculate a German aviation emissions register (TÜV 2000). It was further differentiated for the Emissions Calculator by incorporating the separate capture and interpolation of climb, cruising and descent phases.

2.5 Wind, detours, holding patterns and taxiing at the airport

Headwind, detours from the great circle distance as the shortest connection between two points, holding patterns in the vicinity of the airport and taxiing to and from the runway consume fuel. The Emissions Calculator does not take explicit account of the effect of wind since it assumes that this effect is cancelled out in the course of a return flight. The other factors are taken into account by means of standard fixed corrections which have mostly been derived from aviation studies in Germany.

2.5.1 Wind

The aircraft is always exposed to the prevailing wind conditions en route from the departure to the destination airport. In our region (Europe) the characteristic feature is the West Wind Drift. The headwind on westward flights therefore increases fuel consumption on average per 100 kilometres and the tailwind reduces it on eastward flights.

The Emissions Calculator assumes that most flights are undertaken in pairs, i.e. there is a corresponding return flight for each outward flight. Thus the effects of a headwind or tailwind on fuel consumption cancel each other out on average, and no further allowance is therefore made for them.

2.5.2 Detours

The kilometres flown by an aircraft en route from the departure to the destination airport in addition to the great circle distance (which corresponds to the shortest connection between two points on the earth) are deemed detours. These do not include the holding patterns which are counted separately (see below). Detours are captured statistically. Fig. 3 shows the detours on flights in Germany, in the form of the detour factor (quotient of actual flight distance including detour divided by great circle distance) as a function of the great circle distance. If the detour is expressed in absolute terms, it is in the region of 50 kilometres for almost all flight distances. Similar studies of long-haul flights come to the same results.

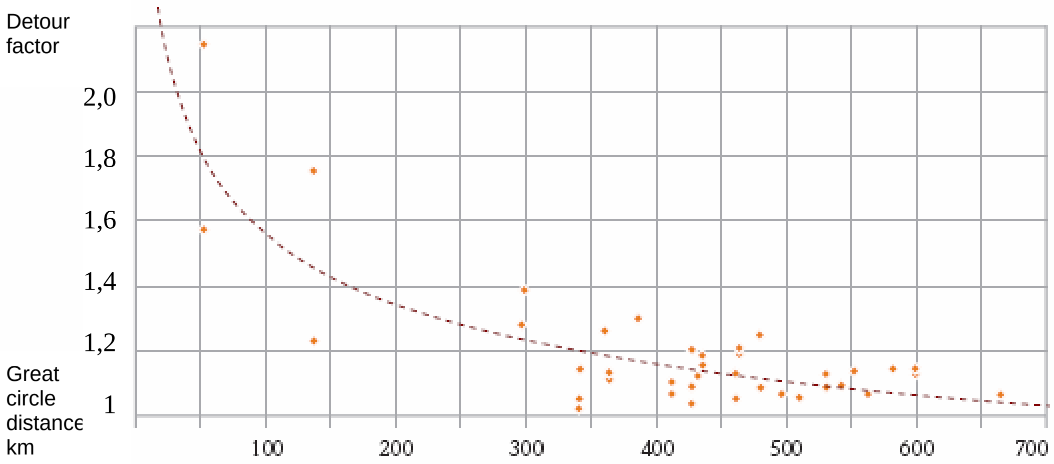


Fig. 3: Correlation between detour factor and great circle distance

The Emissions Calculator takes account of this empirical result by multiplying the detour function as a fixed figure to all flights. This seems adequately precise in view of the low significance of this factor.

2.5.3 *Holding patterns*

Aircraft fly in holding patterns at the destination airport if the landing runways are not yet free. The Lufthansa Environmental Report shows that almost 1 kilogram fuel is consumed per passenger on average (Lufthansa 2002). Since further details were not available, the Emissions Calculator uses this factor here as a fixed surcharge for all flights, even if they do not touch Germany. While this is undoubtedly inexact, it seems appropriate, given the low overall significance of this effect.

2.5.4 *Taxiing before take-off and after landing*

Before taking off, aircraft have to taxi from the terminal to the runway and use up fuel which is not included in the flight profiles. The same applies to taxiing to the terminal after landing. In Germany an aircraft spends on average almost 15 minutes per flight taxiing on the ground. The engines are running at low power during this time. A study of the fuel consumption for taxiing at domestic German airports concludes that approx. 2.5 kilograms kerosene were consumed per passenger for the two taxiing processes together (Brockhagen 1995). This quantity is also assumed by the Emissions Calculator as a fixed surcharge for all other flights from and to as well as outside Germany. While this is undoubtedly inexact, it seems appropriate, given the low overall significance of this effect.

3. On what data sources is the emissions calculator based?

The specifications of the clients, Germany's Federal Ministry for the Environment and Germanwatch, were complied with in designing the Emissions Calculator, i.e. only independent scientific data sources were to be used for the Emissions Calculator. All the main sources for the Emissions Calculator are therefore the results of independent scientific studies commissioned by the German Federal Environmental Agency, the United Nations or the EU. Further data is derived from the published specialist literature or relevant directories. Only in two cases were figures from aerospace industry publications used because they were the only ones available. These relate to the fuel consumption in holding patterns and the seat occupancy rate of aircraft on scheduled flights in different regions. In terms of their weight these are small (holding patterns) or consistent with the known degrees of magnitude (seat occupancy rate), as a result of which their use is uncontroversial.

3.1 DLR database

The German Aerospace Center (DLR) conducted emissions calculations for the commonest jet aircraft types in a research project for the German Federal Environmental Agency (UBA). The results are summarised in a database containing the consumption and emissions data as a function of altitude and distance (DLR 2000). The aircraft type/engine combinations are shown in Table 3 together with the standard distances. This database is at the heart of all the Emissions Calculator's calculations.

3.2 QinetiQ data base

The QinetiQ institute conducted a series of studies on behalf of atmosfair to deliver emissions calculations for jet aircraft types. They were derived by coupling real flight data of 2004 from over 500.000 flights all over the world with emissions calculations based on the given engine airframe combinations.

3.3 UBA study

A study into polluter-related pollution reduction in the aviation sector was conducted between 1996 and 2000 on behalf of the UBA. This study recorded in detail the air traffic from, to, in and over Germany and Europe in 1995 (TÜV 2000), coupling observed movements, jet types and fuel consumption data.

Fuel consumption and CO_2 emissions data are calculated by the atmosfair emissions calculator, drawing on a database brought together from the three above sources.

3.4 IPCC

The United Nations Intergovernmental Panel on Climate Change (IPCC) is the world's ultimate scientific authority on climate change. Its reports always formed the basis for the international climate negotiations of the member states of the United Nations (see www.ipcc.ch). The IPCC published a special report on aviation in 1999 (www.grida.no/climate/ipcc/aviation/index.htm). This details all the fundamental effects of aviation on the climate in detail. The Radiative Forcing Index for determining the equivalent climate impact of non-CO_2 emissions (see section 2.1), in particular, was derived from the Fourth Assessment report of the IPCC (2007), as analysed in Graßl et. al. (2007).

3.5 Specialist literature

A few constant factors such as the average taxiing time at German airports were taken from the published specialist literature (Brockhagen 1995).

3.6 Aircraft directories and fleet databases

The publishers Bucher and Jane publish annual directories containing a wealth of technical details on the equipment configurations of aircraft and fleets (Bucher, Jane`s). These were used as the basis for calculating the number of seats on board a particular aircraft type.

3.7 Aerospace industry publications

This includes Lufthansa's Environmental Report, which contains information on fuel consumption in holding patterns, and the annual report of the Association of European Airlines (AEA), which contains detailed information on the seat occupancy rates of the major European airlines in different flight regions.

Statistics from the ADV were used to address the extra consumption as a result of the additional cargo (ADV 2006).

3.8 Experts' estimates

For some data there was no up-to-date published literature. In these cases experts' estimates or unpublished research reports were used, both from the German Aerospace Center. This applies to the detours flown for different flight distances.

3.9 *Overview of data sources*

Table 2 summarises the data sources for the Emissions Calculator's individual parameters.

Table 2: Data sources for the Emissions Calculator

Parameter in the Emissions Calculator	Data source
Pollutants, climate impact, RFI	IPCC 1999, 2007
Fuel consumption, aircraft types, engines, transported cargo	DLR 2000, Qinetic 2005, TÜV 2000
Standard distances, flight altitude, flight profile	DLR 2000, QinetiQ 2005
Hybrid aircraft, composition	TÜV 2000, Qinetic 2005
Number of seats on board an aircraft	Bucher 2006, Jane's 2003
Seat occupancy rate	Ökoinstitut 2004, AEA 2006
Detours DLR, unpublished fuel consumption in holding patterns	Lufthansa 2002, QinetiQ 2005
Fuel consumption, taxiing to and from runway	Brockhagen 1995
Additional cargo	DLR 2000 and ADV 2006

4. How accurate are the methods and results?

The Emissions Calculator is based on methods and data sources which permit the equivalent climate impact of a flight to be calculated with an appropriate degree of accuracy. The Calculator works with different levels of accuracy depending on the customer’s input. The central factors for the equivalent climate impact of a flight are captured and simulated by the Emissions Calculator. The data sources and methods are of high quality and represent the scientific state of the art.

4.1 Uncertainty factors

A compromise between accuracy and data volume was struck when designing the Emissions Calculator. The most important factors are simulated, if at all possible, without giving an exaggerated impression of accuracy. Table 3 lists the main uncertainty factors which play a role in the accuracy of the result in the chain from the passenger via the aircraft type and the airline to the equivalent climate impact of the emissions.

Table 3: Overview of the uncertainty factors in the Emissions Calculator

Field	Factors	Estimated impact on the result	How addressed in Emissions Calculator
Aircraft	Aircraft type	Moderate (approx. 25%)	Detailed
	Seating	Moderate (approx. 25%)	Average
	Seat occupancy rate	Moderate (approx. 25%)	Detailed
	Engine type	Moderate (approx. 10%)	As standard
	Maintainance of aircraft and engines	Low (<5%)	Average
Flight	Specific fuel consumption as a function of flight distance and flight profile	High (50%)	Detailed
	Detours	Low (<5%)	Regional averages
	Holding patterns	Low (<5%)	Regional averages
	Weather (wind, temperature etc.)	Low (<10%)	Average
Emissions	Current state of atmosphere (temperature, humidity etc.)	High (approx. 100%)	Average
Climate impact	Scientific knowledge level to IPCC 1999	Moderate (approx. 30%)	Average

The factors have different weightings. The factors with low weighting were adequately addressed by inclusion as a fixed surcharge. Allowances for external factors, such as the present state of the atmosphere at the time of the flight, were made by using averages. Averages were also used to deal with those uncertainties which result from different equipment configurations for aircraft of the same type. The Emissions Calculator takes detailed account of those factors which would, if fixed surcharges were used, have a highly uncertain impact on the result, particularly the aircraft type, the seat occupancy rate and the dependence of the specific fuel consumption on the flight distance.

The only important factor which is not taken into account is the airline. This would have a direct impact on emissions in that the airline itself determines the number of seats on board a particular aircraft type directly and spends more or less on maintaining the airframe and engines. It could be desirable in the long term to simulate the former factor in the Emissions Calculator too. However, this could only be achieved at the cost of an increase in the amount of data gathered since the seating can change and even within an airline there are often the same aircraft types with different seating configurations. At present this seems to be out of proportion to the targeted result.

4.2 *Data quality*

At the heart of the data sources used is the database containing the fuel consumption profiles of individual aircraft over different basic distances. This data is provided by the German Aerospace Center (DLR 2000). The quality of this data is high, and it was used as the starting point for emissions registers in the IPCC report commissioned by the United Nations.

4.3 *Methodological quality*

The emissions calculations are based on the method of distance- and altitude-dependent fuel consumption (see section 2.4). This method is a refinement of an existing method. The basic method was developed in 2000 in a study for the German Federal Environmental Agency by TÜV and the DLR to calculate a German aviation emissions register. It was further differentiated for the Emissions Calculator by incorporating the separate capture and interpolation of climb, cruising and descent phases.

4.4 *No pseudo accuracy*

Table 3 also shows that it is impossible to give a fixed figure of X or Y% for the overall accuracy of the Emissions Calculator. On an individual flight the seat occupancy rate or the atmospheric properties, for example, can vary greatly in the case from the averages used. This would mean that the climate impact of this one flight would differ very greatly from the calculated average. These inaccuracies are, however, specified by the system, and it would not be sensible to want to eradicate them, even if the ability to do so were available. Ultimately neither an airline nor a customer can do anything if the general weather situation at the time of his flight is such that harmful condensation trails form at the specified flight altitude. In future it may be feasible and desirable to fly above or below these critical atmospheric layers by specifically varying the altitude. Until such time there is no point in including this factor in the calculation.

It is also true with reference to the seat occupancy rate on a particular flight that a customer may by chance fly on an aircraft where every seat is occupied and he therefore consumes less fuel in relative terms than in an empty aircraft. Since this result is purely fortuitous for him, however, the system would give the customer the pretence of accuracy if this actual factor were to be included when ultimately it is a matter of chance.

4.5 Three different accuracy levels

The Emissions Calculator operates at three different accuracy levels. Which of these applies depends, firstly, on whether the customer knows the aircraft type and, secondly, whether or not the flight touches Germany.

If the customer knows the aircraft type and inputs it from the input screen, the emissions are calculated directly via the aircraft type. This means that in this case the Emissions Calculator can deliver accurate data, irrespective of a customer’s destination.

If the customer does not know the aircraft type, the first step is to determine the flight region (e.g. EU West or Germany). Then a “hybrid aircraft” is used as a function of the distance to calculate the emissions (see section 2.3.1). The composition of this hybrid aircraft is based on empirical flights to and from Germany.

If the customer does not know the aircraft and he enters a flight which does not touch Germany (e.g. from New York to Rio de Janeiro), the Emissions Calculator works on the basis of aircraft types which are most commonly used worldwide on particular routes. This means that accuracy is reduced by comparison with the first two accuracy levels.

The seat occupancy rates are also captured more accurately at levels 1 and 2 because regionally-dependent figures are available here for scheduled flights.

5. Overview: aircraft types and engines

Table 4: aircraft types and assumed standard engines.

Nr.	aircraft type	RepAirID	engines	EngID
1	Airbus A300-600R	A306	CF6-80C2B1F	1PW058
2	Airbus A310-300	A310	CF6-80C2A2	1PW058
3	Airbus A319	A319	CFM56-5C4	2CM015
4	Airbus A320-200	A320	CFM56-5A1	2CM015
5	Airbus A320-201	A320	CFM56-5A2	2CM015
6	Airbus A321-100	A321	CFM56-5C4	2CM015
7	Airbus A330-300	A330	PW4168	5GE085
8	Airbus A340-300	A340	CFM56-5C2	2CM015
9	ATR72-210	AT72	PW127	TP3
10	Boeing B707-320C	B703	D-30KP-2	1AA002
11	Boeing B717-200	B712	BR700-715C1	4BR007
12	Boeing B727-200A	B722	JT8D-15	1PW010
13	Boeing B737-200	B732	JT8D-15	1PW010
14	Boeing B737-300	B733	CFM56-3-B1	1CM006
15	Boeing B737-400	B734	CFM56-3C-1	1CM007
16	Boeing B737-500	B735	CFM56-3B-1	1CM006
17	Boeing B737-600	B736	CFM56-7B26	3CM033
18	Boeing B737-700	B737	CFM56-7B26	3CM033
19	Boeing B737-800	B738	CFM56-7B26	3CM033
20	Boeing B737-900	B739	CFM56-7B26	3CM033
21	Boeing B747-200B	B742	CF6-50E2	1PW029
22	Boeing B747-400	B744	CF6-80C2B1F	1PW058
23	Boeing B757-200	B752	RB211-535E4	4PW073
24	Boeing B767-300ER	B763	PW4060	1PW058
25	Boeing B777-200	B772	PW4090	3PW066
26	Rombac 1-11	BA11	SPEY Mk511	1RR016
27	Avro RJ 85	BA46	ALF 502L-2	1TL001
28	Lockheed Martin L100/C130	C130	TP4	TP4
29	Cessna Citation III	C550	PW530A	BJ1
30	Douglas DC 9-34	DC9	JT8D-11	1PW010
31	Douglas DC 10	DC10	CF6-50C2	1PW050
32	Embraer EMB-145	E145	ALF502L2	1TL001
33	Fokker F100	F100	TAY620-15	1RR021
34	Dassault Falcon 2000	F2TH	CFE738	1AS002
35	Fokker F50	F50	PW127	TP3
36	Fokker F70	F70	Tay 611-8	1RR019
37	Dassault Falcon 900 C	F900	TFE731	1AS002
38	Gulfstream G IV-SP	GLF4	Tay 611-8	1RR019
39	Lockheed L1011 Tri-Star	L101	RB211-524B	1PW024
40	Lockheed L188 Electra	L188	TP1	TP1
41	McDonnell Douglas MD-11	MD11	PW4460	1PW058
42	McDonnell Douglas MD-80	MD80	JT8D-217	1PW010
43	McDonnell Douglas MD-82	MD82	JT8D-217	1PW011
44	McDonnell Douglas MD-90	MD90	CFM56-5C4	2CM015
45	Saab 340B	SF34	GE CT7-9B	TP2
46	Tupolev-154M	TU54	NK-8-2U	NK82U
47	Yakovlev Yak-42M	YK42	D-36	1ZM001

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