The myclimate Flight Emission Calculator

The flight emission calculator quantifies the direct and indirect CO2-equivalent emissions per passenger for a given flight distance. The estimated emissions represent an average value for the distance between a given pair of origin and destination airports. The quantification is based on the most recent international statistics on passenger and cargo loads and aircraft type usage. The estimated emissions per passenger represent the amount of CO2 equivalents to be reduced in myclimate carbon offset projects.

In the following the calculation of flight emissions are detailed step-by-step. The factors used are all based on estimates in literature and recent statistics. Wherever possible emission calculations and assumptions are in line with the European standard DIN EN 16258.

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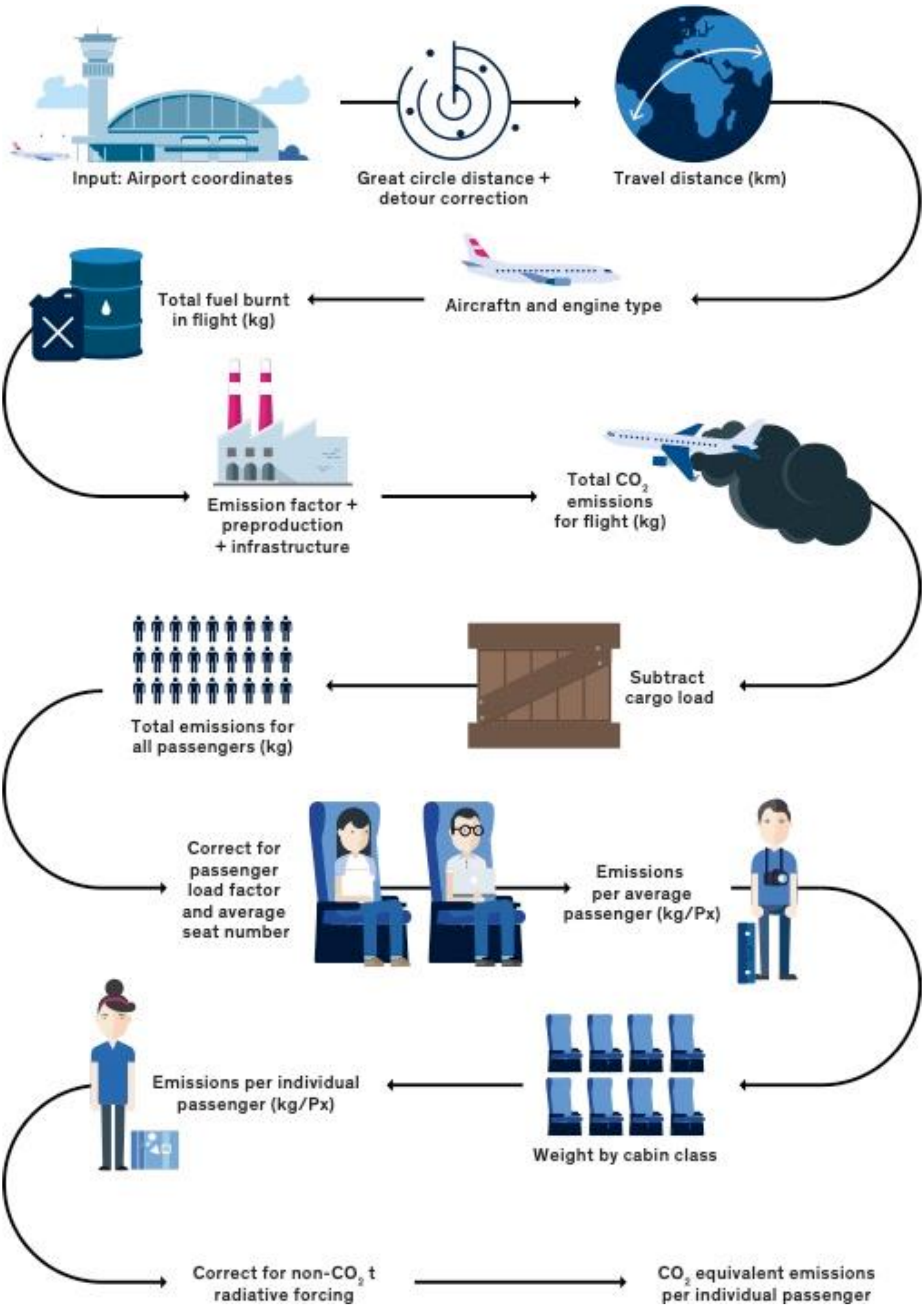
1. Summary of steps

The following diagram illustrates the different steps used in the flight calculator



2. Flight distance

The flight distance between two airports is based on the Great Circle Distance, the shortest distance between two airports. In case of non-direct flights with stopover, the two stages are treated as individual flights. Since the type of aircrafts and the passenger load factors depend on the flight distance, we differentiate between short-haul (<1500 km) and long-haul flights (>2500km). Since there is no distinct limit for short-haul we interpolate for flight distances in between 1500 and 2500km to get a smooth transition.

The actual flight distance between two airports is often considerably longer than the shortest distance between two airports. The extra mileage is mainly due to inefficiencies in the air traffic control systems, due to storm systems or other weather events as well as holding patterns (waiting loops) before landing (Kettunen 2005). While there are no reliable global statistics on the extra mileage, regional estimates amount to 6-8% over the US and 10% over Europe (Kettunen 2005). However, with such a relative approach the extra mileage on long haul flights tends to be overestimated. Therefore, the approach suggested by the European standard DIN EN 16258 (2012) is adopted and an extra mileage/distance correction (DC) of 95km for all flights is added.

3. Fuel consumption per aircraft kilometre

The fuel consumption per distance is based on fuel burn rates from aircrafts used on short-haul (<1500 km) and long-haul (>2500 km) flights. Emissions of fuel burnt per aircraft kilometre are based on the EMEP/EEA air pollutant emission inventory guidebook (EEA 2016). In addition, a constant fuel amount is added to each flight in order to account for the usage of the aircraft during landing and take-off (LTO) as well as during the taxi phase (ground movement on airport) (EEA 2016).

Consumption for the aircraft is based on a weighted average of fuel burn rates and usage for landing/take-off cycles for most used aircraft types. The weighting of the aircraft types is derived from total kilometers flown per aircraft type (ICAODATA 2019) and is based on data of the largest airlines. The weighting scheme includes the most frequently used short-haul (e.g. Airbus A310, Airbus A320) and long-haul aircrafts (e.g. Boeing 747, Boeing 777, Airbus A330 and Airbus A340).

Based on this scheme, weighted average fuel consumption is calculated for distinct flight distances. A generalized function for the fuel consumption of any flight distance is approximated with a second-order polynomial fit for short-haul and long-haul flights.

$$\boldsymbol{f}(\boldsymbol{x}) + \boldsymbol{LTO} = \boldsymbol{a}\boldsymbol{x}^2 + \boldsymbol{b}\boldsymbol{x} + \boldsymbol{c}$$

with $x = GCD + DC$, where GCD is the Great Circle Distance [km], DC the Distance Correction [km] for extra mileage and LTO the extra fuel used per landing and take-off cycle. The fuel consumption for distances between 1500 and 2500km is linearly interpolated.

4. CO_2 emissions and fuel pre-production

The calculator accounts for the CO_2 emissions through pre-production of jet fuel/kerosene (including transport and refinery processes) and fuel combustion. The emission factor for combustion of jet fuel (kerosene) is 3.15 kg CO_2e/kg jet fuel (IPCC 2013) and the factor for pre-production used here is 0.538 kg CO_2e/kg jet fuel (ecoinvent 2018).

5. Allocation to cargo load

Passenger aircrafts often transport considerable amounts of freight and mail, in particular in wide-body aircrafts on long-haul flights. Thus, it is necessary to allocate some of the total aircraft emissions to the cargo load.

To stay in line with the European standard DIN EN 16258 (2012), cargo of air transport is now[1] allocated according to its weight (mass approach). Due to its higher payload (LH 2014) on international flights, emissions from air cargo are considerably higher.

6. CO_2 emissions per passenger

The CO_2 emissions per aircraft are distributed across the average number of passengers on short-haul and long-haul flights. The number of passengers is here defined as the number of seats per aircraft type (ICAODATA 2019) multiplied by the passenger load factor published by the International Air Transport Association (ICAO 2018). The numbers are calculated for each aircraft type and then weighted according to the weighting scheme described above.

7. Cabin class weighting scheme

The passenger capacity of aircrafts is often limited because seats in first and business class take up more space. In other words, the same aircraft could transport more persons if the seating space was minimized. Thus, the emissions calculator allows for a selection of the cabin class. The emissions are allocated to the different cabin classes according to the average seat area in the selected cabin class (seatguru 2012). The cabin class weighting factor is calculated for each aircraft type and then weighted by the weighting scheme described above.

8. Accounting for non-CO_2 effects of aviation

Aircrafts do not only emit CO_2 but also other forcing agents that affect the Earth's radiative balance and thus the climate. Amongst other factors, emissions from aviation also lead to short-term increases in tropospheric ozone as a consequence of nitrogen oxide (NO_x) emissions, initiate condensation trails (contrails) and may affect the formation of cirrus clouds. The total

[1] Before, myclimate used a monetary approach, i.e. emissions were allocated according to the operational revenue of the leading airlines from passenger and freight/mail business.

radiative effects have thus been estimated to be two to four times larger than the direct CO_2 radiative forcing. However, research is ongoing in order to constrain the uncertainties. Furthermore, a comparison of CO_2 and non-CO_2 effects is particularly challenging as they act on different time scales. Still, ignoring these effects would not be a far-sighted scientific approach. Latest studies (Jungbluth & Meili 2018)[2], based on the correct interpretation of the most recent scientific publications, recommend an RFI factor of 2 on total aircraft CO2 emissions. This substantiates the myclimate calculations, as myclimate already decided to multiply the estimated CO_2 emissions by a factor of 2 (referred to as multiplier) to account for the warming effect due to non-CO_2 aircraft emissions (Jungbluth & Meili 2018, Kollmuss & Crimmins 2009).

9. Aircraft and infrastructure emissions

Aircrafts are firstly produced, then maintained and at the end of their life disposed. The emissions related to these activities are included in form of a factor, which allocates the emissions to the total number of flown kilometres. Furthermore, flying requires a certain infrastructure; these emissions from airport operations are also included (Messmer & Frischknecht, 2016).

10. Formula

The following formula is used to calculate the total CO_2-equivalent emissions:

$$\boldsymbol{E} = \frac{\boldsymbol{ax^2 + bx + c}}{\boldsymbol{S * PLF}} * (\boldsymbol{1 - CF}) * \boldsymbol{CW} * (\boldsymbol{EF * M + P}) + \mathbf{AF * x + A}$$

with

E: CO2-eq emissions per passenger [kg]
x: Flight Distance [km] which is defined as the sum of GCD, the great circle distance, and DC, a distance correction for detours and holding patterns, and inefficiencies in the air traffic control systems [km]
S: Average number of seats (total across all cabin classes)
PLF: Passenger load factor
CF: Cargo factor
CW: Cabin class weighting factor
EF: CO2 emission factor for jet fuel combustion (kerosene)
M: Multiplier accounting for potential non-CO2 effects
P: CO2e emission factor for preproduction jet fuel, kerosene
AF: Aircraft factor
A: Airport infrastructure emissions

The part $\mathrm{ax^2 + bx + c}$ is a nonlinear approximation of $\mathrm{f(x) + LTO}$
LTO: Fuel consumption during landing and takeoff cycle including taxi [kg]
Short-haul is defined as x<1500km and long-haul as x>2500km. In between, a linear interpolation is used.

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[2] Further information and comparisons: http://www.esu-services.ch/fileadmin/download/jungbluth-2018-IntJLCA-GWP-aviation-recommendations.pdf

The following parameters are used for the calculation:

Aircraft type	Generic short-haul	Generic long-haul
Average seat number (S)	153.51	280.21
Passenger load factor (PLF)	0.82	0.82
Detour constant (DC)	95	95
1 - Cargo factor (1 - CF)	0.93	0.74
Economy class (CW)	0.96	0.80
Business class weight (CW)	1.26	1.54
First class weight (CW)	2.40	2.40
Emission factor (EF)	3.15	3.15
Preproduction (P)	0.54	0.54
Multiplier (M)	2	2
Aircraftfactor (AF)	0.00038	0.00038
Airport/Infrastructure (A)	11.68	11.68
a	±0.0000	0.0001
b	2.714	7.104
c	1166.52	5044.93

11. References

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