Flight emissions calculation methodology: Detailed

Flight emissions are very complex to calculate and various methodologies are available. South Pole does its best to reach a realistic estimate based on the most reliable data sources available, in this case supplied by the UK Government.

1. Passenger flights

South Pole's calculation procedure for GHG emissions from flights is based on the Greenhouse Gas Protocol (GHG Protocol)[1], the most widely used international accounting tool for government and business leaders to understand, quantify and manage greenhouse gas emissions. The GHG Protocol was developed by the World Resources Institute and the World Business Council for Sustainable Development.

South Pole also follows the UK Department for Business, Energy & Industrial Strategy (UK BEIS) methodology (previously published by DEFRA and DECC) for determining flight emission factors and uses UK BEIS data to calculate flight emissions. The UK BEIS guidelines on the calculation of GHG emissions from flights are one of the de-facto standards of our industry, since they are one of the few reliable and up to date sources for data on flight emissions. The latest UK BEIS emission factors for flights can be found in the UK Government web page.

UK BEIS divides flight emissions into three different distance brackets: domestic, short-haul and long-haul. UK BEIS current preferred definition is that domestic flights are those that start and end in the United Kingdom (assumed to be below 463 km[2]), and considers all fights to "Europe" (or those of similar distance, up to a 3,700km maximum) as short-haul, and those to non-European destinations (or for flights over 3,700km) as long-haul. Nonetheless, it leaves it up to the user to use their best judgement in deciding on the appropriate category for each flight.

South Pole follows the guidance from UK BEIS, although it has re-named the distance brackets to make them applicable to other countries outside the UK and Europe, as shown in Table 1:

Table 1. Flight classification based on distance

South Pole classification	UK BEIS classification	Distance (km)
Short-haul	Domestic	<463 km
Medium-haul	Short-haul	463 – 3,700 km
Long-haul	Long-haul	>3,700 km

[1] WRI and WBCSD, GHG Protocol, available at: http://www.ghgprotocol.org
[2] The 463 km value is the maximum distance within the sample of "domestic flights" presented in the 2018 UK BEIS methodology paper for emission factors (table 29). Available in: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2018

Using the relevant emission factor for short-haul, medium-haul or long-haul travel, South Pole then calculates emissions for a given distance (in passenger-km or pkm). The UK BEIS emission factors, which South Pole uses, include an 8% uplift factor to scale up Great Circle Distances (GCD) between airports to account for indirect flight paths, delays and circling (see Section 4: Great Circle Fight Distances).

To the emission factors based on distance, multipliers for different seating classes are also applied. Premium priced seating, as in First and Business class, takes up considerably more room in the aircraft than economy seating and therefore reduces the total number of passengers that can be carried[3]. This increases the average CO_2 emissions per passenger-km. South Pole follows UK BEIS guidance and applies the following seating class multipliers (for more details see Section 5: Seating Class Factors):

- For **short-haul** flights, only Economy class is considered.
- For **medium-haul** flights, First and Business class are considered equal to 1.5 economy seats.
- For **long-haul** flights, the Premium Economy or Economy+ class is considered equal to 1.6 economy seats, the Business class is equal to 2.9 and First class is equal to 4 economy seats.

Finally, South Pole's methodology also takes into account indirect emissions such as Well-to-tank (WTT) emissions from the aviation fuel lifecycle (i.e. production and distribution), and a Radiative Forcing Index (RFI) multiplier of 1.9 to account for non-CO_2 climate change effects from air travel. This includes contrails, water vapour, NO_x emissions, etc. UK BEIS recommends a multiplier of 1.9 as a central estimate, based on research from the European Assessment of Transport Impacts on Climate Change and Ozone Depletion (ATTICA, http://ssa-attica.eu)[4] and analysis by Lee et al (2009) reported on by the Committee on Climate Change (2009)[5]. For more details see Section 5: Non-CO2 Impacts and Radiative Forcing (RF).

As new GHG emissions research becomes available (incl. conversion factors from UK BEIS), South Pole updates its emission factors yearly to incorporate the best available data for the calculation of flight emissions and to account for improvements from the aviation industry in recent years.

2. Taking Account of Air Freight (from UK BEIS, 2018)[6]

Freight, including mail, is transported by two types of aircraft – dedicated cargo aircraft which carry freight only, and passenger aircraft which carry both passengers and their luggage, as well as freight. Data from the UK Civil Aviation Authority (CAA) shows that almost all freight carried by passenger aircraft is done on scheduled long-haul flights. In fact, the quantity of freight carried on scheduled long-haul passenger flights is nearly eight times higher than the quantity of freight carried on scheduled long-haul cargo services. The apparent importance of freight movements by passenger services creates a complicating factor in calculating emission factors.

[3] UK BEIS, 2018. 2018 Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors, available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2018
[4] R. Sausen et al. (2005). Aviation radiative forcing in 2000: An update on IPCC (1999) Meteorologische Zeitschrift 14: 555-561, available at: http://elib.dlr.de/19906/1/s13.pdf
[5] CCC (2009). Meeting the UK Aviation target – options for reducing emissions to 2050, available at: http://www.theccc.org.uk/publication/meeting-the-uk-aviation-target-options-for-reducing-emissions-to-2050
[6] UK BEIS, 2018. 2018 Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors, available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2018

Back in 2007, emission factors for passenger services were calculated assuming all the CO_2 is allocated to the passengers. However, given the significance of air freight transport on passenger services there were good arguments for developing a method to divide the CO_2 between passengers and freight. This was developed for the 2008 emission factors update and has continued to be used since.

The CAA data provides a split of tonne-kilometre (tkm) for freight and passengers (plus luggage) by airline for both passenger and cargo services. This data may be used as a basis for an allocation methodology. There are essentially three options, with the resulting emission factors presented in Table 2:

a. **No Freight Weighting**: Assume all the CO_2 is allocated to passengers on these services.
b. **Freight Weighting Option 1**: Use the CAA tkm data directly to apportion the CO_2 between passengers and freight. However, in this case the derived emission factors for freight are significantly higher than those derived for dedicated cargo services using similar aircraft.
c. **Freight Weighting Option 2**: Use the CAA tkm data modified to treat freight on a more equivalent /consistent basis to dedicated cargo services. This takes into account the additional weight of equipment specific to passenger services (e.g. seats, galleys, etc.) in the calculations.

Table 2: CO_2 emission factors for alternative freight allocation options for passenger flights based on 2018 GHG Conversion Factors

Freight weighting:	None		Option 1: Direct		Option 2: Equivalent	
Mode	passenger-tkm % of total	gCO_2 /pkm	passenger-tkm % of total	gCO_2 /pkm	passenger-tkm % of total	gCO_2/ pkm
Short-haul	100.00%	144.9	99.77%	144.6	99.77%	144.6
Medium-haul	100.00%	80.2	98.70%	78.7	98.70%	78.7
Long-haul	100.00%	122.1	65.71%	79.5	85.13%	103.1

Source: Reprinted [adapted] from UK BEIS, 2018, Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors

The basis of freight weighting Option 2 is to take into account the supplementary equipment (such as seating, galley) and other weight for passenger aircraft compared to dedicated cargo aircraft in the allocation. In comparing the freight capacities of the cargo configuration compared to passenger configurations, we may assume that the difference represents the tonne capacity for passenger transport. This will include the weight of passengers and their luggage (around 100 kg per passenger according to IATA), plus the additional weight of seating, the galley, and other airframe adjustments necessary for passenger service operations. The derived weight per passenger seat used in the calculations for the GHG Conversion Factors were calculated for the specific aircraft used and are on average over twice the weight per passenger and their luggage alone. In the Option 2 methodology the derived ratios for different aircraft types were used to scale up the CAA passenger tkm data, increasing this as a percentage of the total tkm – as shown in Table 2.

There does not appear to be a distinction made (other than in purely practical size/bulk terms) in the provision of air freight transport services between something transported by dedicated cargo service or on a passenger service. The related calculation of freight emission factors (discussed in a later section) leads to very similar emission factors for both passenger service freight and dedicated cargo services for domestic and short-haul flights. This is also the case for long-haul flights under freight weighting Option 2, whereas under Option 1 the passenger service factors are substantially higher than those calculated for dedicated cargo services. It therefore seems preferable to treat freight on an equivalent basis by utilising freight weighting Option 2. Option 2 was selected as the preferred methodology to allocate emissions between passengers and freight for the 2008 and subsequent GHG Conversion Factors.

The final average emission factors for aviation from UK BEIS are presented in Table 3. The figures in Table 3 use the freight weighting Option 2 methodology and do not include the 8% uplift for GCD, nor the uplift to account for additional impacts of radiative forcing which are applied to the emission factors provided in the UK Government GHG reporting Conversion Factors document.

Table 3. Final average CO2 emission factors for passenger flights for 2018 GHG Conversion Factors (excluding GCD and RF uplifts)

Mode	Factors for 2018	
	Load factor	gCO_2/pkm
Short-haul	73.7%	144.6
Medium-haul	79.9%	78.7
Long-haul	74.0%	103.1

Source: Reprinted [adapted] from UK BEIS, 2018, Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors

3. Taking Account of Seating Class Factors (from UK BEIS, 2018)[7]

The efficiency of aviation per passenger-kilometre is influenced not only by the technical performance of the aircraft fleet, but also by the occupancy/load factor of the flight. Different airlines provide different seating configurations, which change the total number of seats available on similar aircraft. Premium priced seating, such as in First and Business class, takes up considerably more room in the aircraft than economy seating and therefore reduces the total number of passengers that can be carried. This in turn raises the average CO_2 emissions per passenger-kilometre.

There is no agreed data/methodology for establishing suitable scaling factors representative of average flights. However, in 2008 a review was carried out of the seating configurations from a selection of 16 major airlines and average seating configuration information from Boeing and Airbus websites. This evaluation was used to form a basis for the seating class based emission factors provided in Table 4, together with additional information obtained either directly from airline websites or from other specialist websites that had already collated such information for most of the major airlines.

[7] UK BEIS, 2018. 2018 Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors, available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2018

For long-haul flights, the relative space taken up by premium seats can vary by a significant degree between airlines and aircraft types. The variation is at its most extreme for First class seats, which can account for three to over six times the space taken up by basic economy seating (for the First class sleeper seats/beds frequently used in long-haul flights). Table 4 shows the seating class-based emission factors, together with the assumptions made by UK BEIS in their calculation. An indication is also provided of the typical proportion of the total seats that the different classes represent in short- and long-haul flights. The effect of the scaling is to lower the economy seating emission factor in relation to the average, and increase the Business and First class factors.

The relative share in the number of seats by class for short-haul and long-haul flights was updated/revised in 2015 using data provided by the UK Department for Transport (DfT) aviation team, following checks conducted by them on the validity of the current assumptions based on more recent data.

Table 4: Seating class-based CO2 emission factors for passenger flights for 2018 GHG Conversion Factors (excluding GCD and RF uplifts)

Flight type	Cabin Seating Class	Load Factor %	gCO_2 /pkm	Number of economy seats	% of average gCO_2/ pkm	% Total seats
Short-haul	Weighted average	73.7%	144.6	1.00	100.0%	100.0%
Medium-haul	Weighted average	79.9%	78.7	1.02	100.0%	100.0%
	Economy class	79.9%	77.4	1.00	98.4%	96.7%
	First/Business class	79.9%	116.2	1.50	147.5%	3.3%
Long-haul	Weighted average	74.0%	103.1	1.31	100.0%	100.0%
	Economy class	74.0%	78.9	1.00	76.6%	83.0%
	Economy+ class	74.0%	126.3	1.60	122.5%	3.0%
	Business class	74.0%	228.9	2.90	222.1%	11.9%
	First class	74.0%	315.7	4.00	306.3%	2.0%

Source: Reprinted [adapted] from UK BEIS, 2018, Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors

Notes: Load factors based on data provided by DfT that contains detailed analysis of UK Civil Aviation Authority (CAA) statistics for the year 2016.

4. Great Circle Flight Distances (adapted from UK BEIS, 2018)[8]

UK BEIS would like to see standardisation in the way that emissions from flights are calculated in terms of the distance travelled and any uplift factors applied to account for circling and delay. However, UK BEIS acknowledges that a number of methods are currently used.

A 9% uplift factor has previously been used in the UK GHG Inventory to scale up GCD for flights between airports to take into account indirect flight paths and delays, etc. This factor (also provided previously with previous GHG Conversion Factors) comes from the IPCC Aviation and the global Atmosphere 8.2.2.3, which states that 9-10% should be added to take into account non-direct routes (i.e. not along the straight line great circle distances between destinations) and delays/circling. The DfT has indicated (in discussions with their Aviation team) that recent analysis suggested that for the UK a lower uplift of 8% is more appropriate and this is the factor that has been used since the 2014 update, and therefore also in the 2018 GHG Conversion Factors.

It is not practical to provide a database of origin and destination airports to calculate flight distances in the GHG Conversion Factors. However, the principal of adding a factor of 8% to distances calculated on a Great Circle is recommended (for consistency with the existing approach) to take into account indirect flight paths and delays/congestion/circling. This is the methodology recommended to be used with the GHG Conversion Factors and is applied already to the emission factors presented in the GHG Conversion Factors tables from UK BEIS.

5. Non-CO_2 Impacts and Radiative Forcing (RF) (adapted from UK BEIS, 2018)[9]

The emission factors provided by the UK BEIS in the latest GHG Conversion Factors, sections “Business travel – air” and “Freighting goods”, refer to aviation's direct CO_2, CH_4 and N_2O emissions only. There is currently uncertainty over the other non-CO_2 climate change effects of aviation (including water vapour, contrails, NO_X, etc.) which have been indicatively accounted for by applying a multiplier in some cases.

The application of a ‘multiplier’ to take account of non-CO_2 effects is a possible way of illustratively taking account of the full climate impact of aviation. A multiplier is not a straightforward instrument. In particular, it implies that other emissions and effects are directly linked to production of CO_2, which is not the case. Nor does it reflect accurately the different relative contribution of emissions to climate change over time, or reflect the potential trade-offs between the warming and cooling effects of different emissions.

On the other hand, consideration of the non-CO_2 climate change effects of aviation can be important in some cases, and there is currently no better way of taking these effects into account. A multiplier of 1.9 is recommended by UK BEIS. Such recommendation is based in the

[8] UK BEIS, 2018. 2018 Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors, available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2018
[9] UK BEIS, 2018. 2018 Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors, available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2018

ATTICA research presented in Table 5 below[10] and in analysis by Lee et al (2009) reported on by the Committee on Climate Change (2009)[11].

Note that the value of this 1.9 multiplier is subject to significant uncertainty and should only be applied to the CO_2 component of direct emissions (i.e. not also to the CH_4 and N_2O emissions components).

Table 5: Findings of the ATTICA project

		RF [mW/m^2]							
Year	Study	CO_2	O_3	CH_4	H_2O	Direct Sulphate	Direct Soot	Contrails	Total (w/o) Cirrus
1992	IPCC (1999)	18.0	23.0	−14.0	1.5	−3.0	3.0	20.0	48.5
2000	IPCC (1999) scaled to 2000	25.0	28.9	−18.5	2.0	−4.0	4.0	33.9	71.3
2000	TRADEOFF	25.3	21.9	−10.4	2.0	−3.5	2.5	10.0	47.8

Source: Reprinted from R. Sausen et al. (2005). Aviation radiative forcing in 2000: An update on IPCC (1999) Meteorologische Zeitschrift 14: 555-561.

Note: Estimates for scaling CO_2 emissions to account for Radiative Forcing impacts are not quoted directly in the table, but are derived as follows: IPCC (1999) = 48.5/18.0 = 2.69 ≈ 2.7; TRADEOFF = 47.8/25.3 = 1.89 ≈ 1.9.

It is worth mentioning that some entities do not consider a RF multiplier when calculating emissions due to a lack of consensus. For example, such is the case of the International Civil Aviation Organization (ICAO)[12] and the International Air Transport Association (IATA)[13].

Nevertheless, South Pole considers the inclusion of a RF multiplier important as it is clear that aviation imposes other effects on the climate which are greater than that implied from simply considering its CO_2 emissions alone. Common RF multiplier values range com 1 to 2.7[14]. In this scenario, a 1.9 value is a conservative way to account for such effects based on the most recent evidence. Since this is an open area of research, South Pole is committed to update its emission factors yearly with the latest developments in the aviation industry.

6. Indirect/WTT Emission Factors from Air Transport (adapted from UK BEIS, 2018)[15]

Indirect/WTT emissions factors for air passenger and air freight services include only emissions resulting from the fuel lifecycle (i.e. production and distribution of the relevant transport fuel).

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[10] R. Sausen et al. (2005). Aviation radiative forcing in 2000: An update on IPCC (1999) Meteorologische Zeitschrift 14: 555-561, available at: http://elib.dlr.de/19906/1/s13.pdf

[11] CCC, 2009. Meeting the UK Aviation target – options for reducing emissions to 2050, available at: http://www.theccc.org.uk/publication/meeting-the-uk-aviation-target-options-for-reducing-emissions-to-2050

[12] ICAO, 2019. Carbon Emissions Calculator FAQ available at: https://www.icao.int/environmental-protection/CarbonOffset/Pages/FAQCarbonCalculator.aspx

[13] IATA, 2016. IATA Carbon Offset Program Frequently Asked Questions, available at: https://www.iata.org/whatwedo/environment/PublishingImages/ICOP%20FAQ%20general%20for%20airline%20participants%20jan%202016.pdf

[14] N. Jungbluth and C. Meili (2018). Recommendations for calculation of the global warming potential of aviation including the radiative forcing index. International Journal of LCA.

[15] UK BEIS, 2018. 2018 Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors, available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2018

These indirect/WTT emission factors are derived using simple ratios of the direct CO_2 emission factors and the indirect/WTT emission factors for aviation turbine fuel (kerosene) and the corresponding direct CO_2 emission factors for air passenger and air freight transport in sections "Business travel – air" and "Freighting goods" of the latest GHG reporting Conversion Factors document, published by UK BEIS.