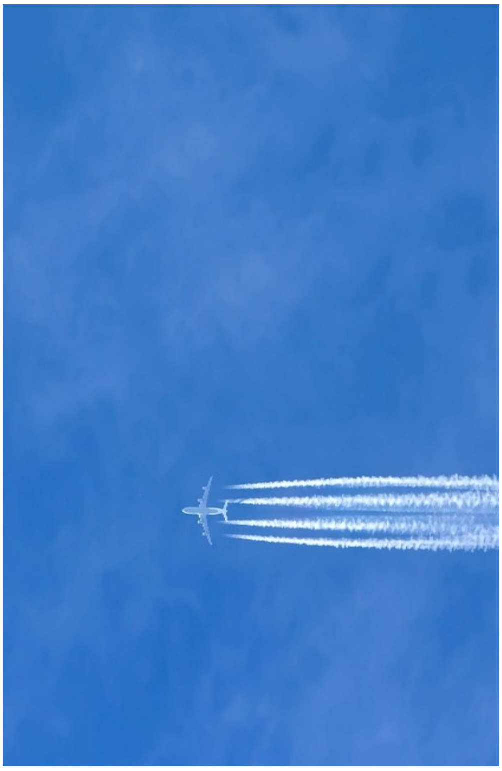
# Harmonized GHG Emission Factors for Air Travel in Germany



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## Summary

Air travel is a significant and growing contributor to global greenhouse gas (GHG) emissions. Although it accounts for around 2-3% of global $CO_2$ emissions, the sector's overall climate impact is substantially higher when non-$CO_2$ effects — such as nitrogen oxides ($NO_x$), water vapor, and contrail-induced cloud formation — are included (Dahlmann et al. 2023). These high-altitude emissions increase radiative forcing and make aviation one of the most climate-intensive modes of transport per passenger kilometre. As climate accountability grows in importance, accurate emission factors become essential for informed decision-making, transparency, and effective climate action.

Emission intensity factors are widely used in climate reporting, including within frameworks such as the Greenhouse Gas Protocol and European Corporate Sustainability Reporting Directive (CSRD), and play a key role in both institutional GHG inventories and personal carbon footprint calculators. But harmonized emission intensity factors are not available for all geographies. Often applied emission intensity factors lack transparency. The aim of this paper is to illustrate how flight emission intensity factors are derived, what influences their variability, and why accurate estimates matter. The data source and calculation method are derived from the Transport Emission Model for Aviation (TREMOD-AV) developed by ifeu for the Federal Environment Agency (Umweltbundesamt). TREMOD-AV allows a wide range of settings to adapt to specific calculation requirements. This paper will present generally applicable emission factors for air travel which can be used by public or private institutions to calculate their GHG emissions from air travel.

## Comparative emission intensity factors per passenger kilometre by distance class and seat category (2024)

| | Very short-haul (<500 km) | Short-haul (500 to <1,500 km) | Medium-haul (1,500 to <4,000 km) | Long-haul (≥4,000 km) |
|---|---|---|---|---|
| **Average** | 284 g/pkm | 195 g/pkm | 156 g/pkm | 207 g/pkm |
| **Economy class** | 284 g/pkm | 195 g/pkm | 141 g/pkm | 186 g/pkm |
| **Business class** | 369 g/pkm | 254 g/pkm | 281 g/pkm | 372 g/pkm |
| **First class** | 369 g/pkm | 254 g/pkm | 406 g/pkm | 538 g/pkm |

*Note: Unit: grams of $CO_2$ equivalents per passenger kilometre (g $CO_2$e/pkm). Data from TREMOD-AV_2025_1. System boundaries see chapter 4. These factors are based on German aviation data and are most applicable to flights departing from or arriving in Germany.*

The displayed data is meant for using general GHG emission intensities in carbon reporting by companies or public institutions. The most recent table with general GHG emission intensities will be updated annually in the TREMOD report for the German Environmental Agency available on the publication platform openUMWELT[1].

[1] https://openumwelt.de/home

## Reporting frameworks and standards

Aviation plays a special role for the path to reduce GHG emissions. Flights have increased substantially over the last decades (IEA 2022; Loveday et al. 2022). COVID-19 has briefly interrupted this massive growth of overall flights and even led to a temporary decline in annual emissions, but the number of flights are on the way back to pre-COVID-19 conditions and even surpassing in some countries (Eurostat 2024). The national and international climate action targets address the reduction of emissions from aviation but often do not specify how emissions from this mode of transport are to be calculated. This raises the issue of transparency and comparability.

The “Greenhouse Gas Protocol Corporate Standard”, developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), is the most widely used international standard for the corporate accounting and reporting of GHG emissions (GHG Protocol Initiative 2004). It provides a guidance for the preparation and reporting of a systematic GHG-inventory. However, it does not specify the exact metric on how to calculate the climate impact from aviation (e.g. metric of non-$CO_2$ effects). The same accounts for the recently adopted delegated act of the European Sustainability Reporting Standard (ESRS) since it refers to the method of the GHG protocol. The ESRS is supposed to provide the framework and methodology for reporting set out in the Corporate Sustainability Reporting Directive (CSRD).

A more specific calculation method for GHG emissions from aviation is described in ISO 14083:2023 (Greenhouse gases — Quantification and reporting of greenhouse gas emissions arising from transport chain operations). It provides a standardized method for calculating GHG emissions from air passenger transport defining a set of parameters to calculate the overall result (e.g. direct and indirect fuel emissions, seat classes, primary vs. secondary data and treatment of offsetting). As the ISO standard focuses primarily on GHG emissions rather than climate impact, it does not directly consider the effects of non-$CO_2$ climate effects. However, it does not explicitly exclude these effects either.

Further selected sources for calculating GHG emissions from flights:

- The calculation **method of the German Aerospace Centre**, developed on behalf of the German Federal Environment Agency for flight emission estimation, offers a simplified calculation of $CO_2$ equivalents for individual flights, in which non-$CO_2$ climate effects due to cirrus clouds, nitrogen oxides and water vapour are taken into account using regression formulas based on global flight data and climate reactions (Thor et al. 2023). This provides a more up-to-date and accurate estimate of these effects than a simple factor (e.g. RFI 3), as has often been used to date to assess climate impact (Dahlmann et al. 2021). The deducted emission calculation tool, provided by the German Federal Environment Agency was developed for five different passenger aircraft size classes and clusters flights based on the proportions of their climate impact components. It does not provide average flight emissions per passenger since different seating categories are not considered (Dahlmann et al. 2024).
- The **ICAO Carbon Emissions Calculator Methodology** is a standardized tool developed by the International Civil Aviation Organization (ICAO) to estimate the $CO_2$ emissions from commercial air passenger travel. It does not include non-$CO_2$ effects (ICAO 2024).
- The **atmosfair calculator** combines real flight-related parameters with verified data and considers all climate-impacting emissions by integrating non-$CO_2$ effects

through quantitative conversion. The methodology is based on the **Verband Deutsches Reisemanagement (VDR) Standard** which defines a harmonized methodology for calculating $CO_2$ emissions from business travel (including flights). The platform is intended to provide a basis for voluntary climate compensation for air travel (atmosfair 2021).

- **EU Emission Trading System (ETS) Directive** requires airlines to report emissions per flight including non-$CO_2$ effects since 2025[1]. The EU Monitoring and Reporting Verification (MRV) provides a tool for airlines to calculate GHG emissions per flight including non-$CO_2$ climate effects.
- The **UK Government GHG Conversion Factors** are a set of standardized emission factors published annually by Department for Energy Security and Net Zero. They are used by organizations to calculate GHG emissions from a wide range of activities, helping ensure consistency and transparency in carbon reporting (Department for Energy Security and Net Zero 2024). The institution uses the European Organisation for the Safety of Air Navigation (Eurocontrol) small emitters tool which is in accordance with the EU ETS reporting requirements. The published emission factors for passenger air transport does not directly include non-$CO_2$ climate effects but recommends a multiplier of 1.7 which is an estimate, based on the available scientific evidence.
- The **Google Travel Impact Model (TIM)** is the methodology of Google Flights' flight-related carbon emissions estimates, developed collaboratively by Google and the Travalyst coalition[2].

As the overview above illustrates, existing frameworks and tools differ considerably in their scope and methodology — particularly regarding the treatment of non-$CO_2$ climate effects, seat classes, and geographical coverage. The methodology underlying this paper is compatible with the general frameworks of GHG Protocol Corporate Standard, ISO 14083:2023, the CSRD/ESRS reporting framework and and is informed by the emission calculation approach of the German Federal Environment Agency.

## Key drivers of flight emissions

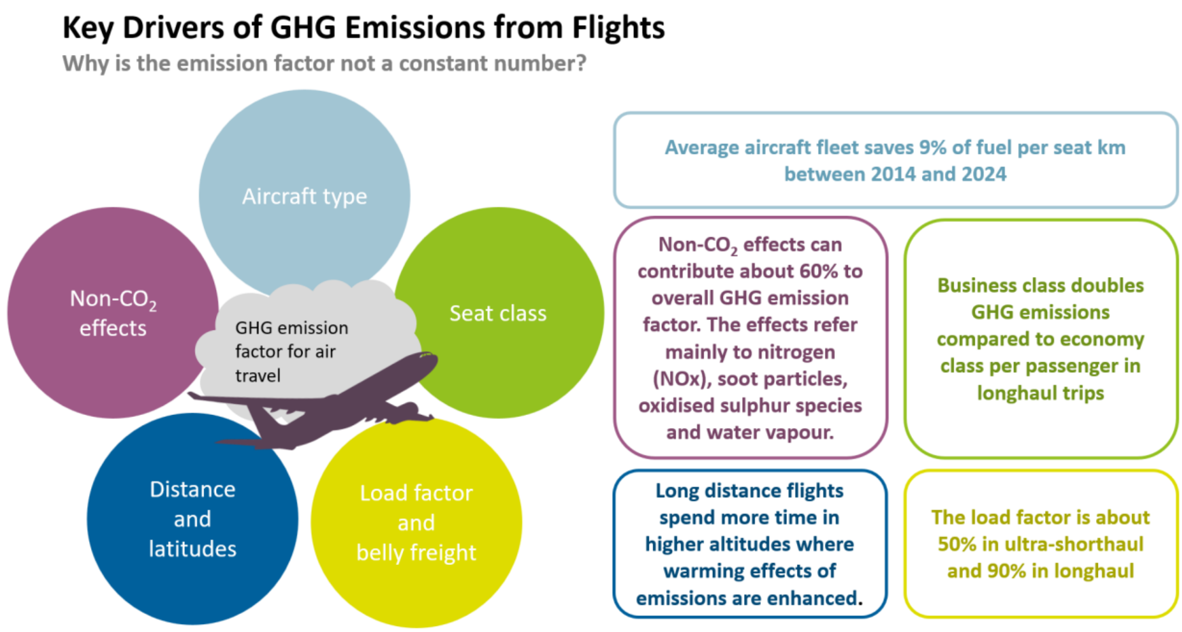
GHG emissions from air travel are influenced by a range of technical, operational, and behavioural factors. Understanding these drivers is essential for accurately estimating emissions and compare results from other sources. These are the main contributing factors:

- **Aircraft type** newer aircraft generally offer better fuel efficiency due to improvements in engine technology, aerodynamics, and materials. For example, a A320neo emits significantly less $CO_2$ per passenger-kilometre than older models like the A320ceo.
- **Seat class** and cabin configuration influence emissions per passenger. Business and first-class seats take up more space and weight, resulting in higher per-passenger emissions. In contrast, economy class offers the lowest emissions per seat. Emissions are also affected by the load factor, or the percentage of seats occupied—higher occupancy reduces per-passenger emissions.

[1] https://climate.ec.europa.eu/news-your-voice/news/new-monitoring-rules-agreed-eu-ets-including-non-co2-emissions-aviation-sector-2024-08-30_en (20.04.2026)
[2] https://github.com/google/travel-impact-model (20.04.2026)

- **Flight distance** and **flight phases** (taxi, take-off, climb, cruise, descent, landing) also play critical roles. Short-haul flights have proportionally higher emissions due to energy-intensive take-off, while long-haul flights benefit from more efficient cruising segments.
- **Non-$CO_2$ climate effects,** including emissions of $NO_x$, soot particles, oxidised sulphur species, and water vapour. These emissions significantly contribute to aviation's climate impact through contrail formation, especially at cruising altitudes.
- **Load factor** is highly dependent on a country's national aircraft fleet and varies over time. Short-haul flights tend to have lower load factors than long-haul flights.
- **Belly freight** can amount for a considerable share of load. The allocation between passengers and freight is necessary.

TREMOD-AV incorporates these variables to provide differentiated, realistic emission factors. Accurately modelling these drivers enables more precise emission estimates. The following figure summarises the influencing variables by their overall impact.




## Recommended methodology for GHG passenger emission factors

If passenger flight emissions must be reported without detailed information on the single flights, such as aircraft type, load factor or departure/destination airport, standard emission intensities must be used. TREMOD-AV provides the basis for these emission intensities. The following methodological specifications are made:

- Use of annual factors: some influencing factors vary annually with considerable impact.
- Geographical boundary of TREMOD-AV is Germany: Emissions may vary depending on the country in question. The emission intensities are suitable for flights departing from Germany but can also be applied to flights landing in Germany.
- Flight type: Non-commercial flights and commercial flights at small airports should not be included in the emission intensities, as these are either not rele-

vant for “standard passenger flights” or the data basis is too inaccurate. Sight-seeing flights are also excluded from the analysis. However, empty flights are included as these are part of the operational business of airlines.

- Aircraft type: Flights with helicopters, zeppelins and aircraft with a maximum take-off weight of less than 2 tonnes are not included in the standard emission intensities.
- Allocation of emissions by mode of transport: Passenger flight emissions with belly freight are partly attributed to freight transport. Allocation is based on weight, if a passenger weighs an average of 100 kg (including luggage).
- Flight efficiency is considered for emission calculation. However, the traffic performance refers to the great circle distance (in accordance with DIN EN 16258).
- Emissions: All relevant greenhouse gases ($CO_2$, $N_2O$, $CH_4$)[1] must be considered. In addition, emissions from fuel supply (Well-to-Tank) are relevant and must be included in the calculation for air travel.
- Non-$CO_2$ climate effects: They contribute significantly to the climate impact of air travel and must also be considered. The climate metric “EGWP100 pulse” is recommended for this purpose.
- Distance classes: Depending on the flight distance, influencing factors vary (aircraft type, proportion of “Landing and Take-off” phase, load factor, etc.). Therefore, flights should be differentiated according to distance classes where possible. The classification proposed here is based on Eurocontrol reporting classes (Eurocontrol 2023): very short-haul (<500 km), short-haul (500-<1500 km), medium-haul (1500-<4000 km) and long-haul (≥4000 km)
- Seat category: The number of seats that can be installed in an aircraft depends on various factors, including the seat category. Since space requirements increase with higher classes, more emissions should be allocated to higher seat classes. The following factors are recommended and should be multiplied by the average emission factor:

| Seat class | Very short-haul & short-haul | Medium-haul & Long-haul |
|---|---|---|
| Economy | 1.0 | 0.9 |
| Business | 1.3 | 1.8 |
| First | 1.3 | 2.6 |

The recommended methodology is in accordance with ISO 14083:2023 as far as possible. Due to data availability restrictions on distinct parameters average values might have been considered. It also complies with methodological frameworks of GHG Protocol and CSRD.

TREMOD-AV allows further detailed settings for the generation of specific emission intensities for individualised applications. Requests can be submitted to michel.allekotte@ifeu.de

[1] Global warming potential of $N_2O$ (GWP: 265) and $CH_4$ (GWP: 28) following IPCC AR5 100 years.

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