

Transportation sector: Domestic and International Aviation Emissions



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1. Introduction

The aviation sector is considered to be part of the top ten global emitting sectors and emissions are expected to climb due to increased demand for aviation fuel (Perlman, 2018; IEA, 2019). Unfortunately, aviation, along with other transportation sectors, was exempted from the Paris treaty and not considered on track to decrease emissions (Twidale and Saul, 2015; Edie, 2020, Climate Action Tracker, 2020). As a result, current efforts to reduce aviation emissions have proven woefully inadequate (Perlman, 2018).

To improve the monitoring and measuring of global aviation greenhouse gas (GHG) emissions, as well as serving as an input for the environmental management of the sector, Climate TRACE employs the International Civil Aviation Organization's (ICAO) methodology to estimate both domestic and international aviation emissions.

The ICAO methodology uses a Tier 3a approach defined by the Intergovernmental Panel on Climate Change (IPCC). The Tier 3a method, which is more detailed, considers information about aircraft movement, such as origin and destination aerodromes (locations where aircraft operations occur) and aircraft model. This method was applied to estimate fuel consumption and emissions of atmospheric pollutants and GHG, allowing for their discrimination based on type of movement, domestic or international.

2. Materials and Methods

Climate TRACE used ICAO Carbon Emissions Calculator Methodology, Version 11 along with Official Airline Guides (OAG) Historical Flight Status Data for all domestic and international passenger, commercial, private flights and general aviation starting from January 1, 2015, to June 30, 2024. The emissions estimates, based on fuel consumption, include direct GHG emissions: carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O).

This sector does not include the following:

- Primary pollutants emissions (carbon monoxide, volatile organic compounds, nitrogen oxide, sulfur dioxide and particulate matter);
- Ethanol-powered aircraft; and

- The calculations are made for each flight between a origin and destination pair for all national aerodromes, except those referring to helicopters, military aircraft and agricultural aircrafts.

2.1 Datasets employed

The Official Airline Guides (OAG) air traffic movement database provides the main source of information for the ICAO method. Additional information was used, such as fuel consumption rates for specific aircraft types and flight distance provided by ICAO, and geographic coordinates of aerodromes from OurAirports.com (<https://ourairports.com/>) and airport data from the Aviation Stack API (<https://aviationstack.com/>).

2.1.1 Activity data: aircraft movement

Historical flight records were obtained from OAG (<https://www.oag.com/>). The data (covering historical flight departures and arrivals) was available on an annual and monthly time scale. Data from 2015 - 2022 was available at an annual scale while data from Jan 2023 - June 2024 was available at a monthly granularity. Thus, OAG data allows for the creation of a database containing flights from 2015 to June 2024. The following attributes were available:

- The annual/monthly frequency of a particular flight between a pair of origin and destination airports (2015-June 2024);
- ICAO aircraft code;
- ICAO code of origin and destination airports;
- Airline/flight operator; and
- Flight origin and destination which can be used to classify into domestic or international trips

2.2 Model

Figure 1 provides an overview of the model applied by Climate TRACE along with the main data sources to calculate GHG emissions by domestic and international aviation.

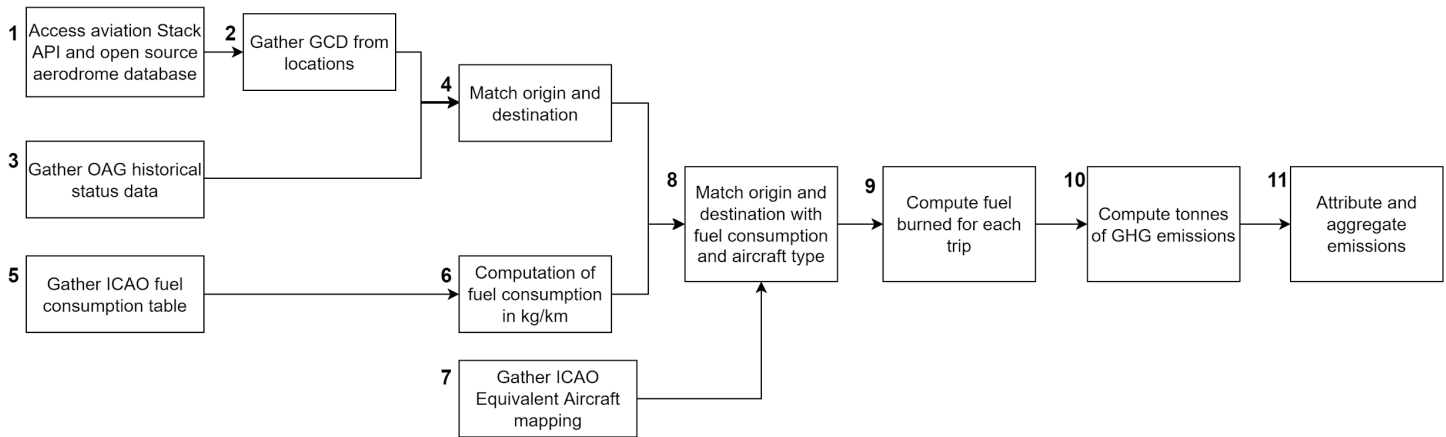


Figure 1 Flow of inputs and outputs to generate aviation emissions. Steps are described in section 2.3.

2.3 Methods

The following was performed to estimate aviation emissions.

The 1) aviation stack API and open source aerodrome database and 2) OAG historical status data were used to calculate 3) the Great Circle Distance (GCD) between every 4) origin and destination pair using airport location data (latitude and longitude) from these sources. A correction factor was applied to the GCD to account for distance flown in excess of the GCD due to stacking, traffic and weather-driven factors. The specific aircraft type used for every route was mapped to an equivalent aircraft type using ICAO’s Equivalent Aircraft Mapping (see Appendix B: ICAO Carbon Emissions Calculator Methodology).

Next, 5) ICAO fuel consumption table (Appendix C: ICAO Carbon Emissions Calculator Methodology) was used to 6) estimate fuel consumption by aircraft type (kg/km). Step 6 was combined with 7) ICAO Equivalent Aircraft mapping to 8) match the origin and destination to the aircraft, the aircraft type and to estimate 9) the fuel consumption. Then the fuel consumption was used in 10) to compute fuel burned for each trip based on the aircraft travel origin and destination, and the aircraft type. Lastly, the fuel burned for each trip was converted to the equivalent GHG emissions using an aviation fuel emissions factor from ICAO Carbon Calculator methodology.

As a last step, 11) the resulting GHG emissions were either attributed fully to a country, if the route was domestic, or divided in half between countries in case of an international route. For airport emissions attribution, the GHG was divided in half between airports and the trip was classified into domestic or international category. The emissions for each country and airport were then aggregated by year to give the total aviation emissions by country and airport for 2015-2024.

2.4 Uncertainty in measurements

There is uncertainty connected to all computed data attributes as part of the modeling process. The uncertainty is defined in terms of standard deviation for each data attribute and provided as *data_attribute_value* +/- *uncertainty_value*.

Table 1: Uncertainty definition for metadata

| Data Attribute | Uncertainty Definition |
|-----------------------|---|
| Capacity | 0. Capacity is defined as the number of flights between two aerodromes and comes from actual historical records of flights that have taken place. |
| Activity | Activity is defined as the amount of fuel consumption in tonnes. There is uncertainty in various steps of the ICAO carbon emissions methodology to estimate fuel consumption like the actual distance covered by each flight which is estimated by the Great Circle Distance with a correction factor and the fuel consumption based on the distance traveled computed from ICAO data on specific aircraft types. Estimated at $\pm 10\%$ for all flights. ^[3] |
| Capacity Factor | Propagated from capacity and activity uncertainty |
| CO2 Emissions Factor | Estimated at $\pm 5\%$ ^[8] |
| CH4 Emissions Factor | Estimated at $\pm 78.5\%$ ^[9] |
| N2O Emissions Factor | Estimated at $\pm 110\%$ ^[9] |
| CO2 Emissions | Propagated from activity and CO2 emissions factor uncertainty |
| CH4 Emissions | Propagated from activity and CH4 emissions factor uncertainty |
| N2O Emissions | Propagated from activity and N2O emissions factor uncertainty |
| CO2e 20 yr Emissions | Propagated from CO2, CH4 and N2O emissions uncertainties |
| CO2e 100 yr Emissions | Propagated from CO2, CH4 and N2O emissions uncertainties |

3. Supplemental data

Table S1 Metadata for *Domestic and International Aviation Emissions*. For users, these terms translate to the following: Capacity = total number of flights between two aerodromes; Capacity factor = fuel burnt per flight in tonnes; Activity = total fuel consumption on a route monthly or annually. Note, Capacity \times Capacity factor = Activity.

| General Description | Definition |
|--------------------------|--|
| Sector definition | <i>Domestic and International Aviation emissions</i> |
| UNFCCC sector equivalent | <i>1.A.3.a - Domestic Aviation and Memo items - International aviation</i> |
| Temporal Coverage | <i>2015 – 2024</i> |

| | |
|--|--|
| Temporal Resolution | <i>Annual for 2015-2022. Monthly from 2023.</i> |
| Data format | <i>CSV</i> |
| Coordinate Reference System | <i>None. ISO3 country code and airport locations (lat, long) provided</i> |
| Number of emitters available for download | <i>4,910 airport locations in 233 countries</i> |
| Ownership | <i>All operations include airline/operator level ownership information.</i> |
| What emission factors were used? | <i>IPCC CH. 3</i> |
| What is the difference between a “0” versus “NULL/none/nan” data field? | <i>“0” values are for non-existent emissions. If the sector has emissions for that specific gas, but the gas was not modeled, this is represented by “NULL” or blanks.</i> |
| total_CO2e_100yrGWP and total_CO2e_20yrGWP conversions | <i>Climate TRACE uses IPCC AR6 CO₂e GWPs. CO₂e conversion guidelines are here: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_FullReport_small.pdf</i> |

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Geographic boundaries and names (iso3_country data attribute): The depiction and use of boundaries, geographic names and related data shown on maps and included in lists, tables, documents, and databases on Climate TRACE are generated from the Global Administrative Areas (GADM) project (Version 4.1 released on 16 July 2022) along with their corresponding ISO3 codes, and with the following adaptations:

- HKG (China, Hong Kong Special Administrative Region) and MAC (China, Macao Special Administrative Region) are reported at GADM level 0 (country/national);
- Kosovo has been assigned the ISO3 code ‘XKX’;
- XCA (Caspian Sea) has been removed from GADM level 0 and the area assigned to countries based on the extent of their territorial waters;
- XAD (Akrotiri and Dhekelia), XCL (Clipperton Island), XPI (Paracel Islands) and XSP (Spratly Islands) are not included in the Climate TRACE dataset;
- ZNC name changed to ‘Turkish Republic of Northern Cyprus’ at GADM level 0;
- The borders between India, Pakistan and China have been assigned to these countries based on GADM codes Z01 to Z09.

The above usage is not warranted to be error free and does not imply the expression of any opinion whatsoever on the part of Climate TRACE Coalition and its partners concerning the

legal status of any country, area or territory or of its authorities, or concerning the delimitation of its borders.

Disclaimer: The emissions provided for this sector are our current best estimates of emissions, and we are committed to continually increasing the accuracy of the models on all levels. Please review our terms of use and the sector-specific methodology documentation before using the data. If you identify an error or would like to participate in our data validation process, please [contact us](#).

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