EASA
European Union Aviation Safety Agency

EUROCONTROL

Gate-to-Gate CO_2 Emissions

EUROCONTROL methodology and cooperation with EASA Data4Safety for a data-driven validation

Introduction and background

Sustainability is one of the most important political, economic and societal issues and the aviation industry has a responsibility to minimise its impact on the environment and the climate.

With the aviation industry now sharing a common goal to achieve net zero carbon emissions by 2050 there is a need to agree on a commonly accepted approach to track progress at industry level.

While everybody acknowledges the immense challenge, there is a wide variety of opinions on how the 2050 target can be achieved. Like other models, the latest EUROCONTROL Outlook 2050 [1] considers the uptake of sustainable aviation fuels (SAF) as the main factor (33%) to achieve the goal by 2050, followed by out of sector measures (37%), new aircraft technology (20%) and operations and infrastructure (10%).

However, with benefits from aircraft technology and SAF only taking real effect beyond 2030, ATM has a vital role in reducing emissions by addressing operational inefficiencies in the ATM system already in the short term. For every tonne of fuel saved, an equivalent amount of 3.15t of CO_2 can be avoided.

Given the importance of monitoring aviation's environmental impact, EUROCONTROL has put an increased focus on the industry's progress towards the ambitious political and societal environmental targets, and particularly the contribution of ATM in achieving those goals.

Considering the crucial role of ATM in mitigating aviation's climate impact in the years ahead, there is a need for a holistic and commonly accepted approach to identify inefficiencies and to track progress while avoiding duplication and keeping administrative burden to a minimum.

In collaboration with experts from various units and interested stakeholders, EUROCONTROL, with the support of its independent Performance Review Commission (PRC), has developed a methodology to compute CO_2 emissions from a gate-to-gate perspective, based on radar and aircraft performance data.

The calculation of the gate-to-gate CO_2 emissions have been automated by the EUROCONTROL Aviation Intelligence Unit (AIU) and the data is made available to interested stakeholders on the AIU dashboard. The results are also presented in the latest Performance Review Report [2].

This publication briefly explains the methodology developed in close coordination with various industry experts.

It also provides an understanding of the validation process that has been carried out in cooperation with EASA leveraging the advent of the EASA Data4Safety Digital Platform.

Lastly, the paper offers an insight in the future work based on the outcomes of the validation exercise.

History of the cooperation with EASA

EASA has since 2003 been promoting the highest standards of environmental protection for aircraft certification. In addition, EASA is mandated by the European Commission to implement the ReFuelEU Aviation Regulation which promotes the increased use of Sustainable Aviation Fuels (SAF) and aims at climate neutrality by 2050. In its ReFuelEU Aviation Annual Technical Report 2025 - 2024 in review | EASA, the Agency outlines that by 2030, EU SAF production could reach 3.6 Mt in a realistic scenario or 5.2 Mt + 0.7 Mt synthetic in an optimistic scenario (from 1,4 Mt with the current production capacity). Meeting 2030 SAF mandate target (6%) is possible, but synthetic fuels are lagging (no facilities in the EU have reached Final Investment Decision yet).

In April 2021, the European Union Aviation Safety Agency (EASA) and Eurocontrol signed a Memorandum of Cooperation (MoC) affirming

and strengthening the increasing cooperation between the two Agencies.

This MoC provides a framework for the two Agencies and their experts to share information, knowledge and experience in the domains of aviation safety, security and sustainability and related regulatory, scientific or innovation developments of mutual interest.

Among the main areas of cooperation identified as part of this MoC, a specific vehicle (Annex) was put in place to enable Data Sharing and Analysis between the two Agencies, starting first with activities (Use Cases) focusing on aviation safety.

Developing further the cooperation on Data Sharing and Analysis between the two Agencies, the activity presented in this publication contributes to aviation sustainability. This activity leverages on the EASA-led Data4Safety initiative (D4S) and the new innovative D4S Digital Platforms established in cooperation with the EASA Members States and the Aviation Industry Sector since mid-2023 to provide more detailed information about actual fuel burn and emissions observed during commercial flight operations in agreement with partnering European Air Operators.

Project description

The analysis includes all flights operating under instrument flight rules (IFR) that take off and land within the EUROCONTROL area, as well as the portions of the trajectories within the EUROCONTROL area for flights entering or leaving it (Figure 1).

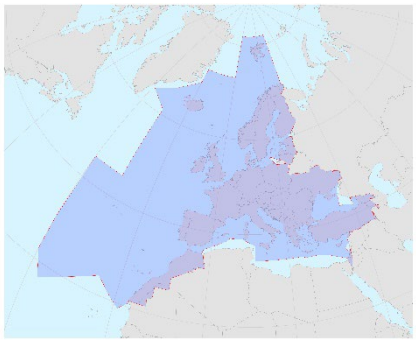

Figure 1 - Geographical scope

The analysis process can be broken down into five consecutive steps (Figure 2).

For each flight, the actual trajectory data is extracted from the European Network Manager (NM) database. The most important elements for the computation are the 4-D positions consisting of longitude, latitude, altitude, and timestamp.

To enable geographical breakdowns and analysis by flight phase, the data is enriched with additional data points such as Flight Information Region (FIR) crossings, crossings at 40NM and 100NM from the departure and arrival airports, and timestamps on the ground (actual off block time, actual take-off time, actual landing time, and actual in block time).

The enriched data is then converted into a specific input format required by the EUROCONTROL Advanced emission model (AEM)[1] which allows estimating the fuel burn and emissions of a flight based on trajectory data and information of the aircraft type.

The AEM tool calculates the fuel burnt and 24 different gaseous and particulate emissions for every segment in the input data. Currently, only CO_2 emissions are analysed, but additional emissions can be included in the future as required.

The results from the AEM tool are processed and aggregated in a way that allows analysis at any level of granularity (FIR level, State level, airline level, ANSP level, flight phase level, etc.).

[1] The AEM is a stand-alone application, developed and maintained by our Innovation Hub in Brétigny. Below 3,000 feet, the fuel burn calculation is based on the landing and take-off (LTO) cycle defined by the ICAO Engine Certification specifications. Above 3,000 feet, during the climb, cruise, descent (CCD) phases of flight, the fuel burn calculation is based on EUROCONTROL's Aircraft Database (BADA).

This process provides a comprehensive analysis of fuel burn and CO_2 emissions, offering valuable insights for environmental impact assessments in aviation.

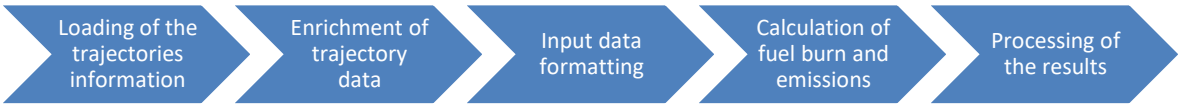

Figure 2 - Different steps of the calculation process

Initial validation

The results of the gate-to-gate model have been cross validated with actual gate-to-gate fuel burn data for 1.19 million flights in 2019 which was provided by the Aviation Sustainability Unit in EUROCONTROL. These data contain the total gate-to-gate fuel burn values for every flight in the dataset, so information per flight phase is not available.

On average, the model underestimates the total gate-to-gate fuel burn by only 2.3% (Figure 3).

A closer analysis of the observed differences shows that the relative difference is generally smaller for longer flights, suggesting that most of the observed differences originate from the ground, climb and/or descent phases.

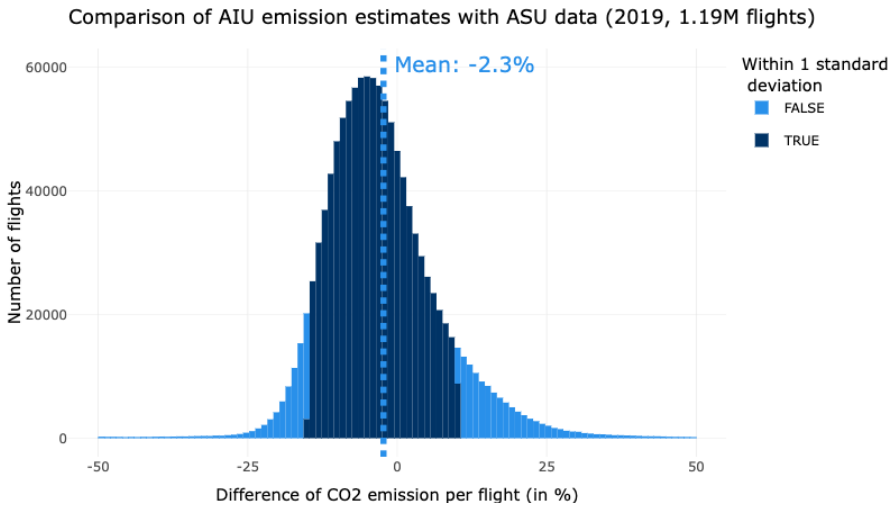

Figure 3 - Validation of the calculated results with real airline data

To further calibrate and cross-validate the model, the EASA Data4Safety team and the EUROCONTROL Aviation Intelligence Unit started working together under the umbrella of the Memorandum of Cooperation between EUROCONTROL and EASA. The EASA Data4Safety Digital Platform offers the possibility to partner with European Air Operators and to leverage under their agreement on datasets originating from their Flight Data Monitoring (FDM). These FDM data sets offer more detailed insights along the complete duration of the flight, thus allow for a comparison by flight phase.

Data4Safety data

In a first step, it was agreed to compare an initial dataset of up to 5000 flights (FDM records) operated by Vueling in 2023 between the 5 airport pairs presented in Table 1 and Figure 4. The data in this dataset only refer to flights in the directions as shown in Table 1. The opposite directions are not part of the dataset. The 5000 flights have been operated with 5 aircraft types.

The AIU has provided fuel burn estimates for 13167 flights to be able to match as many flights as possible in the Data4Safety dataset. Fuel burn estimates aggregated by the 9 flight phases defined in Table 2 were provided.

The final comparison dataset contains the flights that successfully passed the FDM data quality process and that could be matched in the two datasets. As part of this process, FDM records that did not contain all nine defined flight phases were excluded. After applying these criteria, the final dataset includes 4,504 flights.

Airport of departure [ICAO code]	**Airport of destination [ICAO code]**
Schiphol, AMSTERDAM, NLD [EHAM]	El Prat, BARCELONA, ESP [LEBL]
El Prat, BARCELONA, ESP [LEBL]	Federico Garcia Lorca, GRANADA, ESP [LEGR]
Fiumicino, ROME, ITA [LIRF]	Orly, PARIS, FRA [LFPO]
Bilbao, BILBAO, ESP [LEBB]	Gatwick, LONDON, GBR [EGKK]
Gatwick, LONDON, GBR [EGKK]	Fiumicino, ROME, ITA [LIRF]

Table 1 - Airport pairs

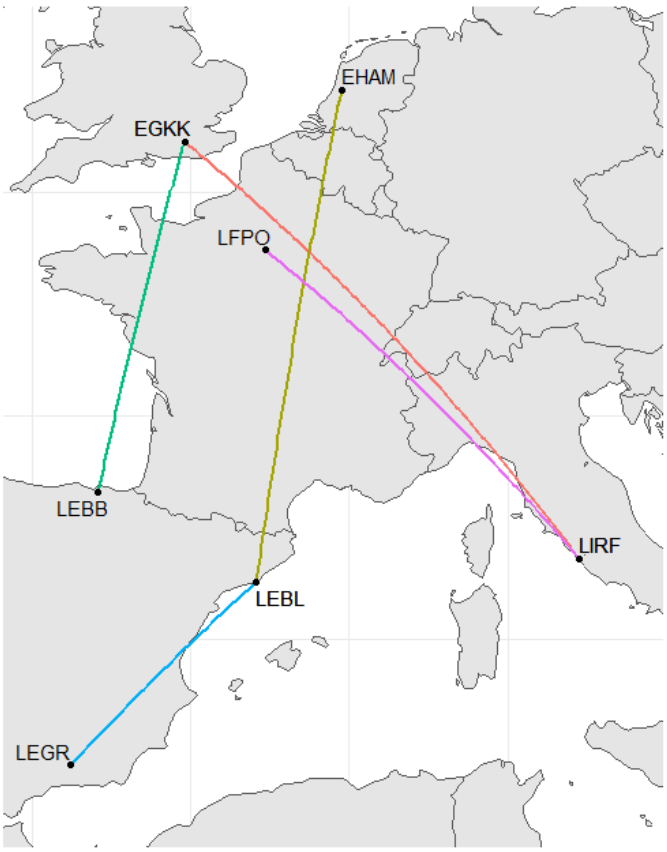

Figure 4 - Airport pairs covered in the comparison dataset

Flight Phase	Start	End
Taxi-Out	Actual Off-Block Time	Actual Take-Off Time - 42 seconds
Take-Off	Actual Take-Off Time - 42 seconds	Actual Take-Off Time
Climb-Out	Actual Take-Off Time	First crossing of 3000 feet Above Ground Level
Climb	First crossing of 3000 feet Above Ground Level	Top of Climb
Cruise	Top of Climb	Top of Descent
Descent	Top of Descent	Last crossing of 3000 feet Above Ground Level
Approach	Last crossing of 3000 feet Above Ground Level	Actual Landing Time
Landing	Actual Landing Time	Actual Landing Time + 40 seconds
Taxi-In	Actual Landing Time + 40 seconds	Actual In-Block Time

Table 2 - Flight phases

Validation results

The first step of the validation looks at the discrepancies on a flight-by-flight level as was done for Figure 3. These results are presented in Figure 4. The actual fuel data (derived from FDM records) are taken as reference data, meaning positive values indicate a higher value in the estimated (EUROCONTROL) dataset than in the actual dataset.

Although the dataset is much smaller in terms of number of flights and aircraft types, the distribution of differences of fuel burn is similar to the distribution in Figure 3. Overall, the fuel burn estimations of EUROCONTROL underestimate the actual fuel burn by only 0.6% (see Figure 5).

This result confirms the previous comparison performed with the dataset of 1.19 million flights. Nevertheless, the purpose of this additional validation exercise is to identify in which flight phases the discrepancies occur.

In Figure 6, the total estimated and actual fuel burn for all flights in the comparison dataset is shown per flight phase.

The estimated and actual fuel burn corresponds quite well during the climb-out, climb, cruise, landing and taxi-in phases, which accounts for 81.1% of the total fuel burn in the comparison dataset. The largest discrepancy is seen for the descent phase.

During the analysis of the actual and estimated fuel burn data, it was observed that the take-off and landing times in the EUROCONTROL dataset don't always correspond to the actual values. EUROCONTROL's information on these timings originates from different data sources so the accuracy of the take-off and landing times depends on the quality of these data sources.

Additionally, the take-off and landing rolls are estimated to last respectively 42 and 40 seconds as defined by the standard ICAO Landing and Take-Off cycle. These standard values are used since no other information on the start of the take-off roll and end of the landing roll are available.

Taking a closer look at the actual data, it was apparent that the data coverage in the taxi-out and taxi-in phases is sometimes partial. In some cases, the trajectory data start after the beginning of the taxi-out phase and end before the end of the taxi-in phase. As a result, actual fuel burn values during these flight phases tend to be lower than the estimated values.

All these observations indicate that a closer look should be taken at the results of the flight phases on the ground with a special attention to the start and end points of these phases. Nevertheless, as can be seen in Figure 6, the total fuel burn in these

flight phases is relatively small compared to the airborne flight phases.

When looking at the relative errors per flight phase, it is clear that the climb-out, climb and cruise phases are accurately calculated by EUROCONTROL (see Figure 7). On the other hand, the descent, approach and ground phases are characterised by a quite high relative error. The reasons for the discrepancies during the ground flight phases have been highlighted before.

The causes for the differences during the descent and approach phases is not immediately clear so further investigation is necessary.

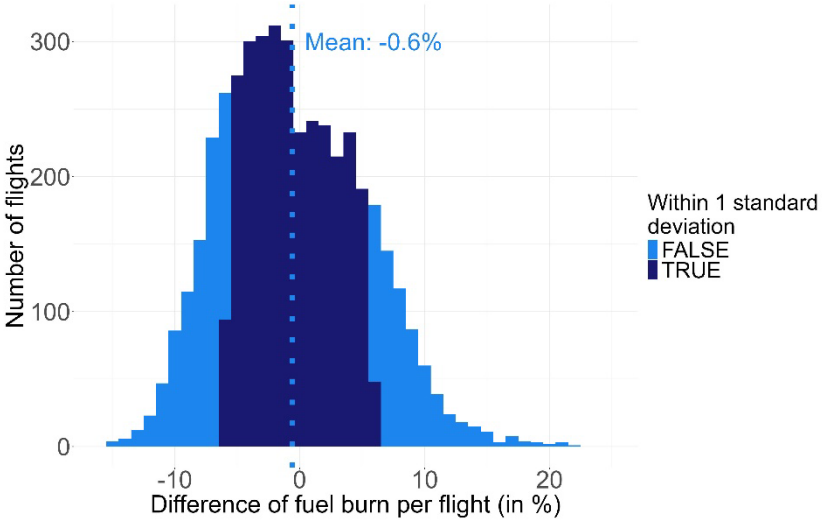

Figure 6 - Validation of the calculated results with Data4Safety data

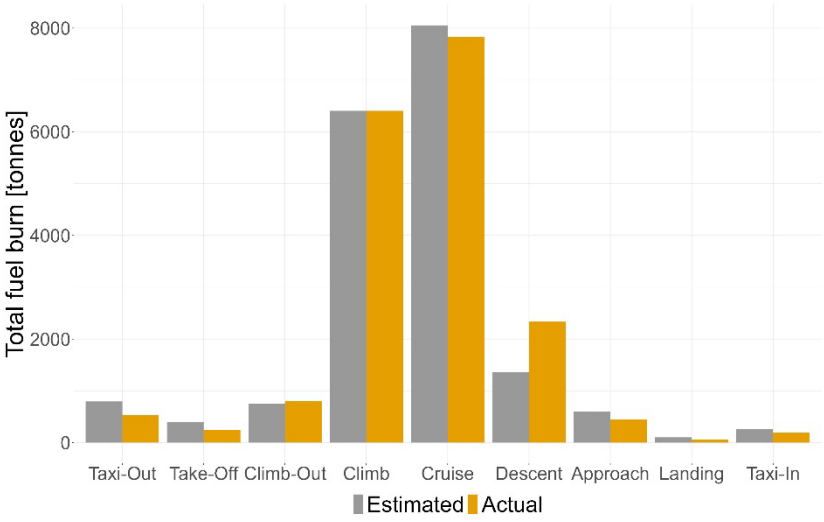

Figure 7 - Actual and estimated fuel burn

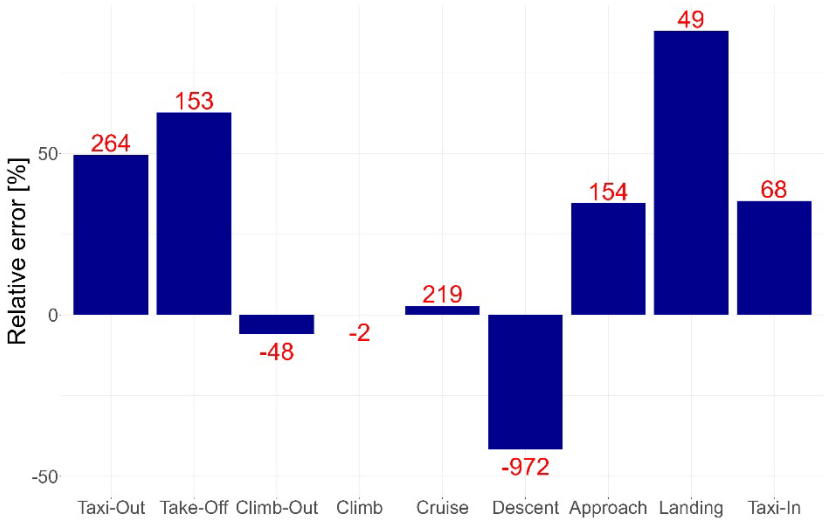

Figure 8 - Relative error by flight phase – absolute mean error in tonnes highlighted in red

Conclusions and next steps

The discussion about fuel efficiency and emissions in Europe will be a prevailing topic for the near future.

The validation exercises using real airline data have demonstrated a high level of accuracy of the results on an overall scale. However, diving deeper into the results at flight phase level, underestimations are observed during the descent phases while the fuel burn is overestimated during the ground phases and approach phase. Overall, these discrepancies almost balance out.

Nonetheless, a further refinement of the calculation method during the descent and approach phases will be undertaken to enable more detailed fuel burn analyses.

In a next step, the data sources with the start and end points of the ground flight phases will be reviewed to improve their accuracy.

Further partnering with EASA and volunteer European Air Operators participating in the EASA Data4Safety initiative and willing to make available actual fuel burn data is a key requisite to continue improving estimation methods like the fuel burn estimation implemented by EUROCONTROL.

EUROCONTROL will report on the continued progress of this project in future publications.

Next steps

1. To enable a further comparison of the results per flight phase, the determination of the start and end points of every flight phase should be performed based on the actual data (derived from FDM records). These points should then be compared with the start and end points of the estimated (EUROCONTROL) flight phases. The related fuel burn values can then be compared between the actual (with start and end points derived from FDM records) and estimated (with EUROCONTROL start and end points) fuel burn.
2. To eliminate the effect of prevailing winds, flights in the opposite directions of the considered airport pairs should be included in the analysis.
3. To expand the comparison scope, more airport pairs with longer distances and very short distances should be analysed to cover a wider distribution of flight distances.
4. To improve the robustness of the analysis, even more flights and aircraft types should be added to the analysis.

Notice

The EUROCONTROL Aviation intelligence Unit (AIU) has made every effort to ensure that the information and analysis contained in this document are as accurate and complete as possible. Despite these precautions, should you find any errors or inconsistencies we would be grateful if you could please bring them to the AIU's attention.

Should you wish to comment on this publication,
Please email us @: pru-support@eurocontrol.int.
For more data, please visit: www.ansperformance.eu

References

[1] EUROCONTROL, "Aviation Outlook 2050," April 2022. [Online]. Available: https://www.eurocontrol.int/publication/eurocontrol-aviation-outlook-2050.

[2] Performance Review Commission, "Performance Review Report (PRR) 2024," 03 2025. [Online]. Available: https://www.eurocontrol.int/publication/performance-review-report-prr-2024.

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