Performance Insight

Gate-to-gate CO_2 emissions in Europe - a holistic approach

Measuring European Aviation Performance

Powered by the Aviation Intelligence Unit

Performance Review Commission
Rue de la Fusée 96, B-1130 Brussels, Belgium
Email : pru-support@eurocontrol.int

BACKGROUND

This PRC Performance Insight has been prepared by the EUROCONTROL Performance Review Unit (PRU) for the Performance Review Commission (PRC).

The PRC conducts independent measurement, assessment and review of the performance of the Pan-European Air Navigation Services (ANS) system, including its contribution to the efficiency of Pan-European aviation. The PRC strives to identify future improvements and makes recommendations as appropriate.

The PRC maintains an open and transparent dialogue with relevant parties, including but not limited to States, Air Navigation Service Providers, Airspace Users, Airports, social dialogue partners, civil-military organisations, international and national organisations, etc. The PRC conducts research into the development of performance measurement. This includes, inter alia, investigating how performance could best be described/measured in the long-term, developing and testing proposals for future indicators and metrics and contributing to future improvements in performance.

The PRC disseminates the results of its analysis to relevant parties, provided that no sensitive data are involved, to demonstrate the PRC's commitment to transparency and to promote the application of PRC analysis.

The PRC produces independent ad-hoc studies, either on its own initiative and/or at the request of relevant parties. The PRC's website address is: https://www.eurocontrol.int/air-navigation-services-performance-review.

NOTICE

The PRC 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 PRU's attention.

The PRU's e-mail address is pru-support@eurocontrol.int.

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 (41%) to achieve the goal by 2050, followed by market based measures (32%), new aircraft technology (19%) and Air Traffic Management (8%).

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

To support stakeholders in their decarbonisation efforts, EUROCONTROL has started to set up the "FlyingGreen" platform offering a wide variety of tools and information in support of the transition from fossil fuels to sustainable aviation [2]. Once the calculation of the gate-to-gate CO_2 emissions has been automated by the EUROCONTROL Aviation Intelligence Unit, the data will be made available to interested stakeholders on the platform.

Objective

This PRC Performance Insight edition explains the methodology developed by the PRC in close coordination with various industry experts.

It also provides an understanding of the validation process that has been carried out and presents initial results on the estimated total CO_2 emissions by geographical area, flight phase, and stakeholder groups.

Lastly, the paper offers preliminary insights into the work conducted to identify the level of operational inefficiencies in the network and to formulate potential actions to mitigate their environmental impact.

Scope

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).

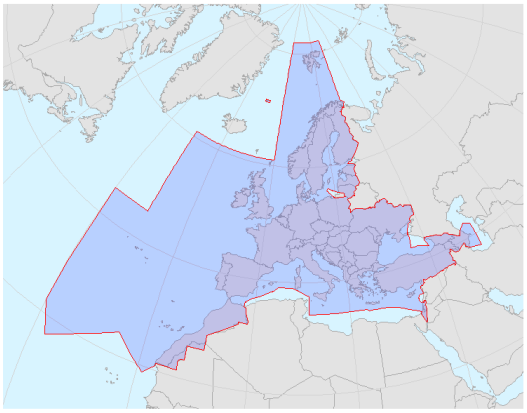

Figure 1 - Geographical scope

Methodology

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

- **Data loading:** the actual flown trajectory of the flight is derived from correlated[1] position reports transmitted to the European Network Manager (NM) by ATC surveillance systems across Europe. The most important elements for the computation are the 4-D positions consisting of longitude, latitude, altitude, and timestamp. To remove erroneous trajectories in the data, several logic checks and filters have been put in place.
- **Data enrichment**: 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).

  Different from many other models which use standard times for the landing and take-off cycle, the PRC computation is based on actual timestamps[2] along the entire trajectory which provides a much better accuracy.
- **Data formatting**: The enriched data is then converted into a specific input format required by the EUROCONTROL Advanced emission model (AEM)[3] which allows estimating the fuel burn and emissions of a flight based on trajectory data and information of the aircraft type. This involves converting trajectory data points into segments defined by 4D (3D + time) information of the begin and end points. Additional fields like aircraft type and flight phase of every segment are also defined as required input for the model.

  Until consistent data on the actual aircraft weight is available the calculation is based on the nominal weight[4] of each aircraft type.

  Work is in progress to better reflect the actual take-off weight (ATOW) of an aircraft in the gate-to-gate calculation, which is usually not readily available. This work is supported by a joint initiative with the OpenSky Network aimed at estimating the ATOW based on the trajectory and ancillary data.
- **Fuel burn and Emissions calculation**: 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.

[1] The data is called "correlated" because the 4D position is augmented with flight information such as CALLSIGN, ADEP, ADES and ICAO 24-bit address. Correlated Position Reports (CPRs) are based on ANSPs' real-time surveillance data enriched with spaced-based ADS-B surveillance data. The EUROCONTROL Enhanced Tactical Flow Management System (ETFMS) currently receives CPRs from most countries in the NM area of operations. The Integration of space-based ADS-B real-time surveillance data covers the traffic inside NM area, the adjacent airspace around NM area, and the long-haul traffic 6h before it reaches the NM area.

[2] Timestamps are taken from the well-established Airport Operator Data Flow (APDF) and the Air Transport Operator Data Flow (AODF). Missing data is complemented by data from the Network Manager.

[3] 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).

[4] The nominal weight is a standardised weight value used in the AEM to estimate emissions for each aircraft type.

- **Processing of the Results**: 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.). The output data is further augmented by flight-specific data to enable more detailed breakdowns and analyses.

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

The fuel burn and CO_2 emissions are calculated for each individual flight. Although this requires quite some computational effort, it is necessary to obtain as accurate as possible results. Presently, it takes on average 20 minutes to perform the calculations for 1 day of traffic but the ongoing transfer to a cloud infrastructure will reduce calculation times and also enable further analyses.

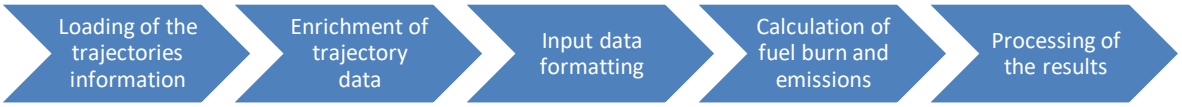

Figure 2 – Different steps of the calculation process

Validation

The primary source for the calculation of the CO_2 emissions is the data provided by the various ATC surveillance systems to the Network Manager.

Although the data could be further enhanced by ADS-B data, validation checks suggest that the granularity of the available data from the NM is sufficient for the calculation of gate-to-gate fuel burn and emissions.

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.

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 delta is generally smaller for longer flights, suggesting that most of the observed differences originate from the ground, climb, or descent phases.

To further calibrate and cross-validate the model, the PRC is collaborating with airlines in a dedicated working group. This collaboration will enable further fine-tuning of the emissions model and calculation method.

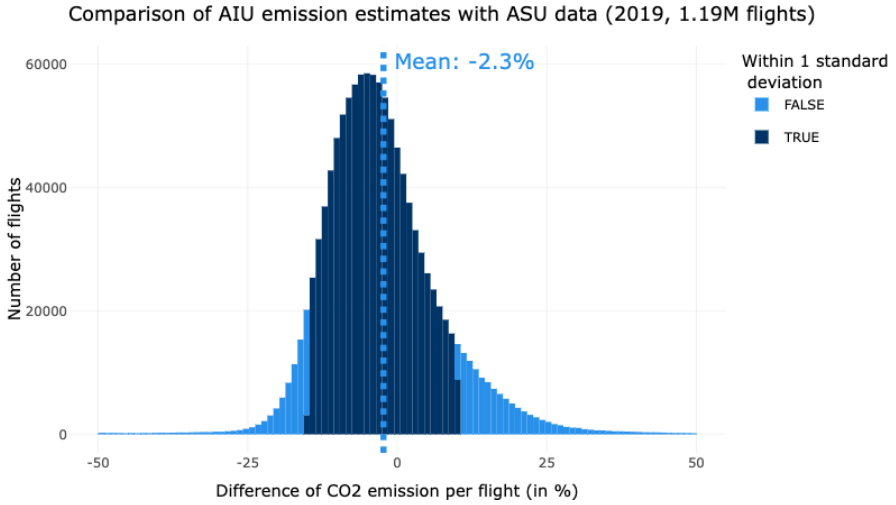

Figure 3 – Validation of the calculated results with real airline data

Total CO_2 emissions in the EUROCONTROL area

The total gate-to-gate CO_2 emissions within the EUROCONTROL area in 2023 were 180.2 million tonnes which represents an increase of 14% over 2022.

It is worth recalling that the results only refer to CO_2 emitted within the EUROCONTROL area. The portion of the trajectory outside the EUROCONTROL area is not considered in the calculation, even though long-haul flights contribute a substantial share to the total CO_2 emissions.

The analyses in this section illustrate some selected examples of the model's capabilities. The results enable analysis across many more dimensions and their combinations, including over time, by flight phase, geographical area, market segment, traffic flow, and aircraft type.

Additionally, it is possible to develop 'what if' scenarios, such as assessing the environmental impact of accelerating fleet renewal with more fuel-efficient aircraft. The PRC will present more comprehensive analyses in future publications.

Total CO_2 emissions by flight phase

Figure 4 shows a breakdown of the total CO_2 emissions by flight phase.

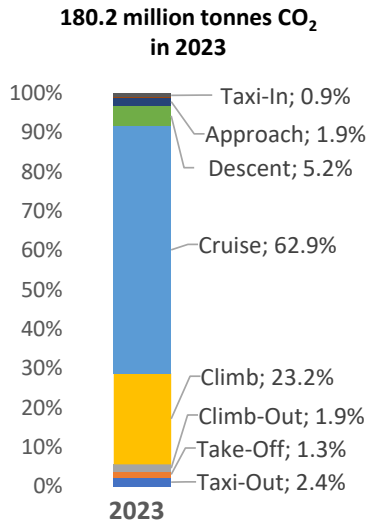

Figure 4 – Total CO_2 emissions by flight phase (EUROCONTROL area, 2023)

As expected, the majority of CO_2 emissions are produced during the cruise phase, followed by the climb phase, where power settings are high and the aircraft weight is greater, than during the descent phase, due to unburned fuel.

Total CO_2 emissions by region

Figure 5 shows the total CO_2 emissions per flight information region (FIR) in 2023. There are wide variations across the EUROCONTROL area.

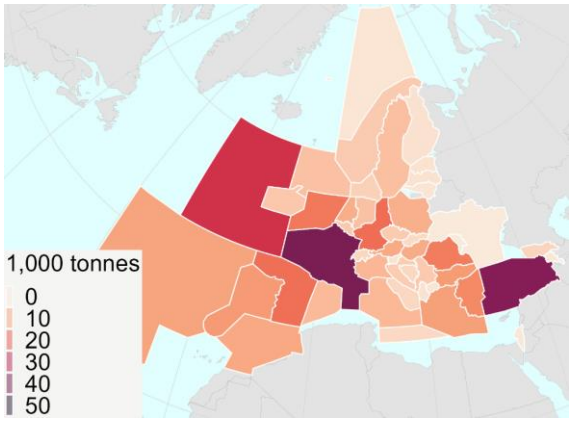

Figure 5 – Total CO_2 emissions per flight information region (2023)

The results are primarily influenced by traffic volume, distance flown, and aircraft mix, but they do not provide information about efficiency levels within the respective airspace. There is a strong correlation with traffic density, particularly in the European core area, which includes major airport hubs and serves as a crossroads for major traffic flows.

Total CO_2 emissions by market segment

Figure 6 shows the CO_2 emitted per distance flown for each market segment in 2023.

Cargo aircraft emit the highest amount of CO_2 per flown nautical mile, which is expected due to their larger size, higher nominal weights, frequent use of more than two engines, and tendency to be older.

The analysis also indicates that the low-cost market segment emits less CO_2 per nautical mile compared to mainline carriers. Both segments represent the majority of the distance flown within the EUROCONTROL area, as shown on the x-axis of Figure 6.

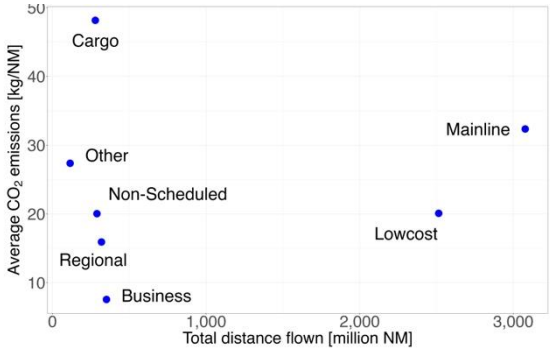

Figure 6 – CO_2 emissions by market segment (2023)

Although low-cost carriers tend to operate newer, more fuel-efficient aircraft, the observed difference is primarily due to variations in fleet composition. Low-cost carriers primarily operate narrow-body aircraft, whereas mainline carriers also operate larger long-haul aircraft. These larger aircraft burn more fuel per distance but also carry heavier weights.

Average CO_2 emissions per aircraft weight

A complementary perspective to the CO_2 emissions per distance is the CO_2 emissions per nominal aircraft weight[5].

The total flight hours on the x-axis of Figure 7 provide an indication of the use of the respective aircraft type in the European network.

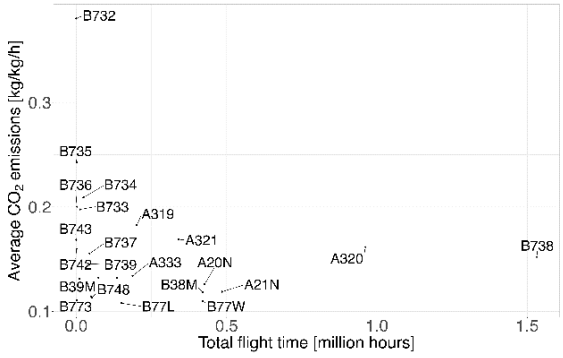

Figure 7 – Average CO_2 emissions per aircraft weight (2023)

The analysis only considers the cruise phase and concentrates on aircraft types for which newer, more fuel-efficient versions are also available on the market (e.g., A320 vs. A320 Neo). The sample shown in Figure 7 represents 71.3% of the total traffic and 73.1% of the gate-to-gate CO_2 emissions in the EUROCONTROL area in 2023.

Some very significant efficiency gains in terms of CO_2 emissions per aircraft weight are visible for the Airbus Neo family but also for the Boeing MAX compared to the older 737 models.

What if older aircraft could be replaced quicker?

The analysis below provides an estimate of the potential CO_2 savings if all the older aircraft models could be replaced with the newest, most fuel-efficient, versions on the market.

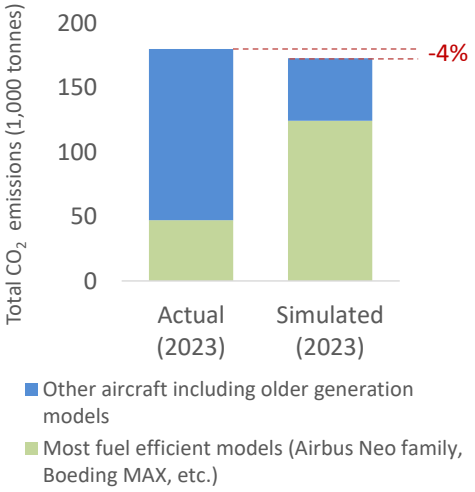

Figure 8 – Total CO_2 emissions in the EUROCONTROL area with older aircraft models replaced (2023)

All else equal, the replacement of the remaining older models with the most fuel-efficient models would save approximately 7.2 million tonnes of CO_2 (2023 traffic).

This corresponds to some 4% of the total gate-to-gate CO_2 emissions within the EUROCONTROL area in 2023.

[5] As the actual take-off weight of each flight is currently not available, the analysis has been based on the nominal take-off weight for each aircraft type.

Determining ATM related inefficiencies

As a next step, the PRC is working in cooperation with airlines on a methodology to identify and attribute inefficiencies directly along the full gate-to-gate trajectory.

Although numerous analyses exist, with varying scopes (geography, flight phases) and methodologies, it is difficult to obtain a comprehensive gate-to-gate perspective on operational inefficiencies and the 'benefit pool' that can be realistically addressed by ATM. In this context it is important to point out that a certain level of inefficiency will remain.

To identify and attribute inefficiencies along the full gate-to-gate trajectory, reference trajectories and their associated emissions are needed for comparison with the emissions of actual flown trajectories. Ideally those reference trajectories should consider factors such as prevailing meteorological conditions (including wind), aircraft performance, route availability, route constraints and, if available, aircraft weights.

For a first high-level estimate [3], the PRC used a percentile approach[6] (10th percentile) based on gate-to-gate fuel burn for trajectories within the EUROCONTROL area, categorised by airport pair and aircraft type combination. The results suggest an ATM-related benefit pool of 9.3% for the EUROCONTROL area in 2023 (9.4% in 2022).

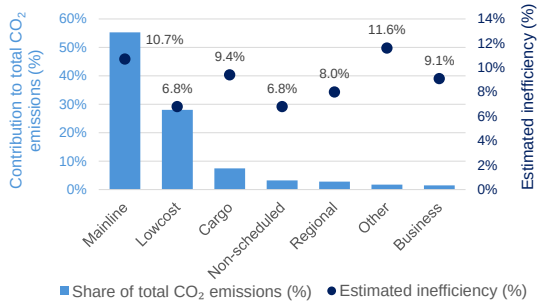

Figure 9 – Contribution to total CO_2 emissions and additional CO_2 by market segment (2023)

The simplistic percentile approach also allows to get a first estimate of the inefficiencies by market segment (Figure 9) (dark blue dot) and the respective share of the total CO_2 emissions (bars).

Mainline carriers and all-cargo flights show a comparatively high level of inefficiency. Conversely, low-cost carriers, along with non-scheduled flights, displayed the highest level of efficiency in 2023.

Complementary to this simplistic approach, the PRC is exploring, together with interested airlines, various ways to further refine and validate the quantification of ATM-related inefficiencies and attribute them to underlying causes; for example, the Optimal Green Trajectory Working Group.

The objective is twofold: (1) to further cross validate and calibrate the computed CO_2 emissions and (2) to develop suitable and widely accepted reference trajectories for assessing inefficiencies along the trajectory.

Two types of reference trajectories are being developed:

- theoretical fuel optimal unconstrained trajectory (no route restrictions, level capping or adverse weather); and,
- realistic fuel optimal constrained trajectory (taking network constraints into account).

These two references will enable the determination of the ATM/network impact, the influence of flight planning and flight execution, and the potential benefit pool in terms of CO_2 emissions.

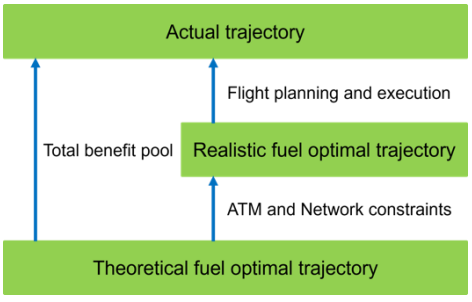

Figure 10 –Reference trajectories for the calculation of inefficiencies in the network

[6] The reference value for measuring inefficiency is set by the 10th percentile, which corresponds to the value at which 10% of all gate-to-gate CO_2 emissions are lower than or equal to. This reference value is calculated for each airport and aircraft type combination.

Conclusions and next steps

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

The PRC is committed to provide input to the political and strategic decision-making by providing reliable and robust data.

The gate-to-gate CO_2 computations enable the tracking of progress over time and will provide a holistic view of the level of inefficiencies as well as a breakdown by stakeholder group, phase of flight and geographical area.

The validation exercise using real airline data has demonstrated a sufficiently high level of accuracy of the results, which will be further improved as more and better data become available. To fine-tune the calculations, work is in progress with interested airlines to investigate reasons for observed differences.

Feeding the model with data closer to the actual aircraft take-off weight, rather than the nominal weight, will further improve the results.

One of the challenges ahead is the development of well understood and agreed references to determine operational inefficiencies and to identify underlying drivers.

The ongoing collaborative work with airspace users and interested stakeholders, based on detailed case studies, will help in the development and validation of robust, well understood reference trajectories. These references will facilitate meaningful analysis for the formulation of strategies aimed at mitigating operational inefficiencies leading to additional CO_2 emissions.

For example, initial analyses indicate that 4% of the CO_2 emissions in 2023 could have been saved if older aircraft types would have been already replaced by new generation aircraft types. Looking at inefficiencies, the possible ATM-related benefit pool in terms of CO_2 emissions is estimated to be 9.3% in 2023.

In addition to the current analysis of gate-to-gate CO_2 emissions within the EUROCONTROL area, there are furthermore plans to expand the model to incorporate segments of trajectories outside the EUROCONTROL area. This expansion aims to provide a more comprehensive overview of the total CO_2 emissions originating from European aviation.

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

Should you wish to comment on this publication, or to contact the PRC,
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References

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

[2] EUROCONTROL, "Flying Green platform," [Online]. Available: https://www.eurocontrol.int/platform/flyinggreen.

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