

Carbon Footprint of Scientific Missions at APC

2021 – 2025

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May 26, 2026

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1 Scope and methodological assumptions

This study is conducted in the context of the French national decarbonization strategy, defined by the *Stratégie nationale bas-carbone* (SNBC). The SNBC provides the national roadmap for reducing greenhouse-gas emissions across all sectors, with the objective of reaching carbon neutrality by 2050 and substantially lowering emissions already by 2030. In its current third version, the strategy aims at reducing territorial emissions by about a factor of two by 2030 relative to 1990, corresponding to an average reduction of approximately 5% per year up to 2030.

Understanding and reducing the carbon footprint of scientific activities is becoming a central challenge for research institutions. In this study, we quantify the CO₂ emissions associated with professional travel within the APC laboratory and aim to provide a robust basis for future mitigation strategies.

This work is intended to provide an objective, data-driven assessment of current emission levels. Its primary goal is to support the definition of concrete actions towards achieving a 5% reduction per year in mission-related CO₂ emissions over the next five years. Beyond quantification, the study also aims to evaluate how potential mitigation strategies may affect the scientific activity of APC, in particular whether such measures are both sustainable and compatible with the laboratory's research objectives.

A central methodological assumption is that **the carbon emissions associated with a mission are attributed to APC whenever the mission is funded through a budget administered by APC**. The accounting perimeter adopted here is therefore budget-based: if APC manages the budget that finances the trip, the corresponding CO₂ emissions are counted as part of APC's travel footprint.

Consistently with this definition, **the dataset does not include missions carried out by APC members but funded through external (non-APC) sources**. These correspond to trips performed within external collaborations or financed by partner institutions, for which the relevant data are not accessible. This avoids double counting across institutions and ensures a coherent and comparable accounting framework.

It is nevertheless important to stress that externally funded missions may represent a non-negligible fraction of the overall travel activity of APC members. Although they fall outside the perimeter defined here, they still contribute to the broader environmental impact of scientific practices. From this perspective, beyond institutional accounting, there is a collective and individual responsibility to reflect on the necessity and frequency of all professional travel, independently of the funding source.

Finally, **missions funded through University budgets are not included in the present analysis**. This exclusion reflects a methodological limitation, as these missions are recorded in separate administrative databases, subject to different access conditions and relying on non-homogeneous data structures. We estimated that, in 2025, these missions represented approximately 6% of the total CO₂ emissions associated with APC-related travel. This fraction was likely larger in previous years, when LabEx UnivEarthS funding from the University was more substantial. The results presented here should therefore be interpreted as a partial, though representative, subset of the full emission footprint.

Taken together, these elements imply that the results presented here should be interpreted as a robust lower-bound estimate of APC travel-related emissions, with a consistent internal structure that allows meaningful comparisons across projects and groups.

2 Dataset and methodology

2.1 Data extraction and preprocessing

This study is based on the reconstruction of travel activity and associated CO₂ emissions using administrative data from the Geslab system, covering the period 2021–2025. The primary challenge of this work is the construction of an aggregated mission database in which each trip can be linked to the traveler, the personnel status at the time of the mission, the corresponding budget line, the associated project and scientific group, the geolocalized origin and destination of the travel segment, and the resulting CO₂ emissions, computed according to the *1point5* methodology.

The first approach consisted in reproducing the methodology developed by the APC Ecology Group, which is based on the historical mission tables available in Geslab together with an aggregated CO₂ table, specifically designed for carbon accounting and also available within Geslab. Using these two sources, we are able to reproduce the global results obtained by the Ecology Group for the 2024 dataset, providing an important cross-check of the overall consistency of the method.

At the same time, this exercise reveals the intrinsic fragility of these datasets as a basis for a systematic analysis. In particular, the standard mission tables rely strongly on self-declared information and exhibit significant inconsistencies, including variations and errors in city names, ambiguities in the definition of travel segments (especially the distinction between outbound and return trips), heterogeneous naming conventions, and incomplete transport information. As a consequence, although these datasets are sufficient to reproduce global estimates, they do not provide a sufficiently robust and reproducible basis for a detailed analysis of travel activity.

For this reason, we explored other data exports available in Geslab and identified two complementary mission-related datasets that provide a more robust basis for the analysis.

The first consists of a direct export of all missions from the Geslab interface. In this format, missions are listed individually and broken down into their travel segments, with explicit information on mission identifiers, traveler, date, origin and destination locations, and transport modes. This dataset therefore makes it possible to reconstruct travel trajectories and transportation modes in a systematic and reproducible way, with each segment unambiguously associated with a mission number, an agent, and a date.

The second dataset provides, for each budget line, the corresponding list of mission identifiers and associated dates. It therefore establishes a one-to-one correspondence, via the mission identifier, between mission records and budgetary information. By merging this dataset with the mission-segment export, each travel segment can be associated not only with a specific traveler and mission date, but also with a budget line and, through the budget structure, with a project and a scientific group.

A key advantage of these two datasets is that their relevant fields are generated directly within Geslab rather than relying on self-declared mission summaries. This considerably reduces ambiguities and inconsistencies, in particular for travel dates, mission identifiers, transport modes, and the structure of travel segments. As a result, they provide a much more robust basis for reconstructing travel activity and assigning each trip to the corresponding scientific and administrative context.

The only field requiring manual intervention is the budget-line name. In practice, this label may vary from one year to another, sometimes only through minimal differences (for example a missing space), but these are sufficient to make a fully automated matching procedure based on regular expressions fragile and unreliable. We therefore compiled the complete list of budget-line names, harmonized them through an aliasing procedure mapping budget lines onto projects, and then associated each project with its corresponding scientific group. The final project-to-group mapping is provided in Appendix A.

In addition to this mission- and budget-based reconstruction, a third dataset is obtained from the CNRS “Portail Data” and provides information on laboratory personnel over the same period. This dataset includes, for each individual, the employment category (e.g. researcher, engineer, doctoral student) and contract status, together with the corresponding validity periods. By combining this information with mission dates, it becomes possible to assign to each trip not only its scientific and budgetary context, but also the status of the traveler at the time of the mission.

A residual limitation concerns a small fraction of missions recorded in Geslab that are not fully finalized or are only partially completed from an administrative point of view. For these missions, the information related to travel segments (origin and destination locations and transport modes) is available, allowing for the reconstruction of trajectories and the calculation of the associated CO₂ emissions. However, key administrative fields such as the mission date, the traveler, and the budget line are missing.

In order to retain these entries in the analysis, the missing temporal information is inferred from the mission identifier, which is monotonically increasing and therefore provides an approximate chronological ordering. The year is assigned by comparison with the closest neighboring mission identifiers for which the date is known.

Because the traveler and budget information cannot be reliably reconstructed, these missions are included in the computation of total CO₂ emissions but are excluded from the breakdown by project, group, and personnel category. Their contribution ranges from 1.8% to 12.4% of the annual emissions, depending on the year, and has a limited impact on the aggregated results. All reconstructed entries are explicitly flagged in the dataset to ensure full transparency.

Taking these elements into account, the resulting combined dataset provides a consistent and reproducible basis for the analysis of travel-related CO₂ emissions presented in this report.

For privacy reasons, the raw data were neither shared nor uploaded to external cloud services. They remained stored exclusively on local systems throughout the analysis and will be deleted once the validation of the present study is completed.

2.2 Geolocation and CO₂ computation

For each travel segment, the origin and destination locations are converted into geographical coordinates using standard geocoding services. To ensure consistency and efficiency, a caching procedure is implemented so that each location is resolved only once and then reused throughout the analysis.

Distances between locations are then computed from the geographical coordinates using the haversine formula, which provides the great-circle distance between two points on the Earth’s surface:

$$d = 2R \arctan \left(\sqrt{\frac{a}{1-a}} \right), \quad (1)$$

where R is the Earth’s radius and a depends on the differences in latitude and longitude between the two points.

Based on these distances and the associated transport modes, travel-related CO₂ emissions are estimated using the methodology developed by *Labos1point5*¹, which provides standardized emission factors for the main modes of transport and is widely used within the French research community.

In practice, the implementation used in this work is calibrated to reproduce the results of the *Labos1point5* travel simulator. In particular, the treatment of distances and the transport-dependent emission factors are adjusted so that representative travel routes yield CO₂ estimates consistent with those obtained with the reference tool.

¹<https://labos1point5.org>

For each travel segment, emissions are computed as the product of the travel distance and a transport-dependent emission factor. The main numerical assumptions used in the present implementation are summarized below.

For air travel, emission factors depend on flight distance in order to account for the different efficiencies of short-, medium-, and long-haul flights:

- short-haul flights (< 1000 km): ~ 0.26 kg CO₂ per km,
- medium-haul flights (1000–3500 km): ~ 0.19 kg CO₂ per km,
- long-haul flights (> 3500 km): ~ 0.15 kg CO₂ per km.

For rail transport, emission factors depend on the countries involved in the journey, reflecting differences in the carbon intensity of national electricity mixes. Typical values used in this study are:

- France: ~ 0.0035 kg CO₂ per km,
- Switzerland: ~ 0.004 kg CO₂ per km,
- Italy: ~ 0.038 kg CO₂ per km,
- cross-border travel (e.g. France–Italy): intermediate values (~ 0.017 kg CO₂ per km).

For road transport, fixed average emission factors are used:

- car and rental vehicles: ~ 0.15 kg CO₂ per km,
- bus transport: ~ 0.05 kg CO₂ per km.

When transport information is missing or ambiguous, a conservative assignment is adopted based on travel distance and mission context, typically favoring rail for short distances and air travel for long distances. This procedure ensures a homogeneous and reproducible estimation of travel-related emissions across the full dataset.

2.3 Laboratory context and population

In order to contextualize the evolution of travel-related CO₂ emissions, we first examine the overall activity of the laboratory over the period 2021–2025, focusing on both the size of the personnel and the fraction of individuals involved in professional travel.

The APC personnel is divided into two main categories. The *core personnel* includes researchers, faculty members, technical and administrative staff (IT), postdoctoral researchers, and PhD students. These categories define the reference population used throughout the analysis. In addition, *non-core personnel* comprises apprentices, interns, and visitors, who are present in the laboratory but are not part of the core workforce.

The evolution of these populations is shown in Fig. 1, while the corresponding numbers are reported in Table 1. Over the period considered, the core laboratory population remains relatively stable, increasing from about 230 individuals in 2021 to a maximum of 263 in 2024, followed by a slight decrease to 253 in 2025. This evolution is driven primarily by a steady increase in the number of PhD students and a moderate growth of the research staff, while the number of faculty members shows a slight decrease in the last year.

In contrast, the non-core population exhibits much larger fluctuations, dominated by variations in the number of interns. In particular, a significant increase is observed from 2023 onward, with more than 50 interns recorded each year. This mainly reflects a change in administrative practice, whereby interns have been systematically entered into the RESEDA personnel database over the last three years, rather than a genuine change in long-term staffing.

Year	Res.	Fac.	IT	Postdoc	PhD	Total	Appr.	Intern	Visitor
2021	68	33	83	0	49	233	2	4	9
2022	64	34	79	3	49	229	1	10	10
2023	70	33	85	7	56	251	5	55	10
2024	76	32	87	9	59	263	4	47	13
2025	71	28	87	5	62	253	6	55	12

Table 1: Number of personnel per category and year over the period 2021–2025. The category “IT” (Technical and Administrative Staff) includes engineering, technical, and administrative personnel. The total corresponds to the core laboratory population (Researcher, Faculty, IT, Postdoc, PhD), excluding apprentices, interns, and visitors.

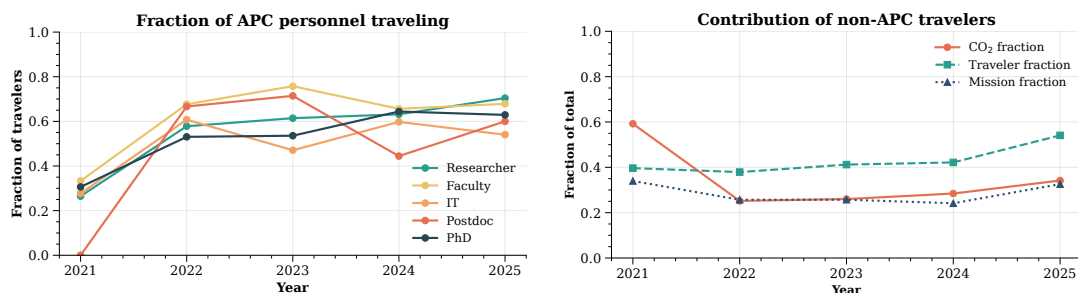


Figure 2: Left. Fraction of APC personnel traveling at least once per year, by category. Only individuals matched to the laboratory personnel database are included. Right. Fraction of missions associated with individuals not matched to the APC personnel database (“Others”).

After characterizing the laboratory population, we now introduce the notion of active travelers. We define travelers as individuals who perform at least one mission in a given year. The level of travel activity is then quantified by the fraction of personnel who become active travelers during that year. This quantity is shown in Fig. 2 for the different categories of core personnel.

Excluding the year 2021, which is strongly affected by the COVID-19 pandemic, the fraction of personnel traveling stabilizes at a relatively high level across all categories. From 2022 onward, typically between 55% and 75% of individuals perform at least one mission per year, with moderate variations depending on the category and year. Overall, this indicates that professional travel involves a majority of the laboratory personnel on a regular basis.

Finally, it is important to account for travelers present in the mission dataset but not matched to the APC personnel database (denoted as “Others”). These correspond to external collaborators or participants whose employment status is not defined within APC. Their contribution to the overall activity can be quantified in terms of missions. As shown in Fig. 2, these external participants account for a non-negligible fraction of the total number of missions, of the order of 20%–30% depending on the year. This indicates that a significant part of the travel activity associated with APC involves individuals outside the laboratory personnel database. While these missions are included in the total CO₂ budget, they are excluded from analyses normalized to the laboratory population.

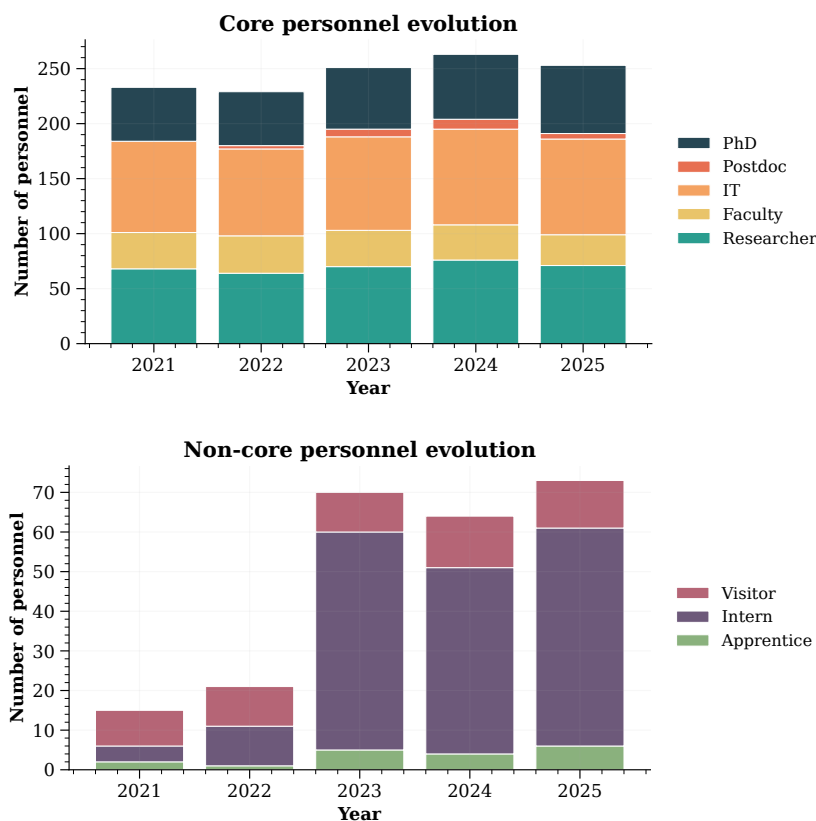


Figure 1: Evolution of laboratory personnel over the period 2021–2025. Top: core personnel (Researcher, Faculty, IT, Postdoc, PhD). Bottom: non-core categories (Apprentices, Interns, Visitors).

3 Drivers of travel-related CO₂ emissions

3.1 Travel emissions: overview and benchmark

We now turn to the evolution of travel-related CO₂ emissions and their interpretation in terms of laboratory activity and travel behavior.

Figure 3 presents the total emissions associated with APC missions over the period 2021–2025. The contribution from missions lacking sufficient metadata for project attribution (“unknown”) remains limited, typically below a few percent after 2021. This indicates that the overall emission budget is robust against missing information and that the observed trends are not driven by incomplete data reconstruction.

A strong increase in total emissions is observed from 2021 to 2025. While the low level in 2021 is largely explained by the COVID-19 pandemic, the upward trend continues well beyond the recovery phase. This increase cannot be solely attributed to the evolution of the laboratory size, as the number of personnel remains relatively stable over the same period. Instead, the number of active travelers shows a significant rise, indicating an intensification of travel activity.

An important aspect to consider is the presence of missions associated with individuals not matched to the APC personnel database (“Others”), already discussed in the previous section. These external participants account for a non-negligible fraction of the travel activity and contribute to the total CO₂ budget. As a consequence, care must be taken when defining normalized indicators, as the choice of numerator and denominator can significantly affect the interpretation.

This is illustrated in Figure 4, which compares different normalizations of the emission

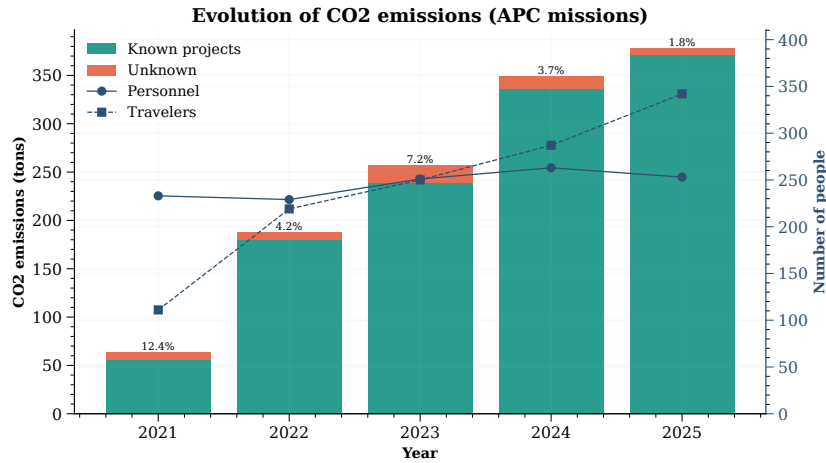


Figure 3: Evolution of APC mission-related CO₂ emissions between 2021 and 2025. The total emissions are decomposed into contributions from missions associated with identified projects (“known”) and missions lacking sufficient metadata for project attribution (“unknown”). The evolution of the workforce is overlaid on the right axis.

intensity. When normalized to the total number of laboratory personnel, emissions increase steadily over time, reflecting the growing global footprint of travel. A normalization per traveler leads to a lower apparent intensity, due to the inclusion of external participants. In contrast, when restricting both the emissions and the population to APC personnel only, the emission intensity per traveler is significantly higher and exhibits a marked increase. This demonstrates that internal travel behavior is the primary driver of the observed trend, while the inclusion of external participants tends to dilute the average emission intensity.

A useful point of comparison is provided by the recent synthesis of greenhouse-gas assessments performed across CNRS physics laboratories.² In this analysis, carbon footprints are normalized per person in order to compare laboratories of different sizes. The mean total footprint is reported to be about 8 ton of CO₂ per person, with purchases and capital goods representing the dominant contribution (53% of total emissions), while missions account for about 9% of the overall footprint. This corresponds to an average contribution of order 0.7 ton of CO₂ per person from professional travel. The same synthesis also shows that mission-related emissions have decreased by more than 40% between 2019 and 2024, remaining below their pre-pandemic level.

This benchmark is directly relevant to the present study because it is based on research laboratories and uses the same type of normalization, namely emissions per person rather than per traveler. In our case, the travel-related intensity reaches significantly larger values in the most recent years. This suggests that APC is characterized by a stronger contribution from high-intensity trips than the average laboratory included in the CNRS-INP sample. This interpretation is fully consistent with Fig. 5, which shows that a limited fraction of long-distance trips accounts for the majority of the total CO₂ budget.

To our knowledge, no consolidated carbon footprint assessment at the scale of the IN2P3 community, with a consistent normalization per person or per traveler, has been published so far.

²CNRS Physique, [Les laboratoires de physique évaluent leur empreinte carbone.](#)

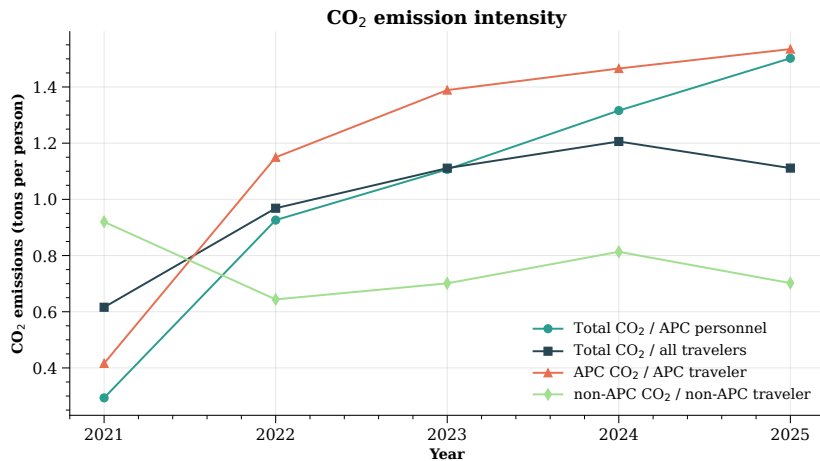


Figure 4: Evolution of travel-related CO₂ emission intensity at APC. Global normalizations (per personnel and per traveler) are compared with consistent indicators computed separately for APC and non-APC travelers.

3.2 CO₂ contribution by trip type

Beyond the global trends discussed above, it is important to identify the origin of CO₂ emissions in terms of the intrinsic characteristics of travel. In particular, the goal is to distinguish structural drivers, related to the nature of trips themselves, from effects associated with individual behaviors.

A first key element is the role of travel distance, which directly determines the emission scale. Travellers are classified according to the most distant trip performed within a given year, and their relative contributions are summarized in Table 2 and illustrated in Fig. 5.

Category	2021		2022		2023		2024		2025	
	T	CO ₂	T	CO ₂	T	CO ₂	T	CO ₂	T	CO ₂
Train	82.9	3.2	68.5	4.6	62.4	4.2	45.3	1.5	52.3	1.5
Short	0	0	0	0	4.4	4.0	15.3	13.5	9.9	9.1
Medium	9.0	21.1	9.1	15.9	8.8	8.4	16.4	17.4	13.2	14.2
Long	8.1	75.7	22.4	79.4	24.4	83.4	23.0	67.5	24.6	75.3

Table 2: Fraction of travelers (T) classified according to the most distant trip performed in a given year, and corresponding share of CO₂ emissions by transport mode. Values are expressed in %.

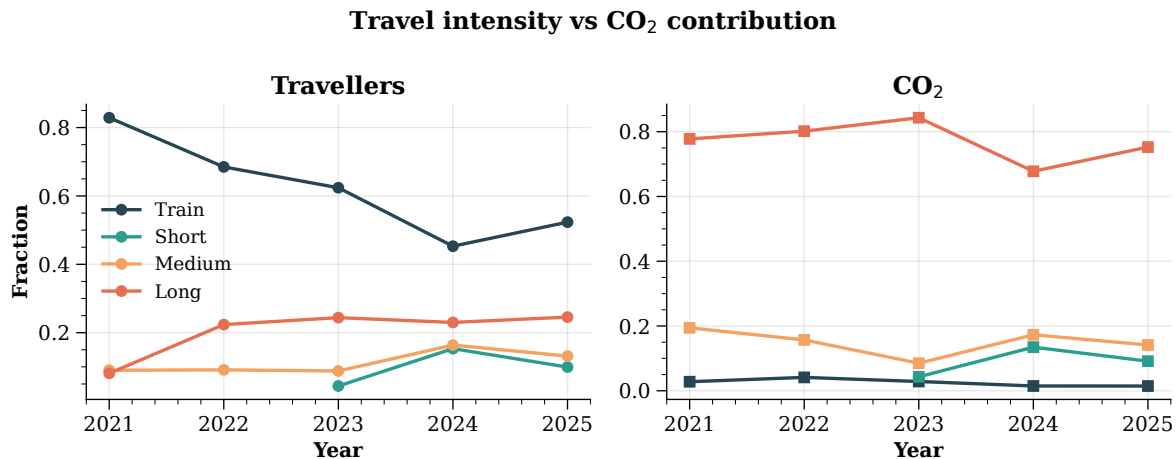


Figure 5: Evolution of travel patterns and associated CO₂ emissions by travel distance category. For each year, travellers are classified according to the most distant trip performed (train, short, medium, long). *Left*: fraction of travellers in each category. *Right*: corresponding fraction of total CO₂ emissions attributed to each category.

This classification reveals a strong imbalance between participation and impact. While only about 20–25% of travelers perform long-distance trips, these account for approximately 70%–80% of total emissions. This clearly identifies long-haul travel as the dominant driver of emission intensity.

At the same time, a large fraction of individuals, of the order of 50% in the most recent years, travel without using air transport, relying primarily on rail. The associated contribution to total CO₂ emissions is negligible. In contrast, short-haul flights are used by a relatively small fraction of travelers (about 5% and 10% in 2024 and 2025, respectively), but their contribution to total emissions has increased to around 10%.

A dedicated analysis of flight segments shows that a significant fraction of short-haul flights corresponds to connections within multi-leg itineraries. In the present dataset, only about 35% of short-haul segments are associated with travelers performing exclusively short-distance flights, while the remaining ~65% originate from individuals also performing medium- or long-haul travel.

In terms of emissions, this effect is somewhat reduced: 36.5% of the CO₂ attributed to short-haul flights corresponds to stand-alone short-distance travel, while the remaining fraction is associated with connecting segments of longer journeys. As a consequence, the contribution of short-haul flights to the total CO₂ budget should be interpreted as an upper bound.

After correcting for this effect, the effective contribution of stand-alone short-distance air travel is reduced to about 4% of total emissions. A route-level inspection further shows that this activity is concentrated on a limited number of recurrent European destinations. The ten most frequent destinations over the period 2021–2025 are Milan (30), Pisa (27), Florence (17), Bologna (16), Venice (15), Berlin (12), Dublin (11), Hamburg (10), Toulouse (8), and Edinburgh (6).

These destinations define a small number of well-identified intra-European corridors, indicating that stand-alone short-haul air travel is not only a minor component of the overall CO₂ budget, but also a highly localized one. Although its contribution remains small compared with the dominant role of long-haul travel, it is also the most straightforward to reduce, as flights below 1000 km could be replaced by rail alternatives when they do not form part of a longer itinerary.

3.3 Emission metrics at the traveler level

The analysis presented in the previous section has shown that the dominant driver of CO₂ emissions is the nature of the trips performed, in particular the occurrence of long-haul travel. We now investigate how this structure manifests itself at the level of individual travelers.

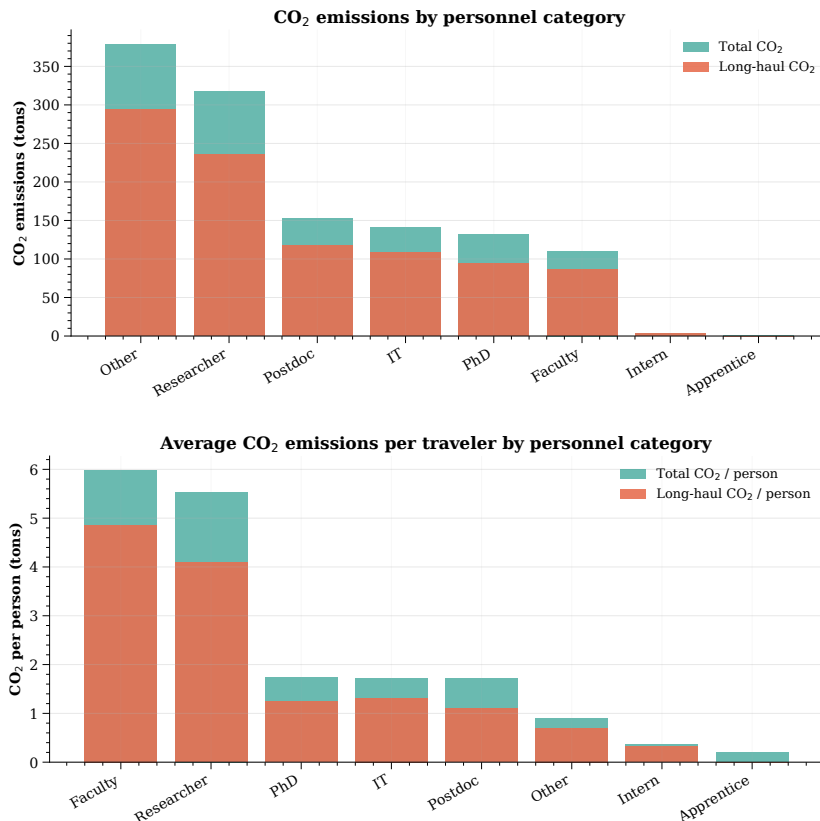


Figure 6: Total CO₂ emissions by personnel category (top) and average emissions per traveler (bottom). The red overlay indicates the contribution from long-haul trips, highlighting their dominant role across all categories.

A first question is whether the contribution of long-distance travel is associated with specific categories of personnel or reflects a more general pattern across the laboratory. Figure 6 (top) shows the total CO₂ emissions by personnel category, together with the contribution from long-haul trips. A similar comparison is reported in Fig. 6 (bottom), where emissions are normalized per traveler.

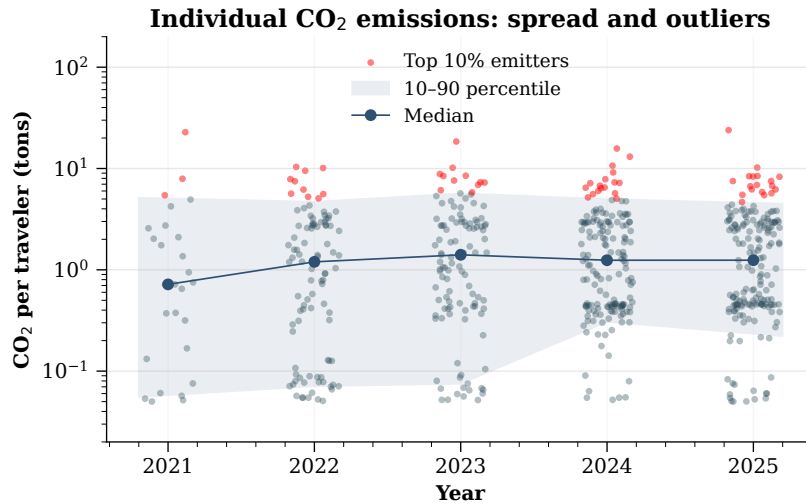


Figure 7: Distribution of annual CO₂ emissions per traveler. Each point represents an individual, with the shaded band indicating the 10th–90th percentile range and the solid line showing the median. Travelers in the top 10% of emissions are highlighted in red.

These figures show that, although the overall emission levels differ across categories, the contribution of long-haul travel is systematically dominant in all cases. This indicates that the emission structure is not driven by a specific subgroup of the laboratory, but reflects a common pattern of activity shared across personnel categories. Higher emission levels observed for faculty and senior researchers are therefore primarily associated with a higher frequency of long-distance travel, rather than with fundamentally different travel behaviors.

We next examine the distribution of emissions across individual travelers. Figure 7 shows the annual CO₂ emissions per traveler, highlighting both the bulk of the distribution and the most emitting individuals.

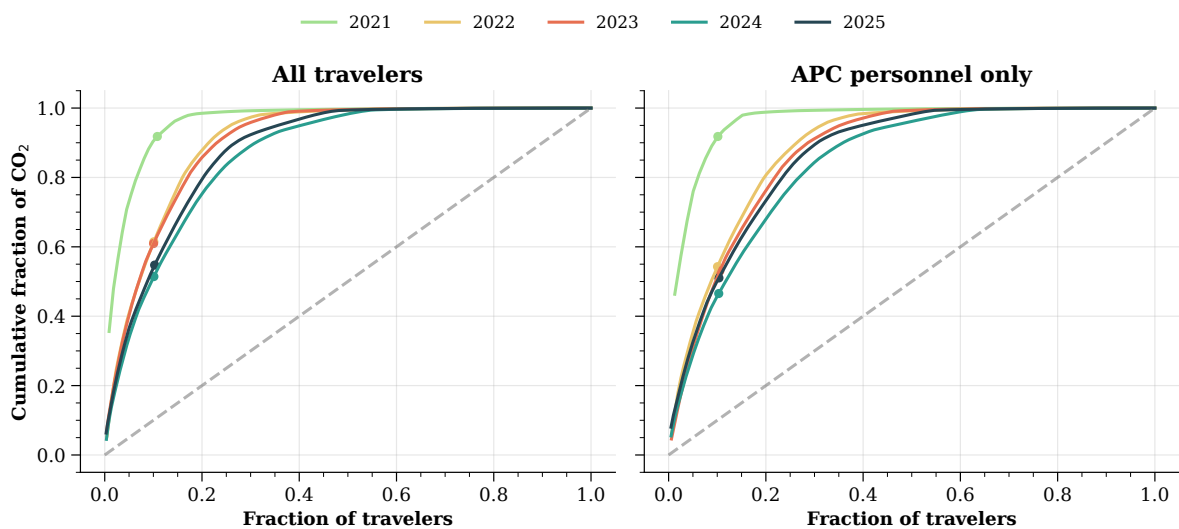


Figure 8: Cumulative distribution of CO₂ emissions across travelers. Left: full dataset. Right: APC personnel only. Travelers are ordered by decreasing individual emissions, and markers indicate the contribution of the top 10% of travelers.

The distribution is strongly skewed, with a relatively small number of high-emission individ-

uals extending the upper tail by more than one order of magnitude. However, this variability does not imply that the total emission budget is dominated by a few extreme outliers.

This is quantified in Fig. 8, which shows the cumulative contribution of travelers ordered by decreasing emission.

The results show that the top 10% of travelers account for approximately 50–60% of the total CO₂ emissions over the period 2022–2025, indicating that emissions are moderately concentrated, but not dominated by extreme outliers. The year 2021 exhibits a significantly higher concentration, which can be attributed to the reduced number of travelers during the COVID-19 period. Importantly, the close agreement between the full dataset and the APC-only selection demonstrates that this structure is intrinsic to the laboratory activity and not driven by external contributors.

Finally, we investigate whether high emission levels are associated with anomalous travel patterns, such as short-duration missions with disproportionately large CO₂ footprints. Figure 9 shows the relation between emission and mission duration.

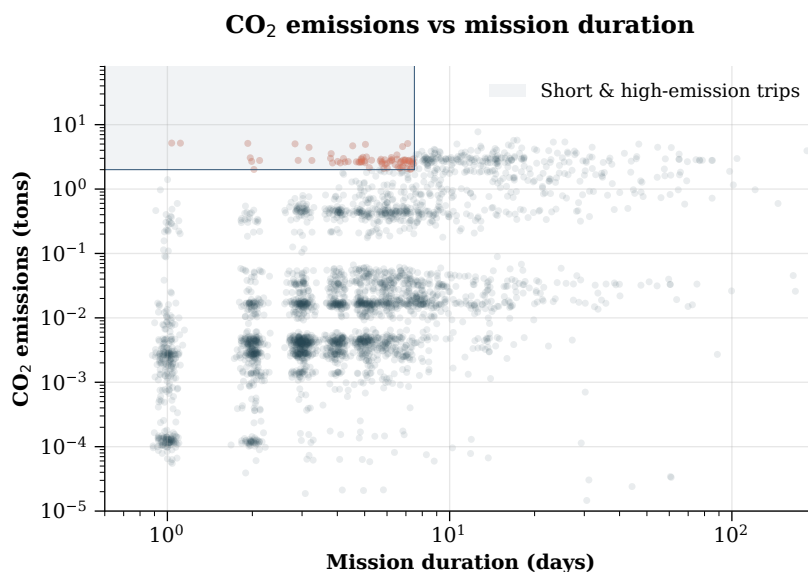


Figure 9: CO₂ emissions as a function of mission duration. The shaded region highlights short-duration, high-emission trips, corresponding to potentially inefficient travel patterns. Only about 1.5% of missions fall in this region.

The large vertical spread of points at fixed duration indicates that emission levels are primarily driven by travel distance, although duration may indirectly reflect travel efficiency strategies. Short-duration, high-emission trips are rare, representing only about 1.5% of the dataset. This confirms that the overall emission budget is not driven by anomalous individual behaviors, but by the structural characteristics of travel activity, in particular the occurrence of long-distance trips.

3.4 Evolution of CO₂ emissions by scientific group

The evolution of CO₂ emissions across the main scientific groups of APC is shown in Fig. 10.

All groups exhibit a similar temporal evolution, characterized by a sharp rise after 2021, reflecting the global recovery of scientific activity after the COVID-19 period, followed by sustained high levels in 2023–2025. The increase remains significant throughout the period and does not appear to saturate by 2025, when the direct impact of the pandemic can reasonably be considered exhausted.

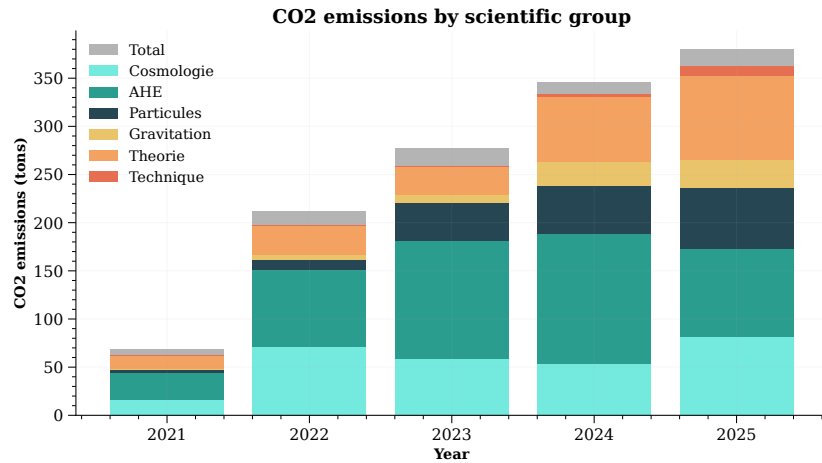


Figure 10: Evolution of total CO₂ emissions from APC missions, broken down by scientific group.

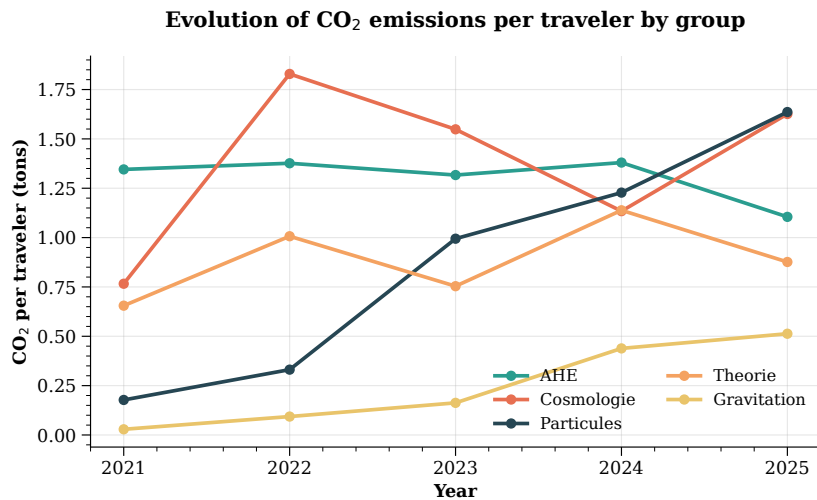


Figure 11: Evolution of mission-related CO₂ emissions per active traveler for the main APC scientific groups.

At the traveler level, Figure 11 shows substantial differences across the main APC scientific groups. These variations reflect the heterogeneous nature of the corresponding scientific activities and their associated travel patterns.

AHE exhibits a relatively stable behavior over the full period, with values around 1.3–1.4 ton of CO₂ per traveler until 2024, followed by a moderate decrease in 2025. Cosmologie shows a stronger year-to-year variability, with a peak in 2022 and another increase in 2025, likely reflecting fluctuations in long-haul missions associated with international collaborations and conferences.

Particules displays the strongest long-term increase, rising from a low level in 2021 to more than 1.5 ton of CO₂ per traveler in 2025. This evolution is consistent with the progressive recovery of travel activity after the COVID period and with increasing participation in large international experimental programs.

Theorie remains at intermediate values, typically around 0.7–1.1 ton of CO₂ per traveler, while Gravitation remains the least travel-intensive group throughout the period, despite a gradual increase after 2022.

Overall, this figure highlights that the carbon intensity of scientific travel strongly depends on the structure of the underlying scientific activity, in particular on the dependence on international collaborations, large-scale infrastructures, and intercontinental mobility.

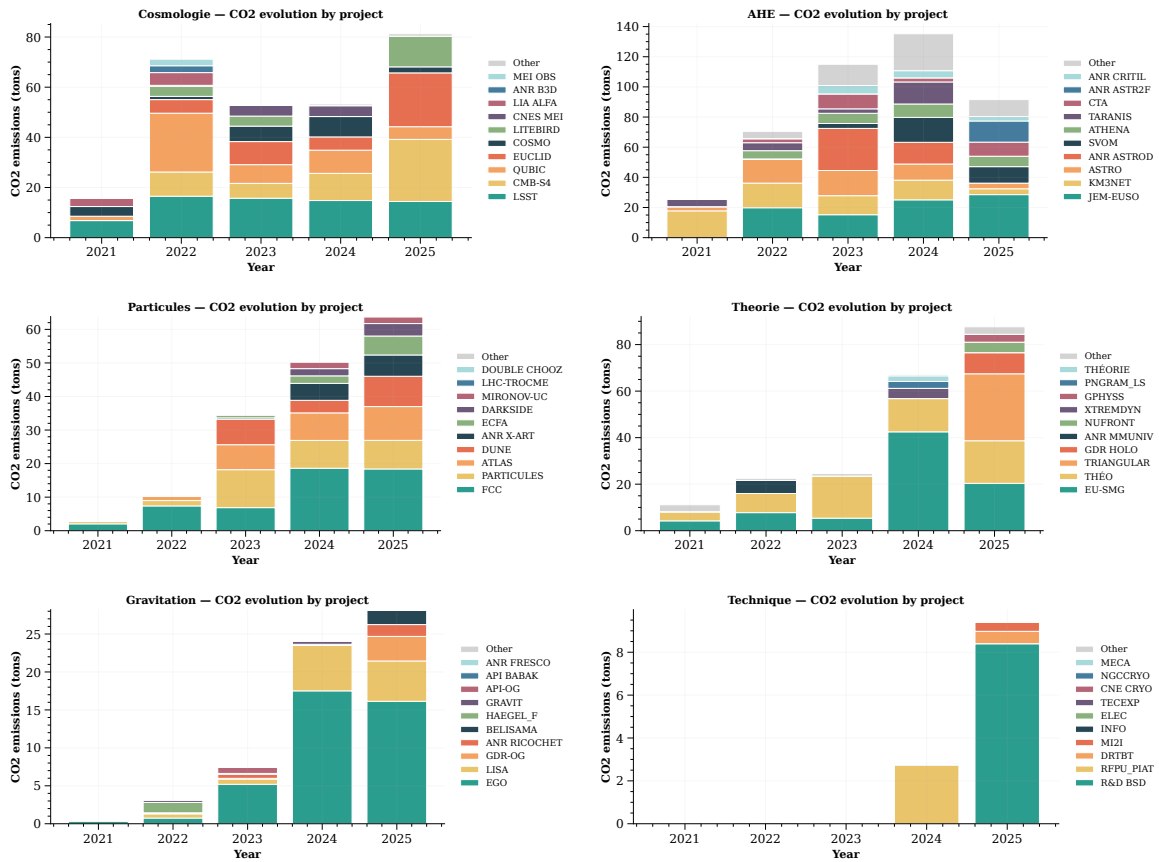


Figure 12: Evolution of CO₂ emissions for the main scientific groups of APC, with contributions broken down by project.

The heterogeneous nature of travel-related emissions is further confirmed by the detailed group-level trends. Excluding 2021, Cosmologie remains comparatively stable, while AHE shows a strong increase up to 2024 followed by a contraction in 2025. By contrast, Particules, Théorie, and Gravitation exhibit sustained growth over the whole period. This indicates that the global increase in emissions reflects both a common recovery of activity and specific developments within individual scientific domains.

To better understand these different trajectories, we examine in more detail how the emissions are distributed among projects within each group. The analysis includes all core scientific groups (AHE, Cosmologie, Particules, Théorie, Gravitation), as well as the Service Technique, which plays a central operational role in the laboratory.

A common pattern emerges across all groups: the emission budget is typically dominated by a limited number of large-scale international projects.

In Cosmologie, emissions are primarily driven by major survey and instrumentation programs such as LSST, Euclid, and CMB-S4, with a relatively stable internal structure over time. In AHE, the increase is associated with several large collaborations including CTA, KM3NET, ATHENA, and SVOM, leading to a strong rise between 2022 and 2024 followed by a slight contraction in 2025. The Particules group shows a broad and sustained increase, with contributions distributed across major projects such as ATLAS, FCC, DUNE, and DarkSide, reflecting a diversified engagement in multiple international programs. In Théorie, the contributions are more fragmented across many smaller projects, consistent with the distributed nature of theoretical

research, but still show a clear overall increase. The Gravitation group, while contributing at a lower absolute level, exhibits a strong rise after 2022, largely associated with projects such as LISA, Virgo-related activities, and associated ANR programs. Finally, the Service Technique contributes at a lower level but follows a similar temporal trend, reflecting the operational support required for large experimental infrastructures.

This analysis shows that the increase in emissions is not driven by a single project or domain, but rather by the combined growth of several major scientific activities. Within each group, the rise is typically associated with a limited number of flagship projects rather than a uniform increase across all activities.

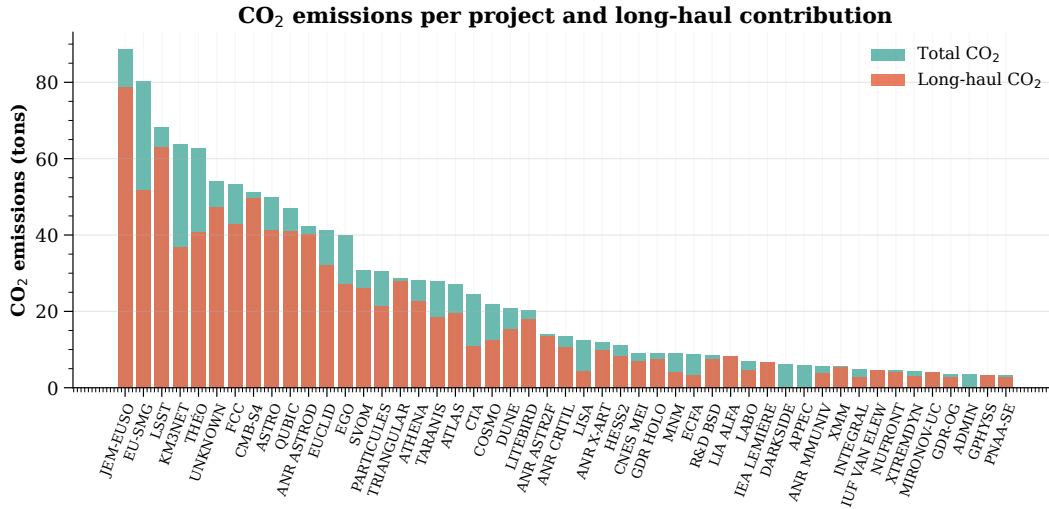


Figure 13: Total CO₂ emissions per project integrated over the period 2021–2025, together with the contribution from long-haul travel. Projects are ordered by decreasing total emissions.

To further clarify the origin of emissions, Fig. 13 shows the distribution of CO₂ emissions across projects, integrated over the period 2021–2025, together with the contribution from long-haul travel.

The project-level distribution is strongly hierarchical, with a limited number of projects accounting for a large fraction of the total CO₂ budget. Importantly, for most high-emission projects, the dominant contribution arises from long-haul travel, indicating that the overall CO₂ footprint is largely determined by participation in geographically distributed international collaborations.

This result provides a direct link between the structure observed at the group level and the global emission patterns discussed in the previous sections. It confirms that the laboratory CO₂ footprint is primarily driven by a limited number of large-scale scientific programs, rather than by diffuse or uniformly distributed travel activity.

Overall, the analysis shows that the observed increase in emissions reflects a structural property of modern scientific activity, in which participation in large international collaborations implies a sustained level of long-distance mobility.

3.5 Geographical distribution of emissions

The geographical distribution of travel-related CO₂ emissions is shown in Fig. 14, where emissions are aggregated by destination country over the period 2021–2025.

The distribution is highly heterogeneous, with a strong concentration of emissions toward a limited number of long-distance destinations. As summarized in Table 3, the United States alone accounts for nearly 30% of total emissions, followed by Japan (12%), Italy (9%), China

(8%), and several South American destinations such as Argentina and Chile.

Country	CO ₂ (tons)	Fraction (%)
United States of America	333.2	29.6
Japan	139.9	12.4
Italy	100.6	8.9
China	73.4	6.5
Argentina	62.3	5.5
Chile	50.2	4.5
Greece	41.2	3.7
France	36.1	3.2
Spain	25.3	2.2
South Korea	24.0	2.1

Table 3: Top destination countries ranked by total travel-related CO₂ emissions. Each trip is assigned to the non-French country involved in the journey, while domestic travel is attributed to France.

This pattern reflects the central role of intercontinental travel in the laboratory emission budget. In particular, the largest contributions are associated with North America, East Asia, and selected South American destinations, despite these representing only a limited fraction of total trips.

To disentangle the effect of travel frequency from intrinsic travel intensity, the lower panel of Fig. 14 shows the average CO₂ emissions per traveler for each destination country.

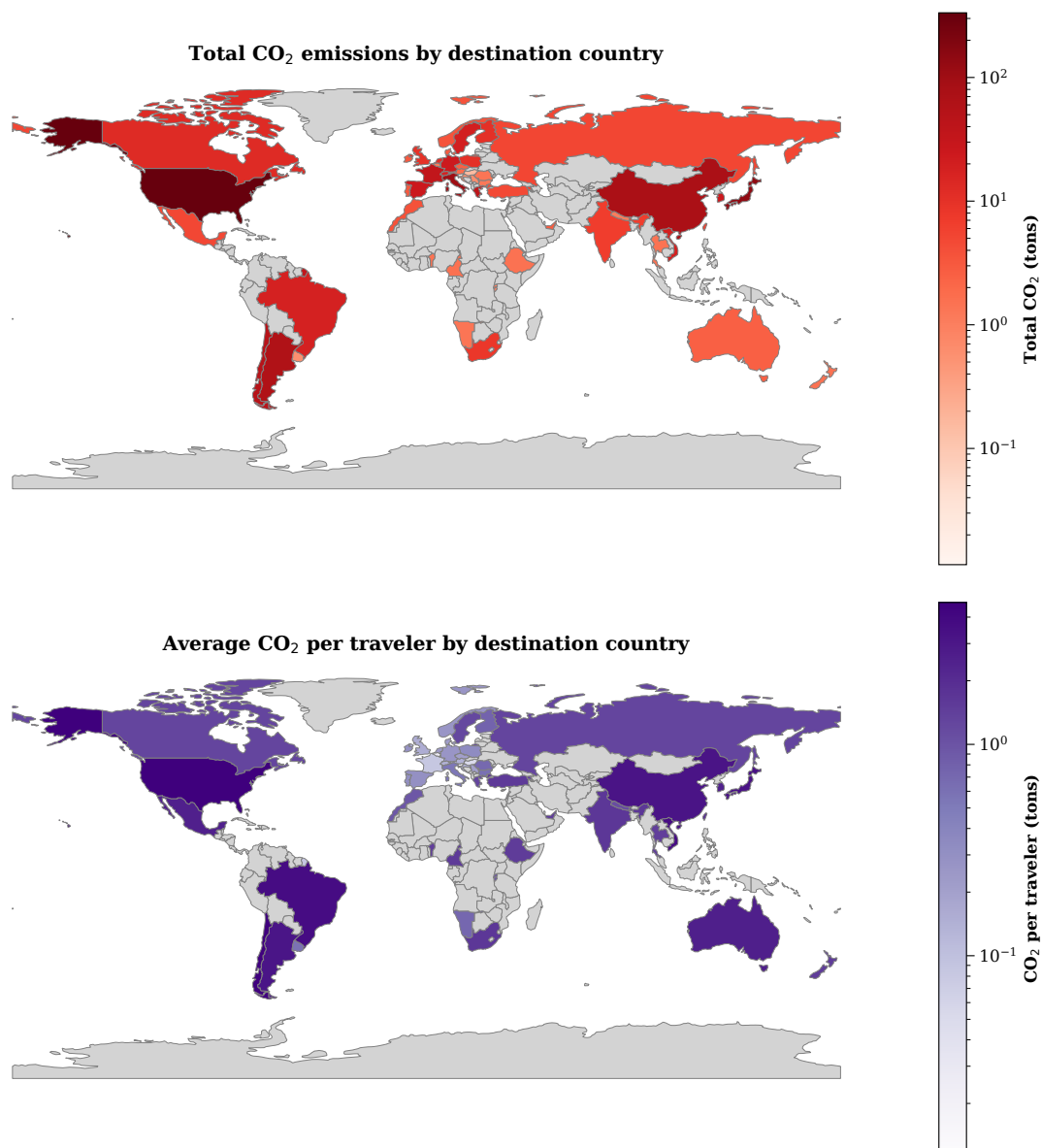


Figure 14: Geographical distribution of travel-related CO₂ emissions integrated over the period 2021–2025. Top: cumulative emissions by destination country. Bottom: average emissions per traveler, computed as the ratio between total emissions and the number of individuals traveling to each country. Each trip, regardless of transport mode, is assigned to the non-French country involved in the journey, while domestic travel is attributed to France. The color scales are logarithmic to account for the wide dynamic range of emissions.

The map highlights a different structure compared to total emissions: countries such as Chile, the United States, China, and Japan exhibit particularly high per-capita emissions, reflecting the impact of long-haul travel. In contrast, European destinations, although frequent, correspond to significantly lower emissions per traveler.

This is quantified in Table 4, where Chile and the United States reach values above 4–5 tons per traveler, compared to much lower values for short- and medium-haul destinations.

Country	CO ₂ (tons)	Individuals	CO ₂ /person
United States of America	333.2	71	4.69
Chile	50.2	11	4.56
Vietnam	18.5	5	3.71
Brazil	18.2	5	3.63
Japan	139.9	43	3.25
China	73.4	23	3.19
Argentina	62.3	20	3.12
Australia	2.6	1	2.58
Mexico	5.1	2	2.54
South Korea	24.0	10	2.40

Table 4: Average travel-related CO₂ emissions per traveler for each destination country. Values are computed over the full 2021–2025 period.

Finally, Fig. 15 provides a direct link between geography and scientific activity by showing the dominant contributing projects for the main destination countries.

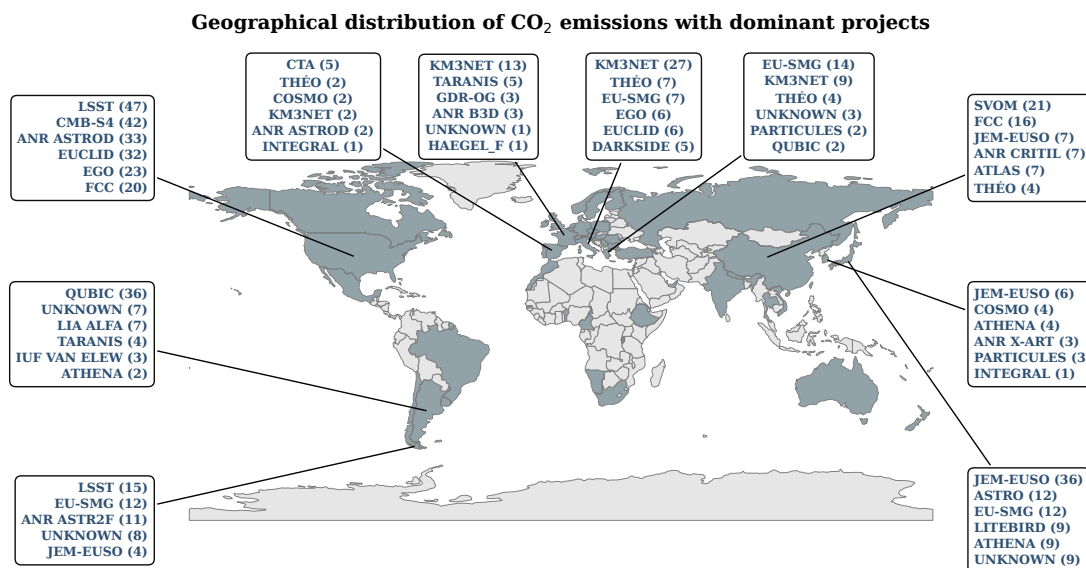


Figure 15: Geographical distribution of CO₂ emissions with the main contributing projects indicated for major destinations. Only projects contributing more than 1 ton over the period 2021–2025 are shown.

As illustrated in the map, emissions toward each region are typically associated with a small number of large-scale international collaborations. For example, travel to the United States is largely driven by cosmology and astroparticle projects such as LSST, CMB-S4, and Euclid, while Asian destinations are strongly connected to projects such as FCC, JEM-EUSO, and SVOM.

This confirms that the geographical structure of emissions is not random, but closely reflects the spatial organization of major scientific infrastructures and collaborations. In particular, the dominance of long-haul destinations directly mirrors the global distribution of large experimental facilities and survey programs.

Overall, the geographical analysis reinforces the conclusions of the previous sections: the CO₂ footprint of APC missions is strongly driven by long-distance travel associated with a limited number of international scientific programs.

4 General Observations

The interpretation of the results presented above is subject to important methodological limitations. Several indicators have been used in this study, including emissions normalized per personnel, per traveler, per mission, and by project or group. Each of these metrics captures a different aspect of the problem, but no unique standard appears to be established for comparing travel-related emissions across research institutions.

In addition, assessing whether the emission reduction targeted for professional travel is significant requires comparison not only with mission-related emissions in other laboratories, but also with other sources of emissions on which the laboratory may act. Without such benchmarks, the absolute level of CO₂ emissions associated with missions is difficult to interpret.

With these limitations in mind, the following observations summarize the main structural features of the emission patterns observed at APC.

Dominant drivers of emissions. The total emission budget is overwhelmingly driven by long-distance travel. Intercontinental destinations, in particular North America and East Asia, account for a disproportionately large fraction of total emissions, despite representing a minority of missions. More generally, CO₂ emissions are found to correlate strongly with travel distance, with only a weak dependence on mission duration. This identifies distance, and therefore the geographical organization of scientific activities, as the primary determinant of the carbon footprint.

Structural rather than individual origin. The distribution of emissions across individuals shows a moderate concentration, with the top 10% of travelers contributing approximately half of the total CO₂. While this indicates some level of inequality, it does not point to extreme outliers dominating the emission budget. Instead, emissions are primarily driven by the structural organization of research activities, rather than anomalous individual behaviors.

Activity versus intensity. The temporal evolution over the period 2021–2025 indicates an increase in emission intensity per individual. This trend is not primarily driven by changes in personnel, but rather by a rebound in travel activity combined with a higher average emission per mission. This suggests a post-pandemic shift toward fewer but more carbon-intensive trips.

Contribution of non-APC travelers. A significant fraction of total emissions originates from non-APC travelers, accounting for approximately 30% of the total CO₂ budget. This reflects the role of external collaborators and visitors in APC-funded missions, and indicates that a non-negligible part of the carbon footprint lies outside the direct control of the laboratory.

Limits of local optimization strategies. Although short-haul flights are often identified as a potential target for emission reduction, a large fraction of these segments correspond to connections within longer itineraries. Once this effect is taken into account, their contribution to total emissions is significantly reduced. More generally, the absence of extreme outliers and the dominant role of long-haul travel imply that individual-level behavioral changes or short-distance optimizations alone are unlikely to yield substantial global reductions.

Implications for mitigation strategies. The metrics presented in this study identify where emissions are generated, but do not, by themselves, determine what can be reduced. The potential for mitigation depends critically on the impact of travel on the laboratory's scientific and teaching activities. In particular, long-haul missions, while dominant in the emission budget, are often associated with core scientific infrastructures and international collaborations. As a result, effective mitigation strategies require a careful balance between emission reduction and

the preservation of scientific output, and must be defined at the level of the laboratory's overall research strategy.

A Project-to-group mapping

In the analysis, budget lines are first harmonized at the project level through an aliasing procedure, and projects are then associated with the corresponding APC group. The final mapping used in the analysis is given in Table 5.

Group	Projects
AHE	ACME, ANR ASTR2F, ANR COCOA, ANR COCOAP, ANR CRITIL, ANTARES, API CERRUT, ASTRO, ATHENA, CTA, GPHYSC, HESS, IEA LEMIERE, INTEGRAL, INTERCOSSG, IUF VAN ELEW, JEM-EUSO, KM3NET, MMTE 2023, MNM, PNAA-SE, SKA, SKA-LOFAR, SVOM, SWAN, TARANIS, XMM
Cosmologie	ANR B3D, ANR BXB, CMB_ERRARD, CMB-S4, CMB-SO, CNES MEI, COSMO, CRCN RICCI, EUCLID, LIA ALFA, LITE-BIRD, LSST, MEI OBS, QUBIC, SCIPOL
Gravitation	ANR FRESCO, ANR RICOCHET, API BABAK, API-OG, EGO, GDR-OG, GRAVIT, HAEGEL_F, LISA, VIRGO
Particules	ANR X-ART, ATLAS, DARKSIDE, DOUBLE CHOOZ, DUNE, ECFA, FCC, GIF2024, LHC-TROCME, MIRONOV-UC, PARTICULES
Theorie	ANR LACTEL, ANR MBH WAVES, ANR MMUNIV, ANR TIDALF, ANR XTREMF, COSMAG, CRCN SANTO, EUHOL, EU-SMG, GDR HOLO, GPHYSS, IEA NITTI, IEA ONDES, IEA VENNIN, NUFROnt, PHD LS, PHD LS-DL, PNGRAM_LS, THEO, THÉO, THÉORIE, TH-LEMOINE, TRIANGULAR, XTREMDYN
Technique	CNE CRYO, COMPUTEOPS, CRYOMAT, DRTBT, ELEC, INFO, ING SYST P, MECA, MICROE, MI2I, NGCCRYO, R&D BSD, RFPU_PIAT, SVMEC, TECEXP
Labo	ADMIN, BIENNALE, COMPUTEOPS, CQAP, CQAPP, FACe, FORMATION, LABO, PROSPECTIVES, QUAL, SECU
Outreach Direction	COMM, EU_PICO, MB-ARLES, PHYSIS APPEC, CQUIUM, LABOS

Table 5: Mapping between projects and APC groups used in the analysis.