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The elephant in the room: Long-haul air services and climate change

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ABSTRACT

This paper extends previous research that has examined the impact of banning (super) short-haul flights on climate change. Looking at all scheduled passenger flights worldwide, our results confirm that policies focused on super short-haul flights would have very limited climate benefits. Flights of less than 500 km account for 26.7 % of flights but only 5.2 % of fuel burnt, while flights of 4000 km or more account for just 5.1 % of flights, but 39.0 % of fuel burnt. When the results are broken down by region and country, it appears that the share of fuel burnt by long-haul flights varies according to social, political, economic and geographical factors, including remoteness. While fuel burnt is highly correlated with GDP at the country level, this is less true for long-haul flights, arguably because long-haul services are so geographically selective that not all countries can be expected to host them. We also find that since the mid-1990s, the long-haul segment has grown much more rapidly (+163 % seat-km) than the super-short-haul one (+28 %). These findings have important policy implications and suggest that "avoid" strategies should receive more attention than "shift" and "improve" strategies in aviation climate policy.

1. Introduction

Aviation is estimated to have accounted for about 2.4 % of anthropogenic CO_2 emissions in 2018 (including land use change) and 3.5 % of the net anthropogenic effective radiative forcing (ERF) in 2011 (Lee et al., 2021). The latter includes non-CO_2 effects, which are estimated to be two-thirds of the effect, although with significantly large error ranges (in other words, non-CO_2 effects could be much smaller or much larger).

The airline industry has argued that these proportions are small. For instance, a factsheet issued by the International Air Transport Association asks:

> *"Are airlines major contributors to climate change?*
> *The aviation industry emitted 915 million tonnes of CO_2 in 2019, roughly 2 % of total global CO_2 emissions."* (IATA, 2024).

Moreover, the Air Transport Action Group reports that:

> *"The global aviation industry produces around 2.1% of all human-induced CO_2 emissions".*

and that:

> *"Aviation is responsible for 12% of CO_2 emissions from all transports sources, compared to 74% from road transport."*[1]

Similarly, Ryanair writes that:

> *"Aviation is the most efficient form of mass point-to-point transport, accounting for just 2% of EU man-made CO_2 emissions. (Road transport creates 26%)."* (Ryanair, 2019).

These quotes implicitly suggest efforts should be made by other sectors or transport modes. This would perpetuate a pattern of "aviation exceptionalism", whereby the sector is subject to climate policy regulation that is less stringent than for other sectors, if not completely absent (Higham et al., 2022; Huwe et al., 2024). Highlighting a sector's small share of emissions is also typical of 'whataboutist' discourses of climate delay, which are used to opportunistically shift responsibility for climate action to others (Lamb et al., 2020).

A more reasoned approach is to compare like for like, bearing in mind that aviation is only a sub-sector within the broader transport sector. For instance, the "industry" sector is estimated to have accounted for 24 % direct (scope 1) GHG emissions in 2019, but if the "chemical industry" is isolated, the share falls to 3.4 % (IPCC, 2022). Similarly, the

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[1] https://atag.org/facts-figures/ (accessed on 12.04.2024).

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figures for "transport" and "aviation" would be 15 % and 1.65 %, respectively (IPCC, 2022). In that sense, aviation emissions are not abnormally low, especially for a sector that benefits a small share of the global population (only an estimated 11 % of the global population flew in 2018, with 1 % being responsible for around half of emissions from passenger air travel, see Gössling and Humpe, 2020). Given its very low energy efficiency, aviation's contribution to climate change is also disproportionately high compared to its use, estimated at 8472 billion passenger-km and 231 billion tonne-km (for freight) in 2018.[2] By comparison, railways covered 4085 billion passenger-km and carried 11,372 billion tonne-km in the same year,[3] but accounted for one eleventh of aviation's contribution to global GHG emissions.[4] But the most important reason to focus on aviation is that both its share and absolute contribution to anthropogenic climate change are likely to increase dramatically in the coming decades given both the growth in air traffic and improved efficiency in other sectors (see, e.g., Gössling and Humpe, 2024, Transport and Environment, 2024).

In this context, the aviation industry, academic researchers, policy-makers and activists have been reflecting on potential measures to mitigate the impact of commercial aviation on climate. Based on the "Avoid-Shift-Improve" framework (Creutzig et al., 2018), a key issue is the extent to which the mitigation of aviation GHG emissions should and could come from technological progress ("Improve") versus changes in travel behaviour, such as reduced long-distance travel activity ("Avoid"), and shift to lower-carbon transport modes such as rail ("Shift"). "Improve" strategies call for incentives to innovate and for significant public funding, which has not yet made a technological revolution a reality. Indeed, progress in fuel or climate efficiency (i.e. fuel burnt or GHG emitted per passenger-km or per seat-km) has been more than offset by the growth in air traffic to date (i.e. number of flights and distance flown) (Lee et al., 2021; Dobruszkes and Ibrahim, 2022). Alternative technological solutions are immature and/or difficult to implement (Gössling and Humpe, 2024), to the point that some consider them "useful myths" (Peeters et al., 2016) and question the very idea of "sustainable aviation" (Hopkins et al., 2023). This is particularly the case for the long-haul segment, in which technological decarbonisation is even more challenging (EUROCONTROL, 2023). When it comes to pursuing changes in travel behaviour, an increasing number of stakeholders agree that this involves regulations to discourage air travel (leading to debates between focusing on industry and governments versus individuals, see Dolšak and Prakash, 2022).

In recent decades, the emphasis has been overwhelmingly on supporting technological innovation and (to some extent) persuading air travellers to shift to high-speed rail (HSR) services, where possible. Introducing constraints to the growth of the aviation industry and air travel activity has thus remained a "transport policy taboo" (Gössling and Cohen, 2014) in most political and industrial circles, in contrast to some research centres and several environmental NGOs. However, Austria and France have recently decided to ban domestic (super) short-haul flights under certain conditions, including the existence of alternative rail services.

Such seemingly radical measures have quickly spawned a new body of literature aimed at assessing the efficiency of such bans. Scholars have considered both existing and potential bans. All of the published research concludes that banning (super) short-haul flight results only in limited climate benefits. The reason is simple: while short-haul flights are inefficient (a single flight emits a lot of GHGs per passenger-km), a focus on *absolute* emissions shows that a long-haul flight emits more GHG than a shorter flight (Fig. 1). The key issue, then, is the balance between shorter flights (very many but with lower emissions per flight) and longer flights (fewer but with much higher impacts per flight). For example, looking at all flights departing from 31 European countries, Dobruszkes et al. (2022) found that "flights shorter than 500 km account for 27.9% of departures but only 5.9% of fuel burnt. In contrast, flights longer than 4,000 km account for 6.2% of departures but 47.0% of fuel burnt". EUROCONTROL (2023) found similar results for 28 European countries, with flights shorter than 500 km accounting for 29.3 % of departures but 6.1 % of CO_2 emissions, and flights from 3000 km accounting for 8.7 % of departures but 54.9% of CO_2 emissions. Gössling et al. (2017), who focused on holiday trips from Germany,[5] found that air trips of at least 10,000 km accounted for 1.9% of trips but 14 % of CO_2 emissions, all transport modes being considered (the figures increase to 5 % and 18 %, respectively, when they are recalculated among air trips only). In addition, prospective research on potential zero-emission pathways for tourism have highlighted the key role of the distance travelled, both directly (going further requires more energy) and indirectly through the use of transport modes per distance range (Peeters and Papp, 2024).

Other estimates confirm the limited climate benefits of short-haul flight bans for the usual thresholds considered by actual policies, namely 500 km or 2.5–3 h by rail (Table 1). A limitation of all these published works is the restricted scope of the analysis, ranging from one single country to a macro-region (Table 1). In addition, some works have considered changes in trips, flying time or aircraft movements but not in terms of fuel burnt or of GHG emissions.

In a nutshell, previous research has been limited to Europe or one single country and has shown that short-haul flights contribute little to climate change, while long-haul flights account for the lion's share of the impact on climate change. As a result, while bans on short-haul flights would reduce the sectors' emissions to some extent, much more policy attention should be paid to the long-haul segment, as it seems to constitute the proverbial "elephant in the room" when it comes to aviation and climate change. At the same time, to the best of our knowledge, and despite the emergent interest in the challenge of long-haul travel for climate change debates (see, e.g., Peeters and Landré, 2012; Vorster et al., 2012; Gössling et al., 2017; Sun and Lin, 2019), similar investigations have not been carried out at the global level, so it is not clear to what extent these conclusions can be generalised at the level at which climate change ultimately plays out. As a result, the aim of our paper is to extend this analysis to the global passenger aviation market, with a particular focus on the long-haul segment, and how its importance varies across different countries and world regions.

The remainder of the paper is as follows. The next section introduces the methodology and data used. Section 3 presents the results, and Section 4 discusses the results and concludes.

2. Methods and data

Our overall strategy is to use a simplified model of fuel burnt that is fed by airline data describing the provision of air services. Among the available simplified models of fuel consumption, we have opted for the Fuel Estimation in Air Transportation (FAET) non-linear model proposed by Seymour et al. (2020), in which fuel is a quadratic function of the distance flown, with specific parameters for each aircraft type. FAET is available as a list of equations, with one equation per aircraft type (see Seymour et al., 2020, Appendix M, Table M.7). The quadratic shape of these functions is due to the extra fuel needed for a longer flight; indeed, flying longer involves more fuel, and this makes the aircraft heavier on take-off. Since the aircraft is heavier, it then requires even more fuel to take-off. In addition, these functions already take into account the inevitable detours faced by commercial flights compared to the shortest

[2] Source: ICAO. Figures include international non-scheduled passenger traffic.

[3] Source: UIC.

[4] About 0.089 Gt CO_2-eq for rail vs 0.979 for aviation. Source: IPCC (2022), Figure 2.20.

[5] Stay of five days or more by German-speaking individuals of at least 14 years old.

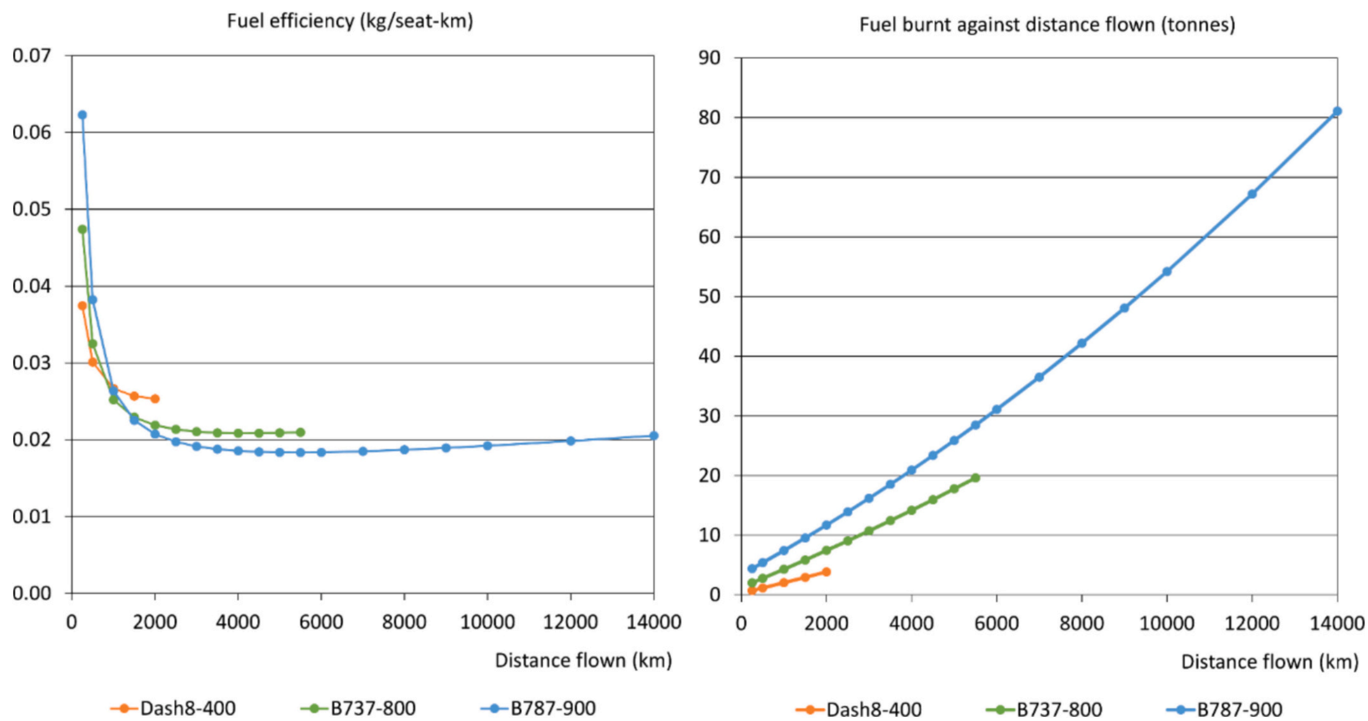

Fig. 1. Fuel efficiency (left) versus absolute fuel burnt (right) against the distance flown. Source: based on Seymour et al. (2020) (fuel burnt) and OAG Schedules (average seat capacity).

route.

As for input data, for each flight the FAET model simply requires two key parameters related to air supply, i.e. the aircraft type and great-circle distance flown. This information was extracted from OAG Schedules, from which all 2018 scheduled passenger air services have been extracted. We also extracted the annual frequency and the operating airline. The result takes the form of disaggregated data, with one database row for each airport-pair/airline/aircraft type combination (n = 207,700). In several cases, the aircraft type was too general. For instance, it could be referred to as the "A330 series", while the FAET model requires the specific type (e.g., A330–200 or A330–300). Disambiguation was obtained mostly through the systematic use of the AeroTransport Data Bank (http://www.aerotransport.org), and from various other websites when needed.

It is worth noting that given our research aim, this paper is fundamentally based on the supply (provision of air services) rather than demand (actual trips made by the passengers). As such, our objective is not to estimate the impact of individual trips but the impact of a whole sector of activity (passenger aviation) and of different travel segments within it (e.g., short-haul vs. long-haul). In this sense, our paper differs from papers in which the authors have estimated the share of short-haul flights that could be banned under different time and connectivity constraints (e.g., Reiter et al., 2022). This also implies that this paper does not distinguish between the use of (super-) short-haul flights for connecting purposes and for point-to-point travel.

The output of the FAET model is the estimated amount of fuel burnt for one flight, which is then multiplied by the annual frequency. Fuel burnt is considered here as a proxy for climate change, bearing in mind that CO_2 emissions are strictly proportional to fuel burnt. In contrast, the non-CO_2 component of aviation climate change depends on where and when emissions occur, making it very difficult to estimate the climate footprint of a single flight (see Dahlmann et al., 2023). We therefore have chosen to consider fuel burnt as the key metric, which also allows our global assessment to be compared with the results obtained by Dobruszkes et al. (2022) for 31 European countries.

Results at the country level are mapped. They are also regressed against gross domestic product (GDP) using simple linear regression models. Models are set for our whole dataset, then also for specific distance range. The residuals of the long-haul model are mapped and discussed. Mapping the residuals has long been recognised as an effective way of thinking beyond the models about additional factors that shape the phenomena under investigation (King, 1969: 148).

In addition, it is worth noting that there is no agreed definition of "super-short", "short", "medium" and "long-haul" flights in the literature, with authors and (inter)national organisations adopting diverse definitions. For instance, EUROCONTROL has defined long-haul flights based on 3000 km, 4000 km and 5000 km (EUROCONTROL, 2023, EUROCONTROL, 2022 and EUROCONTROL, 2020, respectively). In this paper, we defined "super short-haul" and "long-haul" flights as those shorter than 500 km, and 4000 km or more, respectively.

Lastly, it is worth noting that there is no perfect threshold to consider for a potential flight ban. In Europe, it has been found that the competitive advantage of HSR services over airlines decreases rapidly between 2 and 2.5 h (Dobruszkes et al., 2014). If HSR services are operated at 300 km/h with few stops, this roughly results in an average speed of 250 km/h, and thus 500 km for a two-hour journey. However, the distance could be shorter if high-speed trains run on both high-speed and conventional lines (as in Europe and South Korea) rather than only on high-speed lines (as in China and Japan). The distance could also be longer due to different sensitivities to time across countries to the location of airports compared to HSR stations, to relative fares, etc. For instance, some authors have suggested that in China, HSR services would interact with air services up to a threshold that varies between 800 and 1300 km (Li and Rong, 2022).[6] Overall, this paper puts emphasis on the 500-km threshold but also presents results for lower and higher values. Table A1 (see the Appendix) illustrates these thresholds

[6] The 1300 km match with the Beijing-Shanghai HSR, opened in 2011, where the very high volume of HSR services (several services per hour serviced with long and high seat density trainsets) did not prevent the volume of air services from continuing to increase (+3500 yearly flights and + 643,359 seats offered when comparing 2018 to 2010 in OAG Schedules).

Table 1
Research works on shorter flight bans to date.

Author	Market	Ban	Main conclusions
Avogadro et al. (2021)	Europe (28 countries)	Potential ban based on rail-against-air travel time	When limiting the increase in weighted travel time to 20 %, CO_2 emissions of intra-European air travel could be decreased by 4.72 %.
Bonilla and Ivaldi (2023)	France	Existing ban	Air transport accounts for only 3 % of trips on the affected routes.
Cantos-Sánchez et al. (2023)	Madrid-Barcelona and Madrid-Valencia corridors	Potential ban	External environmental costs would decrease by 11 % on the Madrid-Barcelona corridor and would increase by 12 % on the Madrid-Valencia corridor.
Dobruszkes et al. (2022)	Europe (31 countries)	Potential ban of all flights based on distance flown	The 500-km threshold would decrease aircraft departures by 27.9% and fuel burnt by 5.9 %. Flights longer than 4000 km represent 47.0 % of fuel burnt for only 6.2 % of departures.
Reiter et al. (2022)	87 non-stop flights from 21 German airports	Potential ban based on rail travel time (3 and 6 h) and the share of connecting passengers	The 3-h (6-h) threshold would decrease airline seat capacity by 4 % (32 %) If flights with less than 10 % (80 %) of connecting seats were banned, the decrease of CO_2 emissions would be 2.7 % (22 %).
Szymczak (2021)	Europe (30 countries)	Potential ban based on rail travel time (3, 4, 5 and 6 h)	The 3-h (6-h) threshold would decrease flying time by 1 % (6 %) and aircraft movements by 3 % (17 %).

for a number of existing air routes.

3. Air services and related fuel consumption: The tyranny of the distance flown

3.1. Global results

Fig. 2 shows the global results as cumulative curves for a range of parameters (flights, seats, km flown, seat-km and fuel burnt). In addition, results for selected distance thresholds are presented in Table 2. It is clear that the provision of passenger air services is dominated by relatively short flights, with 26.7 % of flights being shorter than 500 km and only 45.5 % being longer than 1000 km). However, only 5.2 % of the fuel is burnt by flights shorter than 500 km compared to 82.1 % for flights longer than 1000 km, 46.7 % for flights over 3000 km and 39 % for those over 4000 km. This means that a small proportion of flights is responsible for a large proportion of the fuel burnt, as evidenced by the Lorenz curve, which shows that approximately one half of the fuel consumption is due to the longest 10 % of flights, while more than 70 % of fuel consumption is due to the longest 30 % of flights (Fig. 3).

These global results therefore confirm all previous findings from more limited markets that shorter flights dominate the provision of air services while the fuel burnt (and therefore the climate footprint) is dominated by longer flights. However, the global results differ to some extent from European results (Table 3). While the distribution of flights per distance range is very similar between the two scales, the distribution of fuel burnt is more significantly different when flights longer than 4000 km are considered. Despite a very similar proportion in terms of frequency (5.1 % for the world vs 6.2 % for Europe), the associated fuel burnt is estimated at 39 % for the world against 47 % for Europe.

There are at least two possible explanations for this difference. First, it could be that long-haul flights from Europe are longer than average. However, Fig. 4 seems to refute this hypothesis since flight distributions are very similar with respect to distance. Second, it could be that long-haul flights from Europe are not operated by the same aircraft as the global average. Indeed, Fig. 4 shows that global fuel burnt is proportionally higher than from Europe up to 8900 km (this is partly due to less fuel burnt from/within Europe between 2000 and 4000 km, which influences the remainder of the cumulative curve). After 8900 km, the fuel curves cross each other, and the fuel burnt for Europe becomes proportionally higher than that burnt for the whole world. Such differences may be due to aircraft technology and size, with older and heavier aircraft consuming more fuel, all other things being equal. A first examination of our detailed dataset shows the higher share of old four-engine A340s from Europe than for the whole world for flights longer than 8900 km (respectively 10 % and 4 % of departures), which could explain part of the gap. These airliners burn significantly more fuel than their contemporary counterparts – two-engine A350s (Table 4). For instance, an A340–600 burns around 30 % more fuel than an A350–1000.

In addition, it is worth noting that as in the European case (Dobruszkes et al., 2022), the global results show a high correlation between seat-km offered and fuel burnt estimated under the assumption of a simplified fuel consumption model (Fig. 5; see also the closeness of seat-km and fuel burnt curves in Fig. 2). This confirms that seat-km would be acceptable as a first proxy for investigating the climate change footprint of aviation.

Moreover, it is worth considering trends in the airline markets. Indeed, if one considers seat-km supplied (i.e. our best proxy of fuel burnt) by distance range over the 1996–2018 period, we see that the highest growth rates relate to flights of more than 1000 km (+212 %), and the second-highest (+163 %) to flights over 4000 km that we define here as 'long-haul' (Table 5). In other words, the most dynamic passenger aviation markets are those that generate the greatest impact on climate and for which "shift" strategies are difficult, if not impossible, to implement. Conversely, this highlights that policies focusing on super-short-haul flights of less than 500 km target the flight segment that has grown the least (+28 %) since the mid-1990s.

3.2. Geographical patterns

Beyond the aggregated results above, the absolute amount of fuel burnt and the share of long-haul flights varies widely between region and countries. At the regional level (Table 6), there is a clear mismatch between fuel burnt and population, as evidenced by the fuel/capita ratio, which ranges between 5.5 kg for the Indian subcontinent to 42 times more (230.2 kg) for the Oceania/Pacific region. This is consistent with existing evidence on striking global inequalities in air travel (Gössling and Humpe, 2020; ICCT, 2022). Furthermore, the split of fuel burnt by distance range also differs across regions. The contribution of long-haul flights ranges from 21 % for the Maghreb to 59 % for Oceania-Pacific. The share of fuel burnt on long-haul services is also higher than the global average of 39 % for Sub-Saharan Africa (although it relates to a very low volume of fuel burnt), the Middle East and Europe.

In addition, Table 7 shows the fuel burnt on long-haul flights per macro-region pairs. Here countries have been grouped into seven areas for ease of reading. The main markets that appear are the interlinks between Asia, Europe and North America (about half of the fuel burnt by long-haul flights). This reflects the dominant patterns of the globalization processes and their dense interactions expressed, for instance, in international trade in value terms, containerised maritime transport and telecommunications. While the purpose of most passenger air travel is

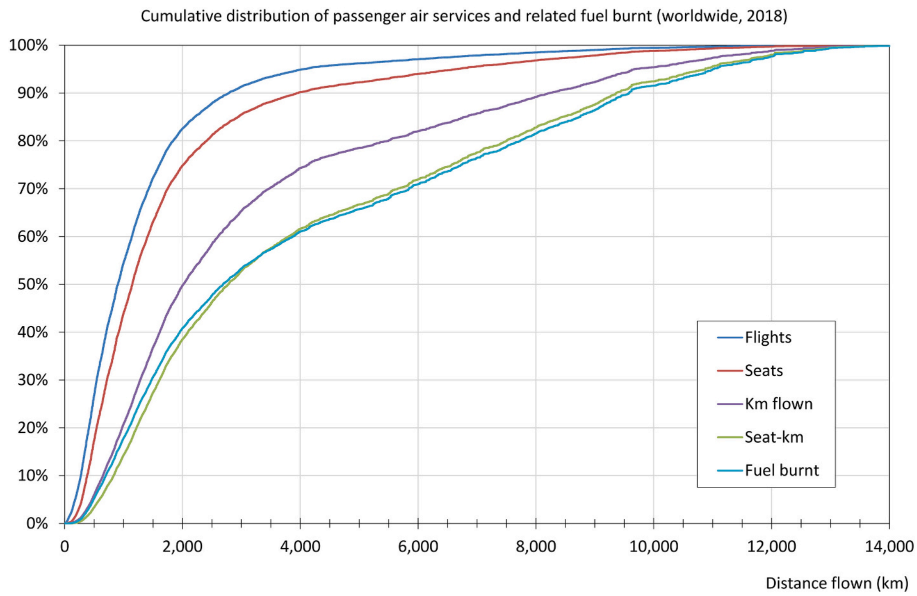

Fig. 2. Cumulative distribution of passenger air services and related fuel burnt (2018).

Table 2
Results by distance threshold.

		Distance	Flights	Seats	Km flown	Seats-km	Fuel burnt
Short-haul	Super short-haul	<200 km	8.7%	3.4%	1.0%	0.4%	0.7%
		<500 km	26.7%	17.3%	6.0%	3.4%	5.2%
		≥500 km	73.3%	82.7%	94.0%	96.6%	94.8%
Medium-haul		≥1000 km	45.5%	56.0%	79.2%	85.7%	82.1%
		≥2000 km	17.4%	25.2%	50.2%	61.5%	59.2%
		≥3000 km	8.7%	14.5%	34.7%	47.2%	46.7%
Long-haul		≥4000 km	5.1%	9.8%	25.7%	38.4%	39.0%

leisure, not business (Dobruszkes et al., 2019), its geographical patterns seem to overlap with those of economic globalization.

A breakdown by country gives more details, showing the large variation in the share of fuel burnt per distance (Fig. 6). Fuel burnt by flights of less than 500 km is usually a few percentage points, but it can occasionally be closer to a quarter in countries with difficult surface transport and/or a "lack" of longer air services (Colombia, Norway). Interestingly, however, there is more variation in the share of fuel burnt by flights longer than 4000 km. Several countries have a low or very low share because they have few air connections with other countries worldwide (e.g., Norway, Sweden,[7] Tunisia, Iran, Pakistan, etc.). This can be due to a small population size, poverty or political isolation. For other countries, the high share of fuel burnt from long-haul flights is likely due to their remoteness from the main markets (e.g., Australia, New Zealand, South Africa and Chile), to the fact they host a global airline hub (e.g., United Arab Emirates, Qatar, UK, Germany, France and the Netherlands) and to them being tourist spots in poor countries where air services benefit mainly long-distance tourists from abroad (e.g., Cuba). Another reason is when a country (France, for example) has retained former, remote territories with its overseas departments. Lastly, many Sub-Saharan African countries have a high share of fuel burnt by long-haul flights, although absolute volumes are low. Here, the high

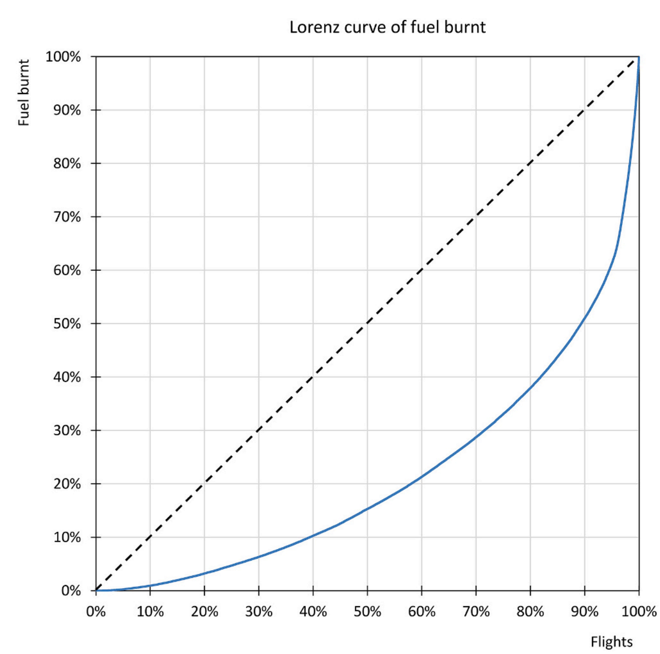

Fig. 3. Lorenz curve for fuel burnt (2018). Gini = 0.57.

[7] Regarding Norway and Sweden, this could be due to the fact their flag carrier SAS is shared with neighbouring Denmark, where the airline's main hub is located.

Table 3
Comparing the world to Europe (31 countries).

		Distance	Flights		Fuel burnt	
			World	Europe-31	World	Europe-31
Short-haul	Super short-haul	<200 km	8.7%	4.5%	0.7%	0.3%
Short-haul	Super short-haul	<500 km	26.7%	27.9%	5.2%	5.9%
Short-haul		≥500 km	73.3%	72.1%	94.8%	94.1%
Medium-haul		≥1000 km	45.5%	43.4%	82.1%	82.1%
Medium-haul		≥2000 km	17.4%	16.0%	59.2%	60.9%
Medium-haul		≥3000 km	8.7%	8.7%	46.7%	51.4%
Long-haul		≥4000 km	5.1%	6.2%	39.0%	47.0%

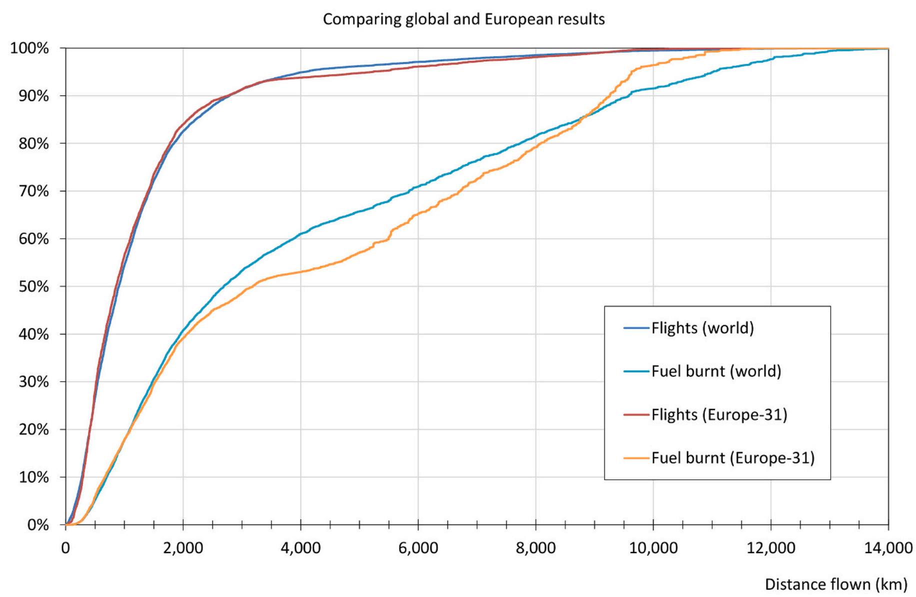

Fig. 4. Cumulative distribution of flights and fuel burnt in the world and in Europe.

Table 4
Fuel consumption of older A340s and new A350s (tonnes). Average seat capacities calculated from OAG based on 2018 air services.

Distance (km)	A340–300 (274 seats)	A340–500 (341 seats)	A340–600 (323 seats)	A350–900 (298 seats)	A350–1000 (330 seats)
6000	46	54	56	42	43
8000	65	74	77	57	59
10,000	85	95	100	72	77
12,000	108	119	125	88	96

share is due mainly to the weakness of short- and medium-haul air services in the context of a poorly integrated continent (Pirie, 2014).

Unsurprisingly, the absolute amount of fuel burnt by a country is highly correlated to GDP (Fig. 7), and therefore to both its population size and wealth. A 1 % increase in GDP would be expected to increase fuel consumption by 0.8 %. However, regression results by distance range give a more nuanced picture (Table 8). Notably, we find that the R^2 for flights longer than 4000 km is substantially lower (0.50) than for shorter flights (in the 0.66–0.70 range). The reason for this somewhat counterintuitive result is probably that long-haul air travel is more geographically selective than short- and medium-haul air travel. For instance, in 2018, only 62 cities worldwide were connected to the three major global/world cities, namely London, New York and Tokyo.[8] In this context, long-haul traffic is operated mostly through the hub-and-spoke model in order to adequately connect long-haul flights with each other and/or with short- and medium-haul flights.[9] Only selected places can be expected to accommodate a high volume of long-haul services. When this happens, the correlation between the provision of long-haul services – and hence the amount of fuel burnt – and country's economic and demographic attributes (the GDP in our regression) is likely weakened.

Fig. 8 shows the residuals of the regression model run for flights longer than 4000 km. Countries with a positive residual (i.e. more fuel burnt on such flights than expected given their GDP) reflect several logics. First, there are countries that are remote from the rest of the world (Australia and New Zealand) or at the edge of their macro-region (South Africa, UK, Ireland) or between two macro-regions (Iceland).

[8] Authors' calculations based on OAG Schedule.

[9] Notwithstanding the growth of point-to-point long-haul flights thanks to the advent of high-range/lower-capacity wide-body jets such as A350s and B787s.

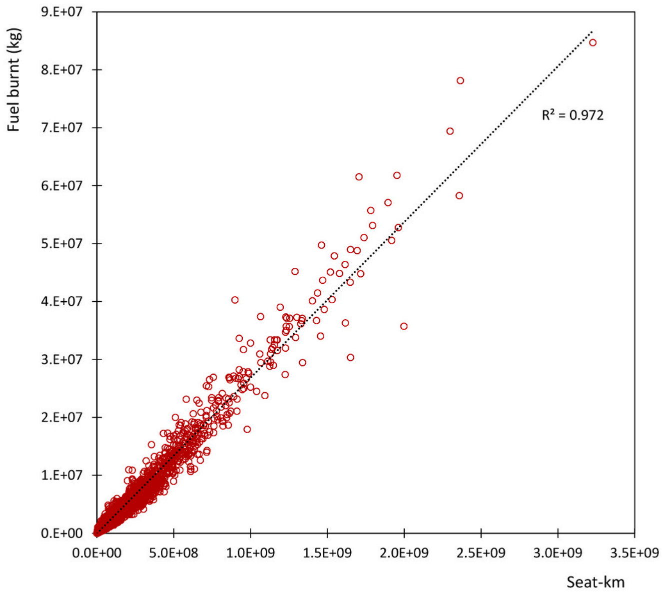

Fig. 5. Fuel burnt (FAET model) against seat-km per airport pair/aircraft type combination in 2018 (n = 26,731).

Table 5
1996–2018 growth of seat-km supplied. Source: computed by the authors based on OAG Schedules.

Distance range	Seat-km (1996)	Seat-km (2018)	Growth rate
<500 km	2.62E+11	3.35E+11	+28 %
500–999 km	5.04E+11	1.10E+12	+118 %
1000–3999 km	1.54E+12	4.80E+12	+212 %
≥4000 km	1.48E+12	3.89E+12	+163 %
Total	3.78E+12	1.01E+13	+168 %

Insularity tends to reinforce this locational effect since residuals are higher for the UK, Iceland, Australia and New Zealand. In a sense, South Korea can also be viewed as an island since surface transport via North Korea is impossible. Another key factor for a positive residual is countries that accommodate one or several hubs beyond their demand for long-haul travel (including all European countries with a positive residual, Canada, USA, Ethiopia, Qatar and the United Arab Emirates). Lastly, several poor countries that attract international tourists from far away (including the Caribbean and Thailand) also burn more fuel than expected on long-haul flights.

4. Conclusions and policy implications

In contrast to previous publications that investigated the contribution of different flight distance ranges to climate change from aviation, this paper considered the whole world. In doing so, it confirmed the disproportionate role of long-haul services, which account for 39 % of fuel burnt for only 5 % of the flights; hence, the idea of "tyranny of distance" (Dobruszkes and Ibrahim, 2022) in aviation climate change concerns. The share of 39 % is somewhat lower than the 47 % found previously for Europe, which confirms the interest of looking beyond this well-explored world region. In contrast, super short-haul flights (shorter than 500 km) account for just 5 % of fuel burnt, despite accounting for no less than 27 % of flights. Another key finding of this study is that the distance split on fuel burnt varies significantly across countries and world regions, based on a complex mix of social, political, economic and geographical factors.

At the same time, our analysis shows that the growth rate of the global air transport market (in seat-km) is faster in segments above 1000 km. From a climate policy perspective, this is an unfortunate development, as these are the routes where technological solutions are more challenging, and mode substitution would be more difficult, if not impossible, to achieve.

Our findings have key implications for "shift-to-rail" policies, such as bans or taxes on super short-haul flights, and measures to increase the

Table 6
Fuel burnt per region.

Region	Fuel (ktonnes)	Global fuel share	Fuel/capita (kg)	<500 km	500–999 km	1000–3999 km	≥4000 km
Indian subcontinent	8940	4 %	5.5	7 %	12 %	58 %	22 %
Sub-Saharan Africa	5810	2 %	6.2	8 %	9 %	28 %	56 %
Maghreb	1302	1%	14.0	5 %	8 %	66 %	21 %
Russia and other CIS countries	7295	3 %	25.5	2 %	11 %	65 %	22 %
South America	10,581	4%	26.0	10 %	17 %	35 %	39 %
East and South-East Asia	68,557	27 %	31.0	5 %	16 %	46 %	33 %
Central America and the Caribbean	7203	3 %	34.3	5 %	9 %	55 %	31 %
Middle East	22,791	9 %	55.1	4%	10 %	38 %	48 %
Europe	51,462	20 %	96.3	6 %	12 %	35 %	47 %
North America	62,411	24 %	177.6	5 %	11 %	47 %	37 %
Oceania-Pacific	8760	3 %	230.2	4 %	9 %	28 %	59 %
Total/average	**255,113**	**100 %**	**35.8**	**5 %**	**13 %**	**43 %**	**39 %**

Table 7
Fuel burnt on long-haul flights per macro-region pairs.

From/to	Africa	Asia	Europe	Latin America	Middle East	North America	Oceania - Pacific	Total
Africa	0.3 %	0.4%	1.7 %	0.1%	0.8 %	0.3 %	0.1 %	**3.7 %**
Asia		3.6%	7.4 %	0.1 %	3.6 %	6.7 %	2.7 %	**24.6 %**
Europe			0.8 %	3.7 %	3.0 %	8.9 %	0.0 %	**25.6%**
Latin America				0.9%	0.2%	1.3 %	0.1 %	**6.4%**
Middle East					0.0%	2.1%	1.2%	**10.9%**
North America						3.0%	1.0%	**23.5 %**
Oceania - Pacific							0.1%	**5.2%**
								100.0%

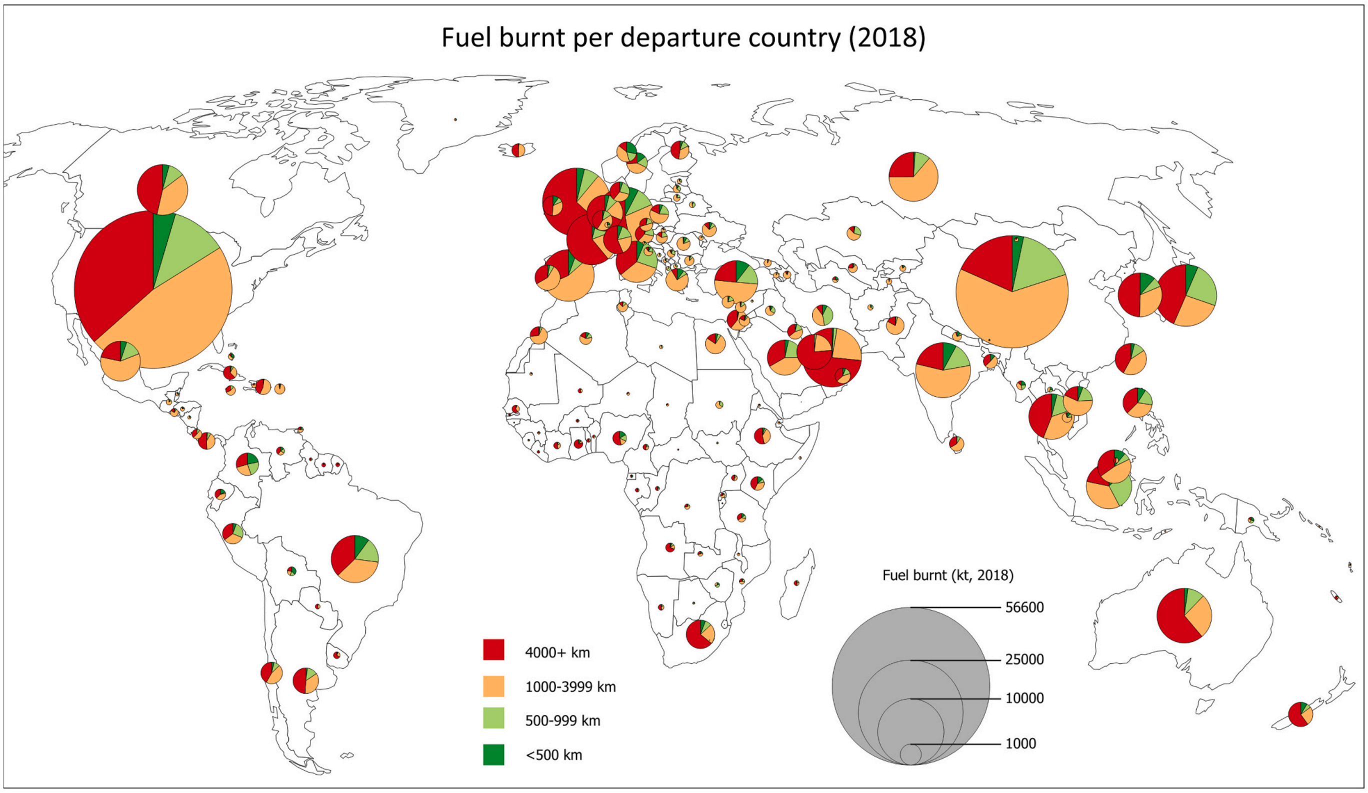

Fig. 6. The spatial distribution of fuel burnt by passenger air services.

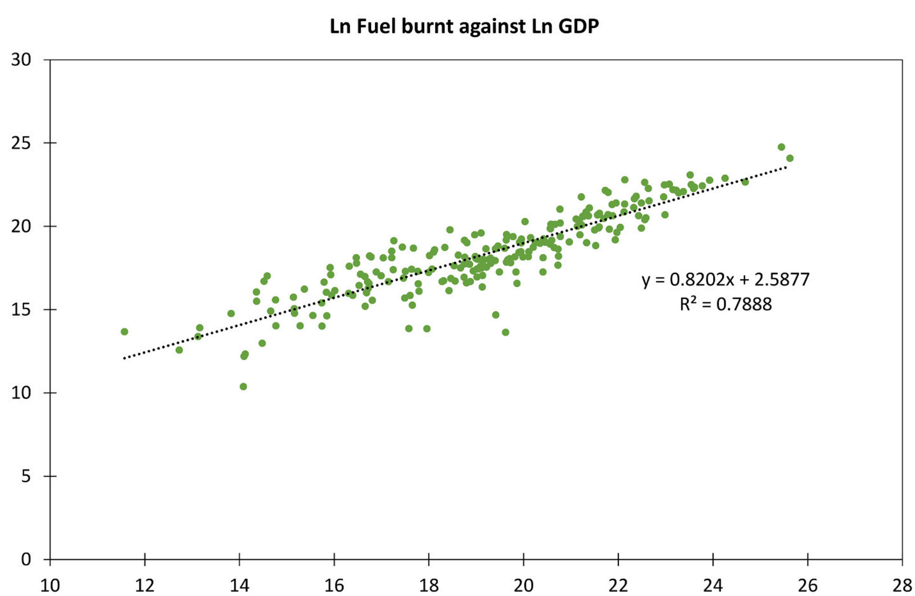

Fig. 7. Ln Fuel burnt vs Ln GDP at the country level.

Table 8
Regressing Ln Fuel burnt against Ln GDP at the country level and by distance range.

Distance (km)	n	Beta	R	R^2
<500	214	0.748	0.81	0.66
500–1000	205	0.884	0.84	0.70
1000-4000	219	0.754	0.83	0.69
>4000	172	0.851	0.71	0.50

convenience and affordability of high-speed rail. While these policies have popular support, for example in Europe (Hodgson, 2024), they can only have really little impact on aviation climate change. It should also be remembered that 'improve' strategies have not been able to tackle climate change in aviation to date, given the rapid growth of the sector and the fact that they are more challenging to implement precisely in the long-haul segment that accounts for the lion's share of emissions, and which is growing more rapidly. Despite these facts, research on the role of long-haul flights in aviation climate change is still emerging. We

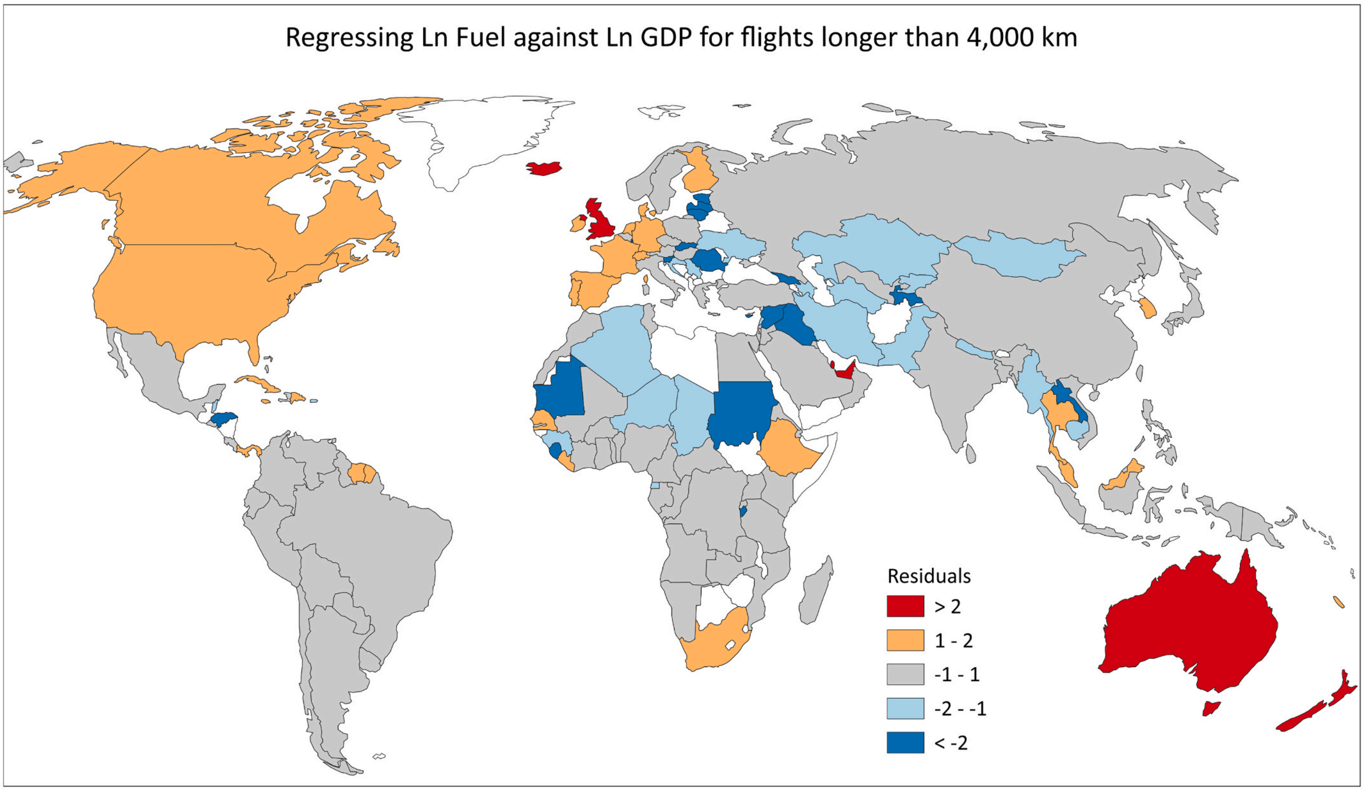

Fig. 8. Regressing Ln Fuel burnt against Ln GDP for long-haul flights: Residuals. In white: countries with no long-haul flights.

suspect this might reflect a perception among policymakers that “shift” policies are not possible in the long-haul segment, while “avoid” policies are considered a ‘policy taboo’. In this sense, long-haul flights are really the elephant in the room.

Introducing climate policy measures to curb long-haul flights is likely to be challenging. First, even banning super short-haul flights when high-speed rail alternatives exist can be politically controversial, as evidenced by the lively parliamentary debate in the French case. Second, long-haul flights are usually much more lucrative for the airlines than short-haul flights, some of which may survive only to feed longer flights. It is thus likely that the aviation industry and its lobbies would do their best to block any attempt to curb long-haul air travel.

At the same time, there are reasons why climate policy measures specifically targeting long-haul air travel might be easier to introduce than policies affecting all flight segments equally. First, even in high-income countries most individuals do not fly in a given year (Büchs and Mattioli, 2021; ICCT, 2022), and even fewer fly long-haul (Hopkinson and Cairns, 2021; Mattioli et al., 2022). Downsizing the long-haul segment is arguably the best means to ensure the largest emission reduction while minimising the number of trips and passengers that would be affected. This would maximise the ‘emission-reduction sensitivity’ metric proposed by Wadud et al. (2024) to assess the efficiency of sustainable transport strategies. If communicated that way, this strategy might find support among the public, the large majority of which do not fly long-haul with any regularity. Flying long-haul is also more likely to be perceived as a ‘luxury’ rather than a ‘need’, notably when the activities that motivate the trip can be performed in a reasonably similar but closer destination (e.g., in the case of a Northern European travelling to the Caribbean rather than to the Mediterranean for a beach holiday). This might further boost public support, including initiatives to promote rail travel as a means to reach tourist destinations at a reasonable distance, and complementary, electric super short-haul transport alternatives for tourists to reach their destinations from rail stations. The rationale for long-haul business-oriented travel can also be questioned to some extent. For instance, it is unclear whether travel to conferences at far-flung destinations is needed for researchers to do academic work, or to advance their career (De Vos et al., 2024; Kreil, 2021; Wynes et al., 2019). In contrast, the specific case of migrants who travel long-haul to visit their home country deserves special consideration, as it is more likely to be perceived as a need (see Büchs and Mattioli, 2024; Mattioli and Scheiner, 2022). Here perhaps emissions could be reduced by encouraging less frequent but longer visits, rather than frequent short visits to the country of origin. Finally, policies targeting the long-haul segment might exploit the divergence of interest between airlines, some of which specialise in shorter flights, and are thus keener on such policies than on short-haul flight bans, for example, which affect them more directly (InfluenceMap, 2022).

Besides policies that target long-haul air travel specifically, pricing instruments such as a carbon price on aviation fuel (Gössling et al., 2021) or a ‘frequent flyer levy’ (ICCT, 2022), or combinations of the two (Fouquet and O'Garra, 2020; Büchs and Mattioli, 2024), should be considered. These would help managing travel demand in the long-haul segment, while placing accountability for emissions incurred where it belongs.

Lastly, this paper could be extended in a number of directions. First, there is a case for broadening the scope of the analysis to include local air pollution and noise issues. At first sight, these issues should be more closely related to the number of flights, as opposed to climate impact, which is closely related to flight distance. However, shorter flights tend to be operated by smaller aircraft, while long-haul flights are typically operated by wide-body (aka heavy) aircraft. Such heavy aircraft emit more local air pollutants (as they burn more fuel) and generate more noise (due to larger engines and lower climb rates) than lighter aircraft. In addition, it would be interesting to consider a more sophisticated fuel burn model to assess the gap with simplified models used in most research works, including the present paper. However, the amount of data required (including actual 3D trajectories, engine model and condition, power setting, actual load and ambient atmospheric conditions) makes this possible only in limited areas.

CRediT authorship contribution statement

Frédéric Dobruszkes: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Giulio Mattioli:** Investigation, Writing – original draft, Writing – review & editing. **Enzo Gozzoli:** Investigation.

Data availability

The authors do not have permission to share data.

Appendix A. Appendix

Table A1
Selected routes per distance threshold (great-circle distances).

Distance	Routes
Around 200 km	Yaounde-Douala (204 km) Fukuoka-Kagoshima (200 km) Milan-Zurich (203 km) Bogota-Yopal (204 km) Amman-Damascus (193 km) Seattle-Vancouver (204 km) Sydney-Orange (200 km)
Around 500 km	Tangiers-Marrakech (497 km) Hong Kong-Xiamen (496 km) London-Düsseldorf (501 km) Rio de Janeiro-Ribeirao Preto (502 km) Kuwait-Riyadh (491 km) Boston-Ottawa (497 km) Auckland-Nelson (494 km)
Around 1000 km	Addis Ababa-Khartoum (998 km) Bandung-Singapore (998 km) Birmingham-Copenhagen (999 km) Lima-Iquitos (1006 km) Baghdad-Bahrain (990 km) Baltimore-Chicago (996 km) Adelaide-Canberra (969 km)
Around 2000 km	Accra-Banjul (1999 km) Guangzhou- Busan (1999 km) Naples-Stockholm (1997 km) Buenos Aires-Rio de Janeiro (1996 km) Istanbul-Tehran (1997 km) Dallas-Los Angeles (1999 km) Sydney-Alice Springs (2018 km)
Around 3000 km	Addis Ababa-Brazzaville (2992 km) Mumbai-Bangkok (3006 km) Lisbon-Stockholm (2997 km) Porto Alegre-Recife (2961 km) Dubai-Istanbul (3006 km) Calgary-Montreal (3005 km) Perth-Hobart (3013 km)
Around 4000 km	Addis Ababa-Cotonou (4017 km) Almaty-Bangkok (3998 km) Baku-London (3998 km) Buenos Aires-Fortaleza (4020 km) Dubai-Budapest (4006 km) Boston-Seattle (4004 km) Brisbane-Apia (3912 km)

Routes are given in the following order: Africa, Asia, Europe, Latin America, the Middle-East, North America and Oceania.

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