Policy brief

Airports, air pollution and climate change

Building an accessible global database to support advocacy

Shandelle Steadman and Sam Pickard
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Key messages

The aviation sector is a major contributor to climate change and air pollution. Despite a decline in 2020, CO_2 emissions from aviation are on an upward trend, and are expected to pass pre-pandemic levels around 2025.

This brief presents findings from the updated Airport Tracker, the first global inventory of CO_2 and local air pollutants at the airport level. The Tracker now includes two substantial additions: the impacts of air freight as well as passenger flights, and emissions of local air pollutants.

Airport Tracker data reveals that passenger and freight flights from the 20 most carbon-polluting airports created 231 million tonnes of CO_2 ($MtCO_2$) emissions in 2019. These 20 airports were responsible for 25% of all CO2 emissions from all 1,300 airports analysed.

The majority of the top 100 most polluting airports for each of the pollutants (CO_2 emissions, NOx and $PM_{2.5}$) are in three regions: Asia-Pacific, North America and Europe.

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Contributors and the Airport Tracker Project

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The Airport Tracker (www.airporttracker.org) is an ongoing project attempting to visualise the climate and air quality impact of the world's largest airports. We make this data available to help those working to limit the aviation sector's negative impacts and to provide transparency, accountability, and comparability for global airport infrastructure-related emissions. The data provide policymakers and campaigners with robust estimates of the climate and air quality impacts of existing airport capacity to inform discussions around proposed capacity expansions, and to better understand how the aviation industry can align with a climate-safe world. Details on how to use the tracker and how the data was compiled are available on the Airport Tracker pages. The brief lays out recent updates in the sector more broadly, explains the importance of focusing on airports, and presents the findings from the updated Airport Tracker: the first global inventory of CO_2 and local air pollutants at the airport level.

About the authors

Shandelle Steadman is a Senior Research Officer in the Climate and Sustainability Programme at ODI where her work currently focuses on energy transitions.

Sam Pickard is a Research Associate in the Climate and Sustainability Programme at ODI.

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Acronyms

ACG	Air Quality Guidelines
CO_2	Carbon Dioxide
CORSIA	Carbon Offsetting and Reduction Scheme for Aviation
GHG	Greenhouse Gas
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
IPCC	Intergovernmental Panel on Climate Change
NO_x	Nitrogen
PM	Particulate Matter
SAF	Sustainable Aviation Fuel
SO_2	Sulphur
VOC	Volatile Organic Compound
WHO	World Health Organization

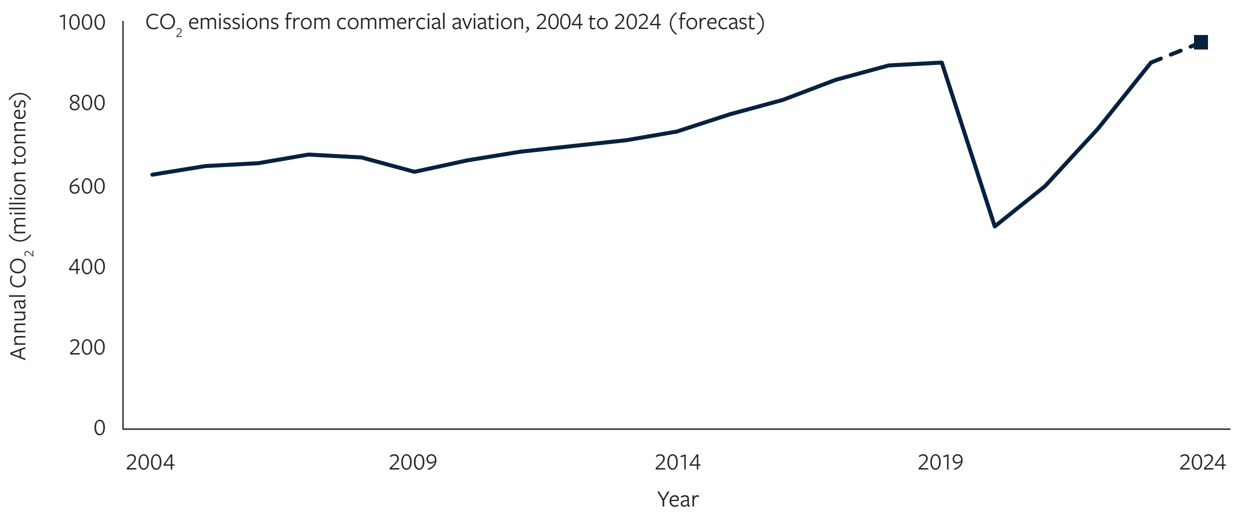
1 A primer: things to know about flying, pollution and equality

1 Covid hit aviation hard, but it's back and set to grow rapidly

The Covid-19 pandemic and the travel restrictions put in place in response hit the aviation industry hard, grounding planes, emptying airport terminals and leading to a 60% contraction in passenger air traffic in 2020 compared to 2019 (ICAO, 2023). However, thanks to at least $120 billion in public subsidies (Welker, Roth and Gerasimchuk, n.d.), the sector has already almost entirely bounced back. Globally, by November 2023 passenger demand[1] had reached 99% of pre-pandemic levels, and passenger capacity[2] was at 98.2% (IATA, 2024a). After significant growth in November 2023, air cargo demand[3] was 2.5% below 2019 levels, while capacity[4] was already above 2019 levels (IATA, 2024b).

The industry's trade body, the International Air Transport Association (IATA), expects air passenger growth to increase on average by 4.2% a year between 2023 and 2040, reaching more than double pre-pandemic levels by 2040 (IATA, 2023a). It is a similar story for air freight, where the industry has already surpassed pre-pandemic capacity levels, driven mostly by growth in passenger aircraft belly-hold capacity on international routes. Air cargo demand is projected to grow by 4.5% in 2024 (IATA, 2023a).

Figure 1 Global carbon emissions from aviation



Source: IATA

1 Measured in revenue passenger-kilometers (RPKs).
2 Measured in available seat-kilometers (ASKs).
3 Measured in air cargo tonne-kilometers (CTKs).
4 Measured in available cargo tonne-kilometers (ACTKs).

2 The sector is a major contributor to climate change and poor air quality

More than 99.9% of all flights are powered by burning fossil fuels, adding over a billion tonnes of CO_2 to the atmosphere every year. This was 2% of global energy-related CO_2 emissions in 2022 (IEA, 2023a) and in 2018 represented a carbon footprint more than two and a half times larger than the UK economy's (AEF, 2019). After a decline in CO_2 emissions in 2020 (Figure 1), 2022 and 2023 saw aviation emissions continue an upward trend. Emissions are expected to surpass pre-pandemic levels around 2025 (IEA, 2023a).

Combustion reactions mainly occur at high altitudes and also create water vapour and other products, leading to other global warming effects. Precisely how much extra warming these 'non-CO_2' effects create depends on several factors, but overall they between double and triple the sector's total climate impact (Lee et al., 2021). Historically, the industry contributed approximately 4% to observed human-induced global warming up to 2019 (Klöwer et al., 2021).

Burning fossil fuels also creates a host of other combustion products that worsen air quality, while also causing noise pollution. Air pollution in the vicinity of airports is generated by aircraft operations and by ground activities and access road transport. Key pollutants include oxides of nitrogen (NO_x) and sulphur (SO_2), volatile organic compounds (VOCs), ozone and particulate matter (PM: extremely fine particles of unburned carbon). While CO_2 and water vapour have global climate impacts, these other emissions don't tend to travel so widely and mainly create local air pollution for airport workers and local communities, which can be hazardous to human health (Riley et al., 2021; Bendtsen et al., 2021; Stay Grounded, 2024). NO_x and PM can lead to respiratory and cardiovascular disease, while VOCs can be carcinogenic or carry toxic substances that damage the genetic information in cells (EASA, 2019). PM exposure has increased by 40% since 1990.

Globally in 2019, air pollution from all sources (ambient and household) was the fourth-largest risk factor for human health, resulting in 213 million lost life years (Health Effects Institute, 2020). Aviation-generated $PM_{2.5}$ (particles that measure less than 2.5 micrometers in diameter) and ozone alone lead to 16,000 premature deaths each year (Yim et al., 2015). Air pollution also has negative environmental impacts (e.g. acid rain or eutrophication), though the range of impacts and pathways is much broader here and thus data is less conclusive (Manisalidis, 2020).

3 The industry's plans for reducing aviation's environmental impact are insufficient

Climate change

In 2022, seven years after national governments agreed to limit emissions when they signed the Paris Agreement, and more than two decades after the Intergovernmental Panel on Climate Change (IPCC) warned increasing traffic growth was a clear climate risk (IPCC, 1999), the global aviation industry finally recognised that it was a contributor to climate change and agreed an aspirational goal of becoming net zero by 2050 (ICAO, 2022). Bound by its own projected growth in traffic, it has based its decarbonisation strategy on nascent technological solutions and carbon dioxide removal strategies (Mission Possible Partnership, 2022).

However, as set out in Table 1, for each strategy, while possible in theory, the practical, political and financial realities of decarbonising the sector at the pace and scale needed pose several challenges to advancing the transition to net zero.

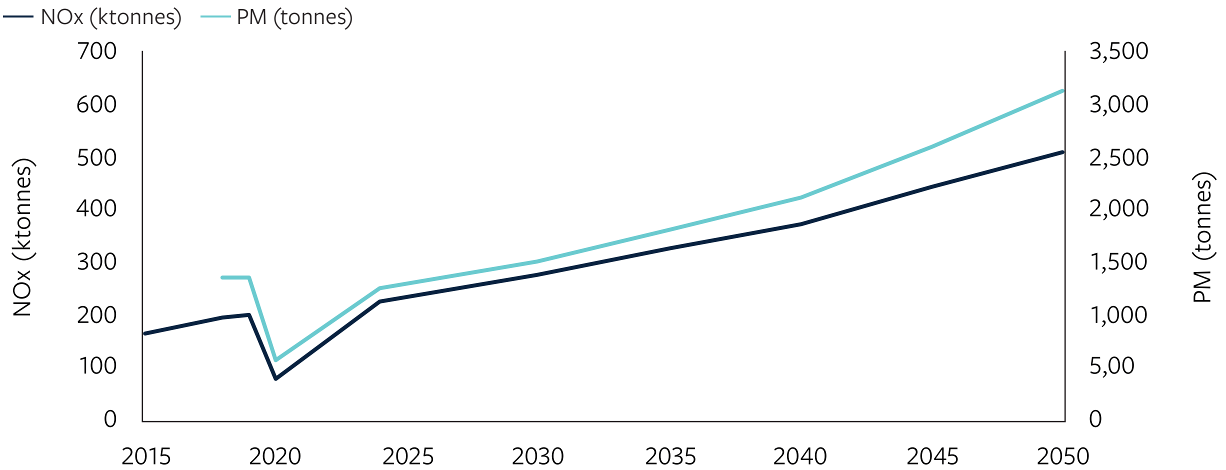
Table 1 Challenges and limitations to industry strategies to reduce aviation's environmental impact

Industry strategies to net zero	Challenges and limitations
'Sustainable aviation fuels' (SAFs) produced from non-fossil carbon sources	Only 0.1% of aviation's fuel consumption can be met by SAFs today. To replace fossil fuels, the annual supply needs to rise from a few hundred million litres to over 400 billion litres by 2050. However, SAFs are also sought by other sectors (Transport & Environment and Travel Smart, 2023). Currently, SAFs cost 2–4 times more than fossil jet fuel (IATA, 2023b), yet need to be brought to market immediately to permit the scale-up needed (Esqué et al., 2022). The small starting base, cost differential, competition with other sectors and rate of scale-up required make it unlikely that SAFs will be available in the quantities needed to sufficiently substitute for fossil fuels to achieve meaningful emissions reductions.
New aircraft technology, such as electric and hydrogen power, removes the need to burn fossil fuels	Most emissions today are caused by long-haul flights. Technological constraints limit hydrogen- and battery-powered flight to short-haul journeys (Transport and Environment, 2022) and even these are only projected to materially impact markets from the late 2030s or 2040s (Esqué et al., 2022). Airplanes' long working life (often several decades) is a barrier to deploying new aircraft technology in time to meet net zero targets, alongside range limitations, technology development risk and market introduction lead time (Mission Possible Partnership, 2022).
Infrastructure and operational efficiencies reduce fuel burned per passenger/tonne of freight	Technological and operational innovation has increased the fuel-efficiency of flying, slowing the increase in GHGs arising from the rapid growth in civil aviation. Yet, despite improvements in aircraft efficiency, air traffic growth has always outstripped any potential emissions savings, resulting in continued growth in emissions (Graver et al., 2020; EASA, 2022).
Offsets and carbon capture to compensate for aviation emissions	Carbon dioxide removal solutions do not replace decarbonisation and need to be introduced in addition to deep decarbonisation (Esqué et al., 2022; Mission Possible Partnership, 2022). The Carbon Offsetting and Reduction Scheme for Aviation (CORSIA) aims to become mandatory only from 2027, although many countries have not confirmed their intention to join the scheme. It will potentially cover less than one-third of emissions from international flights (Olmer and Rutherford, 2017), and may not deliver sufficient price signals to encourage decarbonisation (Transport and Environment, 2022).

Other air pollutants

There are no globally agreed strategies for limiting emissions of the types of non-GHG air pollutants produced by the aviation industry. The International Civil Aviation Organization (ICAO) maintains a 'living document' of guidance, but this has not been updated since the 2015 revision (ICAO, 2016), and its approach has 'consistently avoided technology-forcing requirements ... essentially ratif[ying] what the principal aircraft manufacturers had already achieved' (Lattanzio, 2023: 2). ICAO's own documents show how engine standards are not reducing NOx emissions (ICAO, 2021), nor are they projected to do so in the future, as Figure 2 shows.

Figure 2 Projected NOx and PM emissions up to 3,000 ft from international aviation, 2015–2050



Source: ICAO (2022b)

The World Health Organization (WHO) maintains air quality guidelines (AQGs) on the ambient pollutant levels necessary to avoid harm, and individual countries (or regions, like the European Union (EU)) interpret these into policies related to emissions standards (for individual or types of pollutant sources) and ambient concentrations. In 2021, WHO amended the AQGs, substantially revising down the safe limits for most pollutants in the light of evidence of the negative impacts of even small amounts of ambient pollution. National targets were generally less stringent than the original WHO guidelines, and even these were often exceeded (EEA, 2018). The revisions made to the AQGs in 2021 have made the gap even starker, with 96% of Europe's urban population breathing air WHO deems unsafe (EEA, 2022b).

As the largest environmental health risk in Europe, responsible for more than 311,000 deaths in 2020 (EEA, 2022b) and associated economic costs of more than $166 billion in 2018 (de Bruyn and de Vries, 2020), air quality was specifically included in an EU Green Deal proposal aiming to more closely align local targets with the WHO limits by 2030.[5] Elsewhere, regulations are further

5 As of early 2024, this was still under discussion awaiting a plenary vote (Halleaux, 2023).

behind. In the US, aviation sector emissions are linked to broader legislation including the Clean Air Act and National Ambient Air Quality Standards (FAA, 2015), though in practice are mainly regulated by manufacturers demonstrating that jet engine emissions do not exceed certain thresholds under test conditions, rather than real-world measurement (Lattanzio, 2023). This is despite even ICAO recognising that gains from technological advances (e.g. more efficient engines) 'may be offset by the [sector's] forecast growth' (ICAO, 2016).

Box 1 Emerging signs of future policy: limiting air traffic is essential to reducing carbon emissions and air pollution

Air travel growth has mostly been driven by passenger demand, artificially low ticket prices, the competitiveness of international tourist destinations and increasing air travel capacity (Chapman, 2023). Flying clearly generates some economic benefits, although the scale of these benefits is debatable given the subsidies the sector enjoys, dependence on multiple other factors and the failure to recognise currently externalised social and environmental costs of tourism and air travel in standard measurements (e.g. Chapman, 2023; FAA, 2022).

Nonetheless, major investments in effective marketing that frames the industry solely in terms of its benefits (Stay Grounded, 2023) has historically tended to prevent policy-makers from openly discussing limiting air traffic on environmental grounds. Despite the fact that the sector's increasing contribution to climate change was clear more than two decades ago (IPCC, 1999), it is only in recent years that we have finally seen the beginnings of regulatory change as the need to limit the sector's negative environmental impacts has become impossible to ignore. As a result, independent and government advisors have increasingly called for action to limit demand, and nascent policies have started to emerge. These include:

- The European Investment Bank considering whether to stop financing airport expansion (Abnett and Jessop, 2020).
- The IEA's 'Net Zero by 2050' roadmap shows that shifting to high-speed rail and placing caps on business flights and long-haul leisure flights would potentially reduce emissions from aviation by 50% by 2050 (IEA, 2021).
- The European Scientific Advisory Board on Climate Change is calling for 'activating demand-side management levers' and a modal shift away from aviation to align with 2030 and 2050 climate objectives (ESABCC, 2024).
- The UK Climate Change Committee's recommendation that 'No airport expansions should proceed until a UK-wide capacity management framework is in place' to ensure adherence to climate and air quality goals (CCC, 2023: 15).
- The French government has cited climate targets when banning domestic flights for routes reachable in 2.5 hours by train (Le Monde and AFP, 2023).
- Capacity at Schiphol airport in the Netherlands has been limited to 11% below 2019 levels on climate, air and noise pollution grounds (Gallagher, 2022).
- Nonetheless, such approaches are still far from universal: a recent report by the US Congressional Research Service (Lattanzio, 2023) does not even mention the possibility of limiting the number of flights as a mechanism to reduce pollution levels.

4 The triple inequality of aviation

Inequality within countries

Between income groups

There is significant inequality within countries, with *many people in many countries entirely excluded from aviation* (Oswald et al., 2020). Propensity to fly is associated with rising income (Ivanova and Wood, 2020). **In 2018 an estimated 11% of the world's population travelled by air, and only 2–4% flew internationally** (Gössling and Humpe, 2020). Frequent fliers (just 1% of the global population) are estimated to account for more than half of all passenger flight emissions (Gössling and Humpe, 2020). Put another way, if everyone in the world flew like the wealthiest 10% of Europeans, aviation's climate impact would be more than 20 times larger than it is (Transport and Environment, 2022). This implies a significant ongoing transfer of welfare from the global majority – who suffer the negative climate, air and noise impacts – to a wealthy minority of frequent flyers.

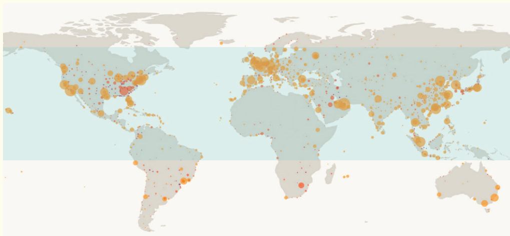
Between sectors

Aviation alone could consume 12–27% of the total carbon budget by 2050 (Carbon Brief, 2016). Although the Paris Agreement does not specify global or country-level pathways, 'immediate and deep emissions reductions across all sectors' are required to limit climate change to 1.5°C (IPCC, 2018). Legal analysis has found that the aviation sector is subject to the Paris Agreement (Transport and Environment, 2021). Yet the industry has often argued that it is excluded from mandatory emissions reductions as these emissions are released beyond national borders, instead opting for a non-binding ambition of achieving net zero by 2050 (ICAO, 2022). Thus, while many countries have reduced emissions from other sectors including electricity, industry and housing, **aviation emissions have continued to increase, growing faster than those from rail, road and shipping** (IEA, 2023a). Much of this growth is supported by government subsidies to the aviation sector. In the EU, partial or complete avoidance of fuel levies and VAT or sales tax on services, and direct and in-kind subsidies to airports, run to the tens of billions of Euros every year (Transport and Environment, 2023).

Inequality between countries

Global Inequality:

Most major international airports lie within a clustered band running from North America to China.



In 2018, 40% of people from high-income countries flew at least once a year, compared to 10% of people in upper-middle income countries, 3% in lower-middle income countries and 0.7% from low-income countries (Gössling and Humpe, 2020). **Nationals of just five countries – the UK, US, China, Germany and France – accounted for one-third of all international passengers in 2018** (IATA, 2019). These 488.8 million passengers represented around 6% of the global population. If anything, the Covid-19 pandemic exacerbated this inequality, with *air traffic bouncing back faster in areas where it was already dominant*. **Air traffic in regions such as North America rebounded faster than other parts of the world** (IATA, 2024a), with emissions in 2019 in 'advanced economies' regaining 85% of 2019 levels, compared to 73% in 'emerging market' and 'developing' economies (IEA, 2023b). Highlighting the disproportional effects of some routes, it was found that *reducing just 12% of flights could potentially lead to a 50% reduction in global aviation emissions* (IEA, 2021).

2 Airports are the key: both to unleashing worse problems and to curbing current ones

Airport capacity unlocks passenger and freight demand, exacerbating global climate change and increasing local air and noise impacts. Airport expansion in Europe was a driving factor in the sector's increasing emissions between 2005 and 2019 (Transport and Environment, 2022). Airport infrastructure is long-lived and, once built, creates latent pressure to be utilised. Thus, any new capacity both creates new emissions and then locks them in for decades to follow. Infrastructure decisions made now will determine whether we are on a path to a climate-safe future (New Climate Economy, 2016).

The barriers to existing decarbonisation solutions mean decisions to expand airports without simultaneous retirement of other capacity will ultimately lead to more air traffic and more (not less) emissions and pollutants. That this is patently incompatible with climate targets helps explains concern with the many airports that are planning expansion projects (often based on industry projected demand growth). In the UK, nine airports have expansion plans which, if realised, could lead to 200 million more passengers per year by 2050 (AEF, 2023). In January the Spanish government announced a €2.4 billion investment to expand Madrid's main airport (Gualtieri, 2024).

Conversely, moves to limit departures from Schiphol in the Netherlands (Government of the Netherlands, 2022) show that airports are also a leading entry point for keeping air traffic to climate-compatible levels (AEF, 2022). The IEA's Net Zero by 2050 scenario found that measures to reduce passenger aviation demand could cut emissions by 50% by 2050 (IEA, 2021). Additionally, the unprecedented downturn in air pollutants between 2019 and 2020 shows that limiting traffic can also reduce most negative non-CO_2 impacts (EASA, n.d.). However, it is important to note that the effects of the Covid-19 pandemic – where a 72% reduction in air traffic in 2020 compared to 2019 resulted in a 54% fall in GHG emissions (Transport and Environment, 2022) – highlighted that attempts to limit air traffic must be complementary to technological decarbonisation strategies rather than substitutes.

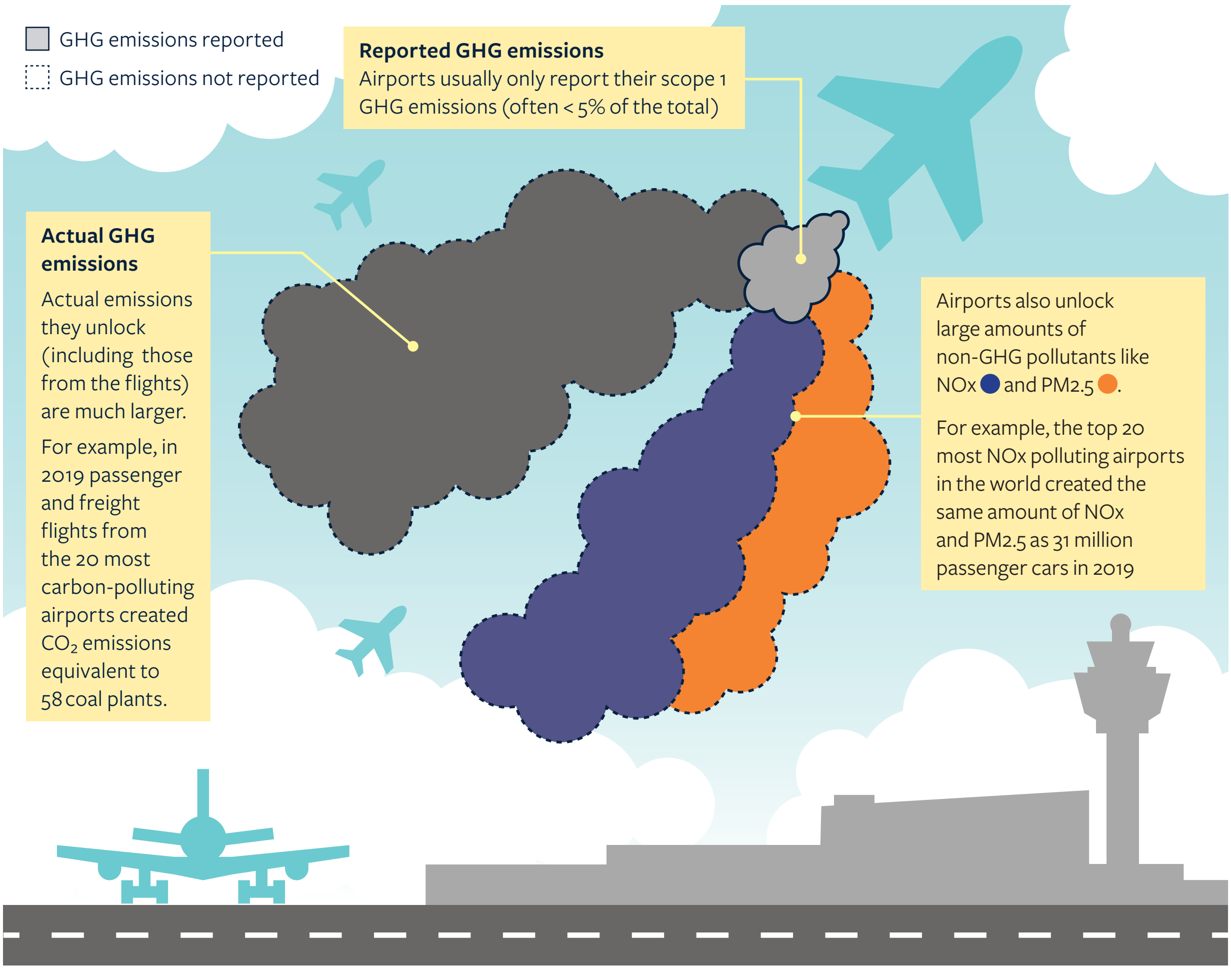
3 The long shadow of airport impacts

Current reporting standards focus on the climate impact of airport terminals and ground operations, ignoring the much larger carbon and other pollutant emissions that arise from the flights that airports generate. This creates three main problems:

- It allows airports to significantly obfuscate their contribution to climate change and local air pollution.
- It focuses their emission-reduction efforts on important but much lesser drivers (like switching terminals to run on renewable electricity).
- In the case of those that purchase equivalent numbers of offsets, it allows airports to paradoxically claim carbon neutrality (e.g. Guardian, 2023).

As Figure 3 shows, just as fossil fuel producers are increasingly required to report on the climate impact of the products and services they sell, the global and local pollution airports create should be seen in terms of the total impacts they have.

Figure 3 The long shadow of airport impacts



4 Building an accessible global baseline dataset

The lack of publicly accessible data on the total emissions airports create has been a substantial challenge for campaigners seeking to limit aviation's climate and local environmental impact. To remedy this, in 2021 a collaborative team built the Airport Tracker, an interactive web-based tool. The first version of the Airport Tracker presented CO_2 emissions from 1,300 airports, covering 99% of all passenger travel in 2019. An accompanying policy brief illustrated the utility of the Tracker and presented headline findings from the data (Pickard and Gençsü, 2021).

Data in the Airport Tracker has been updated and now includes two substantial additions.

1. The Tracker now includes the impacts of air freight as well as passenger flights.
2. The Tracker now includes emissions of local air pollutants.

All the data is for 2019. This is an important milestone providing both a baseline and a methodology against which to compare the total impacts of the aviation sector going forward. A technical note available on the Airport Tracker website explains how the data was calculated.

The main output of this work is the global dataset, and the main outcome is to promote its use among those advocating for a just and environmentally sustainable aviation sector. The following section provides headline findings for the baseline data.

5 Revealing airports' total impact (climate and air pollution)

Together, passenger and freight flights from the 20 most carbon-polluting airports created 231 million tonnes of CO_2 ($MtCO_2$) emissions in 2019, equivalent to the annual emissions of around 58 coal-fired power plants. Together, these 20 airports were responsible for 25% of all CO_2 emissions from all 1,300 airports analysed.

Many of these 20 also created the largest amounts of air pollution (NOx and $PM_{2.5}$ emissions). For example, Dubai International Airport features first on all three lists, emitting CO_2 emissions equivalent to five coal-fired power plants and NOx and $PM_{2.5}$ equivalent to 2.75 million passenger cars. The 20 airports that created the most NOx emissions were responsible for 87,000 tonnes (23% of all NOx created by all airports), and the 20 airports that created the most $PM_{2.5}$ emissions were responsible for 863 tonnes (17% of all $PM_{2.5}$ created by all airports).

Most emissions were generated by passenger flights. However, the 20 airports with the largest freight emissions created 71 $MtCO_2$ – 40% of all air freight-related emissions (from the 1,300 airports studied). Although smaller, these emissions can be extremely impactful – for example, emissions from Anchorage airport's freight activities were nearly double those created by the total of all Anchorage's other emissions.[6]

6 Airport CO_2 emissions in 2019 were 6.33 $MtCO_2$ (Airport Tracker). In 2020, the municipality reported total emissions of 5.03 $MtCO_2$, 1.5 $MtCO_2$ of which were associated with aviation (Municipality of Anchorage, 2022).

Table 2 The 20 airports that generated the most CO_2 emissions, NOx and $PM_{2.5}$ in 2019

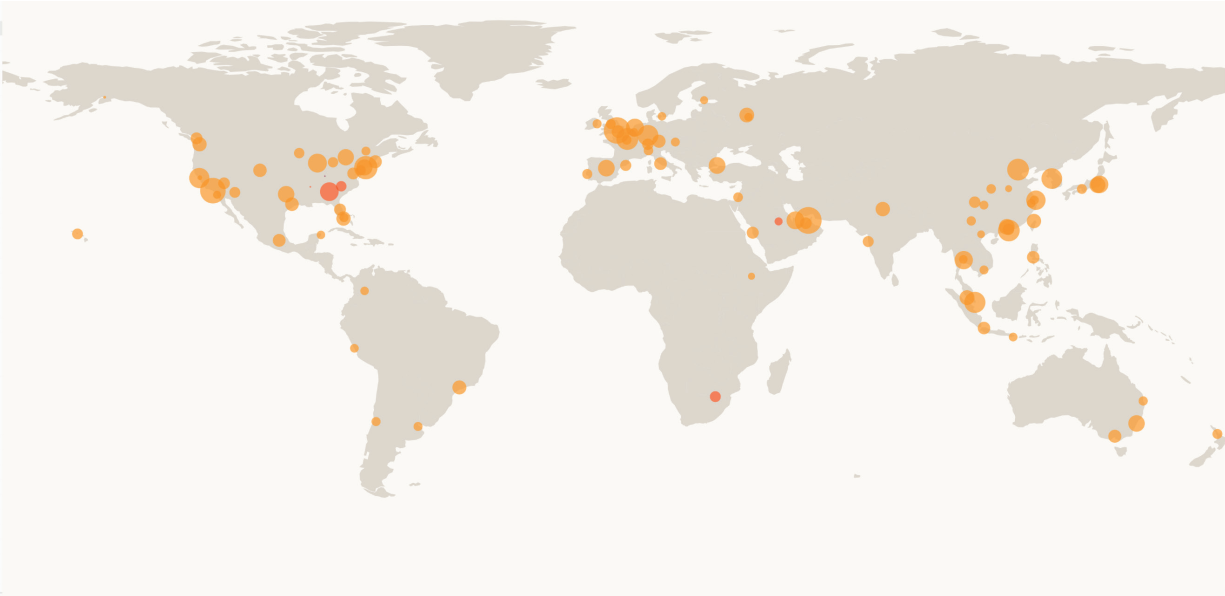
	Total carbon emissions			Total air pollution			
Rank	Airport name	Total CO_2 ($MtCO_2$)	Passengers / Freight	Airport name	Total NOx (tonnes)	Airport name	Total $PM_{2.5}$ (tonnes)
1	Dubai	20.1	83%/17%	Dubai	7,531	Dubai	71
2	London Heathrow	19.1	85%/15%	London Heathrow	5,844	Atlanta Hartsfield-Jackson	60
3	Los Angeles	18.7	82%/18%	Beijing Capital	5,736	Beijing Capital	54
4	Hong Kong	17.4	65%/35%	Hong Kong	5,678	Shanghai Pudong	51
5	New York John F. Kennedy	14.7	88%/12%	Tokyo Haneda	5,172	Guangzhou Baiyun	49
6	Seoul Incheon	14.4	72%/28%	Seoul Incheon	4,491	Frankfurt	45
7	Paris Charles de Gaulle	14.2	81%/19%	Singapore Changi	4,462	Singapore Changi	41
8	Frankfurt	13.9	76%/14%	Bangkok Suvarnabhumi	4,228	Seoul Incheon	41
9	Shanghai Pudong	13.8	67%/33%	Shanghai Pudong	4,223	Sao Paulo/Guarulhos	40
10	Singapore Changi	13.5	80%/20%	Los Angeles	4,187	Moscow Sheremetyevo	39
11	Beijing Capital	13.1	87%/13%	Atlanta Hartsfield-Jackson	4,130	Los Angeles	39
12	Chicago O'Hare	11.2	79%/21%	Istanbul	4,097	Kunming Changshui	38
13	San Francisco	11.1	90%/10%	Guangzhou Baiyun	3,757	Tokyo Haneda	38
14	Doha Hamad	10.9	73%/27%	Paris Charles de Gaulle	3,715	Paris Charles de Gaulle	38
15	Tokyo Narita	10.8	72%/28%	Doha Hamad	3,670	Chengdu Shuangliu	37
16	Amsterdam Schiphol	10.6	76%/24%	Frankfurt	3,491	London Heathrow	37
17	Bangkok Suvarnabhumi	10.1	83%/17%	Taipei Taiwan Taoyuan	3,477	Taipei Taiwan Taoyuan	36
18	Atlanta Hartsfield-Jackson	9.7	90%/10%	Chicago O'Hare	3,245	Shenzhen Bao'an	36
19	Sydney Kingsford Smith	8.5	82%/18%	New York John F. Kennedy	3,212	Bangkok Suvarnabhumi	36
20	Istanbul	8.4	85%/15%	Tokyo Narita	3,033	Hong Kong	35

Table 3 Top 20 airports that generated the most CO_2 emissions from passenger travel and freight in 2019

	Passenger			Freight		
Rank	Airport	$MtCO_2$	Coal-fired power plants	Airport	$MtCO_2$	Coal-fired power plants
1	Dubai	16.6	4.2	Memphis	7.16	1.8
2	London Heathrow	16.2	4.1	Anchorage	6.33	1.6
3	Los Angeles	15.3	3.8	Hong Kong	6.11	1.5
4	New York John F. Kennedy	12.9	3.2	Louisville	5.99	1.5
5	Paris Charles de Gaulle	11.5	2.9	Shanghai Pudong	4.59	1.1
6	Beijing Capital	11.4	2.9	Seoul Incheon	4.03	1
7	Hong Kong	11.3	2.8	Dubai	3.50	0.9
8	Singapore Changi	10.8	2.7	Los Angeles	3.41	0.9
9	Frankfurt	10.6	2.7	Frankfurt	3.29	0.8
10	Seoul Incheon	10.4	2.6	Tokyo Narita	3.02	0.8
11	San Francisco	10	2.5	Doha Hamad	2.93	0.7
12	Shanghai Pudong	9.2	2.3	London Heathrow	2.87	0.7
13	Chicago O'Hare	8.9	2.2	Singapore Changi	2.74	0.7
14	Atlanta Hartsfield-Jackson	8.7	2.2	Paris Charles de Gaulle	2.73	0.7
15	Bangkok Suvarnabhumi	8.36	2.1	Amsterdam Schiphol	2.50	0.6
16	Amsterdam Schiphol	8.11	2	Chicago O'Hare	2.36	0.6
17	Doha Hamad	8.01	2	Taipei Taiwan Taoyuan	2.36	0.6
18	Tokyo Narita	7.82	2	Miami	1.99	0.5
19	Istanbul	7.14	1.8	New York John F. Kennedy	1.79	0.4
20	Madrid-Barajas	7.12	1.8	Ontario	1.72	0.4

Going beyond these lists, the 100 most-polluting airports created 610 $MtCO_2$ (equivalent to 152 coal plants and accounting for 65% of total passenger and freight CO_2 emissions), along with 213,000 tonnes of NOx and 2,400 tonnes $PM_{2.5}$, equivalent to 83 million passenger vehicles.

Figure 4 The 100 most polluting airports



Source: Airport Tracker

CO_2, NOx and $PM_{2.5}$ emissions are not perfectly proportional and can even be traded off against each other (Lee et al., 2023; Cumpsty et al., 2019). Nonetheless, the majority of the most polluting airports for each of the pollutants are in three regions. Asia-Pacific has 32 of the 100 airports that created the most CO_2, 37 of the 100 airports that created the most NOx, and 42 of the 100 that created the most $PM_{2.5}$. The other two major regions are North America (32 of the largest CO_2 emitters, 28 of the largest NOx emitters, 24 of the largest $PM_{2.5}$ emitters) and Europe (22 CO_2, 20 NOx, 22 $PM_{2.5}$). Appendix 1 shows the 10 most polluting airports in each region.

Given the localised impacts of NOx and $PM_{2.5}$, we highlight cities where negative air quality issues may be particularly significant. London creates the most air pollution from aviation, as its six airports contributed 8,861 tonnes of NOx and 83 tonnes of $PM_{2.5}$ (equivalent to approximately 3.2 million cars). London was closely followed by the two airports each in Tokyo and Dubai, where aviation-related NOx and $PM_{2.5}$ emissions were equivalent to approximately 2.8 million passenger cars.

Table 4 Cities with the most air pollution from aviation

Rank	City	Country	Number of airports	Total NOx (tonnes)	Total $PM_{2.5}$ (tonnes)	NOx and $PM_{2.5}$ million passenger car equivalents
1	London	United Kingdom	6	8,861	83	3.23
2	Tokyo	Japan	2	8,205	61	2.78
3	Dubai	United Arab Emirates	2	7,611	72	2.78
4	Shanghai	China	2	6,448	79	2.60
5	New York	United States	4	6,488	65	2.42
6	Beijing	China	3	6,024	60	2.24
7	Sao Paulo	Brazil	3	4,723	74	2.12
8	Bangkok	Thailand	2	5,206	56	1.99
9	Seoul	Republic of Korea	2	5,424	49	1.95
10	Paris	France	3	4,793	54	1.87
11	Hong Kong	Hong Kong	1	5,678	35	1.84
12	Moscow	Russia	3	3,751	70	1.81
13	Atlanta	United States	1	4,130	60	1.79
14	Istanbul	Turkey	2	4,613	44	1.68
15	Singapore	Singapore	1	4,462	41	1.61
16	Guangzhou	China	1	3,757	49	1.55
17	Los Angeles	United States	1	4,187	39	1.52
18	Chicago	United States	2	4,050	41	1.52
19	Frankfurt	Germany	2	3,551	46	1.46
20	Taipei	Taiwan	2	3,793	41	1.45

6 Conclusion

This brief accompanies a major update of the Airport Tracker which now displays the impacts of air freight as well as passenger flights, and emissions of local air pollutants at 1,300 airports. The brief provides an introduction to the data and a recap on the global state of knowledge around the aviation sector's negative social and environmental impacts. It lays out clearly that the aviation sector is not on track to limit these impacts in line with globally agreed targets, and that the sector is profoundly unequal across several dimensions.

We argue that airports are a key entry point for those seeking to align the aviation sector with local and global goals. However, because the context varies so substantially between airports (and between countries) we do not offer general recommendations. Instead, we point those interested towards more local ongoing efforts advocating for a less environmentally damaging, more socially equal aviation sector.

References

Abnett, K. and Jessop, S. (2020) 'EU lending arm considers ending airport expansion support: draft'. Reuters (https://www.reuters.com/article/idUSKBN27L1O2/).

AEF (2019) *Raising the public visibility of aviation emission*. Report by AEF for the Foundation for Integrated Transport. London: Aviation Environment Federation (https://www.aef.org.uk/uploads/2022/05/AEF-Report-Raising-the-Visibility-5-Sept-2019.pdf).

AEF (2022) *The role of aviation demand reduction in UK decarbonisation*. Report. London: Aviation Environment Federation (https://www.aef.org.uk/uploads/2022/05/The-Role-of-Aviation-Demand-in-Decarbonisation-Full-Report.pdf).

AEF (2023) 'Why increasing levels of air travel won't lead to growth in UK productivity or GDP'. Website. AEF (https://www.aef.org.uk/2023/07/17/why-increasing-levels-of-air-travel-wont-lead-to-growth-in-uk-productivity-or-gdp/).

Bendtsen, K.M. et al. (2021) 'A review of health effects associated with exposure to jet engine emissions in and around airports' *Environmental Health* 20(10) (https://doi.org/10.1186/s12940-020-00690-y).

de Bruyn, S. and de Vries, J. (2020) 'Health costs of air pollution in European cities and the linkage with transport'. Report 190272. Delft: CE Delft.

Carbon Brief (2016) 'Analysis: aviation could consume a quarter of 1.5C carbon budget by 2050' *Carbon Brief* (https://www.carbonbrief.org/aviation-consume-quarter-carbon-budget/).

CCC (2023) 'Progress in reducing UK emissions 2023'. Report to Parliament. London: UK Climate Change Committee (https://www.theccc.org.uk/publication/2023-progress-report-to-parliament/).

Chapman, A. (2023) *Losing altitude: the economics of air transport in Great Britain*. New Economics Foundation (https://neweconomics.org/uploads/files/NEF_Losing-altitude.pdf).

Cumpsty, N., Mavris, D. and Kirby, M. (2019) 'Aviation and the environment: outlook'. In *Aviation and Environmental Outlook*. Quebec: International Civil Aviation Authority (https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2019/ENVReport2019_pg24-38.pdf).

EASA (2019) *European aviation environmental report 2019*. Report by European Union Aviation Safety Agency (EASA), the European Environment Agency (EEA) and EUROCONTRO (https://www.easa.europa.eu/eco/sites/default/files/2021-09/219473_EASA_EAER_2019_WEB_HI-RES_190311.pdf).

EASA (2022) *European aviation environmental report 2022*. Report by the European Union Aviation Safety Agency (EASA), the European Environment Agency (EEA) and EUROCONTRO. EASA, EEA and EUROCONTRO https://www.easa.europa.eu/eco/eaer

EASA (n.d.) 'Air quality'. Webpage. EASA (https://www.easa.europa.eu/eco/eaer/topics/adapting-changing-climate/air-quality).

EASBCC (2024) 'Towards EU climate neutrality: progress, policy gaps and opportunities'. European Scientific Advisory Board on Climate Change (https://climate-advisory-board.europa.eu/news/eu-climate-advisory-board-focus-on-immediate-implementation-and-continued-action-to-achieve-eu-climate-goals).

EEA (2018) *Unequal exposure and unequal impacts: social vulnerability to air pollution, noise and extreme temperatures in Europe*. 22/2018. Copenhagen: European Environment Agency (https://www.eea.europa.eu/publications/unequal-exposure-and-unequal-impacts/).

EEA (2022a) 'Impacts of air pollution on ecosystems'. European Environment Agency. November (https://www.eea.europa.eu/publications/air-quality-in-europe-2022/impacts-of-air-pollution-on-ecosystems).

EEA (2022b) 'Air quality in Europe 2022'. European Environment Agency. November (https://www.eea.europa.eu/publications/air-quality-in-europe-2022/air-quality-in-europe-2022).

Esqué, A. et al. (2022) 'Decarbonizing the aviation sector: making net zero aviation possible'. Executive Briefing. McKinsey & Company (https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/decarbonizing-the-aviation-sector-making-net-zero-aviation-possible#/).

FAA (2015) 'Aviation emissions and air quality handbook version 3 update 1'. Federal Aviation Administration. Office of Environment and Energy. January (https://www.faa.gov/sites/faa.gov/files/regulations_policies/policy_guidance/envir_policy/airquality_handbook/Air_Quality_Handbook_Appendices.pdf).

FAA (2022) 'The economic impact of US civil aviation: 2020'. Federal Aviation Administration. Office of Environment and Energy (https://www.faa.gov/about/plans_reports/2020-economic-impact-report).

Gallagher, T. (2022) 'Schiphol airport in Amsterdam limits flights to prevent emissions, in world first'. Euronews (https://www.euronews.com/green/2022/06/27/amsterdams-schiphol-airport-becomes-first-in-the-world-to-cap-flights-to-limit-emissions).

Government of the Netherlands (2022) 'Government limits flight movements at Amsterdam Schiphol Airport'. Government of the Netherlands (https://www.government.nl/latest/news/2022/06/24/government-limits-flight-movements-at-amsterdam-schiphol-airport).

Gössling, S. and Humpe, A. (2020) 'The global scale, distribution and growth of aviation: implications for climate change' *Global Environmental Change* 65: 102194.

Graver, B., Rutherford, D. and Zheng, S. (2020) 'CO_2 emissions from commercial aviation 2013, 2018 and 2019'. Washington DC: International Council on Clean Transportation (https://theicct.org/publications/co2-emissions-commercial-aviation-2020).

Gualtieri, T. (2024) 'Spain plans €2.4 billion investment to expand Madrid Airport'. Bloomberg (https://www.bloomberg.com/news/articles/2024-01-26/spain-plans-2-4-billion-investment-to-expand-madrid-airport).

Guardian (2023) 'Delta Air Lines faces lawsuit over $1bn carbon neutrality claim' (https://www.theguardian.com/environment/2023/may/30/delta-air-lines-lawsuit-carbon-neutrality-aoe).

Halleux, V. (2023) 'Revision of EU air quality legislation. Setting a zero pollution objective for air'. Briefing. EU Legislation in Progress. European Parliamentary Research Service PE 747.087.

Health Effects Institute (2020) *State of global air 2020*. *Special Report*. Boston, MA: Health Effects Institute.

IATA (2019) 'More connectivity and improved efficiency – 2018 airline industry statistics released'. Press Release (https://www.iata.org/en/pressroom/pressroom-archive/2019-press-releases/2019-07-31-01/).

IATA (2023a) 'Global outlook for air transport: a local sweet spot'. IATA (iata.org/en/iata-repository/publications/economic-reports/global-outlook-for-air-transport---december-2023---report/).

IATA (2023b) 'Global outlook for air transport: highly resilient, less robust'. IATA (iata.org/en/iata-repository/publications/economic-reports/global-outlook-for-air-transport----june-2023/).

IATA (2024a) 'Air passenger market analysis November 2023'. Air Passenger Monthly Analysis. IATA: Montreal (https://www.iata.org/en/iata-repository/publications/economic-reports/air-passenger-market-analysis---november-2023/).

IATA (2024b) 'Air cargo market analysis November 2023'. Air Cargo Monthly Analysis. IATA (https://www.iata.org/en/iata-repository/publications/economic-reports/air-cargo-market-analysis---november-2023/).

ICAO (2016) Airport Air Quality Manual. Doc 9899. CAEP10 Steering Group 2015 Approved Revision (Based on the First Edition – 2011). Quebec: International Civil Aviation Authority.

ICAO (2021) COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP), TWELFTH MEETING, Agenda Item 16: Future work. VIEWS OF THE UNITED STATES ON EMISSIONS FUTURE WORK DURING THE CAEP/13 CYCLE. CAEP/12-WP/62. Quebec: International Civil Aviation Authority. https://icao.usmission.gov/wp-content/uploads/sites/280/CAEP.12.WP_.062.16.en-VIEWS-OF-THE-UNITED-STATES-ON-EMISSIONS-FUTURE-WORK-DURING-THE-CAEP13-CYCLE.pdf

ICAO (2022) 'States adopt net-zero 2050 global aspirational goal for international flight operations'. News release, 7th October (https://www.icao.int/Newsroom/Pages/States-adopts-netzero-2050-aspirational-goal-for-international-flight-operations.aspx).

ICAO (2022b) 'ASSEMBLY — 41ST SESSION. EXECUTIVE COMMITTEE. Agenda Item 16: Environmental Protection – General provisions, Aircraft Noise and Local Air Quality'. A41-WP/93. Quebec: International Civil Aviation Authority. https://www.icao.int/Meetings/a41/Documents/WP/wp_093_rev_en.pdf

ICAO (2023) 'Effects of Novel Coronavirus (COVID-19) on civil aviation: Economic Impact Analysis'. ICAO (https://www.icao.int/sustainability/Documents/COVID-19/ICAO_Coronavirus_Econ_Impact.pdf).

IEA (2021) 'Net zero by 2050: a roadmap for the global energy sector'. Report. Paris: IEA (https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf).

IEA (2023a) 'Aviation'. IEA (https://www.iea.org/energy-system/transport/aviation).

IEA (2023b) 'CO_2 emissions in 2022'. IEA (https://www.iea.org/reports/co2-emissions-in-2022).

IPCC (1999) 'IPCC special report aviation and the global atmosphere. Summary for policymakers'. Intergovernmental Panel on Climate Change (https://www.ipcc.ch/site/assets/uploads/2018/03/av-en-1.pdf).

Ivanova, D. and Wood, R. (2020) 'The unequal distribution of household carbon footprints in Europe and its link to sustainability' *Global Sustainability* 3:e18.

Klöwer, M. et al. (2021) 'Quantifying aviation's contribution to global warming' *Environmental Research Letters* 16(10): 104027.

Lattanzio, R.K. (2023) 'Aviation, air pollution, and climate change'. US Congressional Research Service.IF11696. Version 6. Updated (https://crsreports.congress.gov).

Le Monde and AFP (2023) 'France's short-haul flight ban comes into force'. Le Monde (https://www.lemonde.fr/en/france/article/2023/05/23/france-s-short-haul-flight-ban-comes-into-force_6027699_7.html).

Lee, D.S. et al. (2021) 'The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018' *Atmospheric Environment* 244: 117834.

Lee, D.S. et al. (2023) 'Uncertainties in mitigating aviation non-CO_2 emissions for climate and air quality using hydrocarbon fuels' *Environ. Sci.: Atmos.* 3: 1693.

Manisalidis, I. et al. (2020) 'Environmental and health impacts of air pollution: a review' *Frontiers in public health* 8: 14.

Mission Possible Partnership (2022) 'Making net-zero aviation possible. An industry-backed, 1.5°C-aligned transition strategy'. Mission Possible Partnership (MPP), Energy Transitions Commission (ETC), Clean Skies for Tomorrow (CST), McKinsey & Company and World Economic Forum (WEF) (https://www.mckinsey.com/~/media/mckinsey/industries/aerospace%20and%20defense/our%20insights/decarbonizing%20the%20aviation%20sector%20making%20net%20zero%20aviation%20possible/making-net-zero-aviation-possible-full-report.pdf?shouldIndex=false).

Municipality of Anchorage (2022) 'Anchorage 2015 & 2020 Community Greenhouse Gas Inventory'. Municipality of Anchorage (https://www.muni.org/Departments/SWS/Documents/Anchorage%20GHG%20Inventory_2015_2020_FINAL.pdf).

New Climate Economy (2016) 'The sustainable infrastructure imperative. Financing for better growth and development. The 2016 New Climate Economy Report'. Washington DC and London: New Climate Economy, WRI and ODI (https://newclimateeconomy.net/Downloaded_Pdf/Global_report/2016/The-Sustainable-Infrastructure-Imperative/Global-Report-and-Sections/NCE_2016Report.pdf).

Olmer N. and Rutherford, D. (2017) 'International civil aviation organisation's carbon offset and reduction scheme for international aviation (CORSIA)'. Policy update (https://theicct.org/publications/ICAO-carbon-offset-and-reduction-scheme-international-aviation).

Oswald, Y., Owen, A. and Steinberger, J.K. (2020) 'Large inequality in international and intranational energy footprints between income groups and across consumption categories' *Nature Energy* 5(3): 231–239.

Pickard, S. and Gençsü, I. (2021) 'The airport tracker'. London: ODI.

Riley, K. et al. (2021) 'A systematic review of the impact of commercial aircraft activity on air quality near airports' *City and Environment Interactions* 11: 100066 (https://doi.org/10.1016/j.cacint.2021.100066).

Stay Grounded (2023) 'Common destination'. Reframing aviation to ensure a safe landing and lay the tracks towards a fair planet (https://reframeaviation.stay-grounded.org/download/).

Stay Grounded (2024) 'Aviation is a health issue'. Fact Sheet. February.

Transport and Environment (2021) 'Don't sink Paris: legal basis for inclusion of aviation and shipping emissions in Paris targets'. Brussels: Transport and Environment (https://www.transportenvironment.org/discover/shipping-and-aviation-are-subject-to-the-paris-agreement-legal-analysis-shows/).

Transport and Environment (2022) 'Roadmap to climate neutral aviation in Europe'. Transport and Environment (https://www.transportenvironment.org/wp-content/uploads/2022/03/TE-aviation-decarbonisation-roadmap-FINAL.pdf).

Transport and Environment (2023) 'Every hour European governments lose out on €4 million in aviation taxes'. Brussels: Transport and Environment (https://www.transportenvironment.org/discover/every-hour-european-governments-lose-out-on-e4-million-in-aviation-taxes/).

Transport & Environment and Travel Smart (2023) 'Sustainable aviation fuels sustainability guide for corporate buyers'. Brussels: Transport and Environment (https://www.transportenvironment.org/discover/sustainable-aviation-fuels-sustainability-guide-for-corporate-buyers/).

Welker, L., Roth, J. and Gerasimchuk, I. (n.d.) '2020–21 recovery analysis'. Webpage. Energy Policy Tracker (https://www.energypolicytracker.org/2020-21-global-recovery-analysis/).

WHO (2021) 'WHO global air quality guidelines. Particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide'. Geneva: World Health Organization (https://www.who.int/publications/i/item/9789240034228).

Yim, S.H.L., et al (2015). 'Global, regional and local health impacts of civil aviation emissions.' *Environmental Research Letters* 10.3: 034001.

Appendix 1 Most polluting airports by region

Table A1 Most polluting airports in Asia/Pacific

	Total carbon emissions		Total air pollution			
Rank	**Airport name**	**Total CO_2 (Mt)**	**Airport name**	**Total NOx (tonnes)**	**Airport name**	**Total $PM_{2.5}$ (tonnes)**
1	Hong Kong	17.4	Beijing Capital	5,736	Beijing Capital	54
2	Seoul | Incheon	14.4	Hong Kong	5,678	Shanghai Pudong	51
3	Shanghai Pudong	13.8	Tokyo | Haneda	5,172	Guangzhou Baiyun	49
4	Singapore Changi	13.5	Seoul | Incheon	4,491	Singapore Changi	41
5	Beijing Capital	13.1	Singapore Changi	4,462	Seoul | Incheon	41
6	Tokyo | Narita	10.8	Bangkok Suvarnabhumi	4,228	Kunming Changshui	38
7	Bangkok Suvarnabhumi	10.1	Shanghai Pudong	4,223	Tokyo | Haneda	38
8	Sydney Kingsford Smith	8.5	Guangzhou Baiyun	3,757	Chengdu Shuangliu	37
9	Guangzhou Baiyun	8.1	Taipei | Taiwan Taoyuan	3,477	Taipei | Taiwan Taoyuan	36
10	Taipei | Taiwan Taoyuan	7.9	Tokyo | Narita	3,033	Shenzhen Bao'an	36
11	Tokyo | Haneda	7.7	Chengdu Shuangliu	2,564	Bangkok | Suvarnabhumi	36
12	Kuala Lumpur	6.7	Delhi | Indira Gandhi	2,563	Hong Kong	35
13	Delhi | Indira Gandhi	6.4	Kuala Lumpur	2,503	Xi'an Xianyang	35
14	Melbourne	5.4	Shenzhen Bao'an	2,404	Kuala Lumpur	34
15	Manila | Ninoy Aquino	4.9	Shanghai Hongqiao	2,225	Jakarta | Soekarno-Hatta	34
16	Jakarta | Soekarno-Hatta	4.9	Sydney Kingsford Smith	2,221	Chongqing Jiangbei	32
17	Shenzhen Bao'an	4.5	Jakarta | Soekarno-Hatta	2,173	Ho Chi Minh City | Tan Son Nhat	29
18	Osaka | Kansai	4.3	Mumbai | Chhatrapati Shivaji Maharaj	1,891	Shanghai Hongqiao	28
19	Mumbai | Chhatrapati Shivaji Maharaj	4.3	Ho Chi Minh City | Tan Son Nhat	1,890	Hangzhou Xiaoshan	27
20	Chengdu Shuangliu	4.1	Xi'an Xianyang	1,853	Delhi | Indira Gandhi	27

Table A2 Most polluting airports in North America

	Total carbon emissions		Total air pollution			
Rank	Airport name	Total CO_2 (Mt)	Airport name	Total NOx (tonnes)	Airport name	Total $PM_{2.5}$ (tonnes)
1	Los Angeles	18.7	Los Angeles	4,187	Atlanta | Hartsfield-Jackson	60
2	New York | John F. Kennedy	14.7	Atlanta | Hartsfield-Jackson	4,130	Los Angeles	39
3	Chicago | O'Hare	11.2	Chicago | O'Hare	3,245	Dallas/Fort Worth	33
4	San Francisco	11.1	New York | John F. Kennedy	3,212	New York | John F. Kennedy	32
5	Atlanta | Hartsfield-Jackson	9.7	San Francisco	2,994	Chicago | O'Hare	30
6	Dallas/Fort Worth	8.3	Dallas/Fort Worth	2,720	Minneapolis-Saint Paul	26
7	Newark Liberty	8.1	Denver	2,372	Las Vegas	26
8	Toronto Pearson	7.7	Newark Liberty	2,353	Orlando	26
9	Memphis	7.5	Memphis	2,239	Phoenix | Sky Harbor	25
10	Miami	7.4	Orlando	1,982	Detroit	24
11	Anchorage	6.9	Toronto Pearson	1,964	Denver	24
12	Louisville	6.3	Las Vegas	1,894	Miami	23
13	Seattle/Tacoma	6.2	Miami	1,869	Charlotte	22
14	Houston | George Bush	5.7	Phoenix | Sky Harbor	1,851	Boston Logan	21
15	Denver	5.3	Charlotte	1,721	San Francisco	21
16	Boston Logan	5.0	Boston Logan	1,677	Fort Lauderdale-Hollywood	21
17	Honolulu	4.7	Houston | George Bush	1,662	Toronto Pearson	20
18	Vancouver	4.6	Seattle/Tacoma	1,565	New York | LaGuardia	19
19	Philadelphia	4.5	Fort Lauderdale-Hollywood	1,405	Seattle/Tacoma	17
20	Washington Dulles	4.4	Philadelphia	1,360	Salt Lake City	16

Table A3 Most polluting airports in Europe

	Total carbon emissions		Total air pollution			
Rank	Airport name	Total CO_2 (Mt)	Airport name	Total NOx (tonnes)	Airport name	Total $PM_{2.5}$ (tonnes)
1	London Heathrow	19.1	London Heathrow	5,844	Frankfurt	45
2	Paris Charles de Gaulle	14.2	Istanbul	4,097	Moscow | Sheremetyevo	39
3	Frankfurt	13.9	Paris Charles de Gaulle	3,715	Paris Charles de Gaulle	38
4	Amsterdam | Schiphol	10.6	Frankfurt	3,491	London Heathrow	37
5	Istanbul	8.4	Amsterdam | Schiphol	2,363	Istanbul	35
6	Madrid-Barajas	7.8	Madrid-Barajas	2,357	Munich	32
7	Moscow | Sheremetyevo	7.2	Moscow | Sheremetyevo	2,112	Barcelona El Prat	31
8	Munich	5.4	Munich	2,079	Madrid-Barajas	28
9	Rome | Fiumicino	4.9	Barcelona El Prat	1,757	Amsterdam | Schiphol	23
10	London Gatwick	4.8	Rome | Fiumicino	1,706	Rome | Fiumicino	23
11	Zurich	4.3	London Gatwick	1,465	London Gatwick	19
12	Barcelona El Prat	3.9	Zurich	1,310	Dublin	17
13	Milan Malpensa	3.8	Dublin	1,246	St Petersburg | Pulkovo	16
14	Lisbon | Humberto Delgado	3.3	Lisbon | Humberto Delgado	1,173	Milan Malpensa	16
15	Manchester	3.1	Milan Malpensa	1,147	Moscow | Domodedovo	16
16	Brussels	2.9	Brussels	1,078	Oslo Gardermoen	15
17	Paris Orly	2.9	Oslo Gardermoen	1,061	Moscow | Vnukovo	15
18	Vienna	2.9	Moscow | Domodedovo	1,016	Paris Orly	15
19	Dublin	2.8	Copenhagen Kastrup	1,000	London Stansted	14
20	Copenhagen Kastrup	2.7	Vienna	991	Berlin Tegel	14

Table A4 Most polluting airports in the Middle East

	Total carbon emissions		Total air pollution			
Rank	Airport name	Total CO_2 (Mt)	Airport name	Total NOx (tonnes)	Airport name	Total $PM_{2.5}$ (tonnes)
1	Dubai	20.1	Dubai	7,531	Dubai	71
2	Doha | Hamad	10.9	Doha | Hamad	3,670	Doha | Hamad	31
3	Abu Dhabi	4.8	Jeddah | King Abdulaziz	2,080	Jeddah | King Abdulaziz	22
4	Jeddah | King Abdulaziz	4.6	Riyadh | King Khalid	1,546	Riyadh | King Khalid	21
5	Tel Aviv | Ben Gurion	3.4	Abu Dhabi	1,481	Abu Dhabi	15
6	Riyadh | King Khalid	2.5	Kuwait	1,186	Kuwait	12
7	Kuwait	1.8	Tel Aviv | Ben Gurion	1,024	Tel Aviv | Ben Gurion	10
8	Muscat	1.8	Muscat	707	Sharjah	10
9	Sharjah	1.3	Bahrain	613	Dammam | King Fahd	9
10	Bahrain	1.0	Dammam | King Fahd	589	Bahrain	8
11	Dubai | Al Maktoum	1.0	Beirut | Rafic Hariri	549	Amman | Queen Alia	7
12	Amman | Queen Alia	0.9	Amman | Queen Alia	496	Beirut | Rafic Hariri	7
13	Tehran | Imam Khomeini	0.9	Tehran | Imam Khomeini	475	Muscat	6
14	Beirut | Rafic Hariri	0.9	Sharjah	434	Tehran | Mehrabad	6
15	Dammam | King Fahd	0.8	Medina | Prince Mohammad bin Abdulaziz	429	Medina | Prince Mohammad bin Abdulaziz	5
16	Medina | Prince Mohammad bin Abdulaziz	0.7	Tehran | Mehrabad	410	Abha	4
17	Tehran | Mehrabad	0.5	Mashhad	216	Tehran | Imam Khomeini	4
18	Mashhad	0.3	Abha	192	Mashhad	3
19	Baghdad	0.3	Baghdad	172	Baghdad	3
20	Abha	0.2	Jizan	107	Jizan	3

Table A5 Most polluting airports in Africa

	Total carbon emissions		Total air pollution			
Rank	Airport name	Total CO_2 (Mt)	Airport name	Total NOx (tonnes)	Airport name	Total $PM_{2.5}$ (tonnes)
1	Johannesburg | O.R. Tambo	4.1	Cairo	1,113	Cairo	10
2	Addis Ababa Bole	2.5	Johannesburg | O.R. Tambo	1,055	Johannesburg | O.R. Tambo	9
3	Cairo	2.1	Addis Ababa Bole	972	Tunis-Carthage	7
4	Nairobi | Jomo Kenyatta	1.7	Casablanca | Mohammed V	539	Addis Ababa Bole	6
5	Cape Town	1.5	Cape Town	428	Casablanca | Mohammed V	6
6	Casablanca | Mohammed V	1.4	Algiers | Houari Boumediene	426	Algiers | Houari Boumediene	6
7	Lagos | Murtala Muhammed	1.0	Nairobi | Jomo Kenyatta	421	Lagos | Murtala Muhammed	5
8	Mauritius | Sir Seewoosagur Ramgoolam	0.9	Lagos | Murtala Muhammed	416	Abuja | Nnamdi Azikiwe	4
9	Algiers | Houari Boumediene	0.7	Tunis-Carthage	285	Cape Town	4
10	Accra | Kotoka	0.6	Mauritius | Sir Seewoosagur Ramgoolam	265	Marrakesh Menara	3
11	Saint-Denis | Roland Garros	0.6	Abuja | Nnamdi Azikiwe	233	Nairobi | Jomo Kenyatta	3
12	Luanda | Quatro de Fevereiro	0.5	Accra | Kotoka	226	Mauritius | Sir Seewoosagur Ramgoolam	3
13	Tunis-Carthage	0.5	Durban | King Shaka	208	Khartoum	2
14	Marrakesh Menara	0.5	Marrakesh Menara	207	Alexandria | Borg el Arab	2
15	Hurghada	0.5	Abidjan | Felix-Houphouet-Boigny	188	Durban | King Shaka	2
16	Dakar | Blaise Diagne	0.4	Khartoum	173	Abidjan | Felix-Houphouet-Boigny	2
17	Abidjan | Felix-Houphouet-Boigny	0.4	Dakar | Blaise Diagne	165	Hurghada	2
18	Durban | King Shaka	0.3	Luanda | Quatro de Fevereiro	155	Ahmed Ben Bella	1
19	Abuja | Nnamdi Azikiwe	0.3	Dar es Salaam | Julius Nyerere	148	Accra | Kotoka	1
20	Dar es Salaam | Julius Nyerere	0.3	Saint-Denis | Roland Garros	147	Agadir-Al Massira	

Table A6 Most polluting airports in Latin America/Caribbean

	Total carbon emissions		Total air pollution			
Rank	Airport name	Total CO_2 (Mt)	Airport name	Total NOx (tonnes)	Airport name	Total $PM_{2.5}$ (tonnes)
1	Sao Paulo/Guarulhos	6.1	Sao Paulo/Guarulhos	2,616	Sao Paulo/Guarulhos	40
2	Mexico City	5.2	Lima | Jorge Chavez	1,790	Lima | Jorge Chavez	32
3	Santiago | Arturo Merino Benitez	3.0	Santiago | Arturo Merino Benitez	1,740	Sao Paulo/Congonhas | Deputado Freitas Nobre	31
4	Buenos Aires | Ministro Pistarini	3.0	Sao Paulo/Congonhas | Deputado Freitas Nobre	1,709	Santiago | Arturo Merino Benitez	27
5	Bogota | El Dorado	3.0	Mexico City	1,330	Brasilia | Presidente Juscelino Kubitschek	21
6	Lima | Jorge Chavez	2.8	Brasilia | Presidente Juscelino Kubitschek	1,169	Mexico City	20
7	Cancun	2.4	Bogota | El Dorado	945	Bogota | El Dorado	17
8	Panama City | Tocumen	2.0	Rio de Janeiro/Galeao | Antonio Carlos Jobim	727	Rio de Janeiro/Galeao | Antonio Carlos Jobim	12
9	Rio de Janeiro/Galeao | Antonio Carlos Jobim	1.8	Cancun	721	Rio de Janeiro | Santos Dumont	11
10	Sao Paulo | Viracopos-Campinas	1.1	Buenos Aires | Ministro Pistarini	708	Panama City | Tocumen	11
11	Guadalajara	1.1	Rio de Janeiro | Santos Dumont	627	Buenos Aires | Jorge Newbery	10
12	Brasilia | Presidente Juscelino Kubitschek	1.1	Belo Horizonte/ Confins | Tancredo Neves	577	Cancun	10
13	San Juan | Luis Munoz Marin	1.0	Panama City | Tocumen	575	Buenos Aires | Ministro Pistarini	9
14	Sao Paulo/Congonhas | Deputado Freitas Nobre	0.9	Buenos Aires | Jorge Newbery	497	Belo Horizonte/ Confins | Tancredo Neves	8
15	Punta Cana	0.9	Guadalajara	446	Guadalajara	8
16	Havana | Jose Marti	0.8	Porto Alegre | Salgado Filho	437	Fortaleza | Pinto Martins	7
17	Tijuana	0.7	Fortaleza | Pinto Martins	420	Porto Alegre | Salgado Filho	7
18	Buenos Aires | Jorge Newbery	0.7	Salvador | Deputado Luis Eduardo Magalhaes	403	Salvador | Deputado Luis Eduardo Magalhaes	7
19	San Jose | Juan Santamaria	0.7	Sao Paulo | Viracopos-Campinas	398	Cuzco | Alejandro Velasco Astete	7
20	Recife | Guararapes-Gilberto Freyre	0.7	Curitiba | Afonso Pena	388	Medellin | Jose Maria Cordova	6