Environmental and Energy Study Institute
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Issue Brief

The Growth in Greenhouse Gas Emissions from Commercial Aviation

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This issue brief examines the impact the growth of air travel and freight will have on greenhouse gas emissions. Subsequent briefs will feature the aviation industry's emission mitigation efforts and commitments to reduce its contribution to climate change, as well as the effects of a warming planet on industry operations.

In 1960, 100 million passengers traveled by air,[1] at the time a relatively expensive mode of transportation available only to a small fraction of the public. **By 2019, the total annual world-wide passenger count was 4.56 billion**.[2] The "hypermobility"[3] of air travel is available to greater numbers of people worldwide, with rapid growth in aviation projected for developing nations and sustained growth in the large established aviation markets of developed countries. While our collective use of automobiles, our production of electricity, and the industrial and agricultural sectors each exceed the climate change impact of commercial aviation, **passenger air travel was producing the highest and fastest growth of individual emissions** before the pandemic,[4] despite a significant improvement in efficiency of aircraft and flight operations over the last 60 years.

Airline Energy Intensity and Emissions

Between 1970 and 2019 in the United States, engine and design technology advances, improvements in air traffic operations, denser seat configurations, and higher passenger loads together reduced the energy intensity of air travel, expressed as British Thermal Units (BTUs) per passenger mile, by 77 percent.[5] In the last two decades, carbon dioxide (CO2) emissions from commercial aviation worldwide grew at a slower pace than the growth of the industry,[6] but emissions from aviation have accelerated in recent years as increasing commercial air traffic continued to raise the industry's contribution to global emissions. According to the International Council on Clean Transportation (ICCT), global CO2 from commercial aviation was 707 million tons in 2013. In 2019 that value reached 920 million tons,[7] having increased approximately 30 percent in six years. The United States, with the world's largest commercial air traffic system, accounted for 200 million tons (23 percent) of the 2017 global CO2 total.[8] **EPA reports that commercial airplanes and large business jets contribute 10 percent of U.S. transportation emissions, and account for three percent of the nation's total greenhouse gas (GHG) production**.[9]

Globally, aviation produced 2.4 percent of total CO2 emissions in 2018.[10] While this may seem like a relatively small amount, consider that if global commercial aviation had been a country in the 2019 national GHG emissions standings, the industry would rank number six in the world between Japan and Germany.[11] Non-CO2 effects, such as warming induced by aircraft contrails, add to the total climate influence of aviation. Updated analysis in the journal *Atmospheric Environment* in January 2021 concluded **aviation's climate impact accounted for 3.5 percent of total anthropogenic warming in 2011 and was likely the same percentage in 2018**.[12]

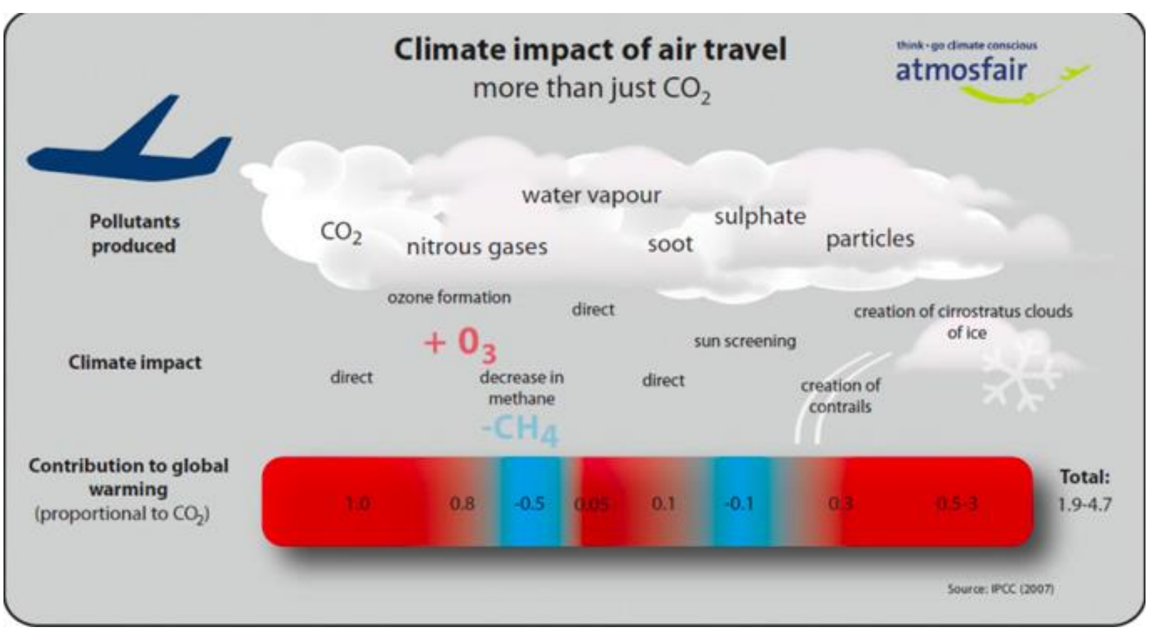
In this issue brief, we will look at both categories of commercial aviation: passenger travel and air freight. In 2018, passenger transport produced 81 percent of global commercial aviation emissions and air freight generated the remaining 19 percent.[13] Both categories have a history of steady growth, and the trend will continue**. By 2050, commercial aircraft emissions could triple** given the projected growth of passenger air travel and freight.[14]

A Snapshot of Aviation Emissions

Commercial aviation's climate change impact is complex, reflecting the variety of emissions from operations at the surface up to cruise altitudes as high as 43,000 feet, across continents and oceans, and over varied time spans. The climate impacts of jet aircraft emissions are summarized in the graphic below, produced by the German site atmosfair, which references material from the United Nations' Intergovernmental Panel on Climate Change (IPCC). Within the cloud trailing the aircraft are the various gases and particulates emitted by burning jet fuel (kerosene). The warming or cooling influence of these gases is described below the cloud (in the line labeled "Climate Impact"), and a comparison of each exhaust product to the warming effect of CO2 is included in the color-coded bar with red for a warming impact and blue representing a cooling effect.

Carbon Dioxide (CO2)

CO2 is the largest component of aircraft emissions, accounting for approximately 70 percent of the exhaust.[15] The gas mixes in the atmosphere with the same direct warming effect that occurs when it is emitted from other fossil fuel combustion sources. Jet fuel consumption produces CO2 at a defined ratio (3.16 kilograms of CO2 per 1 kilogram of fuel consumed), regardless of the phase of flight.[16] Its extended lifetime in the atmosphere makes CO2 especially potent as a greenhouse gas. After being emitted, 30 percent of a given quantity of the gas is removed from the atmosphere naturally over 30 years, an additional 50 percent disappears within a few hundred years, and the remaining 20 percent stays in the atmosphere for thousands of years.[17]



This graphic presents the range of warming from contrail-induced cirrus clouds, identified as cirrostratus. The atmospheric conditions that produce and sustain contrails vary over time and space. Research is underway to fully understand the climate impact of contrail-induced cirrostratus clouds.

Used with permission from atmosfair.[18]

Contrails

Water vapor is also a product of jet fuel consumption, making up about 30 percent of the exhaust.[19] With its short lifespan in the atmosphere as part of the water cycle, water vapor from aircraft has a minimal direct warming impact. However, its presence in the exhaust plume has an indirect impact by contributing to the formation of contrails. Water vapor in the exhaust instantly freezes when the ambient temperature is cold enough, as particulates in the exhaust form the nucleus of ice crystals. When the ambient atmosphere is sufficiently humid and cold, the small ice crystals expand as they draw water vapor from the atmosphere and are sustained as contrails that can spread horizontally and vertically to form contrail-induced cirrus clouds. These lingering contrails and contrail-induced cirrus clouds trap infrared rays, producing a warming effect up to three times the impact of CO2. Even though these cirrus clouds have a relatively short life span, usually a matter of hours,[20] their collective influence, produced by thousands of flights, have a serious warming effect. **The effect is so large today that it exceeds the total warming influence of all the CO2 emitted by aircraft since the beginning of powered flight.**[20]

Nitrous Gases, Particles and Local Air Quality

All the remaining emissions in the graphic make up less than one percent of the exhaust plume.[21] Nitrous gases have both a warming and cooling influence. Nitrogen oxides in the exhaust chemically form ozone (O3), producing a warming effect; but they also act to eliminate methane, a potent greenhouse gas whose reduction in the atmosphere has a cooling effect. The net for nitrous gases is a warming influence. The particles include hydrocarbons, soot, and sulfates. Sulfates reflect the sun's rays producing a small cooling effect. Soot absorbs heat and these black carbon particles readily become ice crystal nuclei. Modern jet engines emit far fewer of these soot particles than earlier models, reducing their contribution to contrail formation and eliminating the black exhaust typical of jet aircraft decades ago. However, together with hydrocarbon particles, black carbon particulates are still numerous enough to make contrail-induced cirrus clouds a major climate impact of aviation.

According to scientists who study aircraft emissions and their climate impacts, more research is required to fully understand the formation and impact of contrails and contrail-induced clouds so that mitigation strategies can be developed. One potential mitigation strategy is the use of sustainable biofuels blended with kerosene jet fuel, which is beginning to enter the commercial aviation market. Biofuels can have a significantly lower lifecycle greenhouse gas assessment than conventional petroleum-based jet fuel. Biofuel blends also reduce soot content, water vapor, and sulfates in the exhaust. Fewer particulates and less water vapor will mean a reduction in contrail formation.[22] Reducing the sulfur content of kerosene jet fuel and engine design changes can also decrease exhaust particulates. Flight planning and altitude changes to avoid ambient conditions that produce contrails is another possible strategy. However, routing changes can create traffic problems and extend flights, adding to CO2 emissions.[23]

Low Altitude and Ground Operations

Approximately 90 percent of aircraft emissions occur higher than 3,000 feet above the ground, with the remaining 10 percent emitted during taxi, takeoff, initial climb, and during the approach and landing. Aircraft ground and low altitude operations produce the same emissions described above, with an added impact on local air quality resulting from nitrogen oxides, sulfur oxides, hydrocarbon and soot particulates. Ground service equipment (GSE) and airport service vehicles generate most or all of these same emissions, further contributing to aviation's impact on climate and local air quality. Although it is not a product of inflight emissions, methane is emitted by GSE and vehicles, as well as by aircraft auxiliary power units (APU).[23] APUs are small engines in the tail of airliners that burn jet fuel and supply air pressure for engine start, as well as electrical power and air conditioning when the main engines are shut down. Aircraft jetways typically have electrical power and air conditioning units that are connected to aircraft at the gate, avoiding the need for APU operation until just prior to pushback for departure.

Regulating Aircraft Emissions

Emissions from low altitude and ground aviation operations are regulated under certification requirements for engines, the *Clean Air Act* tail pipe emission standards for airport vehicles, and off-road standards for ground equipment. Aircraft engine certification requirements address carbon monoxide, hydrocarbons, nitrous oxide, and smoke emissions.[23] In 2016, the United Nations International Civil Aviation Organization (ICAO) established CO2 emission standards for new aircraft in a two tier plan. One standard applies to new aircraft already certified and in production. A more restrictive efficiency standard applies to designs certified after January 1, 2020, for commercial jets and January 1, 2023, for business jets, with each category of aircraft entering service about four years after certification. The efficiency requirements will apply to all new aircraft deliveries starting January 1, 2028. The standards are based on an aircraft's mass and will require on average a four percent reduction in the cruise fuel consumption compared to the performance of new aircraft delivered in 2015.[24]

New aircraft from Boeing, Airbus, and other smaller manufacturers already meet the CO2 emission requirements, and by 2020 the average new aircraft was estimated to "outperform" the standard by approximately 10 percent.[25] The EPA issued a Finding in August of 2016 that aircraft GHG emissions "cause or contribute to air pollution that may reasonably be anticipated to endanger public health and welfare."[26] This permitted the agency to set CO2 emission standards for U.S. aircraft under the *Clean Air Act* that match or exceed the ICAO requirements.[27] The industry favored adopting the ICAO specifications,[28] and EPA established the final rule matching ICAO's carbon emission standards on January 11, 2021.

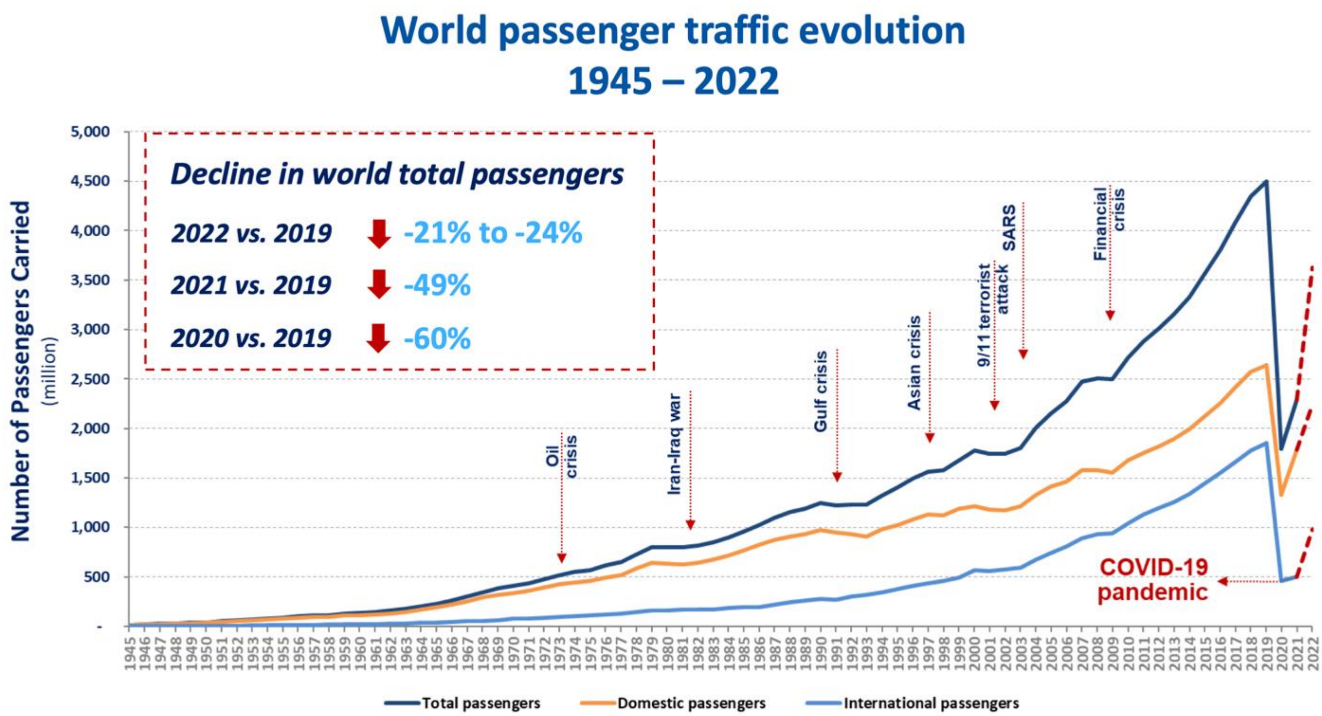
As airlines bring new equipment into their fleets, their overall fleet performance will improve. By 2028, all regional and seven of 10 mainline U.S. carriers will meet the emission standard for their fleet averages. Two of the remaining carriers, Alaska and Southwest, will be in compliance for their fleet average by 2030. This will leave only a single airline, Allegiant, with older aircraft needing major improvements to meet the standard.[29] In January 2022, Allegiant announced a plan to purchase 50 new Boeing 737 Max aircraft with deliveries from 2023–2025 and options for an additional 50 737s. This will improve the airline's overall fleet efficiency.[30] Given the efficiency of new model aircraft, the ICAO standard is not expected to change current projections of CO2 emissions for the industry, and the standard does not address contrail formation.

Carbon Emissions from International Aviation

In its 2019 *Environment Report,* ICAO included aspirational goals for reducing the climate impact of the international aviation sector by improving fuel efficiency by two percent annually through 2050 and ensuring carbon neutral growth from 2020 forward.[31] While domestic aviation is included in national carbon budgets, the Paris Climate Agreement did not address international aviation. This subset comprised 62 percent of pre-pandemic global commercial aviation CO2 emissions.[32] ICAO reports GHG emissions from international aviation could increase by a factor of two to four times 2015 levels by 2050.[33] Projected rapid growth of the post-COVID industry amplifies the challenge of limiting global carbon aviation emissions and non-CO2 climate effects. The growth of demand for passenger and freight traffic is a central barrier to controlling commercial aviation emissions.

Historically Resilient Growth and Projections in Passenger Travel

In looking at growth projections for commercial aviation, it is helpful to examine the historical growth of the sector and the impact of the coronavirus pandemic. The graph below from ICAO presents passenger counts from 1945 to 2021. It is a record of significant and resilient growth before the pandemic. With only temporary declines in passenger traffic during oil crises, following the terrorist attacks on September 11, 2001, and during global recessions, air travel has boasted an average annual growth rate of approximately five percent,[34] and historically has "tended to double every 15 years" (Air Transport Action Group, ATAG).[35]



Used with permission from the International Civil Aviation Organization (ICAO).[36]

After the 2008 global financial crisis, growth in air travel accelerated. From 2010 through 2019, annual global growth rates of revenue ton kilometers (expressing tonnage of passengers and freight carried over kilometers of flight) averaged six percent.[37] Regionally, the highest growth occurred in the Asia-Pacific, which includes China and India, with rates reaching 10.7 percent in 2017.[38] According to ATAG, each day in 2019, the global aviation industry transported approximately 12.5 million passengers and $18 billion worth of goods on 128,000 scheduled flights.[39] In its annual Commercial Market Outlook from 2019, aircraft manufacturer Boeing projected an average global passenger traffic growth rate of approximately 4.6 percent per annum through 2039.[40] In March 2020, COVID-19 changed the outlook for commercial aviation dramatically.

The coronavirus pandemic produced the most severe contraction in commercial aviation's history. In April 2020, RPKs fell 94 percent compared to April 2019; with plunging demand for air transport, airlines grounded 64 percent of the global fleet.[41] According to ICAO, predicting the sector's short-term growth and volume during the coronavirus pandemic is especially challenging given varying global vaccination rates, potential surges of variants,[42] uncertainties regarding the duration of travel restrictions and the restoration of full consumer confidence in air travel, changes in consumer behavior regarding travel (such as video communication replacing some business travel), and fast-shifting global economic conditions.[43]

Post-COVID Growth Forecasts

The forecasts below estimate that pre-COVID volumes and growth rates for both international and domestic commercial air travel will fully recover by 2025 at the latest. According to the Federal Aviation Administration's *Aerospace Forecast Fiscal Years 2021–2041* report, there will be rapid year-over-year growth from the low levels of 2020/2021 until pre-pandemic levels are reached in 2024, and then more typical growth from 2025.

	Projected year of return to pre-COVID (2019) traffic levels	**Anticipated average annual growth**
Boeing[44]	U.S. domestic 2022 International (regional) 2023 International (long haul) 2024	**2019 – 2041:** 4% global domestic & international combined **Unit of measure:** revenue passenger kilometers (RPK)
Federal Aviation Administration[45]	U.S. domestic 2024 U.S. International 2025	**2025 – 2041:** 2.3% U.S. domestic; 3.3% U.S international **Unit of measure:** passenger count
International Civil Aviation Organization (central scenario)[46]	North, South America 2022 Europe, Mid East, SW Asia Asia, Pacific 2023-2024 Africa 2024-2025[47] (ICAO projections are for seat capacity)	**2018 – 2050:** 3.6% global domestic & int. combined (RPK). 3.5% freight (RTK) **Units of measure:** revenue passenger kilometers (RPK); revenue ton kilometers (RTK).
Air Transport Action Group (central scenario)[48]	Global passenger 2024	**2019 – 2050:** 3.1 %. (RPK). Forecast traffic in 2050 approximately 8% lower than pre-COVID forecast. **Unit of measure:** revenue passenger kilometers (RPK)

Although the FAA's prediction for domestic U.S. passenger growth after traffic recovers to 2019 levels is modest (2.3 percent), the increase in actual numbers will nevertheless be significant. The sheer size of the mature U.S. air traffic system means even modest growth will generate an enormous increase in passenger traffic. By 2041, annual domestic enplanements in the United States are projected to reach 1.26 billion, 55 percent higher than in 2019. Total annual international passengers to and from the United States on American and foreign flag carriers should recover to pre-COVID levels by 2025 and climb from 67 million in 2020 to 446 million by 2041.[49]

Fuel consumption by the industry is a direct indicator of CO_2 emissions. According to the October 2021 International Air Transport Association (IATA) report, worldwide airline industry jet fuel usage was 359 billion liters (95 billion gallons) in 2019. In 2020, usage dropped 45.4 percent because of the pandemic. IATA estimates 2021 consumption was 39.5 percent below 2019 levels, and forecasts 2022 consumption will be 25.9 percent below pre-pandemic levels.[50]

The connection between passenger traffic growth estimates and carbon emissions is highlighted in an analysis by the International Council on Clean Transportation (ICCT). A few percentage points difference in growth predictions can generate very different projections of total emissions. ICCT forecasts an annual growth in passenger traffic to 2050 of 3 percent for its central scenario, and 3.7 percent and 2.4 for its high- and low-growth scenarios, respectively. According to the ICCT analysis, if there are "no drastic changes in aircraft design or fuel that would affect emission factors," the difference between a low-growth and high-growth scenario would be 700 million tons of CO_2 by 2050, and 400 million tons between the central and high-growth scenarios. The report cautions that forecasts that are too high risk generating unrealistic mitigation expectations in policy development, whereas those that are too low could produce inadequate mitigation policy responses.[51] With the world's largest air traffic system, the aviation carbon mitigation strategies and implementation by the United States will be especially critical in the global effort to reduce the sector's climate impact.

As the pandemic recedes and the volume and growth of passenger traffic returns, the United States will remain the world leader in per capita jet fuel consumption. The dominance of the U.S. market is presented in the chart below, using data from the International Council on Clean Transportation. U.S. per capita fuel consumption for domestic and international flights was six times the world average, and 37.5 times that of India.

Per Capita Jet Fuel Use: 2016.[52]

	United States	Europe	World	China	India
Gallons	75	32	13	10	2
Factor = U.S.	1	2.3	6	7.5	37.5

Growth in Air Freight

World air cargo, although a much smaller component of global aviation, has a record of growth similar to passenger aviation. In the company's 2019 Commercial Market Outlook, Boeing reported that from 1980, the average annual growth in freight-ton kilometers (FTK) was 5.3 percent.[53] Freight is transported by air in dedicated cargo aircraft, and in the cargo compartments of passenger aircraft (belly freight).

Global air freight declined during the great recession, and growth during the next several years was modest. However, in 2017 growth in demand for air freight was nine percent.[54] Air freight represents one percent of world trade by volume, but 35 percent by value. According to IATA data published before the pandemic, $18.6 billion of goods were shipped by air each day, transported by 100,000 flights (passenger and cargo aircraft). Worldwide daily air shipments included 80,000 flowers; 657 million packages valued at $17.8 billion; 898 million letters; vaccine shipments; and electronics, including 1.1 million cellphones every day. [55]

Global freight experienced a significant reduction in freight ton kilometers (FTK) in 2020 compared to 2019 but the sector recovered by the end of the year. The global recession caused by the pandemic contributed to initial air freight decline, as did a large reduction in cargo hold capacity when airlines parked passenger aircraft because of plunging air travel demand.[56] After hitting a low in April 2020 of 27.7 percent below the April 2019 level, air freight began a steady increase in volume for the remainder of the year but stayed below 2019 FTKs for May through December 2020. Freight volume exceeded the same month 2019 level in January 2021, with North America recording the second-highest regional percentage increase after Africa.[57] The monthly increases for FTKs comparing 2021 to 2019 ranged from +1.1 percent in January 2021 to a high of +12 percent in April 2021 and averaged +7.7 percent higher than 2019 for the months of January through August 2021. [58] The reliance on rapid long-distance air shipping illustrated by the variety of goods listed above and the growth of e-commerce suggest the sector will remain a significant contributor to the growth of commercial aviation.

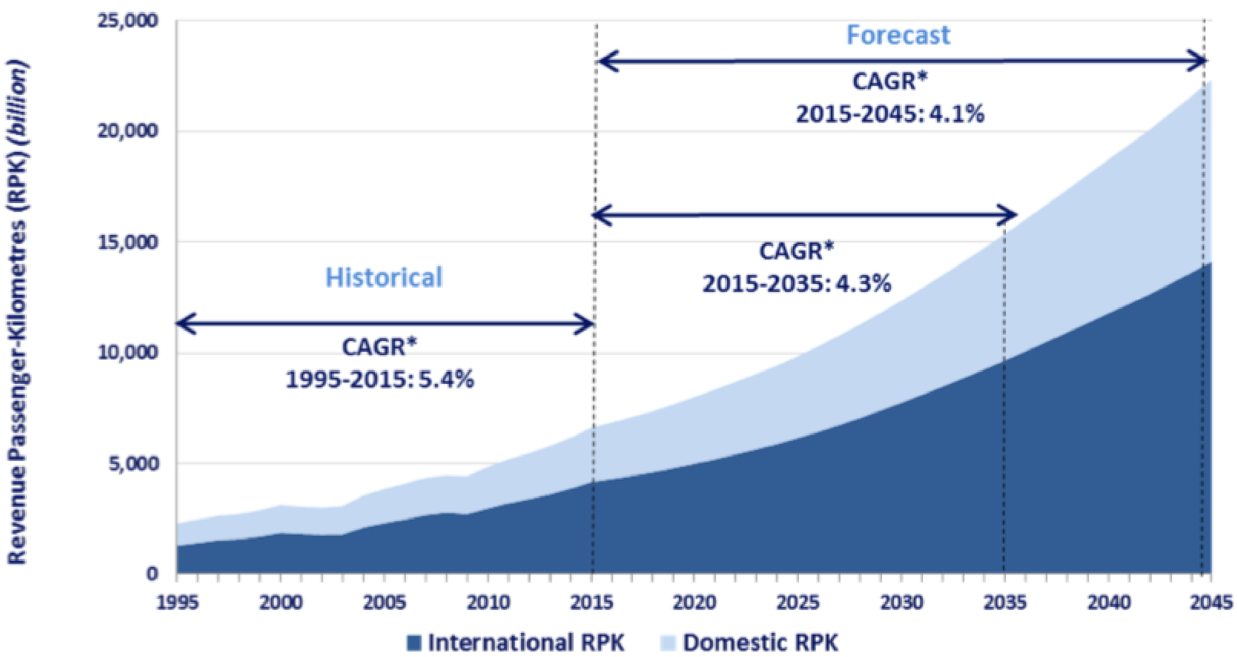
Global Economic Growth and Aviation

Predicting the global economic impact of COVID-19 is difficult and made more so by the continued emergence of new variants. However, trends in pre-COVID passenger and cargo traffic reflect the industry's close connection to economic growth. World Bank data shows a value of $33.8 trillion for global GDP in 2000 and approximately $86.4 trillion in 2018,[59] a 2.5-fold increase—equivalent to air travel's increase in passengers carried of 2.5-fold over the same period.[60] China's GDP climbed from $1.2 trillion to $13.9 trillion from 2000 to 2018, an 11.5-fold increase. India's economy grew 5.7 times, from $468.4 billion in 2000 to $2.7 trillion in 2018. U.S. GDP did not climb as steeply as China's or India's, but the United States remained the world's largest economy with a GDP of $20.5 trillion in 2018, having doubled in 18 years.[61]

The strong growth rates in China, India, and other Asian economies are expected to continue as the pandemic subsides, and over the next 20 years this growth will elevate millions to middle-class economic status. According to pre-COVID estimates by Oxford Economics cited in Boeing's *2019 Commercial Market Outlook*, middle-class household growth in China, South Asia, and Southeast Asia was 3.9 percent annually, compared to a population growth of 1.4 percent.[62] As global economic growth strengthens and the rate of middle-class expansion resumes in developing nations, so will the demand for air travel.

As the pandemic subsides, the additional spending capability of billions more of the world's population, combined with the downward pressure on ticket prices from low-cost and now ultra-low-cost carriers, as well as faster delivery services in a growing e-commerce economy will boost air travel and propel demand for air shipping. These economic forces have already influenced global aviation. For example, the ICAO reported in January 2018 that "more than half of the world's 1.4 billion tourists who travelled across international borders (in 2017) were transported by air," and 90 percent of cross-border business-to-consumer transactions (such as online retail) were carried by air.[63] Growth in commercial passenger aviation since 1995 and projected through 2045 is shown in the 2018 ICAO graph below, depicting global compound annual growth rates (CAGR) in revenue passenger kilometers. One can appreciate the scale of air travel expected through mid-century by noting the RPKs units are numbered in billions, and the values triple between 2019 and 2045. The graph does not reflect the pandemic's impact, but if volume and growth recover as estimated in the various predictions, the challenge of reducing greenhouse emissions produced by the industry will grow in lockstep with revenue passenger miles and revenue ton miles.

World Total Passenger Traffic: History and Forecasts



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This issue brief is available electronically (with hyperlinks and endnotes) at *www.eesi.org/papers*.

The Environmental and Energy Study Institute (EESI) is a non-profit organization founded in 1984 by a bipartisan Congressional caucus and is dedicated to advancing science-based solutions for climate change, energy, and environmental challenges in order to achieve our vision of a sustainable, resilient, and equitable world.

Note: *This issue brief was published in October 2019, but was updated in Spring 2022 to include more up-to-date information about the overall climate impact of aviation as well as the impact of the COVID-19 pandemic on commercial aviation recovery and growth. Previously, commercial aviation was thought to be responsible for approximately 5 percent of the world's climate-warming problem. Newer research, using the metric "effective radiative forcing," concludes aviation accounted for 3.5 percent of total anthropogenic climate warming in 2011, and likely in 2018 as well. According to the Intergovernmental Panel on Climate Change (IPCC), effective radiative forcing is a more accurate metric than radiative forcing as it is "a better indicator of global mean temperature response." Scientists continue to acknowledge uncertainty in determining the influence of non-CO2 factors in aviation's overall climate impact. The revision also reflects the United States' adoption of ICAO's carbon standard for commercial aviation aircraft in January 2021.*

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