Environmental and Energy Study Institute

EESI

Fact Sheet

The Growth in Greenhouse Gas Emissions from Commercial Aviation

Part 1 of a Series on Airlines and Climate Change

October 2019

This fact sheet begins a series on commercial aviation, by examining the impact the growth of air travel and freight will have on greenhouse gas emissions. The second installment will feature mitigation efforts and industry commitments to reduce its contribution to climate change, and our final issue will examine 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 2017, the total annual world-wide passenger count was 4 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 is producing the highest and fastest growth of individual emissions**,[4] despite a significant improvement in efficiency of aircraft and flight operations over the last 60 years.

Airline Energy Intensity and Emissions

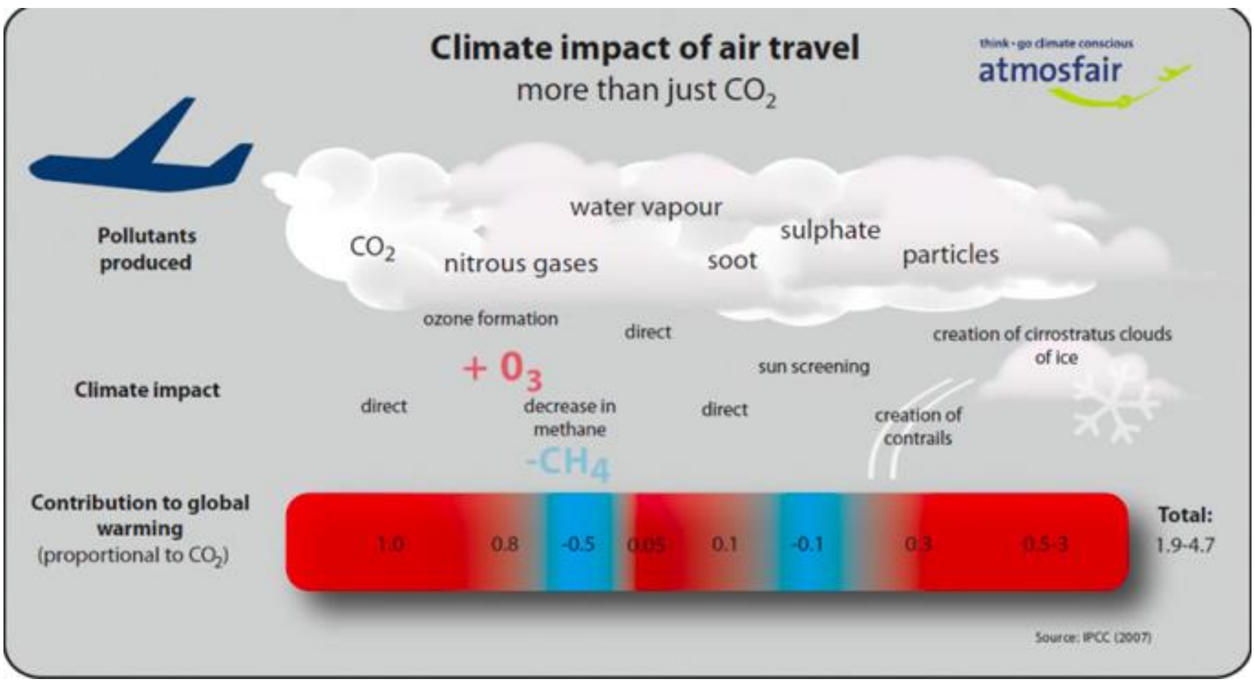
From 1970 to 2016 in the United States, engine and design technology advances, improvements in air traffic operations, denser seat configurations, and higher passenger loads together reduced the energy intensity of air travel, expressed as British Thermal Units (BTUs) per passenger mile, by 75 percent.[5] 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 continues to raise the industry's contribution to global emissions. In 2013, global CO2 from commercial aviation was 710 million tons. In 2017, that number reached 860 million tons, a 21 percent increase in four years, and it climbed another 5 percent to 905 million tons in 2018.[7] The United States, with the world's largest commercial air traffic system, accounted for 202.5 million tons (23.5 percent) of the 2017 global CO2 total.[8] **EPA reports that aircraft contribute 12 percent of U.S. transportation emissions, and account for three percent of the nation's total greenhouse gas 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 were a country in the national CO2 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 and other pollutants, bring the combined **total contribution of commercial aviation to approximately 5 percent of the world's climate-warming problem**.[12]

In this fact sheet, 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.



Used with permission from atmosfair.[15]

CO2

CO2 is the largest component of aircraft emissions, accounting for approximately 70 percent of the exhaust.[16] 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.[17] Its extended lifetime in the atmosphere makes CO2 especially potent as a greenhouse gas. After being emitted, about one half 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.[18]

Contrails

Water vapor is also a product of jet fuel consumption, as hydrogen in the exhaust combines with oxygen in the atmosphere, and makes 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 3 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 of the CO2 emitted by aircraft since the beginning of powered flight.**[21] The atmosfair graphic presents a range of the warming from contrails and contrail-induced cirrus clouds, identified as cirrostratus, since the atmospheric conditions that produce and sustain contrails vary over time and space.

Nitrous Gases, Particles and Local Air Quality

All of the remaining emissions in the graphic make up less than one percent of the exhaust plume.[22] 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 engines, 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 effect, more research is required to fully understand the formation and impact of contrails and contrail-induced clouds so that mitigation strategies can be developed. Using sustainable biofuels blended with kerosene jet fuel, a mixture which is beginning to enter the commercial aviation market, is one potential mitigation strategy. Biofuel blends reduce soot content, water vapor, and sulfates in the exhaust. Fewer particulates and less water vapor will mean a reduction in contrail formation.[23] 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.[24]

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).[25] 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.[26] In 2016, the 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 that will be 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.[27]

New aircraft from Boeing, Airbus, and other smaller manufacturers already meet the CO2 emission requirements, and by 2020 the average new aircraft will "outperform" the standard by approximately 10 percent.[28] 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."[29] This permits the agency to set CO2 emission standards for U.S. aircraft under the *Clean Air Act* that match or exceed the ICAO requirements. However, EPA has not yet established CO2 emission standards for aircraft manufactured in the United States. Without the standard in place for the United States by January 1, 2020, the Federal Aviation Administration (FAA) will not be able to certify that in-production aircraft manufactured by U.S. companies are in compliance with the ICAO rule. Without this certification, new aircraft may not be sold internationally.[30] The industry favors adopting the ICAO standard, and the EPA is expected to establish the rule this fall.[31]

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. 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.

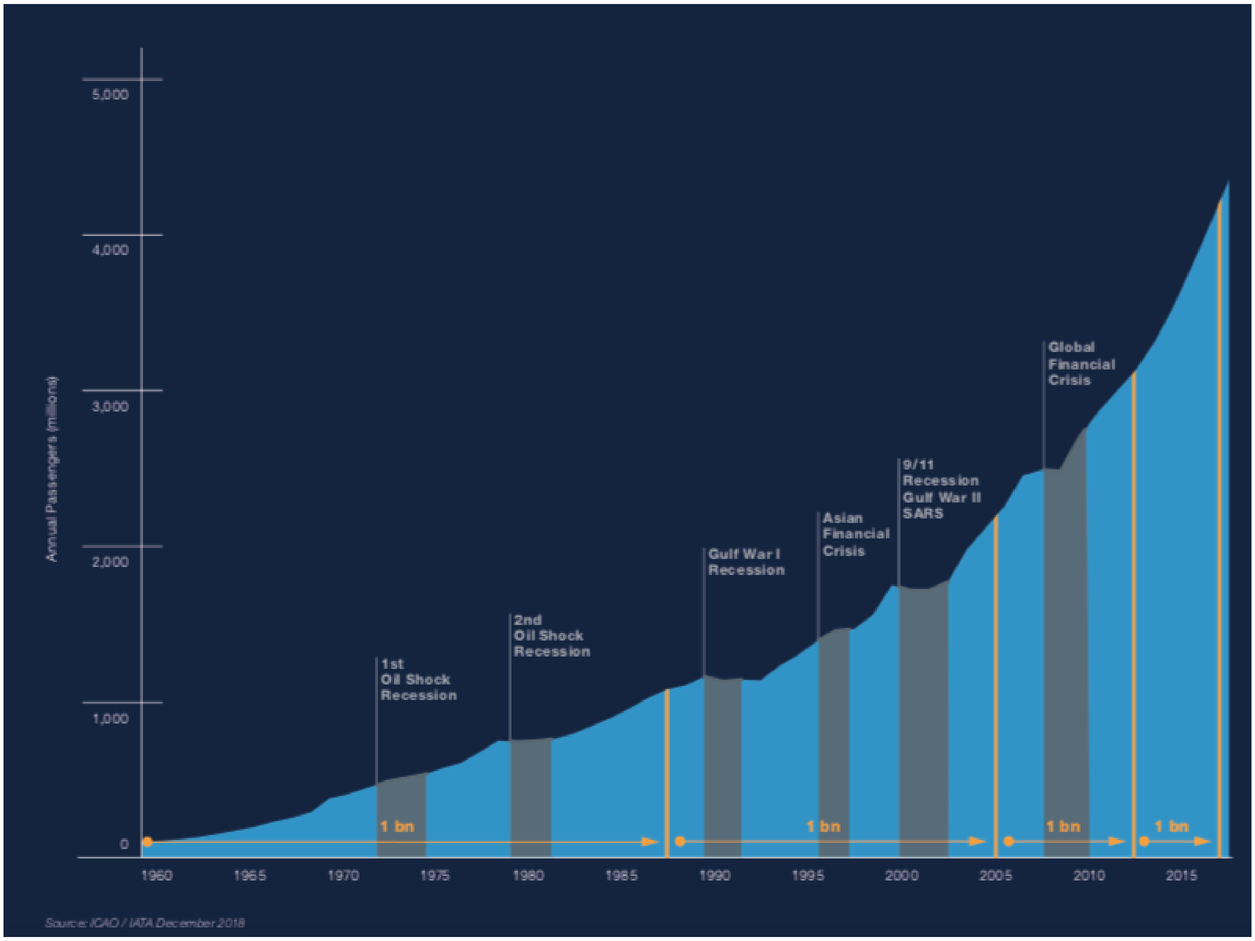
Carbon Emissions from International Aviation

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.[32] While domestic aviation is included in national carbon budgets, the Paris Climate Agreement did not address international aviation. This subset comprises 62 percent of global commercial aviation CO2 emissions[33] and is projected to generate 70 percent higher emissions by 2020 over 2005 levels.[34] Projected rapid growth of the 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 looking at growth projections for commercial aviation, it is helpful to examine the historical growth of the industry. The graph below presents passenger counts beginning in 1960 and extending past 2015. It is a record of significant and resilient growth. With only temporary declines in passenger traffic during oil crises, following 9/11, and during global recessions, air travel boasts an average annual growth rate of approximately five percent. Yellow vertical lines on the graph define the span of years required to reach an additional one billion passengers per year. In 2018, the count exceeded four billion.

RESILIENT AIR TRAVEL



Source: Boeing. *Commercial Market Outlook 2019-2038*. Data from the International Civil Aviation Organization (ICAO) and International Air Transport Association (IATA), December 2018.[35] Used with permission from Boeing.

After the 2008 global financial crisis, growth in air travel accelerated. From 2013 through 2018, annual global growth rates of revenue passenger kilometers (RPKs—one passenger travelling one kilometer is one RPK) ranged from 5.7 to 7.4 percent. Regionally, the highest growth occurred in the Asia-Pacific, which includes China and India, with rates reaching 11 percent in 2016 and 2017.[36] In their annual forecasts, aircraft manufacturers Boeing and Airbus project an average global passenger traffic growth rate of approximately 4.5 percent per annum through 2038.[37] At that rate, air passenger traffic will double by 2035, and double again by mid-century.

Focusing on U.S. traffic and carriers, the FAA reports system revenue passenger miles (RPMs), combining both international and domestic traffic, climbed 4.8 percent in 2018.[38] The agency forecasts 2.2 percent annual growth over the next 20 years. While a smaller growth rate than the global projection, the sheer size of the mature U.S. air traffic system means even modest growth will generate an enormous increase in passenger traffic. By 2039, annual domestic and international air travel in the U.S. system will be 60 percent higher, for a total of 1.6 trillion RPMs.[39] Another way to picture the enormous size of the U.S. aviation system is to look at per capita jet fuel use for 2016, which is presented in the chart below, using data from the International Council on Clean Transportation. The second row of numbers is the multiple required to raise the country's per capita jet fuel use to equal the U.S. value of 75 gallons in 2016. U.S. per capita fuel consumption for domestic and international flights is six times the world average, and 37.5 times that of India.

Per Capita Jet Fuel Use: 2016.[40]

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

Air Freight

World air cargo, although a much smaller component of global aviation, has a record of growth similar to passenger aviation. Since 1980, the average annual growth in freight-ton kilometers (FTK) was 5.3 percent.[41] 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 FTK growth was 9.5 percent over the 2016 total to reach approximately 220 billion tons.[42] This massive tonnage represents only 1 percent of world trade by volume, but 35 percent by value.[43] According to IATA data, $18.6 billion of goods are shipped by air each day, transported by 100,000 flights (passenger and cargo aircraft). Worldwide daily air shipments include 80,000 flowers; 657 million packages valued at $17.8 billion; 898 million letters; vaccine quantities that save lives at a rate of approximately 7,000 daily (2.5 million lives annually); and electronics, including 1.1 million cellphones every day.[44] The ICAO reports recent monthly freight ton kilometers trending below each previous year's monthly totals by approximately five percent beginning in November 2018, "reflecting global trade tensions."[45] However, the economic reliance on rapid long distance air shipping illustrated by the variety of goods listed above indicates the sector will remain a significant contributor to the growth of commercial aviation.

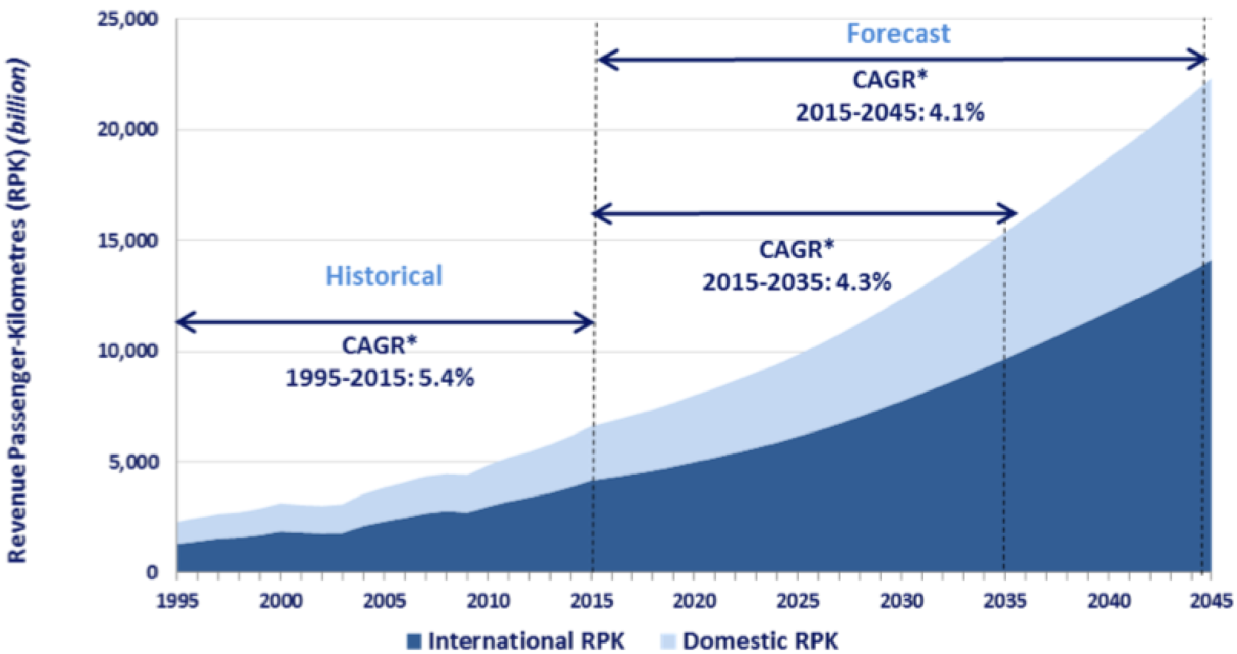
Global Economic Growth and Aviation

Trends in passenger and cargo traffic reflect the industry's direct connection to economic growth. World Bank data shows a value of $33.6 trillion for global GDP in 2000 and approximately $85.8 trillion in 2018, a 2.5-fold increase—equivalent to air travel's increase of 2.5-fold over the same period.[46] China's GDP climbed from $1.2 trillion to $13.6 trillion over the same period, an 11-fold increase. India's economy grew more than 5.9 times, from $468.4 billion in 2000 to $2.7 trillion in 2017. U.S. GDP did not climb as steeply as China and India's, but the United States remained the world's largest economy with a GDP of $20.5 trillion in 2018, doubling in 18 years.[47]

The strong growth rates in China, India, and other Asian economies are expected to continue over the next 20 years, elevating millions to middle class economic status. According to estimates by Oxford Economics, as cited in Airbus forecasts, the middle class could rise from 40 percent of the world's population in 2017 to 57 percent by 2037.[48] As the middle class expands in developing nations, so will the demand for air travel. The IATA predicts 44 percent of the world's additional passenger trips will originate in China and India over the next 20 years.[49] China will become the world's largest passenger market, overtaking the United States in 2025. India will move from number seven in the world to number three, and Indonesia from tenth to fourth by 2031.[50]

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 are already influencing 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.[51] Growth in commercial passenger aviation since 1995 and projected through 2045 is shown in the ICAO chart 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.

World Total Passenger Traffic: History and Forecasts



Used with permission from the International Civil Aviation Organization (ICAO).[52]

With the dramatic growth forecast in aviation over the next 20 years, the challenge of reducing greenhouse emissions produced by the industry will grow in lockstep with revenue passenger miles and revenue ton miles. In our next edition, we will examine efforts underway to mitigate airline emissions and the commitments the industry is making to limit its contribution to climate change.

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

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