# Factsheet 1: Climate-damaging effects of aviation



**Flying is the most climate-damaging mode of transport: Not only does the combustion of fossil kerosene generate $CO_2$ emissions; nitrous gases, condensation trails and changes in cloud cover also contribute to climate heating.**

We summarize the most important information on the climate impacts of air travel in this section. We show the extent to which we fly today and ask: Who flies and for what reasons? And how many emissions thereby arise? What is the concrete impact of air transport on the climate and why should it not simply continue to grow after the end of the Covid-19 pandemic? How harmful to the climate is travelling by plane compared to other modes of transport? What other environmental and health effects does flying have?

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# 1 How we fly today

## 1.1 How much do we fly?

From 2001 until the start of the Covid-19 pandemic, the number of passengers at German airports increased continuously, apart from a slight decline in 2009 and 2010 due to the financial crisis. In 2018, over 247 million people boarded, disembarked or transferred at German airports. Compared to 2001, this constituted an increase of 72%. More than a quarter of all passengers took off or landed at Germany's largest airport in Frankfurt/Main (BMVI 2019, 88f.).

Globally, air transport and the associated environmentally harmful emissions have grown even more strongly. For example, there were more than 4.3 billion passengers in 2018, which was two and a half times as many passengers as in 2000 (The World Bank 2019).

### How many passengers and how many kilometers travelled?

Air travel in Germany accounted for 6% of total passenger kilometres travelled in 2018 (the passenger transport volume is calculated by multiplying the number of people carried by the distance travelled) (BMVI 2019, p. 221). At first glance, this does not sound like much, but flying is by far the most climate-damaging means of transport (see chapter 3). In addition, aviation is growing much faster than all other modes of passenger transport: between 2001 and 2018, it increased by over 60% overall to 70 billion passenger kilometres in Germany, while kilometres travelled in total passenger transport increased only by approx. 11% (BMVI 2019, p. 218-219).

**Passenger transport volume**: Product of the number of passengers and the distance travelled, measured in passenger kilometres (pkm).

**Passenger kilometres:** Also referred to as pkm, this is a unit of measure for transport volume in passenger terms; it is measured as the number of passengers multiplied by the distance travelled in kilometres.

Air travel has also grown steadily in the EU. Measured in passenger kilometres, it increased by approx. 40% overall between 2000 and 2017 (EEA 2019). Europe accounted for about a quarter of global aviation in 2018 measured as passenger transport volume (ICAO 2019b). However, the world's largest growth in annual passenger numbers was recorded in China in that year (IATA 2019).

### Air freight transport

The volume of goods and mail transported by air has also hugely increased. In 2018, there were just under five million tons of goods and mail transported by plane in Germany, which is double the amount transported in 2001 (BMVI 2019, 240f.). However, the goods transported by air accounted for less than 1% of freight transported to Germany and approx. 1.5% of freight exported from Germany in 2018. High-value goods such as electrical equipment, machinery, optical equipment, pharmaceuticals and jewellery accounted for a large share of these goods (BDL 2017).

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### Impact of the Covid-19 pandemic on air transport

In 2019, the German Federal Ministry of Transport predicted that the number of air passengers in Germany would rise from 223 million to 244 million between 2018 and 2021, constituting a growth of 9% within three years (BMVI 2019, p. 344). And in 2018, the International Civil Aviation Organization (ICAO) assumed that aviation would grow globally by 40% by 2038 (ICAO 2018). At that time, no one could have foreseen the Covid-19 pandemic and its impact in 2020. Its effects were and are severe for the airline industry: in April 2020, only approx. 30% of planned flights took off worldwide (ICAO 2020). In Germany and the EU, air transport came to an almost complete standstill in the spring of that year. In Germany, the EU and globally, fewer than half the number of aircraft are expected to be in the air in 2020 overall compared to 2019 (DFS 2020; Eurocontrol 2020; ICAO 2020).

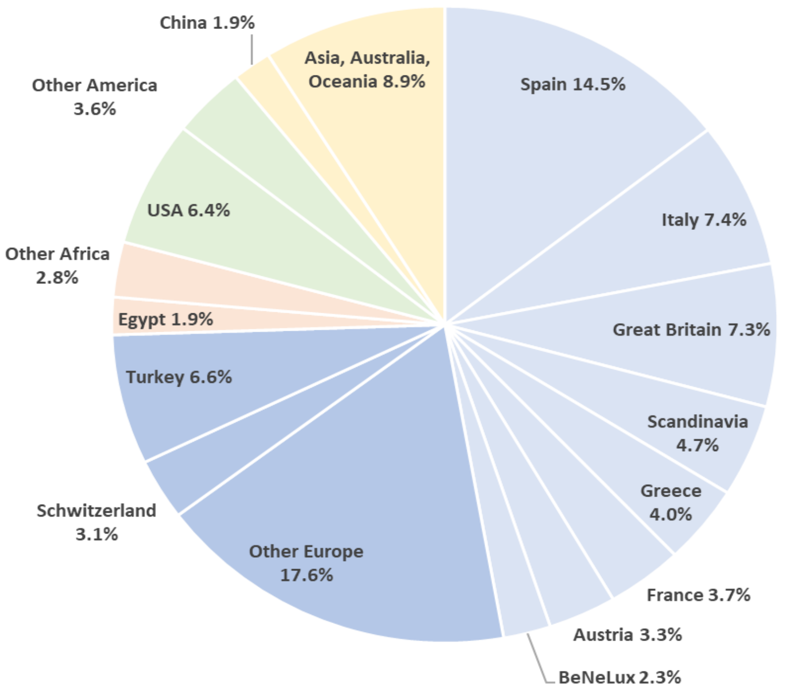
Global freight transport also substantially decreased as a result of the pandemic, plummeting by around 30% in April 2020 compared to the previous year. Nevertheless, the demand for flights carrying freight could not be met because the supply of belly freight, which is transported in passenger aircraft, slumped even more (IATA 2020a). Due to the dynamic development of the pandemic, it is difficult to forecast the development of aviation in the years ahead. Current forecasts suggest that it will take several years for air transport to return to the levels reached before the Covid-19 pandemic (IATA 2020c; Öko-Institut 2020; ICAO 2020). We should not return, however, to the unchecked growth of air transport (see factsheet 5).

## 1.2 Where do we fly to?

In 2018, almost three quarters of all passengers in Germany flew to other European countries, with most of them flying to Spain (BMVI 2019, p. 179).

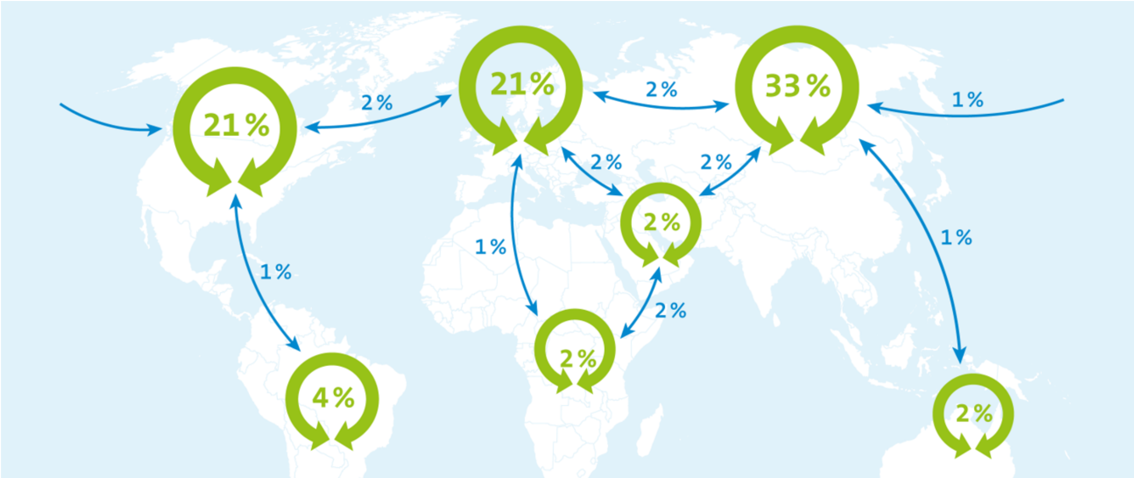
Globally, the Asia-Pacific region accounted for the largest share of global aviation in 2019, with connections within Asia accounting for 33%. Intra-Chinese aviation accounts for 13% of global aviation; connections in North America and Europe each account for 21% (BDL 2020, p. 3). The busiest long-haul route in 2019 was the axis between New York and San Francisco (Official Aviation Guide 2020).

**Figure 1: Passengers travelling from Germany to destination countries (in %)**




Source: Oeko-Institut based on BMVI (2019)

**Figure 2: Distribution of global air transport (based on seating capacity)**




| Continent | Share of seats from/to/in |
|---|---|
| Asia | 39 % |
| Europe | 29 % |
| North Amercia | 26 % |
| Middle East | 7 % |

Source: BDL (2020), p. 3

## 1.3 Domestic flights in Germany

Approx. 20% of passengers from Germany take a domestic flight (UBA 2019a, p. 30). Many domestic flights are also feeders to major airports (BDL 2018). Overall, domestic flights in Germany cause a climate impact of approx. 2.4 million tons of $CO_2$ equivalents (taking into account all the climate-damaging effects of air travel) – that's more than seven times the climate impact of equivalent journeys by rail (UBA 2019a, p. 30).

**Better to travel by train**

Domestic flights in Germany of less than 600 kilometres could and should be shifted to rail. This would have affected 18.5 million passengers in 2015. For a quarter of them, travelling by rail would have been even faster than by air. Half of these travellers could also reach their destination by train in less than four hours – in other words, without losing any time and with the option of making business trips within a day. Incidentally, many people are in favour of banning short-haul flights. 62% of people are in favour of such a ban in Europe, for example; in America and China, 49% and 80% of people are in favour of such a ban (EIB 2019).

Around 1.6 million tons of greenhouse gases could be saved by shifting a large share of domestic flights to rail travel (UBA 2018a, p. 68–74). In Germany, there are already speedy alternatives by rail on many routes, and many of these routes already have enough capacity to take the additional passengers to their destinations. Nevertheless, capacities also need to be expanded further. For example, the reduction in the travel time between Berlin and Munich due to a new high-speed rail route has shown that such a modal shift is possible if good alternatives are available. On this route, rail has supplanted air travel as the most important mode of transport (UBA 2019a, p. 30).

In addition, the seamless onward travel of passengers from long-haul flights to travel by rail should be ensured. To this end, the hubs of rail traffic – i.e. Hamburg, Cologne, Frankfurt am Main, Mannheim and Munich – must be further expanded; connections to smaller hubs also need to be improved (BUND e.V. 2019; Agora Verkehrswende 2020). In this way, unprofitable regional airports could be closed because there would be a fast rail link from all regions to airports with a long-distance network (see factsheet 2).

There is still much to be done across Europe in this respect: connections need to be further expanded and, in particular, more night train services need to be available (see factsheet 3) (Bleijenberg 2020).

**Political signals**

The Covid-19 pandemic could make flying less important. Video conferencing has proven to be a good alternative, especially to domestic travel. France and Austria have taken a step forward by making financial support for Air France and Austrian Airlines during the pandemic conditional on the airlines reducing the number of domestic flights they offer. Unfortunately, the financial assistance provided to Lufthansa by the German government was not linked to a corresponding requirement to reduce domestic flights. Germany should take measures to shift domestic flights to rail. Even though the climate impact of long-haul flights is much greater than that of short-haul flights, domestic flights are unnecessary and should be avoided.

## 1.4 Why do we fly?

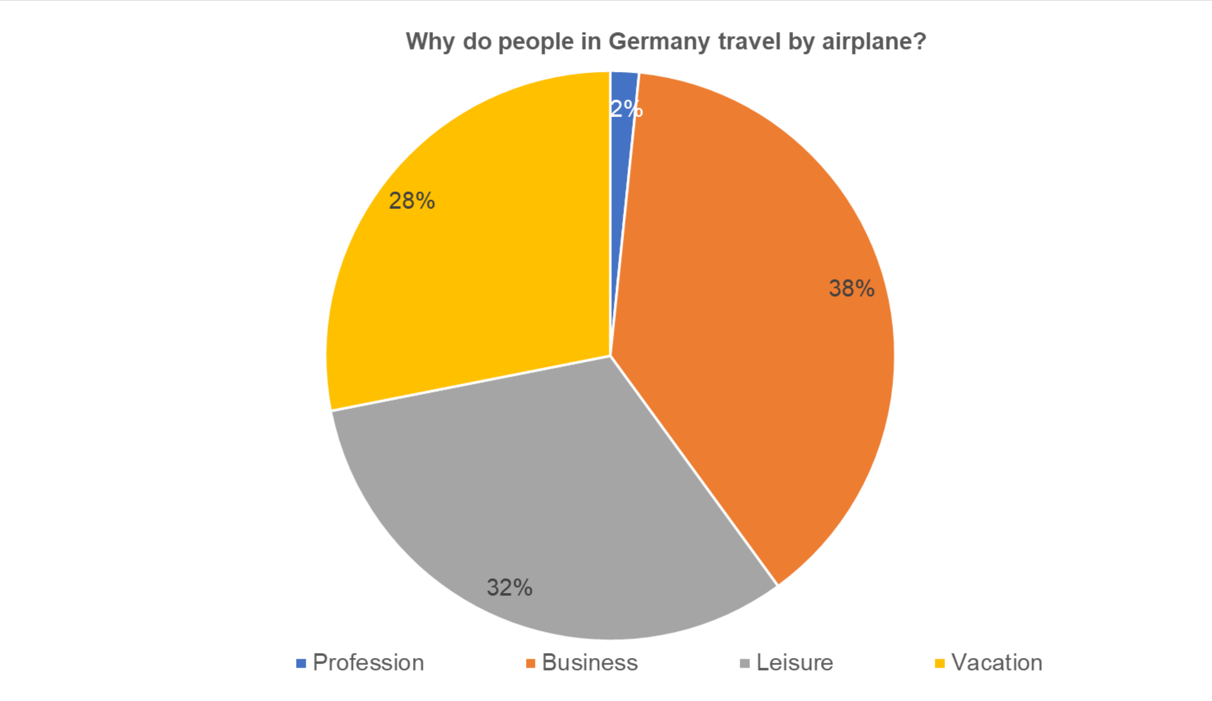
Most people in Germany fly for private reasons: for holidays or leisure. This includes, for example, taking a weekend city break in Budapest, visiting friends in Paris or accompanying a favourite football club to the Champions League match in Barcelona. About 28% of air travel is for holidays that last at least five days (BMVI 2019, pp. 212-214; pp. 222-223).

**Leisure or work?**

In 2017, 60 million trips were made by passengers boarding or transferring planes in Germany. Around 38% of them were travelling for business (BMVI 2019, pp. 212-214; pp. 222-223). While business trips account for the largest share of flights within Germany at around 65%, approx. 60% of trips to other European countries and 70% of intercontinental travel are holiday trips (DLR 2020a; BDL 2018). In the future, these can be made using more climate-friendly modes of transport than aviation (see factsheet 3).

Globally, there is no comprehensive data on the reasons why people take a flight. However, one trend that can be observed is that the number of business trips has decreased in recent years, while the number of so-called VFR flights has increased; VFR stands for visiting friends and relatives, i.e. partners, friends and family members who are increasingly scattered around the globe (Zeit Online 2019).

**Figure 3: Why do people travel by plane?**




Values include double counts of people changing trains. Commuting includes all journeys between home and work. Business travel covers all other work-related journeys; these can be longer business trips, but also regular business trips such as those made by representatives.

Source: Oeko-Institut on the basis of BMVI (2019), pp. 222–223 based on calculations by DLR and DIW

The military accounts for a share of the flights taken; this share constituted 1.4% of flights in Germany before the Covid-19 pandemic (Bundeswehr 2020).

**Air freight transport**

Air transport also includes the transportation of air freight, which is the fastest way to get goods from one place to another. While a container ship takes three to four weeks to travel from Asia to Europe, goods can be at their destination the following day when they're flown there. Air freight is transported either in cargo planes or as belly freight in passenger planes. In addition to perishable goods such as fresh food or cut flowers, the transported goods are particularly capital-intensive. The goods can be sold more quickly this way and capital commitment and the turnaround time can be reduced, and the total cost of putting goods on the market can be decreased despite the significantly higher transport costs. Express deliveries by courier, express and parcel services and the urgent delivery of spare parts also require the high speed offered by air transport. For the globalized world of commodities without warehousing, air freight transport is therefore very important (Kranke et al. 2011). Nevertheless, there are alternatives (see factsheet 3).

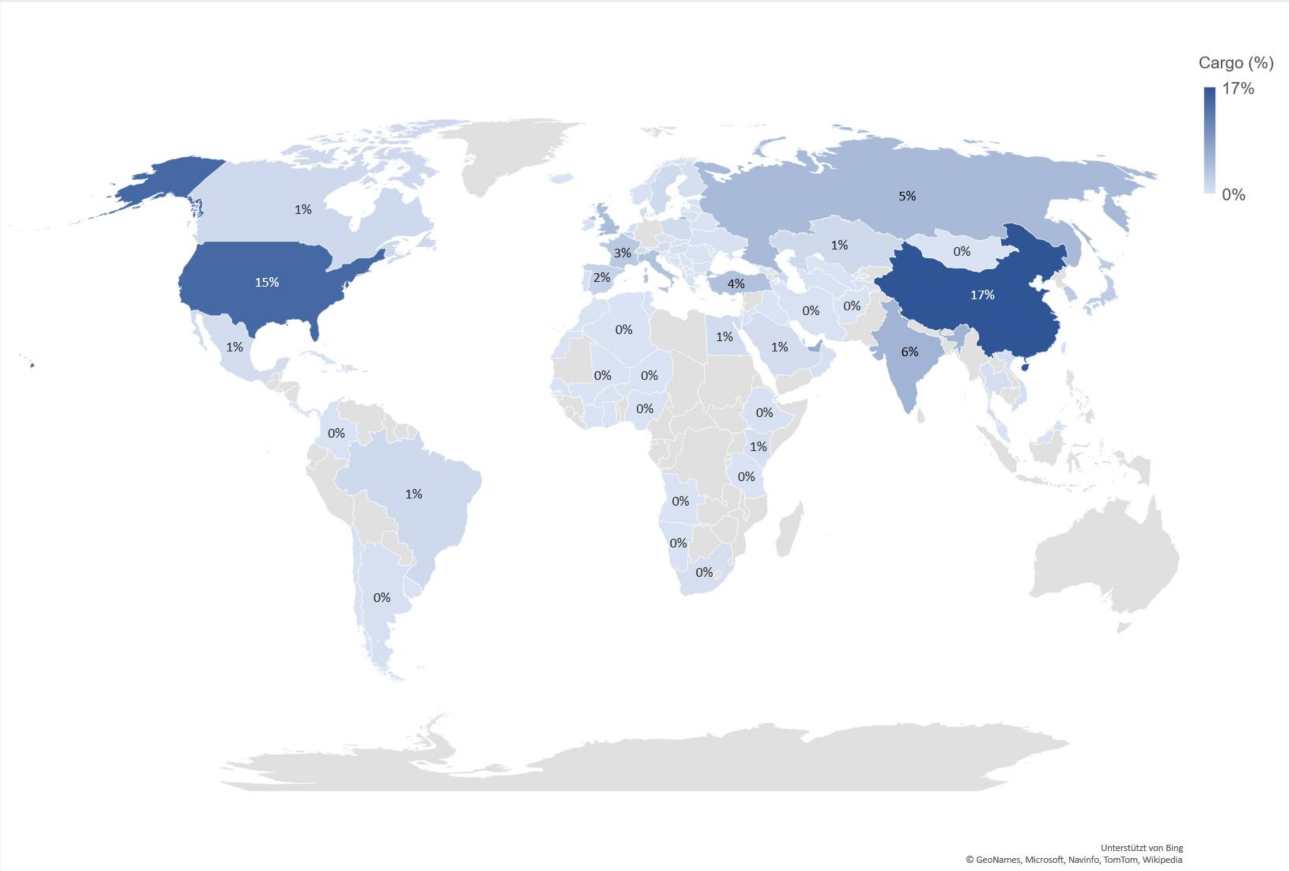
**German exports constitute only a small share of air freight**

In 2019, approx. 2.4 million tons of freight and mail were transported abroad by plane from German commercial airports – primarily to the USA – and around 2.2 million tons arrived in Germany from abroad, primarily from China (Destatis 2020a). This means that air freight accounts for only a very small portion of the volume of freight transport; German exports are transported most often by road and ship.

In terms of general trade, i.e. imports and exports excluding transit trade and intermediate transport of exports, air freight accounted for 0.2% (imports) and 1.5% (exports) of the total weight of freight transported in 2018. In terms of the value of goods, the share of air freight was 9.7% (imports) and 12.8% (exports) due to the higher value of goods (BMVI 2019). However, the volume of goods transported by air freight to and from Germany increased constantly before the Covid-19 pandemic; between 2012 and 2018 alone, it increased by 16%.

When discussing air freight, we must keep in mind the connection with passenger transport. In recent years, approx. half of all goods were transported as belly freight in passenger aircraft. If passengers increasingly stay on the ground, it will have an impact on air freight capacity: In the course of the Covid-19 crisis, for example, the belly freight capacity plummeted internationally by 75% (IATA 2020a), which led to an increase in prices. As a result, prices were 40% higher for air freight to China in the first quarter of 2020 compared to the last quarter of 2019 (Destatis 2020b).

**Figure 4: Unloading cargo and post – connections between German and foreign countries**




Source: Oeko-Institut based on Destatis (2020)

## 1.5 Who flies?

Prior to the Covid-19 pandemic, air transport had been increasing globally for a long time. But while more passenger kilometres are travelled in the air each year, people around the world participated in this trend to very different degrees. Most flights are taken by a small share of people from the world's wealthiest societies.

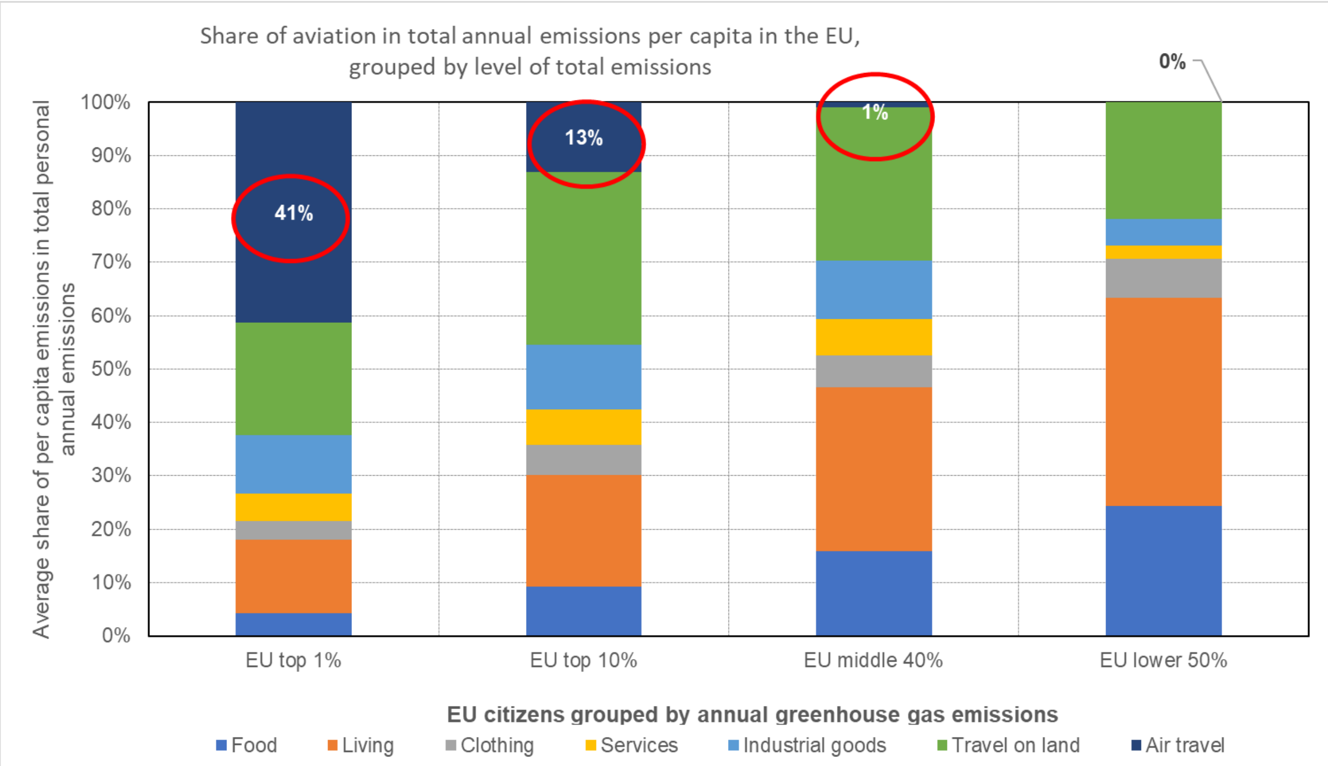
It is estimated that only about 3% of all people fly a year (Gössling 2019). While frequent flyers take over a hundred flights a year (Lassen 2016; Gössling et al. 2009), the vast majority of people have never seen the inside of an aeroplane. Even within affluent countries, people fly to different extents. A British study shows that people with higher incomes fly disproportionately often compared to those with lower incomes (Banister 2018). The introduction of low-cost flights in the 1990s did not significantly change this.

Most passenger kilometres occur in the Asia-Pacific region; this region is predicated to have the strongest growth in the decades ahead. This is due to the rapid expansion of the middle class in this region (Airbus 2019).

In terms of per capital emissions, the share of aviation emissions is substantial among the segment of the population with high GHG emissions. Among the 1% of people who generate the highest emissions – a total of 55 tons of CO2 equivalents per capita on average – air travel accounts for 22.6 tons of CO2 equivalents, or about 41% of emissions. This group, which benefits most from the subsidization of aviation (see factsheet 2), encompasses those with the highest incomes (Ivanova and Wood 2020). If the indirect climate effects of flying are added (see chapter 2), the share of air travel in the total emissions of this group roughly trebles.

In countries of the Global South, in contrast, the question of whether or not to fly does not even arise for many due to a lack of money and/or they are not connected to an airport. In addition, visa regulations around the world considerably restrict the freedom of travel for the majority of people living there. EU citizens can travel to an average of 183 countries without a visa; citizens of the African continent, however, can travel to only 61 countries (Henley & Partners 2020).

**Figure 5: Share of air transport in total annual emissions per capita in the EU, grouped according to total emission levels**

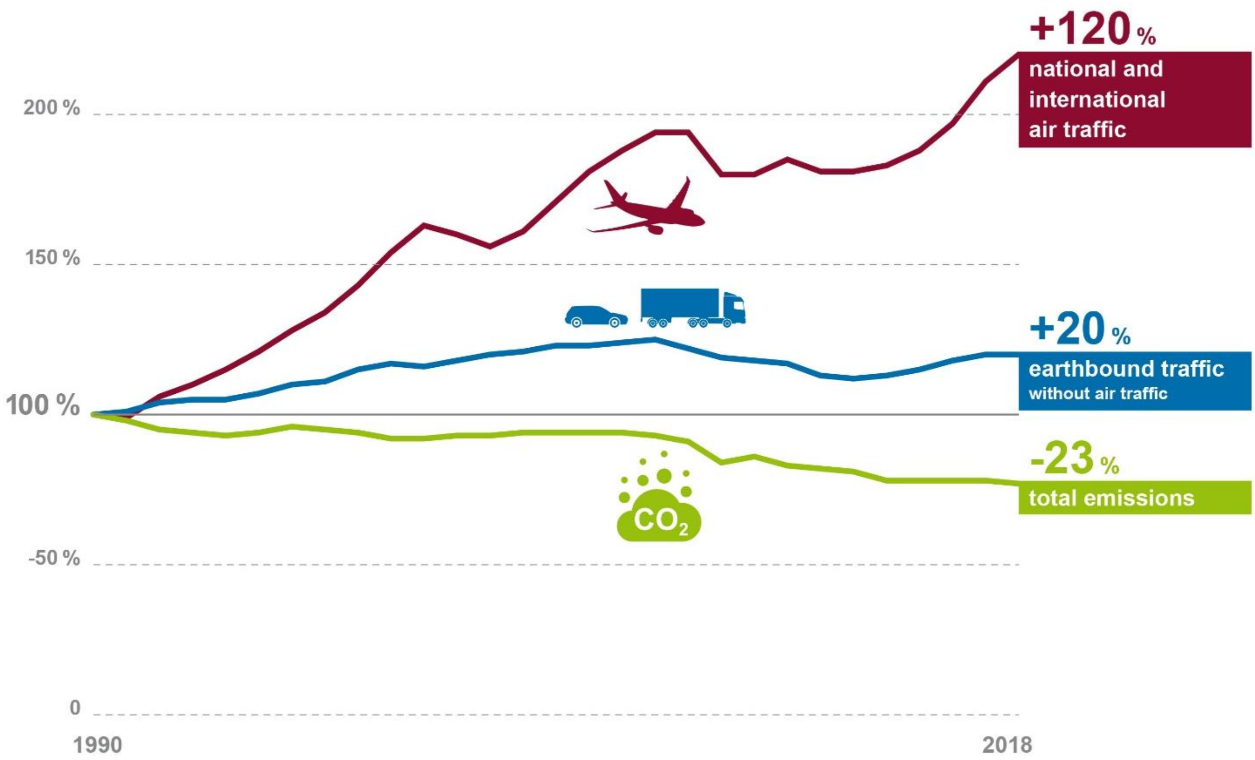



Source: Oeko-Institut based on Ivanova, D.; Wood, R. (2020), p. 7

## 1.6 How high are the greenhouse gas emissions generated by flying?

International air travel from Germany caused a total of 29.4 million tons of $CO_2$ emissions in 2018, excluding domestic flights. It accounted for approx. 3.4% of Germany's total emissions that year, which is as much as Los Angeles annually emits, with a population of nearly four million. $CO_2$ emissions from intra-European aviation and the EU share of international flights accounted for 182 million tons in 2018, which corresponds to approx. 4% of the total emissions of the EU-28. Emissions from international flights from the EU have also increased almost continuously since 1990 (EEA 2020).

**Figure 6: Development of greenhouse gas emissions in the EU**




Source: Oeko-Institut 2020

Globally, aviation accounted for a total of 2.4% of anthropogenic $CO_2$ emissions in 2018 (Lee et al. 2020). In 2019, this amounted to 914 million tons of $CO_2$ (IATA 2020b). That may not sound like much, but it is problematic from a climate protection perspective for several reasons:

- $CO_2$ emissions are only part of the story of aviation's harmful effects on the climate. **Its actual contribution to global heating is about three times greater than the contribution of CO2 emissions alone** (Lee et al. 2020)**.** This is because aviation has other climate-damaging effects, for example through cloud formation (see chapter 2). **According to calculations made by Oeko-Institut, aviation was responsible for a total of about 5.5% of anthropogenic climate heating in 2018.**

- Prior to the Covid-19 pandemic, emissions from aviation had been steadily growing; between 2013 and 2018 they increased globally by about 5% annually (Lee et al. 2020). Forecasts suggest further exponential growth in the decades ahead (see factsheet 5); whether the Covid-19 pandemic will reverse this trend in aviation remains questionable. In 2020, climate-damaging emissions from aviation are expected to continue to rise after the pandemic unless more rigorous measures are taken to regulate the sector and develop sustainable technologies (T&E 2020).

- While emissions have grown steadily, technologies for climate-neutral flying are still not within reach (see factsheet 5). This is not compatible with the global decarbonization that is necessary to meet the goals of the Paris Agreement and limit global heating as much as possible. Without drastic and rapid measures to reduce aviation, it is possible that it accounts for a large share of global emissions in the future.

- If aviation were a country, it would have been in the top ten countries with the highest emissions in 2019. However, unlike countries that have committed under the Paris Agreement to reducing their emissions, making their climate targets more ambitious in the future and developing long-term strategies to decarbonize their economies, the emissions reduction target for aviation is very weak. Under the International Civil Aviation Organization (ICAO), the participating countries have only been able to agree on limiting the growth of air transport beyond existing levels (see factsheet 2). Targets for reducing emissions from air transport have not been defined; this is not compatible with the goals of the Paris Agreement to limit global heating to a temperature increase that is well below 2°C.

## 2 What effect do flight emissions have?

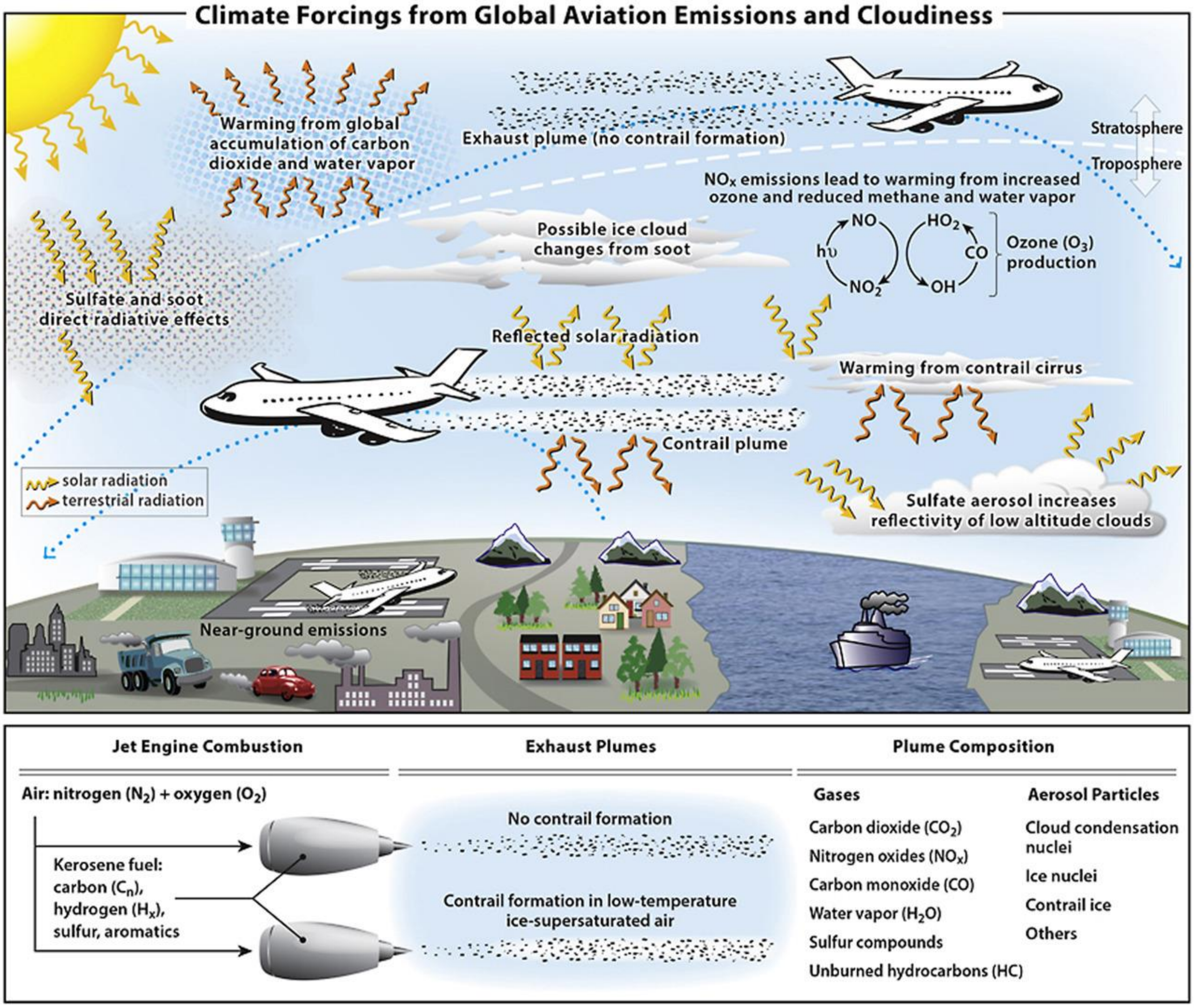
In addition to direct greenhouse gas emissions, aviation has other harmful effects on the climate through cloud formation and other chemical processes (non-CO2 effects) – these effects are not taken into account when analyses consider only the CO2 emissions resulting from the combustion of kerosene. A study published in 2020 estimates that, assuming no change in the growth of aviation, the total climate-damaging effect of aviation is globally on average about three times greater than the effect of CO2 emissions alone.

### 2.1 How does air transport affect the climate?

Aviation has a stronger negative impact on the climate than just the effect of CO2 emissions. Nitrous gases (NOx), water vapour, soot, aerosol and sulphate aerosol particles emitted by aircraft also affect the climate. In addition, flying creates contrails and contrail cirrus, i.e. clouds of ice crystals that can be generated by aircraft engines at high altitudes. This can have both warming and cooling effects.

Nitrogen oxides, for example, can lead to ozone formation, which warms the atmosphere. They can also contribute to the breakdown of methane in the atmosphere, which in turn has a cooling effect. Water vapour and soot particles, which absorb sunlight, have a direct warming effect. Sulphate particles can have a cooling effect by blocking sunlight from the atmosphere. In addition, aerosol particles can lead to the formation of contrails and cirrostratus clouds composed of ice crystals. The contrails trap infrared radiation in the atmosphere and thus have a warming effect. Although they reflect solar radiation back into space and can thus have a cooling effect, the warming effect is stronger. Cirrostratus or cirrus clouds composed of ice crystals absorb solar radiation and cause the atmosphere to become warmer (DLR 2020b; Lee 2018; Tesche et al. 2016; Bock and Burkhardt 2019).

**Figure 7: Climate impact of air travel not limited to $CO_2$**




Source: Lee et al (2020)

**Overall, aviation emissions clearly have a predominantly warming effect.** Cloud formation and the $CO_2$ emitted have the strongest climate impact. The direct impact of emitted particles is well documented by physical science. The exact effect of cloud formation has not yet been conclusively researched (Lee et al. 2020; Lee 2018). The various impacts differ in terms of duration. While $CO_2$ remains in the atmosphere for centuries and warms the climate, cloud formation, soot and aerosols only have an effect over short periods of days to decades:

**Table 1: Effect of different climate forcers from aviation**

| Climate Factors | $CO_2$ | $NO_x$ -> $O_3$ increase | $NO_x$ -> $CH_4$ Decrease | $NO_x$ -> $O_3$ Decrease | Sulfate Aerosols | Soot | Contrails and Cirrus Clouds |
|---|---|---|---|---|---|---|---|
| **Climate Impact** | Warming | Warming | Cooling | Cooling | Cooling | Warming | Warming |
| **Duration** | Centuries | Weeks to months | Decades | Decades | Days to weeks | Days to weeks | Contrails: hours Cirrus Clouds |

| Climate Factors | $CO_2$ | $NO_x$ -> $O_3$ increase | $NO_x$ -> $CH_4$ Decrease | $NO_x$ -> $O_3$ Decrease | Sulfate Aerosols | Soot | Contrails and Cirrus Clouds |
|---|---|---|---|---|---|---|---|
| | | | | | | | hours to days |
| **Spatial Distribution** | Global | Kontinental bis global | Kontinental bis global | Kontinental bis global | Kontinental bis global | Lokal bis global | Lokal bis global |
| **Scientific Understanding** | Good | Fair | Fair | Fair | Direct effects: good indirect effects: poor | Direct effects: good indirect effects: poor | Poor |

Notes: $NO_x$ = nitrous oxide; $O_3$ = ozone; $CH_4$ = methane

Source: Carbon Offset Guide (2020)

## 2.2 How can the total climate impact be measured?

In some studies, the impact of aviation on the earth is estimated using radiative forcing (RF). Radiative forcing is a measure of how the energy balance of the Earth and atmosphere are influenced. A radiative forcing index (RFI), which considers the radiative forcing of all aviation effects relative to that of $CO_2$ emissions, is used in the calculations. The RFI estimates that the total climate-damaging effect of aviation is 1.9 to 4.7 times greater than the effect of $CO_2$ emissions alone (Grassl and Brockhagen 2007).

In a study published in 2020, the climate impact of aviation is measured by what is known as effective radiative forcing (ERF), which is the increase or decrease in the balance between energy coming from the sun and energy emitted by the earth since the pre-industrial era (DLR 2020b). **Based on this metric, the total climate impact of aviation is estimated to be about three times that of CO2 emissions alone** (Lee et al. 2020)**.** The ERF is a better indicator of the warming effect of aviation because it takes greater account of rapid responses of the earth system (Myhre et al. 2013, p. 665).

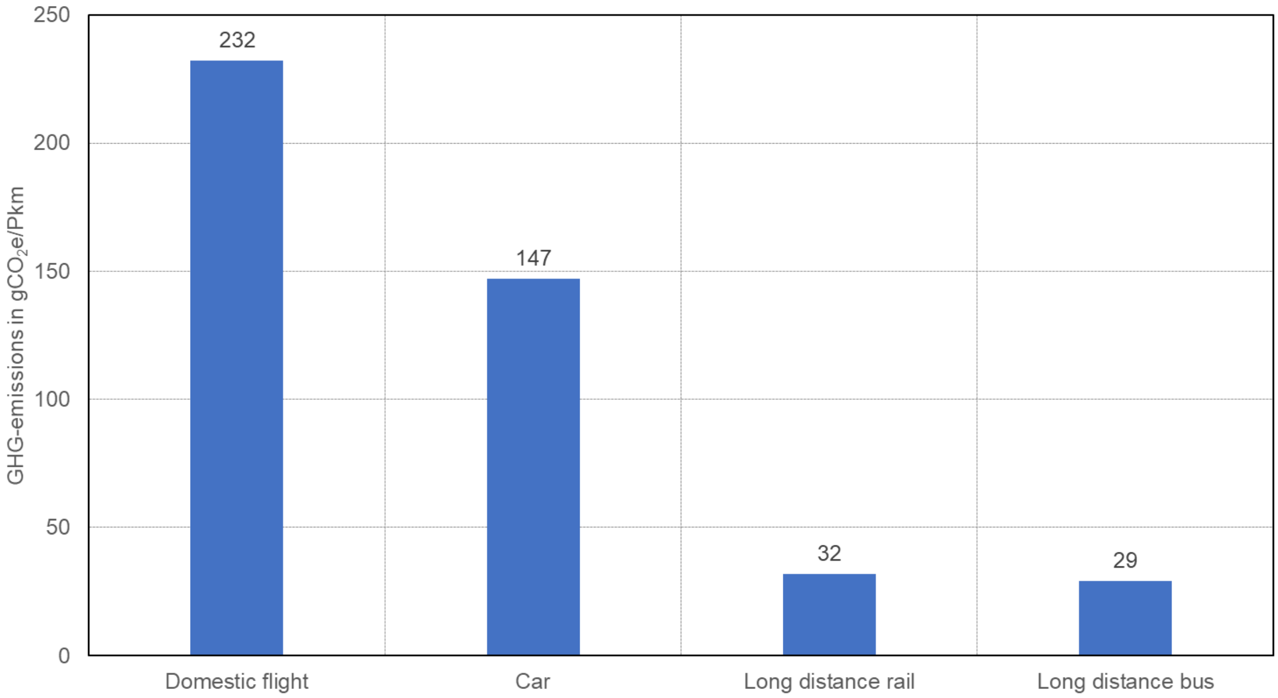
For an individual flight, the specific climate impact depends on other parameters due to the above factors. These other parameters include the altitude of the flight, the prevailing temperature at that altitude, and the humidity in the atmosphere. For the calculation of the climate impact of a single flight it is important to take these conditions into account. An incentive can be created for reducing the climate-damaging effects of flying by, for example, flying at a lower altitude.

# 3 Modes of transport compared

A direct comparison of the average greenhouse gas emissions of different modes of transport clearly shows that flying has the largest climate impact. The total greenhouse gas emissions of a journey are made up of the specific emissions and the distance travelled.

According to the German Federal Environment Agency's Transport Emission Model (TREMOD, Version 6.03), the greenhouse gas emissions per passenger kilometre (pkm) from flights within Germany are around seven to eight times higher than those of more climate-friendly modes of transport such as long-distance trains and buses. But even compared to passenger cars, the specific emissions of domestic flights, i.e. the emissions in relation to the passenger kilometres (pkm) travelled, are around 60 % higher on average.

**Figure 8: Greenhouse gas emissions of different modes of transport compared**




Averaged values for journeys in Germany

Source: Oeko-Institut 2020 based on TREMOD Version 6.03 (Transport Emission Model of the German Federal Environment Agency)

## 3.1 What are the relevant factors of the carbon footprint?

The specific greenhouse gas emissions per passenger kilometre basically depend on several factors:

- the energy consumption of the vehicle per kilometre,
- the type of fuel or energy source used, and
- the capacity of the means of transport and the utilization of capacity.

The energy consumption and the type of fuel used determine the total greenhouse gas emissions of a means of transport. The **energy consumption** of an aircraft depends largely on its characteristics, e.g. the type of aircraft, type of engine, weight of the aircraft and its equipment. The flight mode and external conditions also influence energy consumption: What is the capacity utilization? What cruising speed is selected? What are the ambient conditions, e.g. wind?

Similar factors generally also influence the energy consumption of other means of transport. For example, a passenger car with a petrol engine consumes more energy than a comparable vehicle with a diesel engine. A heavy, high-performance luxury vehicle generally consumes more than a light compact car. A train with an electric drive system is more efficient than one with a diesel drive system.

The influence of the **fuel** used on greenhouse gas emissions depends on two main factors:

- the amount of carbon in the fuel in relation to the energy content – this determines the direct $CO_2$ emissions;
- emissions that occur during fuel production and supply, the so-called upstream chain.

**Upstream chain:** the activities carried out to gather materials and create a product. The upstream chain includes direct environmental impacts and impacts emanating from upstream process chains.

The German Federal Environment Agency's TREMOD model yields the following values for 2018:

- kerosene: direct $CO_2$ emissions: 73.3 g $CO_2$/MJ; greenhouse gas emissions from upstream chain: 15.6 g $CO_2$eq/MJ.
- petrol: direct $CO_2$ emissions: 74.9 g $CO_2$/MJ; greenhouse gas emissions from upstream chain: 12.4 g $CO_2$eq/MJ.
- diesel: direct $CO_2$ emissions: 73.9 g $CO_2$/MJ; greenhouse gas emissions from upstream chain: 12.5 g $CO_2$eq/MJ.

If, for example, long-distance train journeys are powered by electricity or an aircraft is operated purely electrically, no direct emissions are produced. The total emissions are attributable to electricity generation at the power plant and the upstream chain of the energy sources used there. These emission levels depend to a large extent on the emission levels in the electricity mix in the country concerned, i.e. the share of renewable energies in electricity generation.

Other important factors in the context of the carbon footprint are the **capacity** and **capacity utilization** of the means of transport. Capacity is determined by the aircraft model and the seating select-ed: if the distance between seats is small, more passengers can be transported; a larger distance between the seats as in business class in turn reduces capacity. The emissions calculator of Atmosfair takes into account this difference space requirement: for example, it multiplies the average emissions by a factor of 0.8 (economy class), 1.5 (business class) or 2 (first class). First class flights thus generate about two and a half times as many emissions as economy flights.

Goods are often transported in the belly of passenger aircraft as cargo or belly freight, so the aircraft's emissions must be divided between freight and passengers. In practice, this is often carried out based on the transport volume in ton kilometers, each passenger including baggage is counted as 100 kg (Deutscher Speditions- und Logistikverband e.V. 2013).

A lower capacity and/or capacity utilization – which arose, for example, during the Covid-19 pandemic – thus increases the environmentally harmful effect of a flight per person, because the total emissions are distributed among fewer travellers (and goods transported along with them).

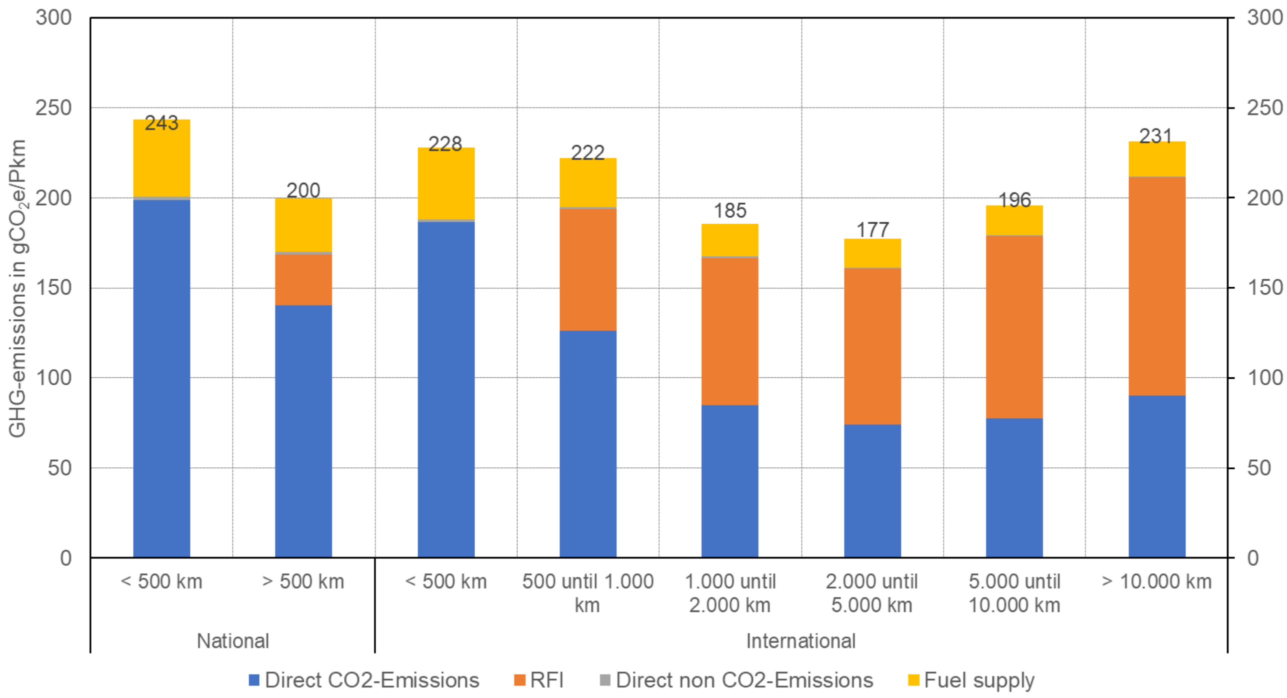
## 3.2 What distinguishes greenhouse gas emissions in air transport?

There are some key particularities in air transport compared to other modes of transport. For example, the emissions are dependent on the distance travelled due to several mechanisms.

The figure shows that over short distances $CO_2$ emissions account for the largest share of the harmful impact of air transport on the climate. The energy-intensive take-off and ascent have a particularly strong impact in flights over short distances. Over long distances, in contrast, the indirect harmful effects on the climate account for approximately half of the total climate impact of a flight, because non-$CO_2$ effects such as the warming effects due to cloud formation play a greater role at higher flight altitudes. Per capita emissions increase for long-haul flights since more fuel must be transported and therefore fewer passengers and less belly freight can be carried. Distances between

1,000 and 5,000 km have the lowest total climate impact converted into greenhouse emissions per passenger kilometre.

**Figure 9: Climate impact of air travel on different routes**




Source: Oeko-Institut based on TREMOD Version 6.03 (Transport Emission Model of the German Federal Environment Agency)

**What influences the greenhouse gas emissions of aviation?**

Take-off and ascent, cruise altitude and fuel quantity have a direct impact on the greenhouse gas emissions of aircraft:

**1. Take-off and ascent**

During the take-off and ascent phases, aircraft consume a particularly large amount of energy as the aircraft accelerates and altitude increases. These energy-intensive phases are more significant in flights over short distances than longer ones. The specific energy consumption per kilometre decreases over longer distance due to this effect.

**2. Cruising altitude**

Non-$CO_2$ effects occur at high cruising altitudes. The longer the flight distance, the larger the share of the flight distance travelled at these high altitudes. Thus, specific emissions from non-$CO_2$ effects increase with distance.

Another particularity of air transport is that, compared to the other modes of transport, it is less dependent on fixed route infrastructure. In practice, this often results in shorter journeys. It is usually assumed that the distance flown is made up of the direct route (great circle distance or as the crow flies on a sphere) and a detour of, for example, 50 km (Atmosfair) or 95 km (DIN EN 16258). If 50 km is taken as a basis, the distance for the example journeys from Frankfurt to Brussels, Paris and Barcelona is between 10% and 17% longer by land than by plane. Air transport may have the advantage that a shorter distance has to be covered than in road or rail transport. Therefore, it is important that comparisons of different modes of transport take account not only of the emissions per person kilometre; rather, these values and the distances travelled should be used to calculate the total emissions of a journey.

**3. Fuel quantity**

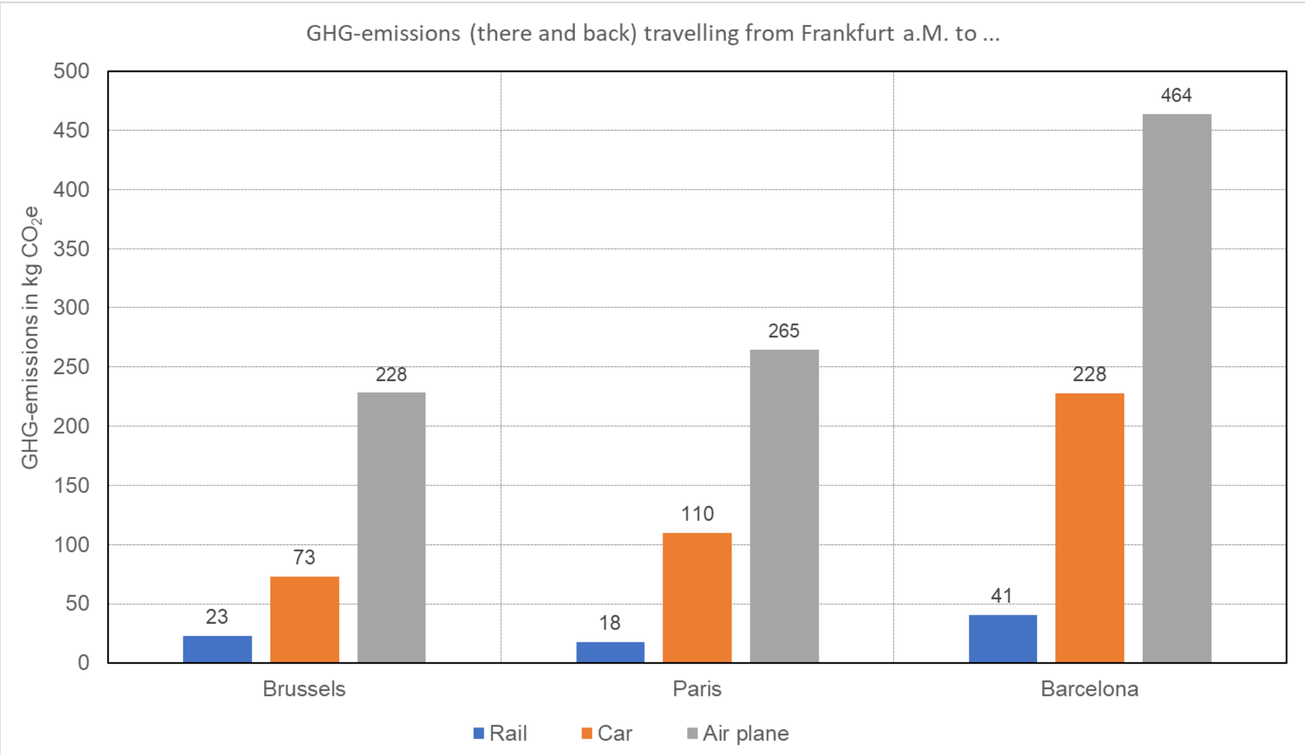
The farther the destination is from the starting point, the more fuel the aircraft must carry. This has two effects. Firstly, energy consumption increases with the increasing distance because of the additional weight of the fuel. Secondly, for a given maximum takeoff weight (MTOW), the amount of fuel used can reduce the amount of cargo that can be carried. The capacity of the aircraft therefore decreases. Specific fuel consumption and specific emissions per passenger kilometre thus rise as the distance increases, because the total energy consumption and emissions are distributed over the utilized capacity.

On long-haul flights, it can therefore make sense to make a stopover for refuelling halfway along the route. In the case of a Boeing 777-300, this leads to a reduction in specific energy consumption for total distances of around 5,500 km or more (UBA 2019c). It should be noted that a stopover also results in higher ground-level air pollutant emissions and noise pollution (see chapter 4).

## 3.3 Greenhouse gas emissions compared

The following figure shows the greenhouse gas emissions for example trips from Frankfurt/Main to Brussels, Paris and Barcelona by train, car and aeroplane. These were calculated using EcoPassenger's online calculation tool and considers both the upstream chains from fuel supply and the non-$CO_2$ effects of flights at high altitudes. An average capacity utilization of aeroplanes and trains is assumed; for passenger cars, a current mid-range vehicle with a petrol engine and two passengers is assumed.

**Figure 10: GHG emissions of a return journey from Frankfurt am Main to selected destinations**



Notes: train and plane: average capacity; passenger cars: mid-range, petrol, 2 people

Source: Oeko-Institut based on ecopassenger.org

Long-distance rail travel performs best in this comparison: rail passengers cause less than 10% of the greenhouse gas emissions of holidaymakers travelling by plane. The low emissions from rail travel also result from the low share of electricity from coal-fired power plants in France. Passenger travelling by car cause greenhouse gas emissions that are about two-thirds lower than those caused by passengers travelling by plane to Brussels. For the longer trip to Barcelona, the lower emissions compared to air travel drop to about half.

The high speed of aeroplanes also makes it possible to travel to faraway destinations that cannot be reached by other means of transport or can only be reached if the significantly longer travel time is not an obstacle. Such long-distance travel made possible by air travel causes very high greenhouse gas emissions. For example, a trip to Southeast Asia with a flight distance of around 9,000 km generates over 6 t of CO2eq (calculated using http://ecopassenger.org).

## 4 Air pollutants and noise pollution

In addition to its climate impact, aviation has other negative impacts. Noise and air pollutants are a burden on people and the environment.

### 4.1 Air pollutants

As with other modes of transport, airline operations and activities at the airport release pollutants such as nitrous gases, hydrocarbons and particulate matter. These have warming effects on the climate and can also have a negative impact on human health (IASS 2013).

In connection with aviation, the impact of ultrafine particles (UFP) – i.e. particles smaller than 100nm – is currently being much discussed. These are produced in all combustion processes. Aircraft engines release particularly large quantities of ultrafine particles (UBA 2018b; Universitätsklinikum Düsseldorf 2018; UBA 2019b, p. 18). These cause increased concentrations of ultrafine particles in the vicinity of airports. Therefore, not only climate protection measures should be taken, but also measures to reduce air pollutants and thus potential health hazards.

### 4.2 Noise

Studies have established a clear link between traffic noise and health risks. Especially in conurbations, people suffer from noise pollution.

To counter the negative health effects of aircraft noise, both active and passive noise abatement measures are possible. Active noise abatement aims to reduce noise directly at the source through technical measures: flight routes can be adjusted or the times at which routes and runways are used can be changed; new flight procedures also make it possible to fly at higher altitudes for longer during the descent to reduce noise on the ground or to fly flight routes more precisely. Passive noise abatement measures protect people through structural measures such as better sound insulation of building components (e.g. windows or roofs).

The regulations of the German Air Traffic Noise Act focus on passive noise abatement measures, settlement restrictions for particularly affected areas and compensation payments for the restricted use of exterior living areas. Active noise protection is often neglected and the technological and navigational possibilities are not used. The threshold values for passive noise abatement provided for by law are also insufficient: both the short-term nuisance and the long-term effects of aircraft noise are greater than was assumed when the legal standards were set (Öko-Institut und GeräuscheRechner 2018).

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