An ambitious policy agenda to improve rail travel may drive down CO2 emissions by 2 to 8 million tonnes on a yearly basis

In 2017, fuel combustion across all transport modes was responsible for 25% of all EU-28 greenhouse gas emissions.[1] If the European Union aims to achieve climate neutrality by 2050, a 90% reduction in transport emissions is required.[2] On distances up to 800 kilometres and potentially even further, rail travel is a promising alternative to air travel, and has the potential to drive down total CO2 emissions by 2 to 8 million tonnes for each year, contributing to the required transport emission reductions. To put this into perspective: all road transport in the Netherlands together emitted 5.6 million tonnes of CO2 in 2018.[3] Unlocking this full potential requires an ambitious policy agenda and involvement of market parties. We recommend that European Commission policy makers recognize the potential of a shift to rail travel and to make these emission reductions an integral part of future transport and climate policies.

In 2018, almost 630 million people travelled by air within the EU. This number is set to grow to 955 million in 2035.

The European Union reports the number of air travellers in the Eurostat database. In 2018 around 485 million passengers were reported on intra-EU routes (between all member states except for Cyprus) and 145 million passengers on national routes (only including France, Germany, Italy, Spain and the UK).

The ICAO expects further 2.5% annual growth per year in the period 2018 – 2035[4] which would bring these numbers to 735 million and 220 million for intra-EU and national routes respectively. This assumes there is no major deviation from current policies.

With this amount of air travel in the EU, aviation CO2 emissions in 2018 amount to around 76 million tonnes. This will rise to 80 million tonnes in 2035. Today, CO2 emissions from aviation in the EU account for 3% of total emissions.

With the number of air travellers reported in 2018, the CO2 emissions would approximately equal 76 million tonnes, based on data provided by ICAO. This source accounts for load factor and type of aircraft on each route. It explicitly does not include any climate change impact of aircraft emissions being at higher altitudes by use of a multiplier.

[1] Eurostat (2019), *Greenhouse gas emissions statistics,* https://ec.europa.eu/eurostat/statistics-explained/pdfscache/1180.pdf

[2] European Commission (2019), *European Green Deal communication,* https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf

[3] https://www.cbs.nl/nl-nl/nieuws/2019/47/luchtvaart-stoot-helft-broeikasgas-transportsector-uit

[4] https://www.icao.int/Meetings/aviationdataseminar/Documents/ICAO-Long-Term-Traffic-Forecasts-July-2016.pdf

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Assuming the yearly growth factor for number of air passengers equals 2.5%, the amount of intra-EU aviation CO2 emissions would rise to approximately 115 million tonnes by 2035. The aviation sector however has presented its ambitions with respect to CO2 emissions in the coming years, which is to keep the total CO2 emissions at 2020 levels. The growth in the number of passengers will be compensated by fleet renewals and the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). If 2020 levels are retained, as we assume in this paper, the CO2 emissions would stabilize at 80 million tonnes per year.

Of these 80 million tonnes of CO2, around 17% is generated by national flights within member states.

According to a 2018 EU *Legislation in Process* Briefing, the direct CO2 emissions from aviation account for about 3% of total emissions in the European Union. This is higher than the global average of 2.1%.[5]

A large share of total CO2 emissions is emitted on long haul flights within the EU (>800km). 15% is emitted on flights between 300 and 800 kilometres. 0.3% is emitted on flights shorter than 300 kilometres.

The majority (67.6 million tonnes, almost 85%) of the CO2 emissions are generated on routes with a distance of over 800 km. Table 1 presents the total number of passengers and CO2 emissions for intra-EU/national relationships and for each distance category, per year. Most of the emissions on intra-EU relationships are generated on long-range flights, while most of the emissions on national relationships are generated on mid-range flights.

	Distance category	Number of passengers (2020)	CO2 emissions (2020) [tonnes]
Intra-EU	**Long > 800 km**	436,200,000	61,747,000
	Mid (300 - 800 km)	70,700,000	4,766,000
	Short (< 300 km)	1,200,000	50,000
National	**Long > 800 km**	45,800,000	5,913,000
	Mid (300 - 800 km)	100,600,000	7,147,000
	Short (< 300 km)	5,200,000	250,000
Total		659,700,000	79,873,000

Table 1: 2020-level intra-EU aviation passengers and CO2 emissions. *(Numbers might not add up due to rounding)*

[5] https://www.europarl.europa.eu/RegData/etudes/BRIE/2017/603925/EPRS_BRI(2017)603925_EN.pdf

Taking into account geographical constraints, we estimate that a medium scenario for a shift to rail on long-distance routes reduces emissions by 0.4 million tonnes (0.6%), on medium distance routes reduces emissions by 4.2 million tonnes (35.9%) and on short routes reduces emissions by 0.2 million tonnes (81.6%).

The amount of CO2 emission savings is calculated by determining the possible savings for all origin-destination pairs within the EU. The following equation describes the possible emission savings:

$$CO2\ savings = \sum_{i=1}^{49}\sum_{j=1}^{49}\left\{[pax, air_{i\to j}] \times [substitution factor_{i\to j}] \times \left[\frac{CO_2}{pax, air_{i\to j}} - \frac{CO_2}{pax, train_{i\to j}}\right]\right\}$$

In the equation, the number of passengers and amount of CO2 emissions of air passengers have been described. Travel by rail is assumed to be powered by energy which does not emit CO2 during production. The remaining factor in the equation is the substitution factor, a measure for how many passengers will shift from air to rail. For the sake of simplicity we assume this factor to correlate with the distance of the trip and have estimated a potential bandwidth for this factor. This results in a low, medium and high substitution scenario. For a more detailed description of the methodology, see Appendix A:.

We have calculated emission reductions for the scenarios. The range of potential savings is presented in Table 2. The total yearly savings are between 1.7-8.4 million tonnes of CO2. When we consider the medium substitution scenario the reduction amounts to 4.8 million tonnes each year.

Note that for around 43% of the CO2 emissions, a shift from air to rail is considered unsuitable due to geographical reasons. This includes flights to for example the Canary Islands, Balearic Islands and Greece. In Appendix B:, the top 10 intra-EU relations are shown for which the potential emissions savings is found to be the highest (based on the medium substitution factor).

Distance category	**CO2 emissions (2020) [tonnes]**	**Potential CO2 savings [tonnes]**
Long > 800 km	67,660,000	0 – 1,660,000
Mid (300 - 800 km)	11,912,000	1,550,000 – 6,395,000
Short (< 300 km)	300,000	195,000 – 300,000
Total	79,873,000	1,745,000 – 8,355,000

Table 2: yearly potential aviation CO2 emission savings. *(Numbers might not add up due to rounding)*

Facilitating this shift requires an ambitious policy agenda aimed at improving the attractiveness of international rail travel for passengers

Based on the methodology presented in this paper we conclude that a saving of 1.7 to 8.4 million tonnes of CO2 per year is possible by facilitating a shift from air to rail. To put this into perspective: all road transport in the Netherlands emitted 5.6 million tonnes of CO_2 in 2018[6]. The amount of emissions which can be avoided is therefore sizeable.

Realizing these savings requires an ambitious policy agenda aimed at making rail travel more attractive to travellers and more competitive. Policy options which are considered to be effective include:

- Realise better utilization of existing infrastructure
  Train travel time is the most important driver for rail market share (see Figure 1). Better utilization – in terms of capacity and speed – of existing infrastructure will reduce train travel times on routes that have the potential to substitute for air travel. Therefore it is necessary to provide focussed investments in infrastructure enhancement to increase technical maximum speeds, and in yearly timetable planning, prioritize international trains and align national timetables to the international trains accordingly, in other to fully utilize the current infrastructure possible travel times. Furthermore it is necessary to invest in innovative technologies, autonomous train driving in particular, to increase travel times and infrastructure capacity.

- Improve awareness of rail as a viable alternative to air travel, with a focus on door-to-door travel time
  Passengers on certain routes are still unaware of the existence of a train connection as viable alternative mode of transport for their trip. Also they tend to underestimate door-to-door travel time of flights, as they focus on in-flight time. This biases their decision on mode of transport toward air travel, even though train travel might in fact be the quicker door-to-door alternative.

- Focus on passenger user experience by creating good information, booking and payment systems for international train travel, and regulate changes between operators on a single trip
  From a passenger point of view, the user experience for train travel can be improved at the *before travel* stage. Compared to air travel, information, booking and payment systems for (international) train travel are often more complicated and less user-friendly.
  When a passenger for a single trip needs to change trains between operators, they will sometimes be required to book separate tickets for both operators. The risk of a missed connection will then be borne by the passenger, decreasing the likeliness that they will choose train travel over air travel

- Enhance the functioning of the single market by removing entrance barriers currently experienced by open access railway operators, such as limited access to station facilities and sales of tickets for on-going rail-travel
  Better functioning of the single market could bring improvement to multiple drivers of rail market share (also see Figure 1). Currently, competition between train operators on long distance routes is – in practice – still limited. Market barriers for new entrants still exist, and lowering them could lead to more competition. The Commission could ensure that train operators in practice have equal rights to access rail infrastructure and facilities and to information, ticketing and payment systems. Better availability of rolling stock, also for example specific rolling stock for overnight

[6] https://www.cbs.nl/nl-nl/nieuws/2019/47/luchtvaart-stoot-helft-broeikasgas-transportsector-uit

train services, (e.g. through ROSCOs) will lower barriers to set up new routes quickly. Also, speeding up infrastructure interoperability projects will decrease entrance barriers.

- Make rail tariffs more competitive to airline cost
  Train tickets are often more expensive than flight tickets among others due to differences in taxation.

- Work together with airlines and airports to move transfer passengers for short distance (feeder) flights to train
  Part of the intra EU air passengers are transfer passengers where their intra EU flight is part of an intercontinental trip. If airlines were to offer these passengers an integrated train ticket as alternative for the intra-EU leg of their trip, this could be an effective manner to shift large groups of passengers from air to rail quickly.

- Encourage member states to implement tailored measures that stimulate national long distance train travel
  A substantial part of the total CO2 savings potential comes from domestic flights. Encouraging and allowing member states to take specific national measures to make the train a more attractive alternative could be an effective way to capture this part of potential CO2 savings

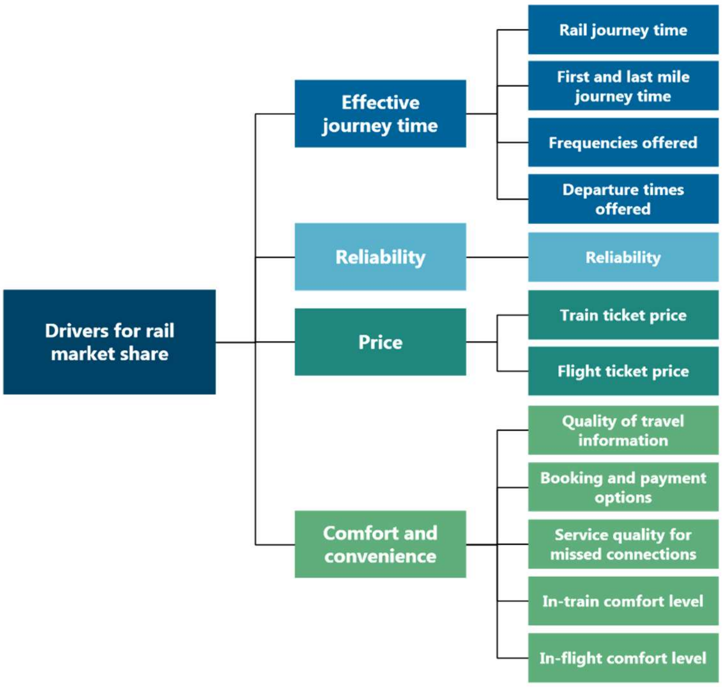
- Invest in an extensive European high-speed rail network to significantly reduce train travel times
  Ultimately, train journey time is the most important driver for rail market share. High-speed rail lines are required to make the train travel times competitive to air travel times on the medium and long distance, and capture the highest share of travellers.

- Make sure the required energy for traction is produced from sources which do not emit CO2
  To realize maximum emission reduction traction energy should be produced from sources not emitting CO2. Several operators in member states have either made significant steps toward this goal or have stated their ambitions.

We have developed a framework of drivers for the market share of rail transport, building on previous research prepared for the Commission.[7] Rail journey time is the single most important driver for rail market share, but other drivers do also have a significant impact. The policy options given above will bring improvement to many of those drivers, hence leading to a shift from air to rail. An overview of the framework is presented in Figure 1. The drivers are presented in descending order of impact.

[7] Steer Davies Gleave (2006), *Air and rail competition and complementarity*

Figure 1: Drivers for rail market share



Some action is already being take to achieve the shift from air to rail. The 3rd and 4th Railway Packages aim at creating an open market for (inter)national train operators and reducing costs through eliminating technical barriers. Furthermore, the regulation on rail passengers' rights and obligations aims to improve information, ticketing and payment systems and regulates passenger rights regarding delays and missed connections.

However, indicators show that further action is required to reach the full potential. For example, the number of international train services operating under the open access model is still limited, indicating that a real open market has not yet become reality. As long as this situation does not change, the envisioned benefits of the single European railway market for (potential) rail passengers will not be fully realized. As another example, the Commission has identified the completion of a European high-speed rail network and the connection of all major European airports to the European rail network by 2050 as two main goals for achieving the 60% greenhouse gasses emission reductions target.[8] However, the length of the European high-speed rail network is not growing fast enough to meet the Commission's 2011 target of tripling the number of kilometres of high-speed rail lines by 2030[9], indicating that the current policy agenda is not sufficient to actually complete the European high-speed rail network by 2050.

In summary: a shift of international passenger travel from air to rail will have a sizeable impact on the reduction of CO2 emissions. We recommend that European Commission policy makers recognize the potential of a shift to rail travel and make these emission reductions an integral part of future transport and climate policies.

[8] European Commission (2011): *Roadmap to a single European transport area*

[9] European Court of Auditors (2018): *A European high-speed rail network: not a reality but an ineffective patchwork*

Appendix A: Detailed description of the methodology

$$CO2\ savings = \sum_{i=1}^{49}\sum_{j=1}^{49}\left\{[pax, air_{i\to j}] \times [substitutionfactor_{i\to j}] \times \left[\frac{CO_2}{pax, air_{i\to j}} - \frac{CO_2}{pax, train_{i\to j}}\right]\right\}$$

The above equation is used to calculate the CO2 emission savings. To calculate each element, the following assumptions have been used:

Number of passengers

We have divided the EU into 49 regions. As there was no distance data for Cyprus and this region is isolated from the EU railway network, this country was excluded from the analysis. Note that Switzerland, an important junction in the European railway network, was not included in the analysis.

Most of the other 27 member states make up 1 region each, except for the 5 largest which also have significant domestic air traffic (Germany, France, Italy, Spain & United Kingdom). They have been split into the following regions:

- Germany has been split into 6 regions: Frankfurt, Stuttgart, Munich, Berlin, Hamburg and Dusseldorf
- France has been split into 6 regions: Paris, Nantes, Bordeaux, Lyon, Nice and Corsica (data for overseas territories such as Martinique and Réunion has been removed from the analysis)
- Italy has been split into 5 regions: Milan, Venice, Rome, Naples and Sardinia/Sicily
- Spain has been split into 5 regions: Madrid, Barcelona, Malaga, Balearic Islands and Canary Islands
- United Kingdom has been split into 5 regions: London, Birmingham, Manchester, Scotland and Northern Ireland

The distance between these regions was calculated using the distance table between NUTS regions, provided by Eurostat[10].

The 49 regions lead to 49 x 48 / 2 = 1.176 origin-destination pairs. Two Eurostat databases were used to gather the number of air passengers for each O-D pair:

- International intra-EU air passenger transport by main airports in each reporting country and EU partner country [avia_painac][11]
- National air passenger transport by main airports in each reporting country [avia_pana][12]

ICAO estimates a compounded annual growth rate of 2.5%[13] for intra-EU traffic in the period 2018 – 2040. We have used this growth rate to extrapolate the passenger data from 2018 to 2020. Assuming the aviation industry's ambition to keep emissions at 2020 level, we have used the passenger numbers for this year.

[10] https://ec.europa.eu/eurostat/tercet/flatfiles.do

[11] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=avia_painac&lang=en

[12] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=avia_pana&lang=en

[13] https://www.icao.int/Meetings/aviationdataseminar/Documents/ICAO-Long-Term-Traffic-Forecasts-July-2016.pdf

Substitution factor

We have defined 3 substitution-factors for different scenarios. The minimum substitution factor assumes current infrastructure. The medium substitution factor assumes a more extensive European high-speed rail network, and is based on empirical evidence of existing rail market share on high-speed lines. In the maximum factor, we also take into account autonomous growth of rail market share to estimate future substitution given a changing public opinion towards zero emission traveling.

The minimum substitution factor is determined based on the distance and whether or not current (high-speed) rail connections exist. If a high-speed rail connection currently exists, the minimum substitution factor is calculated according to the following conditions:

- If the distance between two regions is smaller than 100, the substitution factor is equal to 1
- If the distance between two regions is between 100 and 400, the substitution factor is based on a linear function (where: 100 = 1 & 400 = 0.4)
- If the distance between two regions is between 400 and 800, the substitution factor is based on a linear function (where: 400 = 0.4 & 800 = 0)
- If the distance between two regions is greater than 800, the substitution factor is equal to 0

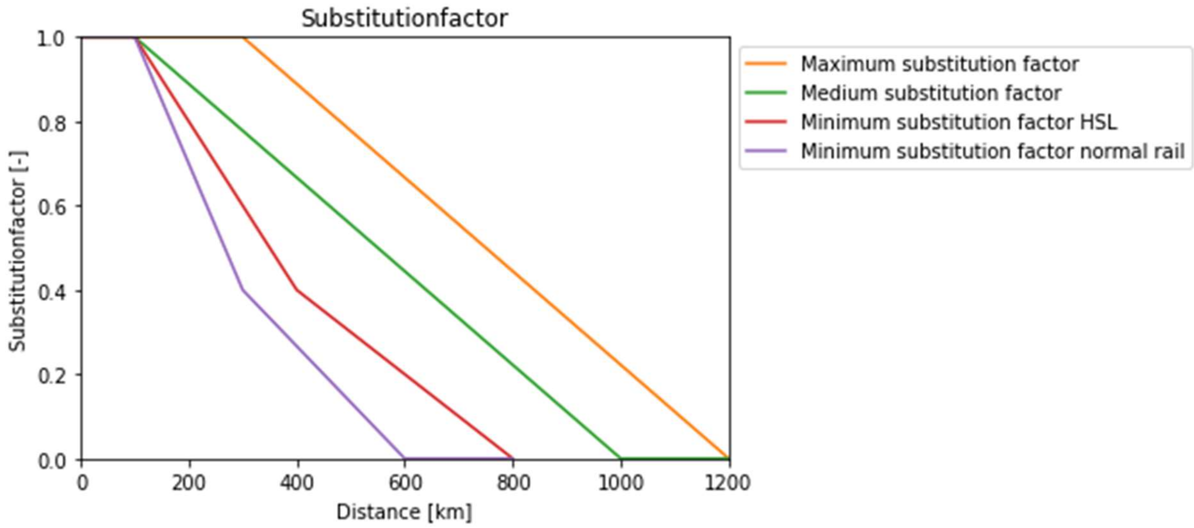
$$Subsitution\ factor = \begin{cases} 1, & d < 100 \\ 0.6 * \frac{(400 - d)}{(400 - 100)} + 0.4, & 100 \leq d < 400 \\ 0.4 * \frac{(800 - d)}{(800 - 400)}, & 400 \leq d \leq 800 \\ 0, & d > 800 \end{cases}$$

If there is only a normal rail connection between two countries, the minimum substitution factor is calculated using the following conditions:

- If the distance between two regions is smaller than 100, the substitution factor is equal to 1
- If the distance between two regions is between 100 and 300, the substitution factor is based on a linear function (where: 100 = 1 & 300 = 0.4)
- If the distance between two regions is between 300 and 600, the substitution factor is based on a linear function (where: 300 = 0.4 & 600 = 0)
- If the distance between two regions is greater than 800, the substitution factor is equal to 0

$$Subsitution\ factor = \begin{cases} 1, & d < 100 \\ 0.6 * \frac{(300 - d)}{(300 - 100)} + 0.4, & 100 \leq d < 300 \\ 0.4 * \frac{(600 - d)}{(600 - 300)}, & 300 \leq d \leq 600 \\ 0, & d > 600 \end{cases}$$

Furthermore we have defined a medium and maximum substitution factor. These are straight lines based on market share data on relations with HSL connections, and assume an extensive high speed network. The market shares are based on travel time, so making assumptions for travel speed (average speed = 180 km/h) leads to a relation between the market share and distance. The results are plotted in the graph below.



If for certain regions a rail connection is currently not possible, the substitution factor is equal to 0. This is the case for:

- Regions isolated by water, namely: Finland, France (Corsica), Ireland, Italy (Sardinia & Sicily), Spain (Canary Islands & Balearic Islands), and the UK (Northern Ireland)
- Specific region combinations which lack railway connections due to natural barriers, namely between Sweden and Baltic states
- Regions isolated by lack of railway connections, namely Bulgaria, Greece and Romania

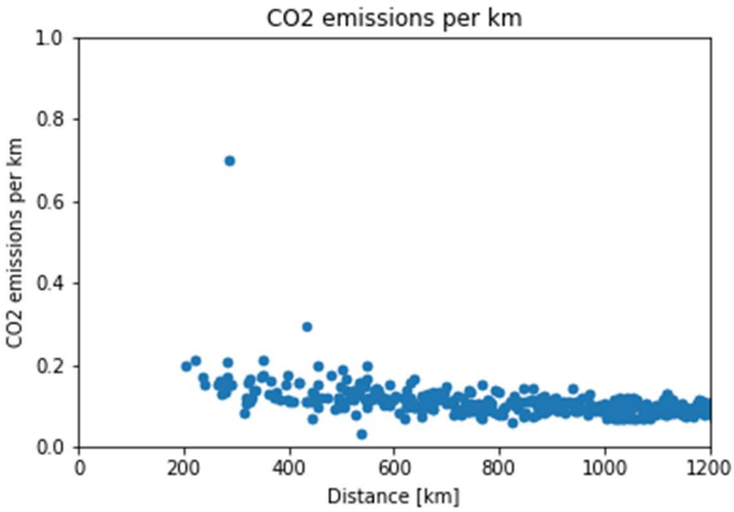
<u>CO2 emissions air travel</u>

The CO2 emissions have been determined using the ICAO carbon emissions calculator[14]. This carbon calculator is based on passenger operations (fuel burn related to freight is not included). It estimates the fuel burn of a route based on specific aircraft type and the ICAO Fuel Consumption Formula. The share of fuel burn for passengers is based on a passenger/freight factor determined from RTK data. Assuming all aircraft are configured with economy seats and a load factor leads to the number of seats occupied. The passenger fuel burn is divided over the occupied seats to get a fuel burn per passenger. This number is then multiplied by 3.16 to get the corresponding number of tonnes CO2 produced by burning a tonne of fuel. The carbon calculator explicitly does not quantify climate change impact of aircraft emissions using Radiative Forcing Index (RFI) or other multipliers.

Input for the carbon calculator is a combination of airports. Every region's largest airport was used to calculate the CO2 emissions to the largest airport of the other regions. The ICAO calculator only works for routes that are currently being operated, which means some combinations were not found. The largest, unfound combinations (with > 100,000 passengers per year) were manually added. For instance, there is no direct flight from Amsterdam to Bratislava so the ICAO calculator could not find the CO2 emissions for this route. The value for the route from Eindhoven to Bratislava was manually

[14] https://applications.icao.int/icec

added. This was done for the largest relations (> 100,000 passengers per annum) which led to CO2 emission values for 80% of the relations. The other 20% of the relations were automatically assigned CO2 emission values based on their distance and the average value of CO2 emissions of routes with similar distance, based on the data points in the figure below.



Appendix B: Top 10 intra-EU relationships with highest potential CO2 emission savings with the medium substitution factor

	Number of passengers	CO2 emissions [kg]	CO2 savings [kg]
London – Amsterdam	6,029,462	364,179,521	193,380,121
London – Paris	3,535,837	200,835,569	117,692,460
Lisbon – Madrid	2,639,444	209,307,926	106,193,640
Düsseldorf – London	2,046,603	151,653,341	64,339,426
Stockholm – Copenhagen	2,027,682	138,085,150	53,494,908
Amsterdam – Paris	1,568,314	93,785,187	52,626,703
Frankfurt – London	2,437,879	209,413,854	51,928,226
Vienna – Frankfurt	2,126,201	164,780,600	45,455,144
Paris – Frankfurt	1,419,750	108,185,024	44,352,780
Amsterdam - Frankfurt	905,561	63,208,158	42,265,352