The Effects of Sustainability-Driven Policies on Transport CO_2 Production: High-Speed Rail Transportation as an Alternative to Passenger Air Transport

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Abstract The purpose of this study is to evaluate to which extent the rail transport mode can improve the environmental situation in Europe if it were to be at the centre of sustainability-driven policies. In particular, it aims at estimating a relative picture of the CO_2 emissions generated by short-distance air passenger transportation in Europe, which could have been transferred to high-speed rail and produce less CO_2. This study follows a three-step methodology. Firstly, it calculates the number of passengers travelling on each route between cities and estimates the total CO_2 emissions. Subsequently, it leverages the current literature on CO_2 consumption from railway passenger transport. Lastly, it estimates the possible scenarios in terms of CO_2 emissions that would have followed adequate sustainability-driven policies. The study found that short-range aviation in EU28 produced 9.2 million tons of CO_2 in 2017, which represents about 5% of total aviation emission, about 1% of total transport emission and about 0.2% of total CO_2emission. Furthermore, the CO_2 production on the 175 routes analysed increased until 2019, while precise policies could have allowed saving 582 MT CO_2. The effects of the COVID-19 outbreak on the European transport sector increases the relevance of this study. To avert the "return to normality" vis a vis Greenhouse Gases (hereinafter "GHG") emissions from the sector, it will be necessary to introduce structural changes. As Austrian Airlines or KLM bailouts show, environmental concerns might finally influence the decision-making process on public transportation. In the context of a green recovery, this study not only lays the foundation for further contributions addressing the CO_2 production from EU-wide sectors but also underlines the role the railway can play in environmentally friendly transportation.

1 Motivation

Traditionally, economic development was thought to be achieved at the expense of the environment and, as a result, the objective of economic growth frequently

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got ahead of the social and environmental objectives. Mobility and transport have represented perhaps the best cases in which this trade-off has been evident. Despite the irruption of new technologies, services and approaches in the mobility sector which are radically transforming the concept of transportation, the transport sector is steadily increasing its GHG emissions since 1990.

As carbon dioxide emissions are directly related to fossil fuels consumption, the role of specific transport modes in improving the sector's share of GHG emissions is clear. The aviation industry plays a prominent part in this trend: studies revealed that 3.16 tons of CO_2 are released out of the consumption of one ton of kerosene, a hydrocarbon liquid commonly used as a fuel.[1] As of 2015, Europe is the second-largest region in the world for commercial passenger flights.[2] In this sense, commercial airlines play a relevant role in the European transport sector GHG emissions. Moreover, studies as the one by Alonso et al. (2014) underline how air traffic in Europe is concentrated on short distances below 1000 km, including almost 60% of all flights and 46% of all passengers. These findings are indeed puzzling, since the Union offers a broad range of surface transport alternatives.

The GHG emissions resulting from the transport sector are not the only cause for concern. In the context of heavy rains, rising temperatures and storms arising from global warming with predicted impacts on the air transport sector, the sustainability of the current trend vis a vis air passengers transport is challenged. The railway's higher resilience, on the other hand, might play a more suitable role in the context of climate change unfortunate effects. In the context of intra-European mobility, can railway transport offer a better, less carbon-intensive alternative than air transport for a sufficient number of cases? As the increase in awareness for environmental issues and carbon dioxide production can have impacts not only on end-user choices of mobility and transport, but also on the policymaking behind transport planning, this study aims at exploring novel possibilities other than aeroplanes to reconcile green policies and high levels of mobility.

The relevance of the question this study aims to address is high not only in relation to the EU goal vis a vis GHG emission, but also in the context of the COVID-19 pandemic aftermath. In particular, despite the Union has been characterised by a low production of GHG emission in the spring of 2020, this trend is expected to reverse course once recovery measures are working at full throttle. Transport will have an important role in the predicted rebound effect of GHG emissions; thus, the development of green new mobility and a high involvement of railway is essential (Tardivo et al., 2020).

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[1] https://www.atmosfair.de/wp-content/uploads/atmosfair-flight-emissions-calculator-englisch-1.pdf.

[2] .https://ec.europa.eu/transport/sites/transport/files/2016_eu_air_transport_industry_analyses_report.pdf.

2 Problem Formulation

The rail transport can improve the environmental situation in Europe if it were to be at the centre of sustainability-driven policies. By calculating the amount of carbon dioxide equivalent produced in the years 2017–2019 by passenger air transport between major cities within the European Union, this study aims at providing a sound evaluation of the amount of carbon dioxide equivalent which could have been saved if better mobility policies would have been in place enhancing the railway's passenger share.

After providing the data for a solid background, this study calls for a more profound cost–benefit analysis not only of traditional air transport in itself but also of low-cost airlines. This analysis is highly relevant for the EU given both its post-COVID-19 pandemic recovery as well as its position in the international system, which as a whole is striving to reach the Sustainable Development Goals (hereinafter "SDGs") by 2030.

This study looks at the results of the lack of policies over last two years with the objective to keep them as a light for the future, since it will be necessary to match the need for governments to avert a deep recession and the needs for safeguarding the environment. Since the transport sector plays a fundamental role in GHG production, it is time to acknowledge this fact and act accordingly.

3 The Position of This Contribution Within Academic Literature

This study is not the first contribution to compare CO_2 emissions from air and rail transport. Prussi and Lonza (2018) calculated in detail the CO_2 emission from rail and air transport on seven routes within the EU. We take advantage of their work and build upon their so-called high-rail scenario, including 175 routes and calculating the precise CO_2 emissions from the air sector. Always related to the topic, Alonso et al (2014) investigated the distribution of air transport traffic and CO_2 emissions within the EU. Despite their focus on the year 2010, their findings must be held into consideration as they calculated total CO_2 emissions from the air sector in 216 million tons, with a large concentration of emissions in a few countries.

On the same line with the previous studies, this contribution aims at providing a solid base for policy measures capable of curb the sector emissions. In this context, Mendes and Santos (2008) provided a forecast on the impacts of incentive-based regulation, suggesting that results were likely to be minimal. The failure of the EU emission trading system (EU ETS) in curbing CO_2 emissions from the aviation sector is evident in the 2020 Commission decision to amend the EU ETS regarding aviation. While academia focused greatly on the effects of aviation's inclusion in the EU ETS (Anger, 2010; Mendes and Santos, 2008; Morrell, 2007), it is clear that the academic literature lacks cross-sectoral analysis vis a vis CO_2 emissions, probably due to the complexity of detailing addressing these trends on a European scale.

Lastly, this contribution aims at developing an understanding of the implications for the CO_2 production by air transport on an international level. Following the footprint of Chèze et al (2013) —which estimated the scenarios for the air transport to reduce emissions to comply with the IPCC scenarios before the Paris Agreement—this contribution stresses the significance of reducing CO_2 emission from the transport sector in regard to the UN Sustainable Development Goals.

4 Objectives

As highlighted above, this study aims at picturing the amount of CO_2 that could have been saved in the 2017–2019 period provided that some of the passenger transport were to be shifted from air travel to railways.

Currently, an increasing number of Europeans are moving towards major urban centres which are interconnected via air, road and rail. The user's choice in transport mode has clear effects on the transport sector CO_2 emissions, thus we aim at understanding the magnitude of the effects of the transport sectors between these urban centres.

There is a number of these conurbations that are less than 800 km away from each other, a distance assumed to be still competitive for rail, and yet have dense air transport connections between them. The threshold of 800 km has been chosen on the blueprint of the Japanese bullet train Shinkansen, capable of having a greater market share than airlines on routes up to 965 km (Albalate and Bel 2012). Since the Shinkansen performance is deeply related to the type of infrastructure present in Japan, this study deemed feasible to take a more conservative approach in relation to the European infrastructure and limit its scope to routes up to 800 km long. The present study calculated the total amount of carbon dioxide equivalent produced between these major cities resulting only from air transportation. The objective is then to compare the level of emissions generated from air and railway transport and understand how much CO_2 could be saved if a modal shift to railway was in place.

Addressing an exact value to CO_2 emission from air transport is not particularly straightforward, as fuel consumption and therefore emission levels are not only related to physical characteristics of the aircraft, as engine types, winglets and number of seating, but also to how the aircraft is operated. Number of passengers carried, cargo loaded, flight distance, airspeed, landing procedure are factors that play a role in how environmentally impacting a flight can be. The flight distance deserves particular attention. At first glance, fuel consumption and carbon emissions are directly proportionate to the total flight distance. However, studies reveal that short-haul flights compared to medium-haul flights consume more fuel per 100 km. This result is based on the fact that the departure and take-off procedures require the use of a large amount of energy, and their implementation is a very energy-intensive step in a flight. Since those flights which are less than three hours long are considered short-haul flights, most domestic and intra-European flights are of this nature. At the same time, long-haul flights consume more fuel than the medium-haul flights per 100 km, as the fuel must be carried for most of the flight.[3]

5 Research

This study aims at identifying the effects of sustainability-driven policies in the transport sector vis a vis its production of carbon dioxide equivalent. After having acknowledged that air transportation plays a crucial role in both Europe's mobility and in the Union's global share of CO_2 emissions, this study undertakes three steps.

Firstly, it calculates the number of passengers travelling between the major European cities and estimates the total CO_2 production from the sector.

Secondly, it takes advantage of the current literature on CO_2 consumption from railway passenger transport and identifies the difference in CO_2 emissions between the two transport modes.

Lastly this study estimates the possible scenarios in terms of CO_2 production that would have followed the application of adequate sustainability-driven policies to the transport sector, analysing the potential carbon dioxide equivalent savings resulting from an ideal transfer of passenger transport from air carriers to the rail network within the European Union.

This study employs quantitative analysis, elaborating data from EU sources as Eurostat, the European Commission, EASA, EEA; from private sources as the Centre for Asia Pacific Aviation Pty. Ltd., Eurocontrol, Ryanair and Lufthansa; and scientific publications as Prussi and Lonza (2018), and Albalate and Bel (2012).

Data, which was produced by different stakeholders prior to this study, has been extracted by open-access websites and included into a new database. This database has been developed and manipulated through Microsoft Excel software.

We recognise that no data set is perfect, thus the present study has limitations in addressing factors such as the number of each type of aeroplanes from any EU country. However, data has been selected amongst public entities' databases with the aim of providing the most possible transparent data. As such, this study, despite focusing on theoretical losses in CO_2 savings which have not been achieved, does employ sound data and it expects to stimulate a new approach to the quantification of GHG emission and its effects on a cross-national EU-wide level.

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[3] https://www.atmosfair.de/wp-content/uploads/atmosfair-flight-emissions-calculator-englisch-1.pdf.

6 Implementation of the Research

The study takes into consideration the routes between European cities with a population larger than 500.000 inhabitants as well as European urban areas with a metropolitan population of over 1 million inhabitants. These thresholds are arbitrary; however, the researchers consider that this selection is representative enough for the target of the study. Having this study as objective the evaluation of the possible effects of sustainability-driven policies on an EU-wide scale, it focuses on major routes and macro-trends.

The selected cities and urban areas together with their respective countries are the following: (Table 1)

As this study will analyse the potential carbon dioxide equivalent saving resulting from a transfer of the passenger transport from air carriers to the rail network, only some air and rail routes were taken into account, and only the current infrastructure

Table 1 Cities with over 500.000 inhabitants and urban areas with a metropolitan population of over 1 million inhabitants within the EU

Country	City						
Austria	Vienna						
Croatia	Zagreb						
Czech Republic	Prague						
Belgium	Brussels	Antwerp					
Bulgaria	Sofia						
Denmark	Copenhagen						
France	Paris	Marseille	Lyon	Lille	Bordeaux	Toulouse	Nantes
Germany	Berlin Dortmund	Hamburg Essen	Munich Leipzig	Cologne Bremen	Frankfurt Dresden	Stuttgart Hanover	Dusseldorf Nuremberg
Greece	Athens	Thessaloniki					
Hungary	Budapest						
Ireland	Dublin						
Italy	Rome	Milan	Naples	Turin	Palermo	Florence	Genoa
Latvia	Riga						
Lithuania	Vilnius						
Poland	Warsaw	Krakow	Lodz	Wroclaw	Poznan	Katowice	Gdansk
Portugal	Lisbon	Porto					
Romania	Bucharest						
Spain	Madrid	Barcelona	Valencia	Seville	Zaragoza	Malaga	
Sweden	Stockholm	Gothenburg					
The Netherlands	Amsterdam	Rotterdam	The Hague				
United Kingdom	London	Birmingham	Leeds	Glasgow	Sheffield	Manchester	Bradford

has been evaluated. As such, Bucharest, Dublin, Helsinki and Palermo were not included in the study. In fact, although being suitable as far as population is concerned, given the long distances between them and the other major EU cities and/or the lack of infrastructure as bridges to connect them to continental Europe, this study would not have benefited from their inclusion.

The data regarding the number of passengers carried on each air route has been obtained from the European Commission´s statistical office Eurostat. Since the provided data display certain discrepancies regarding the passengers' traffic between airports according to each national database, the study provided a mean between the given passengers' data. In those cases in which the Eurostat database: (https://ec.europa.eu/eurostat/web/transport/data/database) does not present information on one of the two airports involved in a selected route, the only value available has been considered. More information on Eurostat and the transport statistics can be found at the following address: https://ec.europa.eu/eurostat/web/transport.

The data regarding each flight´s carbon dioxide equivalent emission has been found employing the Atmosfair online calculator. Atmosfair, a German non-profit organisation, designed a software tool able to calculate precisely the amount of carbon dioxide and non-carbon emission from each flight. In particular, since aircraft engines emit various pollutants that contribute to rising global temperatures, Atmosfair calculates both CO_2 and other pollutants as well, such as methane, perfluorocarbons, nitrous oxide and others. These pollutants and their effects are summarised by Atmosfair and then converted into CO_2. From the "atmosfair Flight Emissions Calculator" of 2016: "first, the Emissions Calculator calculates the fuel consumption per passenger and based on this result, determines the amount of CO_2 that has a comparable effect to that of all other pollutants emitted by the flight added together (effective CO_2 emissions)". Therefore, the calculator's final output is expressed in carbon dioxide.

At the same time, the production of pollutants by air traffic is three times higher than that of carbon emissions alone, due to the high altitude in which they are released. To be able to compare the effects on the environment resulting from CO_2 production at high altitude with the effects of CO_2 production on the ground (as produced by railways or cars), the calculator multiplies by a factor 3 all carbon emissions produced during a flight at over 9 kms to correctly render the flight's climate impact in CO_2. Carbon emissions emitted at altitudes of less than 9 kms are not submitted to any alterations and are directly included in the flight's carbon footprint. The "atmosfair Flight Emissions Calculator" explains how this is a "conservative, quantitative–qualitative average value based on two metrics (RFI and GWP) and their bandwidths. Both metrics present the same numerical value, whereby the higher-value GWP even has a smaller bandwidth. This actual value of 3 is exactly in the middle of the old IPCC bandwidth of the RFI, which was indicated to be 2–4 by the IPCC in 1999". The validity of this assumption has been confirmed both by Lee et al. (2021) and by the European Commission (2020) and EASA, which state "the CO_2-warming-equivalent emissions based on this method indicate that aviation emissions are currently warming the climate at approximately three times the rate of that associated with aviation CO_2emissions alone".

Table 2 Most common aircraft by airline company

Company	Passengers	Most common aircraft–units
Lufthansa group	130,04	Airbus A320–194 units
Ryanair	128,77	Boeing 737–800–430 units
IAG	104,83	Airbus A320–203 units
Air-France KLM	98,72	Airbus A320–36 units
EasyJet	81,63	Airbus A320–168 units

More information on the atmosfair calculator can be found at the following address: https://www.atmosfair.de/en/offset/flight/.

As the fuel consumption and therefore the carbon dioxide production varies between which aircraft is being analysed, the study took the Airbus A320 as an aircraft model. In fact, as far as the five largest airlines companies in Europe are concerned, the Airbus A320 is the most common aircraft with more than 600 operating units. Furthermore, according to the Centre for aviation's forecast, the Airbus A320 NEO leads the orders for narrowbodied aircrafts in Europe, with 1.058 aircrafts ordered (CAPA 2018).[4] The largest airline companies in Europe, together with the number of passengers carried globally in 2017 and the most common aircraft in their fleet are shown in the following table. (Table 2).

The second most common aircraft is the Boeing 737–800 with 450 units and 611 orders for its variants for the future fleets in Europe. The airline company with more Boeing 737–800 in its fleet is Ryanair.

The overall amount of carbon dioxide production between the two aircrafts does not change dramatically. However, the Airbus is slightly less efficient on distances below 340 km, while its greater efficiency on the Boeing is noticeable starting from 360 km. Furthermore, the difference in carbon dioxide production between the two aircrafts increases steadily from the 420 km threshold onwards. A short overview of the differences in carbon dioxide production between the Airbus A320 and Boeing 737–800 with regard to the route distances is provided below. The data has been extrapolated from the Atmosfair calculator (Table 3).

Furthermore, in order to be able to estimate the feasibility of shifting means of transport from air carriers to the rail network, the distances between city centres have been calculated with the online software "Maps" from Google. Three steps have characterized the approach to distance measurement: first, the distance in a straight line between the two cities has been measured, then the distance between such cities has been measured on the already existing railway network. Lastly, those routes which exceed the threshold of the 800 kms on the rail network have been compared with the same route on the existing road network and have been considered in the study in case the distance on the road network was less than 800 km. Ultimately, those routes which are no longer than 800 km on the existing rail network have been classified as "short-distance route", while those which exceed the threshold of 800 km on the

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[4] https://centreforaviation.com/analysis/reports/aircraft-fleets-western-v-easterncentral-europe-airbus-leads-orders-410122.

Table 3 Differences in CO_2 production between airbus A320 and Boeing 737–800 per passenger

Route	Distance in km	Airbus A320 CO_2 production (in Kg, per passenger)	Boeing 737–800 CO_2 production (in Kg, per passenger)
Nuremberg NUE—Munich MUC	150	28	27
Paris CDG—Brussels BRU	260	49	47
Frankfurt FRA— Brussels BRU	315	61	60
Paris CDG—London LHR	340	73	73
London LHR—Amsterdam AMS	360	79	80
Frankfurt FRA—Berlin TXL	420	98	100
Berlin TXL—Cologne CGN	475	106	109
Munich MUC—Berlin TXL	500	110	112
Milan MXP—Frankfurt FRA	520	112	115
Turin TRN—Paris CDG	580	130	135
Budapest BUD – Bucharest OTP	640	146	151
Berlin TXL—Stockholm ARN	810	187	198
London LHR—Naples NAP	1.615	326	357

existing rail network but are no longer than 800 km on the existing road network have been classified as “medium-distance route”. These last routes were included in this study in order to evaluate, in terms of CO_2 savings, the results arising from an enhanced rail network. Routes longer than 800 km on the road network have not been selected for the study. A short explanation of the selection process is shown in the following (Table 4).

All the routes, distances, passengers and estimated carbon dioxide production can be found in the Annex section.

Table 4 Selection process of the suitable routes

Route	Straight distance in km	Rail network-based distance in km	Road network-based distance in km	Classification
Paris CDG—Brussels BRU	260	315	307	Short-distance route
Wroclaw—Frankfurt FRA	600	844	725	Medium-distance route
Hamburg HAM—London LHR	720	1000	934	Not selected

Lastly, this study takes into consideration the basis set by Prussi and Lonza (2018),[5] which identify an annual passenger increment of 3.5%. It also applies the so-called high-rail scenario, in which 25% of the expected aviation passenger growth is shifted to High Speed Rail (hereinafter "HSR") service. A shift of 25% of the expected passengers from air to rail transport would allow a 20% greenhouse gas emission saving. Prussi and Lonza (2018) identified a 20% saving only from analysed routes within five European countries. This study employs the same result in CO_2 saving on an EU-wide analysis. The reason behind accepting this value for the routes and countries other than the originally analysed, is based upon the estimation that a shift in 25% of the expected passenger increment is not an ambitious-enough target for the European transport sector at this time.

7 Analysis of Results Through Comparisons

The following table includes the ten routes with higher CO_2 impact in Europe. It is possible to notice, interestingly, the prevalence of national routes amongst the top 10 most environmentally harmful. While only two of the 10 routes are international (London—Amsterdam and London—Frankfurt), the remaining eight routes are within the borders of different European countries. Of these, Germany is the country with the highest number of national routes (three), followed by France with two (one of which is the most polluting route in the EU) and The United Kingdom, Spain, and Italy, with one national route each (Table 5).

Overall, in 2017, the passengers that flew between major European cities on routes which do not exceed the 800 km threshold on the rail network have been 78.3 million. The estimated carbon dioxide equivalent production resulting from these movements was 7.62 MT.

Combining both short and medium distance flights, the total amount of carbon dioxide equivalent produced in 2017 within these routes alone is 9.2 MT. It is an impressive amount of carbon dioxide, especially when considered that it results from short flights within the major cities in the European Union alone. According to the European Environment Agency (EEA 2019),[6] in 2017, the CO_2 equivalent production in the EU amounted to 4.483 MT. Therefore, if we take into consideration the data resulting from this study, it is possible to notice that the 175 analysed routes accounted for more than 0,21% of the total CO_2 equivalent production within the European Union. If only the 144 routes which have been classified as short-distance routes were taken into account, the carbon dioxide equivalent production would still reach a 0,17% of the total European production.

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[5] https://www.hindawi.com/journals/jat/2018/6205714/abs/.

[6] https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer.

Table 5 Ten most environmentally harmful routes in Europe

Route	Distance in a straight line (km)	Distance on rail network (km)	Distance on road network (km)	Passengers 2017 (millions)	Passengers 2016 (millions)	Passengers 2015 (millions)	CO_2 produced Millions of tons in 2017
Paris—Toulouse	586	816	680	3.25	3.26	3.21	0.45
London—Amsterdam	357	597	534	4.49	4.14	3.85	0.34
London—Glasgow	558	650	657	2.52	2.61	2.51	0.31
London—Frankfurt	636	793	786	1.86	1.95	2.00	0.27
Munich—Hamburg	610	825	775	1.74	1.80	1.81	0.27
Madrid—Barcelona	504	602	621	2.34	2.33	2.25	0.26
Paris—Marseille	660	746	775	1.67	1.65	1.59	0.24
Berlin—Munich	500	732	586	2.06	2.03	1.97	0.22
Berlin—Frankfurt	420	512	547	1.95	1.93	1.91	0.19
Milan—Naples	657	777	774	1.18	0.87	1.03	0.17

As highlighted by Eurostat (2019),[7] the transport sector represents 25% of the carbon dioxide equivalent total production within the European Union with 1.120 MT of carbon dioxide, second only to fuel combustion without transport. Followed by agriculture (10%), industrial processes and product use (8%) and waste management (3%). The carbon dioxide equivalent production in the 175 routes analysed in this study, therefore, accounted for 0,82% of the total transport sector emissions.

According to the data reported by the European Member States to the UN Framework Convention on Climate Change (EASA 2019),[8] the total carbon dioxide emissions of all flights departing from EU28 and EFTA in 2017 have been 163 MT. Those routes which are classified as short distance in this study, therefore, amounted to 4.67% of the total production. Including into this evaluation also the medium distance routes, 5.64% of the total CO_2 production to and from European airports has been produced on the routes analysed in this study. These figures might seem irrelevant to consider in the big scheme of things, but it is worth remembering that, as a reference, the EU greenhouse gas emission in 2016 decreased by 0.4% compared with 2015 and later increased again in 2017 by 0.6% compared to 2016, according to preliminary data.[9] So far then the EU target of reducing greenhouse gas emission by 20% compared to the 1990 levels looks within reach, even if by a narrow margin. However, as set in the 2030 climate and energy policy framework, a binding target of at least 40% cut in greenhouse gas emissions compared with 1990 levels have been determined in 2014, and the possibility of achieving a 0.17% cut in emission by enhancing the rail network on routes shorter than 800 km alone should be fully considered (Graph 1).

Building upon the contribution from Prussi and Lonza, this study considers the possible CO_2 emission savings resulting from shifting 25% of the expected aviation passenger growth to HSR service, in a so-called "high-rail" scenario. Although a total transferability scenario would be highly preferable, at the same time it is also extremely unlikely. Therefore, an achievable target for the reduction of carbon dioxide production must be considered, in order to better identify the steps to undertake towards a sustainable future for the sector.

Prussi and Lonza identify a 20% saving in CO_2 emissions by shifting 25% of the expected passenger growth to the rail sector. As they also identify an annual passenger increment of 3.5%, this study builds upon this projection employing the collected data. As a result, the estimated saving of carbon dioxide equivalent on the 175 routes analysed would have been of around 1.84 MT CO_2, lowering the emission production from 9.2 MT to 7.36. If such a trend were to be implemented systematically, the CO_2 saving on these routes by 2019 could have been of an additional 1.47MT. Such a saving would have allowed the analysed routes to decrease their share in the European CO_2 production resulting from the transport sector from 0.82% to a hypothetical 0.53%. Since 31 of these 175 routes need investments in the rail sector

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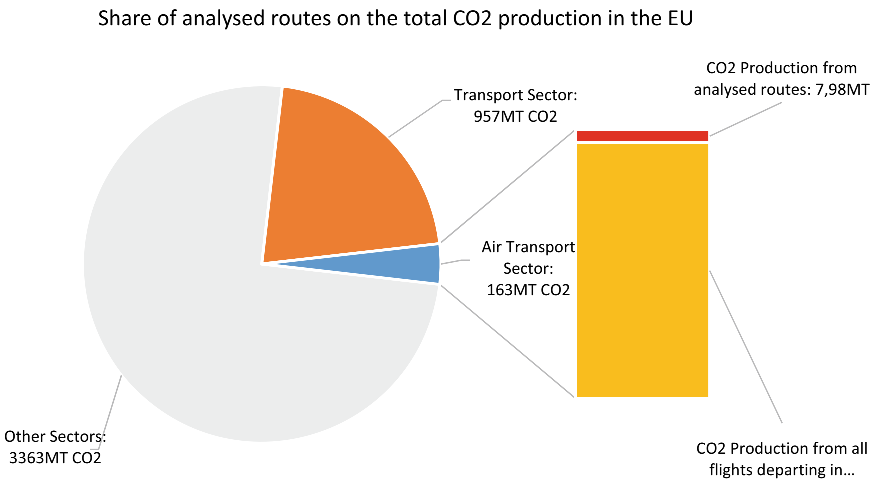
[7] https://ec.europa.eu/eurostat/statistics-explained/pdfscache/1180.pdf.

[8] https://www.easa.europa.eu/eaer/topics/overview-aviation-sector/emissions.

[9] https://www.eea.europa.eu/data-and-maps/indicators/greenhouse-gas-emission-trends-6/assessment-2.



Graph 1 Share of analysed routes on EU CO_2 production

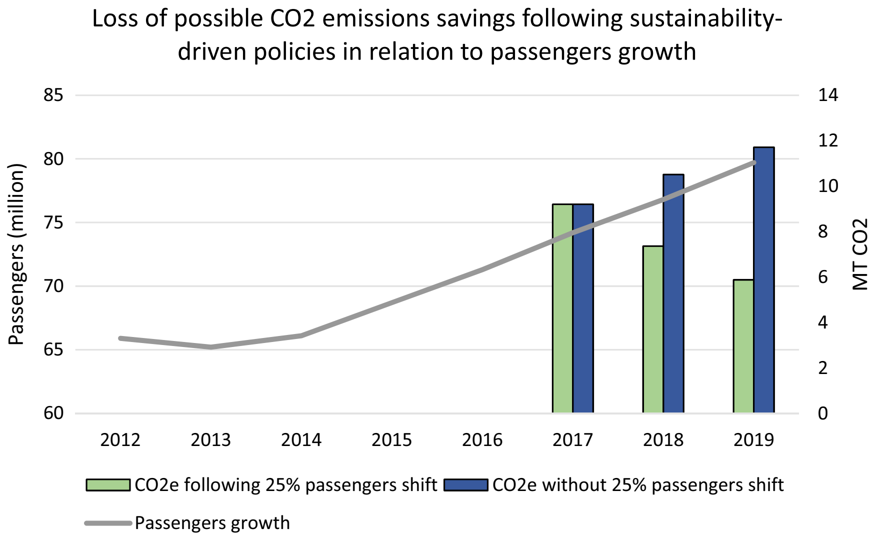
to be competitive with the air transport, enhancement of the network should be considered as an alternative way of cutting CO_2 emission. Furthermore, investments in the current rail network would enlarge the possibility for shifting mean of transport for more end-users even on routes longer than the one analysed in this study. However, it should be noted that the current contribution does not include a detailed calculation of the costs, both in monetary terms and CO_2 production, necessary for the railway infrastructure to accommodate the forecasted modal shift of the passengers.

If 25% of the expected passenger increment on other routes which sits outside the scope of this study were to be substituted with rail transport as well, the saving would be even greater. To give a reference, if the four routes between the five most populous cities which are less than 1500 km long on the rail network were taken into consideration—see in the following table—the production of carbon dioxide equivalent would have been 1.55 MT. In the case of a high-rail scenario, the possible saving on these routes would have been 0.31 MT. These four routes alone would have saved almost one-sixth of all the other 175 routes combined during the year 2018 alone. If both these four high-traffic routes and the previously analysed ones were combined, the total CO_2 production in 2017 would amount to 10.69 MT: 0,95% of the entire greenhouse gas production from the transport sector in the EU. The possible saving in a high-rail scenario from these routes alone could have reached 2.14 MT of CO_2 (Table 6).

On the other hand, however, what did happen as a result of a lack of policies able to alter the CO_2 emission rate? Considering an annual passenger increment of 3.5% on the 175 routes analysed in this study, and not considering the eventual CO_2 production saving from the newest technologies in the air transport field, the results are dangerous. In the first year, the CO_2 emissions increased by 14.24%, with a total carbon dioxide equivalent production of 10.51 MT, from the 9.2 of 2017.

Table 6 CO_2 production on four routes between the five most populous cities in EU

Route	Distance in a straight line (km)	Distance on rail network (km)	Distance on road network (km)	Passengers 2017 (millions)	Passengers 2016 (millions)	Passengers 2015 (millions)	Passengers 2014 (millions)	Passengers 2013 (millions)	Passengers 2012 (millions)	CO_2 produced Millions of tons in 2017
Berlin–Paris	877	1.095	1.053	1.16	1.16	1.17	1.13	1.09	1.07	0.22
Paris–Madrid	1.053	1.431	1.272	2.25	2.24	2.19	1.98	1.93	2.17	0.51
Rome–Paris	1.105	1.438	1.423	1.81	1.86	1.91	1.95	1.89	1.90	0.42
London–Berlin	930	1181	1097	1.99	2.08	1.83	1.61	1.47	1.34	0.34



Graph 2 Effects of sustainability-driven policies on CO_2 emissions

By 2019, assuming that a stable passenger increment of + 3,5% remained, the CO_2 emissions reached 11.71 MT. Furthermore, this growth does take into account only the production resulting from the greater number of flights per se, without considering the emission from infrastructure investments (Graph 2).

On the four high-traffic routes alone, in 2019, CO_2 emissions reached 1.66 MT, with an increment of 7.1% over the 1.55 MT resulting from 2017. If this growth is not to be corrected timely, the transport sector contribution to the achieving of the 2030 objectives would not only be limited, but even harmful.

8 Lessons Learnt

In conclusion, this study highlights the influence of airlines on the GHG emissions resulting from the European transport sector. More importantly, it also analyses to what extent it would be possible to lower these emissions by shifting a relatively small percentage of passengers to railways.

We recognise it is vital to safeguard environmental protection and mobility necessity at the same time, thus this study underlined the importance of actively promoting a shift from transport modes which are not environmentally sustainable anymore to transport modes which are ecologically friendly and can play a great role in tomorrow's mobility.

Enhancement of the rail network, a change of mindset in the end-users regarding air transportation and sustainability-driven policies could start a ripple effect in the entire transport sector. Given the fact that since 1990 the emission levels from this sector constantly increased, a change of paradigm together with a re-consideration of different modes of transport is necessary.

This study does not address the question regarding which airline does produce more of the carbon dioxide equivalent on the analysed routes. However, it should be mentioned that in April 2019 Ryanair, according to data from the EU Emissions Trading System statistics,[10] has become the only airline to be included in a list of Europe's top 10 polluters. According to the data, Ryanair's carbon dioxide emissions rose by 6.9% in 2018. The news produced quite a clamour since it has been the first time a company that does not run a coal power plant has entered in the top 10. Indeed, Ryanair has been identified as one of the top polluters, rather than Lufthansa, which has been the largest airline in Europe in number of passengers carried globally in 2017, or IAG which currently is the third airline in Europe. In response to the public opinion, the company stated that Ryanair is "Europe's greenest and cleanest airline". Furthermore, from June 2019 the company became the "first EU airline to release monthly CO_2 emissions statistics, which show an average of 66 g CO_2 per passenger/km in May 2019". However, this "new transparent course" should not be misleading. In fact, a quick look at the data given by the two major companies will allow noticing that albeit Lufthansa carried more people in 2017 than Ryanair (130.04 versus 128.77 million), the difference in number and length of their respective routes is stark. While Lufthansa (2017) connects 288 airports worldwide,[11] Ryanair (2019) flies to 210 which are all located within Europe, North Africa—where it has nine destinations—and the middle east—with four destinations.[12] Thus, Ryanair's statement claiming to have "the lowest CO_2 emissions per kilometre travelled than any other airline", might be correct but certainly is ambiguous. As such, the fact that 14.1 million people flew with the company in May 2019 alone, according to Ryanair figures, should be highlighted. As already noted earlier in the "methodology" section, Ryanair is the leading company in Europe for Boeing 737–800 presence in its fleet, which presents a higher environmental footprint than the Airbus counterpart from routes longer than 420 km. As a Boeing 737–800 can seat up to 189 passengers, even by taking into account an unrealistic full load scenario through an entire month, in May alone 74.603 flights took off, on average more than 2.406 flights per day.

The medium-term sustainability of these numbers must be addressed by further researches.

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[10] https://ec.europa.eu/clima/policies/ets/registry_en#tab-0-1.

[11] https://newsroom.lufthansagroup.com/english/newsroom/lufthansa-group-airlines-to-offer-many-new-destinations-worldwide-in-winter-2017-18/s/7ded97ba-a414-4e04-8c8a-a9fa906b63d4.

[12] https://corporate.ryanair.com/network/?market=it.

9 Conclusions

This study showed that the share of the short and medium-distance airline flights in the GHG emissions from the European transport sector is not negligible.

The analysis of the short-distance routes alone shows that 78.3 million passengers travelled between major European cities, while the estimated cost of these movements was 7.62 MT of CO_2. These routes alone accounted for 4.67% of the total production carbon dioxide emissions of all flights departing from EU28 and EFTA in 2017, while if the medium-distance routes are also included, the 175 routes are expected to have produced 5.64% of the total CO_2 production to and from EU28 and EFTA airports.

In 2017, the flights on the 175 analysed short and medium-distance routes carried an estimated 90.56 million passengers and produced 9.2 MT CO_2. As a result, these analysed routes accounted for more than 0.21% of the total CO_2 production within the European Union.

The introduction of sustainability-driven policies would have allowed the European transport sector to reduce the share of the analysed routes from 0.82% of the European transport CO_2 production to a hypothetical 0.53%, while ensuring the service without complication for the end-users. In case these policies were implemented as to shift 25% of the expected passenger growth from the air sector to railways on the 175 routes, it would have been possible for the European transport sector to save 1.84 MT of CO_2, lowering the emission production from 9.2 MT to 7.36.

Keeping in mind that the existing capacity of the European railway system might not be able to accommodate the passenger shift outlined in this contribution, it is nevertheless important to recognise the importance of airlines share in the transport sector CO_2 emissions. While further investments will be necessary to expand the rail network accordingly, the advantage of the sector in terms of GHG emissions over air transportation is undisputable.

10 Reflections Beyond—Policy Recommendations

Given the magnitude of the CO_2 values resulting from air passengers transport, we believe it is time to implement effective policies addressing climate challenge, especially regarding the transport sector. The urgency of these policies is evident when considering the aftermath of the Coronavirus crisis. The pandemic had profound effects on the global air transport sector and on European airlines, which have been forced to accept bailout packages from the respective home governments. Although these bailouts are not expected to focus on the environmental damage airlines pose but rather on economic and societal aspects, the aspect of green mobility still influences key policymakers. The development of significant state bailouts can give governments a rare chance to shift transport away from planes to the greener rail sector. In particular, the decision by Austrian Airlines to replace the air transportation on the Vienna—Salzburg route with train service to meet environmental requirements in the recently accepted government bailout package is noteworthy. This development will enhance railway performance by allowing travellers to choose amongst 31 trains between the two domestic cities instead of the previous three rail connections per day. However, the significance of government bailouts might be lower, as in the case of KLM. In this instance, the bailout package requires the general objective of reducing CO_2 emissions per passenger per kilometre by -50% in 2030 compared to 2005. Such a target not only was already set by KLM itself in 2019 but it also only influences the efficiency levels, thus allowing unlimited passengers growth.

Ultimately, scientific research serves as the compass for environmental policy, and legislation can deliver the forward momentum. A re-evaluation of air mobility services is necessary for the European Union not only to cope with the crisis triggered by the COVID-19 pandemic but also to achieve a long-term vision arising from commitments in international cooperation. In particular, this study shows how the nature of air transportation and its constant increase in passengers share hinder the process of reaching the objectives identified by the UN SDGs 12 "Ensure sustainable consumption and production patterns" and 13 "Take urgent action to combat climate change and its impacts".

SDG 12 highlights the following target: "rationalize inefficient fossil-fuel subsidies that encourage wasteful consumption by removing market distortions, in accordance with national circumstances, including by restructuring taxation and phasing out those harmful subsidies, where they exist, to reflect their environmental impacts, taking fully into account the specific needs and conditions of developing countries and minimizing the possible adverse impacts on their development in a manner that protects the poor and the affected communities". It is clear that, in light of this objective, the pre-COVID-19 situation vis a vis CO_2 emission by airlines cannot be restored. The low level of taxation that the air transportation sector benefited from actively pushed forward the trend of high CO_2 emissions. A fairer, more level playing field amongst transport modes is, therefore, necessary to reduce the emissions from the transport sector to reach this Sustainable Development Goal. Furthermore, SDG 13 underlines the target of "integrate climate change measures into national policies, strategies and planning". In this context, the continued growth of air transport, and thus emissions, indicates how national policies have failed in containing the growth of GHG emissions through selected mobility services. Despite its impact on the environment, air transportation has been at least condoned—if not actively promoted—by national measures sacrificing the environment on behalf of economic growth. Sustained steps towards the achievement of these two SDGs by European leaders would not only be further evidence that railways can accommodate the needs for environmental protection and high levels of mobility better than air transportation but would also firmly establish the EU as global leader in transportation and environmental policies.

In line with these objectives, policymakers should consider the development of ad-hoc financial measures for big polluters such as airlines. In particular, measures which might be introduced to curb CO_2 emissions from the air sector could be either taxes on jet fuel, or rather distance-based air passenger taxes or again an increased ticket prices with the aim to reduce demand for air travel and thus reduce emissions. However, the effectiveness of any carbon tax on airlines depends on the reinvestment of income within the transport sector. As the purpose is not taxation per se but rather development of green mobility, policymakers should consider curbing financial support from environmentally harmful travel modes to more eco-friendly options.

Other options, which however should be investigated regarding their possible outcome, could include a quota obligation for biofuels or mandatory electric vehicles for the airport infrastructure. Further studies must examine the results, costs and opportunities of alternative sustainability-oriented policies.

Following the European Union aim to reduce carbon dioxide emissions substantially, the EU climate action strategy requires a change of paradigm in approaching transportation and mobility: the 2030 targets require efforts beyond the currently implemented measures. The transport sector, in particular, cannot continue its path of steadily increasing emissions, since 1990. The need to meet sustainability targets has to lead to a reconsideration of different modes of transport where the railways might play a key role in the mobility's 'promising' future. The EU cannot afford to maintain the current course of action in respect to air transport regulations and taxations within its member states if it wants to lead the global change towards an ecologically sustainable future.

11 Avenues for Future Work

In the context of the existing literature, this study aimed at starting a debate over the need for research focusing on CO_2 emissions from for EU-wide sectors. As this contribution does not focus on infrastructure development but rather on operations, further research might consider the costs in terms of monetary expenses and CO_2 emissions resulting from enhancement of the infrastructure network for the European transport sector on a continental scale. At the same time, further studies will need to provide a detailed evaluation of the feasibility for the railway system to adapt to the passenger shift outlined in this contribution, together with a detailed evaluation for such a shift.

Lastly, this study wanted to fill in the current lack of cross-sectoral analysis by providing a novel contribution. Further researches might focus on the comparison and analysis of other transport solutions and their CO_2 share within the Union. Greater emphasis, we argue, must be placed on the analysis of transport and economic policies in light of CO_2 emission and the 2030 target.

Annex

France: national short-distance routes

Route	Distance in a straight line (km)	Distance on rail network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Paris−Marseille	660	746	1.675.607	1.647.533	1.587.239	1.536.832	1.625.083	1.653.360	242.329.343
Paris−Lyon	392	427	696.547	666.803	646.480	627.489	601.033	595.637	63.158.506
Paris−Bordeaux	498	558	1.520.990	1.641.466	1.598.309	1.544.990	1.603.251	1.534.959	184.747.443
Toulouse−Lyon	359	561	406.982	379.790	372.006	360.098	372.010	393.205	34.593.470
Toulouse−Nice	468	647	151.511	156.932	149.677	140.040	149.227	142.111	17.120.799
Bordeaux−Marseille	505	671	296.067	258.398	214.120	244.975	216.938	277.605	35.231.973
Bordeaux−Lille	700	784	150.241	151.191	139.417	136.357	151.532	83.549	24.940.006
Lille−Lyon	557	639	76.463	71.431	69.437	70.172	80.255	84.146	10.169.579
Lille−Nantes	507	633	75.874	49.205	48.073	48.501	55.278	43.220	9.256.689

Germany: national short-distance routes

Route	Distance in a straight line (km)	Distance on rail network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Berlin—Frankfurt	420	512	1.956.290	1.935.596	1.907.300	1.792.971	1.850.787	1.815.438	191.716.371
Berlin—Cologne	475	580	1.661.630	1.871.736	1.458.740	1.322.289	1.288.102	1.381.906	174.845.621
Berlin—Dusseldorf	475	540	1.144.435	1.146.999	1.115.068	1.115.126	1.083.065	1.012.837	122.454.545
Berlin—Munich	500	732	2.061.817	2.032.997	1.975.195	1.871.623	1.833.360	1.923.488	226.175.162
Berlin—Nuremberg	375	534	212.288	229.846	228.075	248.152	248.073	302.320	17.195.288
Berlin—Stuttgart	510	699	1.037.259	986.828	961.166	1.000.407	933.613	808.545	122.396.562
Hamburg—Frankfurt	392	513	1.395.166	1.371.938	1.360.826	1.345.147	1.367.068	1.394.538	128.355.226
Hamburg—Cologne	356	439	486.021	438.330	392.791	400.809	382.832	419.119	37.909.638
Hamburg—Dusseldorf	338	422	607.220	607.249	560.614	606.191	598.510	621.865	43.112.620
Hamburg—Nuremberg	461	623	175.525	231.428	226.248	226.621	244.731	277.231	18.781.122
Hamburg—Stuttgart	533	705	689.911	720.864	718.690	740.429	707.934	710.551	86.928.786
Frankfurt—Dresden	370	493	344.396	328.775	317.276	329.897	321.610	341.149	29.273.660
Frankfurt—Munich	304	426	1.178.390	1.129.027	1.148.611	1.107.868	1.113.259	1.084.311	70.703.400
Frankfurt—Leipzig	293	375	306.124	271.832	263.657	247.182	211.703	207.099	18.367.440
Frankfurt—Hannover	262	337	375.187	349.458	346.818	361.589	350.180	349.527	20.260.098
Frankfurt—Bremen	330	459	341.196	330.319	323.550	333.720	309.052	319.651	23.883.685
Cologne—Dresden	474	679	144.042	126.722	128.823	136.992	157.723	163.760	14.404.200
Cologne—Munich	456	641	989.158	955.343	971.682	1.005.352	973.743	1.084.043	97.926.593

(continued)

(continued)

Route	Distance in a straight line (km)	Distance on rail network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Cologne—Leipzig	380	560	92.856	83.098	83.687	84.605	95.039	102.790	7.057.056
Munich—Dresden	360	687	234.106	224.564	238.994	241.234	247.704	227.409	16.855.596
Munich—Duesseldorf	486	649	1.554.584	1.566.252	1.557.412	1.530.577	1.560.861	1.557.746	172.558.824
Munich—Leipzig	360	567	166.597	161.116	158.689	164.548	168.233	164.787	11.994.948
Munich—Hannover	488	647	545.365	519.145	517.341	508.449	523.545	600.159	59.990.095
Munich—Bremen	583	769	375.354	348.709	337.134	338.563	362.171	358.065	48.045.248
Munich—Dortmund	477	722	183.150	169.861	166.346	168.462	174.842	166.493	18.498.150
Dusseldorf—Dresden	486	716	200.761	233.936	224.068	214.963	210.108	249.954	22.284.471
Dusseldorf—Nuremberg	363	451	233.419	223.557	202.167	219.736	264.927	294.059	18.440.101
Dusseldorf—Leipzig	389	597	113.915	96.585	95.907	90.439	103.218	107.076	9.454.945
Dusseldorf—Stuttgart	322	408	121.437	158.450	154.985	149.681	189.576	214.141	8.622.027
Stuttgart—Hannover	400	522	182.972	203.222	201.134	202.169	219.685	236.601	17.199.321
Stuttgart—Leipzig	365	532	88.944	78.931	75.351	81.104	91.564	83.692	7.204.424
Stuttgart—Bremen	478	616	164.174	156.535	159.092	150.556	155.076	118.353	18.223.314
Stuttgart—Dresden	412	678	102.073	98.670	97.136	97.221	108.725	118.553	9.288.643
Frankfurt—Nuremberg	185	228	273.862	264.188	265.900	264.630	210.922	206.340	10.132.894
Frankfurt—Dusseldorf	185	223	425.068	376.701	386.257	396.664	374.904	383.904	15.727.516
Frankfurt—Stuttgart	152	185	375.818	349.253	342.845	316.972	256.464	238.582	11.650.343
Munich—Nuremberg	150	198	136.984	134.984	134.810	121.407	121.921	122.063	3.835.538

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Route	Distance in a straight line (km)	Distance on rail network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Munich—Stuttgart	190	239	184.724	179.809	171.522	154.579	183.009	182.294	6.834.788

Greece: national short-distance routes

Route	Distance in a straight line (km)	Distance on rail network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Athens—Thessaloniki	302	501	1.607.930	1.810.271	1.642.959	1.286.429	890.823	976.667	101.299.590

Italy: national short-distance routes

Route	Distance in a straight line (km)	Distance on rail network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Rome—Milan	475	563	1.298.769	1.519.296	1.728.454	1.867.949	2.176.579	2.328.471	140.116.030
Milan—Naples	657	777	1.181.186	877.902	1.036.253	1.080.744	1.139.585	1.333.868	177.219.784
Rome—Turin	523	710	552.145	638.287	669.837	402.491	663.540	881.145	66.809.485
Rome—Naples	188	214	297.844	328.805	303.773	292.241	280.083	283.027	11.318.053
Rome—Genoa	400	709	346.399	377.302	438.227	268.578	402.430	451.464	30.829.467
Rome—Florence	230	257	246.872	227.474	214.799	196.722	223.567	231.382	11.849.856

Poland: national short-distance routes

Route	Distance in a straight line (km)	Distance on rail network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Warsaw—Krakow	251	295	351.701	321.018	300.984	275.411	246.385	278.692	17.233.349
WarsawvWroclaw	300	404	527.684	321.395	232.249	256.077	249.317	359.468	33.771.776
Warsaw—Poznan	275	325	165.556	122.490	92.392	100.427	77.999	110.988	9.436.692
Katowice—Warsaw	260	294	101.861	83.008	76.692	83.646	53.875	79.373	4.889.352
Gdansk—Krakow	485	617	102.437	89.501	40.917	64.153	53.605	76.892	11.063.196
Gdansk—Warsaw	283	322	523.500	312.062	242.069	277.237	276.259	407.019	34.027.532

Portugal: national short-distance routes

Route	Distance in a straight line (km)	Distance on rail network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Lisbon—Porto	273	337	1.084.907	1.031.420	669.207	451.418	401.071	389.137	60.754.792

Spain: national short-distance routes

Route	Distance in a straight line (km)	Distance on rail network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Madrid—Barcelona	504	602	2.341.255	2.328.056	2.251.699	2.204.737	2.213.182	2.550.462	257.538.050
Madrid—Valencia	302	390	342.007	311.192	300.372	262.715	254.557	264.416	19.152.392
Madrid—Seville	387	472	301.028	284.390	264.203	244.866	238.928	351.566	26.189.436
Madrid—Malaga	415	539	319.069	318.579	318.343	330.809	278.051	401.834	31.268.762

Sweden: national short-distance routes

Route	Distance in a straight line (km)	Distance on rail network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Goteborg—Stockholm	396	457	1.342.789	1.332.425	1.356.789	1.360.005	1.309.350	1.270.131	115.117.133

United Kingdom: national short-distance routes

Route	Distance in a straight line (km)	Distance on rail network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
London—Leeds	271	313	161.553	159.972	148.106	131.738	118.368	:	8.239.203
London—Glasgow	550	650	2.523.565	2.607.611	2.510.159	2.270.005	2.245.095	2.214.407	314.890.145
London—Manchester	260	320	663.022	692.631	774.266	876.694	797.233	1.014.816	31.162.011
Birmingham—Glasgow	405	466	221.689	226.364	227.171	230.354	204.348	209.183	19.508.588

European Union: international short-distance routes

Route	Distance in a straight line (km)	Distance on rail network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Berlin—Vienna	522	793	861.549	799.171	779.209	786.821	737.622	733.861	105.648.491
Berlin—Brussels	650	803	621.887	702.091	509.558	438.072	420.897	411.814	87.734.121
Berlin—Amsterdam	577	639	898.328	871.104	788.082	722.859	664.718	597.733	117.048.584
Berlin—Krakow	530	687	107.356	112.611	125.071	127.230	131.155	60.023	13.097.432
Berlin—Warsaw	515	582	108.086	111.309	119.051	125.214	113.879	:	13.078.346
Berlin—Rotterdam	615	672	50.162	60.006	45.424	:	:	:	6.671.546
Berlin–Prague	280	393	87.517	:	:	:	:	:	87.517
Hamburg—Amsterdam	366	487	456.955	499.678	466.508	392.010	370.496	383.474	37.927.224
Hamburg—Brussels	487	662	281.535	177.984	152.531	152.063	140.189	142.414	30.968.795
Hamburg—Prague	490	679	110.445	:	:	:	:	:	12.480.285
Hamburg—Copenhagen	288	509	179.783	182.586	203.819	224.341	164.867	146.944	10.247.631
Frankfurt—Vienna	597	773	1.180.077	1.164.447	1.177.776	1.349.957	1.310.658	1.193.168	166.390.787
Frankfurt—Brussels	316	409	548.283	465.754	517.106	472.273	458.586	449.965	33.445.233
Frankfurt—Prague	410	706	519.591	513.934	551.300	506.908	498.017	484.873	47.282.781
Frankfurt—Amsterdam	363	442	841.591	816.077	799.336	752.964	725.609	716.479	66.485.689
Frankfurt—Lyon	560	717	321.089	295.168	293.225	296.434	269.111	267.986	39.814.974
Cologne—London	497	640	594.321	630.692	662.696	483.048	472.746	482.740	65.859.258
Frankfurt—Paris	477	583	944.070	906.179	964.443	1.053.915	1.041.456	1.114.330	97.239.159

(continued)

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Route	Distance in a straight line (km)	Distance on rail network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Frankfurt—Milan	517	668	824.949	766.169	766.448	745.606	721.675	692.098	94.832.521
Frankfurt—Poznan	627	770	90.610	83.795	76.820	70.880	37.312	52.576	13.138.378
Frankfurt—London	636	793	1.864.255	1.948.862	2.004.808	1.970.538	1.929.011	1.903.271	270.390.653
Munich—Vienna	355	460	547.029	487.231	555.875	542.825	562.934	563.954	41.574.166
Munich—Prague	300	435	208.823	206.119	210.289	198.640	231.447	208.319	10.858.796
Munich—Budapest	561	717	343.143	330.084	323.050	321.154	321.670	316.537	44.951.733
Munich—Milan	348	587	490.865	422.178	449.664	328.091	335.460	382.039	40.699.460
Munich—Turin	453	734	180.986	165.822	167.375	150.007	158.812	129.568	19.546.488
Munich—Florence	486	645	189.128	170.895	176.012	183.717	159.752	148.268	23.073.616
Munich—Genoa	460	733	92.441	90.247	94.869	57.061	94.390	86.788	10.445.777
Munich—Zagreb	423	579	191.842	181.833	181.593	180.355	181.528	174.846	19.184.150
Duesseldorf—Paris	410	576	466.309	445.904	436.439	479.986	475.470	491.932	40.568.883
Duesseldorf—Amsterdam	180	219	234.348	226.624	205.169	184.800	171.676	182.285	8.202.180
Duesseldorf—London	478	630	895.321	754.168	691.468	655.562	645.832	621.847	101.719.803
Nuremberg—Vienna	411	508	77.401	67.332	66.770	66.010	76.761	96.040	7.585.298
Nuremberg—Budapest	625	772	119.181	:	:	:	:	:	16.446.909
Nuremberg—Milan	465	785	102.908	:	:	:	:	:	9.673.305
Nuremberg—Amsterdam	541	670	188.110	191.908	186.317	168.381	160.861	159.534	23.325.640
Hannover—Amsterdam	327	382	178.804	177.510	170.371	168.236	166.610	162.048	12.516.280

(continued)

(continued)

Route	Distance in a straight line (km)	Distance on rail network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Stuttgart—Vienna	533	699	427.883	367.782	344.447	338.863	338.549	342.851	53.485.375
Stuttgart—Brussels	416	597	99.357	76.923	77.337	:	:	:	9.339.511
Stuttgart—Milan	368	619	155.424	139.455	130.075	81.343	88.323	89.912	11.345.952
Stuttgart—Paris	500	602	182.358	178.710	186.075	184.014	199.562	228.251	20.424.040
Stuttgart—Amsterdam	500	627	325.281	312.612	284.093	228.398	210.300	206.128	38.057.819
Dortmund—London	525	720	213.763	207.802	217.228	236.209	160.585	162.044	23.844.358
Dortmund—Wroclaw	666	788	31.843	31.704	30.516	29.754	29.316	27.658	4.489.863
Bremen—Amsterdam	274	372	164.296	155.210	152.309	141.149	143.921	138.104	9.036.280
London—Paris	343	460	2.181.247	2.245.164	2.194.613	2.042.799	1.831.887	1.751.282	157.571.551
London—Amsterdam	357	597	4.488.263	4.141.696	3.847.757	3.442.148	3.229.507	3.117.265	336.498.375
London—Rotterdam	320	529	178.052	219.274	219.991	272.696	235.109	112.983	10.327.016
Birmingham—Paris	502	640	398.933	380.981	388.357	388.862	365.691	358.896	44.281.563
Birmingham—Amsterdam	460	697	676.693	633.081	565.453	508.644	460.633	445.610	67.669.300
Leeds—Paris	612	783	49.051	46.604	49.110	61.148	63.306	64.103	6.425.681
Manchester—Paris	605	780	630.886	568.366	478.819	507.100	503.387	470.466	82.646.066
Sheffield—Paris	570	726	41.697	48.431	:	:	:	:	5.003.640
Vienna—Warsaw	557	664	222.350	205.889	205.113	208.178	207.535	207.423	28.016.037
Vienna—Budapest	215	264	103.411	100.208	104.901	107.372	104.075	106.144	4.239.851
Vienna—Zagreb	268	481	164.100	160.326	163.421	163.748	158.326	163.022	8.533.200

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Route	Distance in a straight line (km)	Distance on rail network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Brussels—Paris	261	315	199.065	203.444	205.727	170.833	156.712	132.912	9.754.161
Brussels—Lyon	560	742	245.347	216.856	239.002	240.540	221.730	226.416	32.140.392
Brussels—Amsterdam	180	219	259.780	219.141	243.416	241.883	223.166	213.768	12.729.220
Brussels—Birmingham	466	488	152.911	133.353	144.297	120.092	107.179	105.405	16.208.566
Brussels—Manchester	535	698	397.564	376.620	385.279	332.714	287.574	262.263	48.321.378
Brussels—London	318	378	651.306	572.195	722.546	673.362	568.996	547.948	48.196.607
Antwerp—London	316	433	50.229	54.422	58.319	54.043	70.810	71.962	3.114.198
Copenhagen—Goteborg	226	339	289.570	331.470	298.020	336.134	306.589	327.313	11.872.350
Budapest—Prague	440	609	109.502	78.296	:	:	:	75.708	12.264.224
Riga—Warsaw	958	676	115.588	95.197	86.196	80.683	65.635	66.016	15.373.138
Riga—Vilnius	265	347	162.870	165.797	165.048	175.214	181.108	178.129	8.794.953
Warsaw – Vilnius	390	568	167.559	121.675	101.614	100.675	94.416	72.707	15.247.869
Barcelona—Lyon	530	680	294.658	308.922	302.408	282.955	294.310	212.719	36.832.250
Barcelona—Marseille	335	580	78.118	78.985	:	:	:	:	5.833.050
Barcelona—Bordeaux	443	678	162.115	120.481	77.669	68.707	61.595	67.767	17.670.480
Amsterdam—Paris	428	522	1.422.740	1.324.720	1.154.023	1.158.098	1.127.698	1.141.903	125.997.340
Paris—Turin	580	731	171.647	174.458	181.807	178.319	178.723	189.469	22.314.045
Warsaw—Prague	517	747	212.637	196.005	179.672	162.341	153.787	160.386	26.366.988

France: national medium-distance routes

Route	Distance in a straight line (km)	Distance on rail network (km)	Distance on road network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Paris−Toulouse	586	816	680	3.254.630	3.258.878	3.214.776	3.169.217	3.192.829	3.154.149	450.067.524
Bordeaux—Lyon	437	985	556	532.009	508.416	474.885	459.698	450.582	451.107	59.052.999

Germany: national medium-distance routes

Route	Distance in a straight line (km)	Distance on rail network (km)	Distance on road network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Munich—Hamburg	610	825	775	1.739.043	1.805.203	1.811.381	1.762.070	1.721.782	1.721.358	269.551.665

Italy: national medium-distance routes

Route	Distance in a straight line (km)	Distance on rail network (km)	Distance on road network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Naples—Genoa	590	923	700	79.120	48.233	55.321	28.979	58.654	78.390	10.681.200

Spain: national medium-distance routes

Route	Distance in a straight line (km)	Distance on rail network (km)	Distance on road network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Valencia—Seville	539	862	654	182.431	113.126	125.082	100.509	151.100	200.946	21.891.720

European Union: international medium-distance routes

Route	Distance in a straight line (km)	Distance on rail network (km)	Distance on road network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Bremen—Paris	650	1042	787	71.977	81.496	94.566	111.216	93.261	86.607	10.220.734
Hannover—Paris	650	832	773	162.607	155.232	154.388	152.446	160.392	155.251	23.252.801
Dresden—Amsterdam	626	935	734	40.541	26.969					5.473.035
Leipzig—Vienna	586	906	582	55.397	50.189	53.549	55.844	53.747	50.139	6.093.670
Nurnberg—Paris	637	808	759	169.229	157.601	161.757	159.913	147.525	146.125	23.861.219
Duesseldorf—Birmingham	611	1054	783	270.567	241.274	219.054	198.654	184.347	175.607	36.797.044
Berlin—Copenhagen	365	803	750	629.851	679.784	634.634	632.246	579.484	525.643	46.356.508
Cologne—Copenhagen	645	948	750	110.729	110.874	:	:	:	:	15.280.602
Frankfurt—Turin	565	819	738	192.261	186.392	206.678	168.617	202.560	189.370	23.648.103
Frankfurt—Wroclaw	600	844	725	148.028	138.459	140.732	108.570	105.793	100.426	20.427.795
Munich—Brussels	602	835	780	403.195	349.794	347.172	351.434	363.450	365.824	54.431.325
Munich—Lyon	570	902	731	186.797	188.556	190.066	202.512	222.971	211.898	25.030.731
Munich—Wroclaw	512	1005	720	137.124	138.119	126.466	126.359	128.033	122.759	15.220.764
Duesseldorf—Prague	554	942	724	234.022	192.126	166.656	178.444	164.417	154.948	29.252.750
Duesseldorf—Copenhagen	625	931	728	312.164	378.972	380.323	379.853	386.314	326.087	44.327.217
Duesseldorf—Lyon	620	1317	759	78.996	:	:	76.649	131.316	137.295	11.296.428
Hamburg—Gdansk	572	767	858	68.010	43.745	:	:	:	:	8.705.280
Zagreb—Stuttgart	610	818	780	55.176	54.103	50.675	50.082	50.270	51.362	10.593.792

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Route	Distance in a straight line (km)	Distance on rail network (km)	Distance on road network (km)	Passengers 2017	Passengers 2016	Passengers 2015	Passengers 2014	Passengers 2013	Passengers 2012	CO_2 produced in 2017 (Kg)
Sofia—Athens	526	850	790	201.971	146.979	95.600	96.364	89.203	96.117	24.640.401
Budapest to Warsaw	550	867	781	238.254	212.363	196.648	172.417	181.743	115.697	30.496.448
Madrid—Lisbon	503	1324	629	1.427.516	1.296.808	1.173.975	1.027.638	974.675	1.109.369	166.970.934
Madrid—Toulouse	552	702	1022	366.401	201.864	154.094	160.710	187.944	206.766	47.265.793
Madrid—Bordeaux	554	686	849	103.995	:	:	46.408	43.146	95.782	13.311.360
Madrid—Porto	422	562	856	615.261	533.548	484.125	395.307	362.452	398.131	63.987.196
Malaga- Lisbon	470	1863	650	88.069	:	:	:	:	:	8.962.026
Seville—Lisbon	312	1790	433	95.730	:	:	:	:	:	6.318.906

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