Short-haul flying and sustainable connectivity

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Contents

Figures and tables

Executive summary

The emergence of global targets to decarbonise have brought with them increased scrutiny of transport and of aviation in particular. One proposed means of reducing greenhouse gas emissions from transport is a modal shift from air to rail. This has been encouraged both through investment in rail infrastructure, and by bans and taxes on short-haul air journeys.

Oxera has been commissioned to assess the environmental impacts of air and rail and the factors that need to be taken into account when assessing the impacts of a modal shift from air to rail. While we focus on CO_2 emissions, we also take account of non-CO_2 impacts, such as effects on biodiversity and noise, and briefly consider social and economic factors.

A direct comparison of the current emissions of rail and air shows that rail has lower CO_2 emissions per passenger than air travel. However, there are a number of factors that need to be taken into account in assessing the environmental impact of shifting passengers from air to rail. Firstly, the potential reduction in emissions that could be achieved depends on the nature of the flight ban. If flights of up to 500km are banned, as is being proposed in a number of European countries, there is a potential saving of around 3–5% of intra-EU emissions or 1–2% of EU aviation emissions, resulting in a reduction of less than 1% of EU transportation emissions overall.

However, if short-haul air travel is banned, some passengers may choose to travel by car instead, which could lead to higher CO_2 emissions. In addition, there is unlikely to be sufficient rail capacity to accommodate all air passengers on a given route, which means that new rolling stock would need to be procured and new rail lines would need to be built. This would have significant environmental impacts, and the carbon payback period for such an investment needs to be considered alongside the timeline in which short-haul air travel is expected to decarbonise.

Figure 1 below sets out some of the factors that deserve consideration when considering the relative environmental impacts of air and rail, and determining the effects of a flight ban.

Figure 1 Environmental benefits and challenges of a modal shift from air to rail

Limits to the substitutability between air and rail, due to distance and geography, means emissions saving potential is up to 3–5% of intra-EU aviation emissions for a ban on flights up to 500km, equivalent to less than 1% of EU transportation emissions overall

A modal shift from air to rail will reduce CO_2 and non-CO_2 emissions of air, and will also reduce other environmental impacts of aviation, including noise and biodiversity impacts around airports. A shift to rail, however, will lead to increased environmental impacts of rail, including from noise, biodiversity impacts and particulate matter.

Connectivity and capacity constraints of railways means rolling stock will have to be added or new railways built to accommodate a modal shift, with large carbon costs

Possibility of consumers substituting to car instead of rail which can have higher emissions per passenger kilometre in some cases

Potential shrinking of the gap between air and rail emissions as both modes of transport decarbonise

Source: Oxera.

These factors need to be taken into account on a case-by-case basis in deciding on the optimal policy for short-haul aviation in Europe. Overall, providing a range of transport options and encouraging intermodality between them is likely to offer the best solution from a social, economic and environmental perspective.

1 Introduction

The European Regions Airline Association (ERA), Airports Council International Europe (ACI EUROPE), the AeroSpace and Defence Industries Association of Europe (ASD Europe), the Civil Air Navigation Services Organisation (CANSO), and Airlines for Europe (A4E) have asked Oxera to provide an overview of the factors that require consideration when assessing the relative environmental impacts of European air and rail passenger transport.

In the context of global targets to decarbonise, and in line with its commitment to global climate action under the Paris agreement, the EU has set an objective to be climate neutral by 2050. As an intermediate step, it is aiming for a 55% net reduction in greenhouse gas emissions relative to 1990 levels by 2030.[1] The decarbonisation of the transport sector, which accounted for 29% of the EU's overall greenhouse gas (GHG) emissions in 2018, will play an important role.[2] Indeed, the European Environment Agency (EEA) predicts that, without further measures, GHG emissions from transport will continue to grow until 2025, and in 2030 will still be 10% above 1990 levels.[3] Road traffic currently accounts for 72% of total GHG emissions from transport (for 73% of passenger-kilometres), aviation accounts for 14% (for 8% of passenger-kilometres), and rail accounts for less than 1% (for 6% of passenger-kilometres).[4]

It is within this context that transport, and in particular air transport, has come under increased scrutiny. In 2021 the EU proposed its 'Fit for 55' package, which targets emissions from sectors such as aviation by proposing measures including a tax on jet fuel (under the Energy Taxation Directive) and phasing out the allocation of free emissions allowances in the Emissions Trading Scheme.[5] At the same time, the European Commission is encouraging a modal shift from air to rail. For instance, Executive Vice President of the European Commission Frans Timmermans has called for a limit to short-haul journeys by air and a modal shift to rail as one of several measures to ensure that all travel under 500km in Europe becomes carbon neutral.[6] Additionally the Commission's 2020 Sustainable and Smart Mobility Strategy, includes a strong focus on modal shift—for instance, setting the milestone that by 2030 'high-speed rail traffic will double across Europe'.[7]

Several EU countries have also introduced national measures to encourage this modal shift. Since 2000, the EU has provided €23.7bn in grants to co-finance high-speed rail (HSR) infrastructure, while the European Investment Bank (EIB) has provided €29.7bn in loans over the same period.[8] In 2021

[1] See European Commission, 'Fit for 55', https://www.consilium.europa.eu/en/policies/green-deal/eu-plan-for-a-green-transition/ (last accessed 18 January 2022).
[2] International Council on Clean Transportation (2021), 'Transport could burn up the EU's entire carbon budget', April, https://theicct.org/transport-could-burn-up-the-eus-entire-carbon-budget/ (last accessed 18 January 2022).
[3] EEA (2021), 'Greenhouse Gas Emissions from Transport in Europe', November.
[4] EEA (2019), 'Share of Greenhouse Gas Emissions', December, https://www.eea.europa.eu/data-and-maps/daviz/share-of-transport-ghg-emissions-2#tab-googlechartid_chart_13 (last accessed 18 January 2022), and the International Road Transport Union (2019), 'Europe needs road transport: IRU manifesto'.
[5] European Council of the European Union (2021), 'Fit for 55', https://www.consilium.europa.eu/en/policies/green-deal/eu-plan-for-a-green-transition/ (last accessed 18 January 2022).
[6] European Commission (2020), 'Remarks by Executive Vice President Timmermans and Commissioner Vălean on the European Climate Pact and Sustainable and Smart Mobility Strategy', December, https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_20_2370 (last accessed 18 January 2022).
[7] Civitas (2020), 'European Commission presents landmark Sustainable and Smart Mobility Strategy', 17 December, https://bit.ly/3w0C862 (last accessed 2 March 2022).
[8] European Court of Auditors (2018), 'A European high-speed rail network: not a reality but an ineffective patchwork', June. In some cases, these loans have been given with the purpose of encouraging modal shift.

France passed a law banning all short-haul domestic flights of less than 2.5 hours where there are rail alternatives, excluding connecting flights,[9] while Italy is considering introducing similar legislation. In January 2022 Belgium announced plans for an air tax of €10 for any flights under 500km; this change is expected to come into force in April.[10] Bans on short-haul flights have also been considered in Germany and Spain,[11,12] and were introduced in Austria in 2020 for domestic flights with train alternatives under three hours, affecting the route between Vienna and Salzburg.[13]

There are a number of studies that compare the environmental impact of air and rail. However, most of these studies focus on a particular route or country, and many do not take account of all of the environmental factors that are important to consider in such an assessment. The results of these assessments should also be viewed in light of wider social and economic impacts, and contribution to other EU goals such as connectivity.[14]

In this report we set out the factors that require consideration when comparing the environmental impacts of air and rail, and particularly the impact of a modal shift from air to rail. We focus predominantly on CO_2 emissions, but also look at other impacts, such as noise and biodiversity, where relevant. We also briefly consider social and economic impacts.

The rest of this report is structured as follows.

- Based on a literature review, section 2 sets out the factors that deserve consideration when comparing the environmental impacts of air and rail, particularly in relation to CO_2.
- Section 3 discusses the implications of a modal shift from air to rail in practice. It considers the reduction in emissions that can be achieved through this shift, and sets out the challenges.
- Section 4 discusses the decarbonisation potential of air and rail transport, and examines the benefits of decarbonising aviation as a measure to complement modal shift.
- Section 5 considers the social and economic benefits of air travel, and the impact of a modal shift from a social and economic perspective.
- Section 6 concludes.

As an example, the EIB website notes that the modernisation of PKP intercity will 'make rail more attractive for passengers by improving comfort, providing more frequent services and promoting a modal shift to rail throughout Poland'. See European Investment Bank (2021), 'Poland: EIB supports the fleet modernisation of PKP Intercity with a PLN 2 billion loan', 10 December, https://www.eib.org/en/press/all/2021-449-poland-eib-supports-the-fleet-modernisation-of-pkp-intercity-with-a-pln-2-billion-loan (last accessed 31 January 2022). Similarly EU policies are encouraging modal shift between other forms of transport, particularly from road to rail. For instance, in Gardanne between Aix-en-Provence and Marseilles in France, the European Commission recently approved French aid of €18.1m for a multimodal transport terminal construction project with the aim of encouraging a shift from road to rail. See European Commission (2021), 'Smart Regions: Gardanne is home to a new multimodal transport hub', April.

[9] BBC (2021), 'France moves to ban short-haul domestic flights', April, https://www.bbc.co.uk/news/world-europe-56716708 (last accessed 18 January 2022).

[10] Ch-aviation (2022), 'Belgium to tax all passenger flight departures', 12 January, https://www.ch-aviation.com/portal/news/111484-belgium-to-tax-all-passenger-flight-departures.

[11] O'Sullivan, F. (2021), 'Germany Confronts the Future of Short-Haul Flights', *Bloomberg*, June, https://www.bloomberg.com/news/articles/2021-06-18/germany-debates-a-short-haul-flight-ban.

[12] *Spanish News Today* (2021), 'Spanish Government proposes ban on short haul flights', May, https://spanishnewstoday.com/spanish-government-proposes-ban-on-short_haul-flights_1602920-a.html.

[13] This was as a condition of government support during COVID-19.

[14] EU goals target greater interconnectivity as well as greener transport. See European Commissions (2021), 'New transport proposals target greater efficiency and more sustainable travel', 14 December, accessible here https://ec.europa.eu/commission/presscorner/detail/en/ip_21_6776.

2 Comparing the environmental impacts of air and rail transport

2.1 Introduction

In general, the literature reviewed finds that air transport has higher CO_2 emissions than rail per passenger-kilometre in most circumstances. Estimates vary as to the scale of this difference. One study commissioned by the European Federation for Transport and Environment finds that, on average, air travel within Europe emits five to six times more CO_2 per passenger-kilometre than travel by train.[15] Another study finds that if flights were replaced by inter-city rail travel, the resulting emissions would be 20% lower.[16] The EEA has estimated the total cost of pollution from different modes of transport in the EU. It finds that total environmental costs, which account for air pollution, climate change impacts, lifecycle CO_2 emissions and noise, are substantially higher for air (€32.7bn) than for rail passenger transport (€7.8bn).[17] It estimates that while rail contributes €2.5 of environmental damage per passenger on a 500km trip, the most common aircraft in Europe contribute between €13 and €15 per passenger for the same journey.

However, the above comparisons do not take account of all of the factors that require consideration when comparing the environmental impact of air and rail. For instance, aviation and rail affect the environment in different ways. While the emissions from aviation come largely from tank-to-wheel emissions and non-CO_2 impacts, emissions from rail come largely from well-to-tank emissions. 'Well-to-tank emissions' refers to the upstream production of a fuel—from production of the energy source (e.g. petrol, diesel, electricity) to emissions involved in fuel supply (e.g. transport to the charging point or fuel pump)—while 'well-to-wheel emissions' includes the former emissions as well as those emissions when the fuel is eventually burned.

In undertaking a comprehensive analysis of the current environmental impact of air and rail travel, it is important to take account of the following factors:

- journey duration;
- load factors;
- emissions from the end-to-end journey, including transport to and from the airport and railway station;
- full life cycle emissions of air and rail, taking into account building and maintenance of air and rail infrastructure, and end-of-life processes for aircraft and train carriages;
- non-CO_2 environmental impacts of air and rail, including effects of other pollutants such as carbon monoxide (CO), nitrogen oxides (NOx) and particulate matter (PM), noise and biodiversity impacts.

These factors are discussed in turn below.

[15] Bleijenberg, Arie, Koios Strategy (2020), 'Air2Rail: Reducing CO2 from intra-European aviation by a modal shift from air to rail', March.
[16] Chapmen, L. (2007), 'Transport and Climate Change: a review', *Journal of Transport Geography*, **15**, pp. 354–67.
[17] European Environment Agency (2020), 'Transport and environment report 2020: Train or Plane?', March.

2.2 Journey duration

The comparison of CO_2 emissions between air and rail travel varies by distance. Emissions per passenger-kilometre tend to be higher on short-haul flights than on long-haul flights as a greater proportion of the flight is made up of take-off and landing, which have higher emissions than the rest of the flight.

Shorter distances are also the routes for which passengers are more likely to substitute to rail transport,[18] and where rail is more likely to already be available. According to the EEA, assessing the environmental impact of a switch from air to rail on distances of over 500km is 'not straightforward'.[19] This is partially due to the environmental impacts of building the infrastructure necessary to accommodate such journeys (discussed in section 3), as well as the fact that consumers are less likely to switch to rail on longer journeys, leading to lower load factors on these routes.[20]

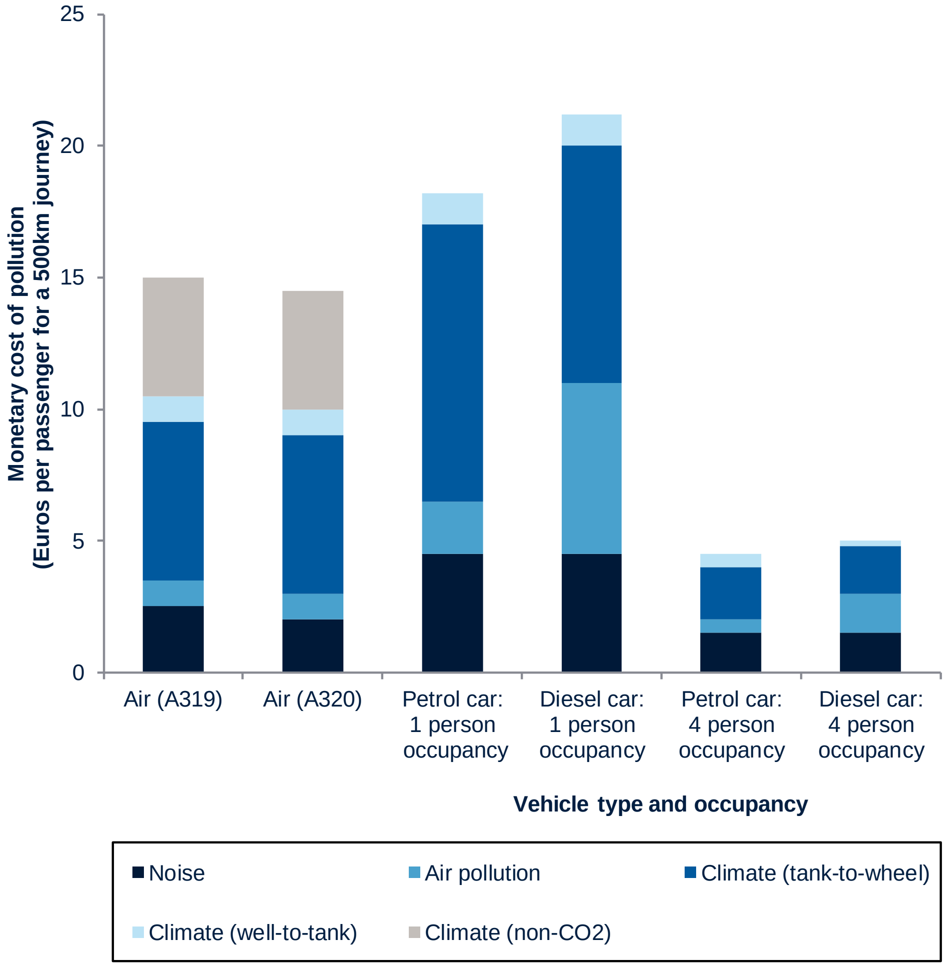
2.3 Load factors

Another factor affecting the relative emissions of air and rail is capacity utilisation. According to the EEA, occupancy level is the single most important factor across all modes of transport in determining their environmental impact per passenger, and this factor alone can make a mode of transport the best or the worst choice for the environment.[21] While air and high-speed rail (HSR) both tend to have high capacity utilisation, conventional rail and car often have much lower capacity utilisation, which reduces the emissions gap between these types of transport.

The EEA has estimated the monetary cost of pollution per passenger for a 500km journey for the five most popular types of aircraft in the EU, HSR, electric intercity train, and petrol, diesel and electric cars with one person and four person occupancy. It assumes a capacity utilisation of 80% for air, 66% for HSR and 36% for intercity train, reflecting their average capacity utilisation in the EU. The results of this analysis for petrol and diesel cars and two of the five types of aircraft, with the highest and lowest emissions respectively, is shown in Figure 2.1 below. While rail has lower CO_2 emissions than air at these load factors, when petrol and diesel cars have a one-person occupancy, aviation can have a lower cost of emissions than road transport.[22] However, it is important to note that electric cars represent a growing share of road transport—discussed further in section 4.

[18] According to a Eurobarometer survey, time is the largest consideration for consumers when deciding between forms of transport. The same survey finds that consumers are willing to switch to a more environmentally friendly form of transport, but only if it matches aviation in terms of time and cost. See the EU (2020), 'Eurobarometer on Mobility and Transport', June, https://data.europa.eu/data/datasets/s2226_92_1_495_eng?locale=en (last accessed 11 March 2022).
[19] European Environment Agency (2020), 'Transport and environment report 2020: Train or Plane?', March.
[20] Ibid.
[21] Ibid.
[22] Ibid. The EEA mentions that there is still some uncertainty about the scale of non-CO_2 climate impacts of aviation. When the full range of possibilities are included, the total cost of pollution from aviation per passenger for a 500km journey is thought to range between €10 and €22. See European Environment Agency (2020), 'Transport and environment report 2020: Train or Plane?', March,

Figure 2.1 Monetary cost of pollution for air relative to car at different occupancy levels



Source: European Environment Agency (2020), 'Transport and environment report 2020: Train or Plane?', March.

While some of the literature, such as the EEA report referenced above, suggests that rail tends to have lower CO_2 emissions per passenger-kilometre than air travel even when occupancy is low on rail, other estimates differ. One study shows that emissions of all major pollutants change with occupancy.[23]

Given that both air and rail can be preferable over car transport with one-person occupancy, another important factor to consider is the substitutability of air and rail with road transport both now and going forward as transport decarbonises. For example, in the absence of short-haul air travel options, some passengers, particularly connecting passengers, may choose to use cars instead of rail. This is discussed in section 3.4 and section 4.

2.4 End-to-end journey

Emissions should also be considered in the context of end-to-end transport, which includes the environmental costs of travelling to and from the railway

[23] European Environment Agency (2020), 'Transport and environment report 2020: Train or Plane?', March.

station or airport. This depends on the location of the railway stations and airports, and their accessibility via public transport.[24,25]

One study by the EEA examines the environmental impact of the first and last leg of the journey for a range of transport modes in several European cities. It finds that these costs are negligible for rail transport, but can be significant for air transport, as airports are often located further away from the city centre.[26] However, many airports are actively encouraging the use of public transport for journeys to/from the airport, and are well connected to rail, coach and sometimes metro networks to the city centre. The proportion of people travelling to and from airports using public transport ranges from between 60% at Copenhagen and Zurich airports to 40% at Frankfurt and Heathrow airports, though it is typically lower at regional airports.[27,28] Some airports, such as Heathrow, are also actively discouraging access to the airport by car through the introduction of a £5 forecourt access charge.[29] These types of measures are likely to lower the end-to-end journey emissions from aviation, and to reduce the gap in first- and last-mile emissions between rail and air transport.

2.5 Full life cycle impacts

Comparisons of emissions between air and rail should also take account of their full life cycle impacts, which includes the direct and indirect processes needed to operate aircraft and rail carriages—for example, raw materials extraction and manufacturing, construction, operation, maintenance, and the end of life of vehicles, infrastructure and fuels.

While aviation has significantly greater tailpipe emissions than rail, the emissions gap shrinks when indirect emissions are taken into account. Indirect emissions account for 21% of overall emissions from aviation, 36% from road, and 39% and 100% from diesel and electric trains respectively.[30] In aviation, indirect emissions come from the production of fuel, while in rail transport, a large proportion stem from infrastructure construction, as well as the operation and maintenance of tracks.[31]

Both air and rail transport also require the use of auxiliary equipment and vehicles. Aviation requires ground support activities, for which various types of equipment are used, such as fuel trucks, aircraft tugs and belt loaders. Rail transport requires machines for shunting, track treatment and infrastructure monitoring.[32]

However it is worth noting that while there is a great deal of literature focusing on the embedded emissions of aviation, there is less literature on the embedded emissions associated with rail—in particular the emissions from

[24] Ibid.
[25] Notably in many cases the availability of HSR stations at airports makes the two modes of transport complementary. For example, a European Commission report finds that HSR and airports can be complementary. See Cordis Europa, 'Interactions between high-speed rail and air passenger transport - COST 318', https://cordis.europa.eu/article/id/13285-interactions-between-highspeed-rail-and-air-passenger-transport-cost-318 (last accessed 3 March 2022).
[26] Ibid.
[27] *Metro Magazine* (2019), 'How European cities are providing surface transport to airports', May 8, https://www.metro-magazine.com/10031475/how-european-cities-are-providing-surface-transport-to-airports (last accessed 28 January 2022).
[28] This does not include connecting flight passengers arriving from another flight.
[29] Heathrow (2020), 'Forecourt access charge announced', 3 December, https://bit.ly/3tSi2rU (last accessed 28 January 2022).
[30] Avinor, the Norwegian Confederation of Trade Unions (LO), the Federation of Norwegian Aviation Industries (NHO Luftfart), Norwegian, SAS and Widerøe (2020), 'Aviation in Norway: Sustainability and social benefit', 4 October.
[31] Ibid.
[32] European Environment Agency (2020), 'Transport and environment report 2020: Train or Plane?', March.

vehicle manufacturing and operational procedures and their impacts.[33] As a result it is difficult to make an accurate comparison between the total life cycle emissions of air and rail, as emissions figures for rail may be an underestimate.

2.6 Other environmental impacts

In addition to CO_2, both air and rail have a variety of other environmental impacts. This includes soil pollution, noise pollution, waste production, biodiversity impacts, and emission of other greenhouse gases, as well as air pollutants such as nitrogen oxides, carbon monoxide and particulate matter.

Aviation emits short-lived climate forcers, including SO_2, NOx and black carbon into the upper atmosphere, which leads to warming of the atmosphere through the formation of contrails and cirrus. Resulting from this, in 2019 the European Commission estimated the total climate change costs of aviation to be twice the costs of the CO_2 emissions alone.[34] To reduce the climate impact of aviation, it is therefore important to consider not just an aircraft's carbon emissions, but its 'climate-optimised trajectory'. This refers to the optimal routes and altitudes that allow aircraft to avoid climate-sensitive regions and minimise contrail formation.[35]

Other environmental impacts of rail include air and soil pollution and the emission of hydrocarbons and particulate matter (PM). Rail can lead to soil pollution from abrasion of brakes, wheels, tracks and overhead lines. One study has found that the 7,200km of tracks in the Swiss Federal Railways Network emit around 2,270t of metals and 1,357t of hydrocarbons annually.[36] Another source suggests that high-speed rail emits up to 30mg of PM per passenger-kilometre.[37] Aviation similarly leads to soil pollution, as burning jet fuel is one of the sources of atmospheric hydrocarbons, which are deposited on the soil. Soil pollution from air travel is likely to be concentrated around airports, while soil pollution from rail transport can extend along the entire route.

Similarly, both air and rail create noise pollution; however, rail creates noise pollution over the entire route, while the impacts of noise from air traffic are concentrated on landing and take-off, and limited to locations near the airport.[38] Therefore there is a trade-off; noise from aviation is expected to impact a smaller proportion of people more heavily, while noise from rail is expected to impact a greater number of people to a lesser extent.

In terms of biodiversity, several studies have found that railways can have adverse effects on wildlife, including through the degradation of the natural habitat of species,[39] and indirect impacts such as noise that can cause disruption to wildlife populations.[40] One study has found that railways can have

[33] European Environment Agency (2020), 'Transport and environment report 2020: Train or Plane?', March.
[34] European Commission (2019), 'Handbook on the external costs of transport'.
[35] Institute of atmospheric physics, 'Climate-compatible air transport system', https://www.dlr.de/pa/en/desktopdefault.aspx/tabid-4618/7598_read-42498/ (last accessed 4 March 2022).
[36] Burkhardt, M. et al. (2008), 'Diffuse release of environmental hazards by railways', *Desalination*, **226**:1–3, DOI: 10.1016/j.desal.2007.02.102, pp. 106–13.
[37] KLM Executive Meeting (2021), 'Future Mobility: How flying will become the most sustainable mid and long distance modality', July.
[38] Ibid.
[39] See, for instance, Lucas, P.S., de Carvalho, R.G. Grilo, C. (2017), 'Railways Disturbances on wildlife: types, effects and mitigation measures', and Forman, R.T. and Alexander, L.E. (1998), 'Roads and their major ecological effects', *Annual Review of Ecology and Systematics*, 207-C2.
[40] See Penone, C., Kerbiriou, C., Julien, J.F., Julliard, R., Machon, N., and Viol, I. (2012), 'Urbanisation effect on orthoptera: Which scale matters?', *Insect Conservation and Diversity*, **6**, pp, 319–27, and Clauzel, C., Girardet, X. and Foltête, J.C. (2013) 'Impact assessment of a high-speed railway line on species distribution: Application to the European tree frog (Hyla arborea) in Franche-Comté', *Journal of Environmental Management*, pp. 127, 125–34.

a similar effect to roads, including reducing the provision of foraging opportunities, disrupting wildlife corridors, and collision of animals with vehicles.[41] The EU taxonomy technical report finds that 'the main potential significant harm […] are attributed to air pollution, noise and vibration pollution, and some potential for water contamination' when new railways are built.[42] Land use change from building new railways is another consideration. Railways require large corridors of land, reducing the amount of land available for carbon sequestration and natural habitats.

Aviation also impacts biodiversity and wildlife—e.g. through bird strikes and local soil and water pollution. Several studies have sought to quantify the impact of air and rail on biodiversity in monetary terms. One study found a total yearly cost of €2.7bn for habitat damage in the EU from rail (€0.006/passenger-km) and a smaller cost (of €0.00007/passenger-km) for air transport.[43] Aviation additionally impacts land use, requiring land for the airport and in the surrounding areas.

2.7 Summary

The key findings from our literature review are as follows.

- CO_2 emissions are currently greater from air than from rail per passenger-kilometre travelled. Estimates vary as to the difference in CO_2 emissions between these two modes of transport. Taking into account only direct tank-to-wheel emissions, aviation is estimated to emit between five to six times more CO_2 than rail.[44]
- However, many of these studies do not take account of factors that are important in determining the environmental impact of air and rail transport in practice (e.g. load factors) or the total environmental impact of each mode of transport (e.g. including full life cycle impacts). When occupancy is taken into account, for instance, the gap between rail and aviation emissions shrink, and aviation has lower CO_2 emissions than a car with single occupancy.[45]
- The gap between rail and aviation emissions is also reduced when full life cycle emissions are taken into account, including the production of infrastructure and fuel. Indirect emissions (including emissions associated with vehicle, fuel and infrastructure) account for 21% of overall emissions from aviation and 39% and 100% from diesel and electric trains respectively.[46]
- Even taking account of these factors, rail emits less CO_2 per passenger-kilometre than air on a number of short-haul routes.
- As such, there is a large body of literature investigating the potential to reduce carbon emissions through a modal shift from air to rail. Scenarios examined by the International Energy Agency (IEA) indicate that limiting the global average temperature increase to below 2°C requires the substitution

[41] Borda-de-Água, L., Barrientos, R., Beja, P. and Pereira, H.M. (2017), 'Railway Ecology'.
[42] EU Technical Expert Group on Sustainable Finance (2019), 'Taxonomy technical Report', June.
[43] See European Environment Agency (2020), 'Transport and environment report 2020: Train or Plane?', March.
[44] Bleijenberg, Arie, Koios Strategy (2020), 'Air2Rail: Reducing CO2 from intra-European aviation by a modal shift from air to rail', March.
[45] European Environment Agency (2020), 'Transport and environment report 2020: Train or Plane?', March.
[46] Avinor, the Norwegian Confederation of Trade Unions (LO), the Federation of Norwegian Aviation Industries (NHO Luftfart), Norwegian, SAS and Widerøe (2020), 'Aviation in Norway: Sustainability and social benefit', 4 October.

of intra-continental flights on medium distances of up to 1000km with HSR.[47] Therefore it follows that keeping the temperature increase below 1.5°C, in line with the Paris Agreement, would require even more substitution of aviation with rail. Another study finds that shifting the 150 busiest intra-EU short-haul flights that have a train alternative under six hours to rail would save 3.5m tonnes of CO_2 per year.[48]

- These studies do not account for the environmental impacts that would be created by a modal shift from air to rail. In the next section we consider the feasibility, and associated environmental impact, of encouraging a modal shift from air to rail transport in Europe.

[47] International Energy Agency (2017), 'Energy technology perspectives 2017'.
[48] Greenpeace (2021), 'Get on track: train alternatives to short-haul flights in Europe'.

3 The environmental impact of substituting air travel with rail transport

3.1 Introduction

As previously mentioned, a number of national governments and the European Commission are focusing on modal shift from air to rail. However, rail can only replace air on routes where the two forms of transport are substitutable. Not all journeys are substitutable for reasons including distance, geography and natural barriers, connectivity and capacity. We therefore consider the maximum emissions savings that could be achieved through a modal shift from air to rail, and then discuss the environmental impacts if such a shift were to take place.

3.2 When is rail a substitute for air?

The extent to which rail travel can be substituted for air travel is limited by a number of factors. First, rail can only substitute for air travel on journeys of up to a certain distance, beyond which there is a lack of supporting rail infrastructure (in addition to the significant additional time cost for passengers). The EEA finds that beyond a distance of 500km it is 'not straightforward' to determine the environmental benefits of a shift to rail,[49] as large investments in rail networks would have to be made, with an environmental cost that may outweigh the CO_2 savings. It is also likely that at longer distances passengers are less likely to switch to rail, meaning that load factors on rail will be low and emissions per passenger-kilometre will be high.

In line with the above, air travel bans are targeting distances of approximately 500km. France's proposed ban on short-haul flights, and proposed plans in other European countries, cover journeys that can be made in 2.5–3 hours by train, of which the longest distance is approximately 500km between Paris and Bordeaux. However, as Table 3.1 shows, over half of the 150 most popular aviation routes within the EU take over eight hours by rail, and only 14% of the most popular routes take less than four hours.

Table 3.1 Top 150 intra-EU routes, by train journey duration

Duration of journey	Number of routes	Proportion of routes among the top-150 intra-EU routes (%)	Cumulative number of air passengers for these routes (million)
Less than four hours	21	14	24.1
4–6 hours	30	20	33.6
6–8 hours	15	10	15.1
8–16 hours	58	39	54.9
More than 16 hours	23	15	21.4
Cannot be travelled by train	3	2	2.4
Total	150	100	151.5

Source: Greenpeace (2021), 'Get on track: the alternative to short-haul flights in Europe', October.

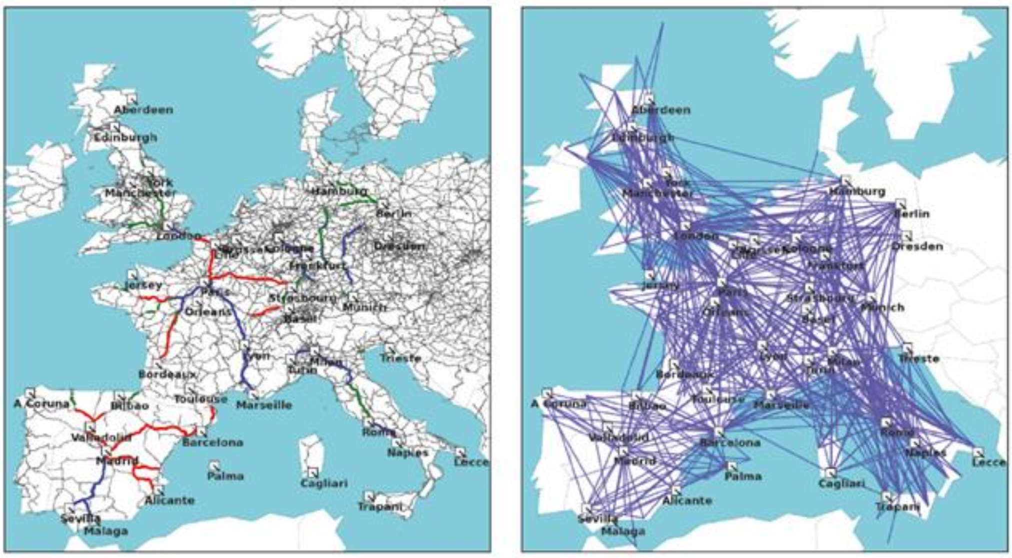
Related to the above, in absence of building new rail networks, rail can only substitute for air where there is already rail connectivity being offered. Since a large barrier to the substitution between air and rail is likely to be time, HSR is

[49] European Environment Agency (2020), 'Transport and environment report 2020: Train or Plane?', March.

often seen as the best substitute for air on mid-length journeys due to the time savings it can create relative to conventional rail.

Figure 3.2 below shows Europe's HSR network compared to the short-haul flight network in Europe. As it indicates, there are very few HSR routes compared to air alternatives. In Italy, which is considering banning all short-haul flights where there is a direct train connection of less than 2.5 hours, the HSR network mainly consists of a corridor from Turin to Naples. By contrast the Italian airport network consists of around 40 airports with regular passenger traffic. In addition, some routes such as between Central Europe and Scandinavia, offer the choice between a long train route and a direct air route, due to geography making the construction of a HSR line difficult. The lack of connectivity of Europe's HSR network has been noted by the European Court of Auditors (ECA), which points out the lack of coordination across borders and describes the network as 'an ineffective patchwork of poorly connected national lines'.[50]

Figure 3.2 High-speed rail and air networks connecting major European cities



(a) HSR network (data source: OpenStreetMap) (b) Airport network (data source: Sabre Airline Solutions)

Source: Sun, X., Zhang, Y. and Wandelt, S. (2017), 'Air Transport versus High-Speed Rail: An Overview and Research Agenda', *Journal of Advanced Transportation*, May, https://doi.org/10.1155/2017/8426926 (last accessed 11 March 2022).

The HSR network has also suffered from reduced services in past years. Since 2010 the supply of night train services, which are frequently seen as an alternative to air travel, has been reduced significantly.[51]

For the reasons outlined above, it is likely that significant investment in Europe's HSR network would be needed for it to become a viable alternative to air travel on most short-haul routes.

[50] European Court of Auditors (2018), 'A European high-speed rail network: not a reality but an ineffective patchwork'.
[51] There have, however, recently been some new developments, including the creation of a new night train service between Brussels and Vienna, see Rankin, J. (2020), 'Brussels-Vienna night train returns as Europe eyes flying alternatives', *The Guardian*, 20 January, https://www.theguardian.com/world/2020/jan/20/brussels-vienna-night-train-returns-as-europe-eyes-flying-alternatives (last accessed 2 March 2022).

3.3 Estimating the emissions savings of a potential shift from air to rail

Given the discussion in section 3.2 above, it is useful to quantify the potential emissions savings that could be achieved by substituting air with rail travel. One study has sought to calculate the potential emissions savings of a modal shift from air to rail under the assumption that the distances that are substitutable are between 200km and 1000km. The authors first examine the share of rail and air on all routes between 200km and 1000km in Europe where both modes of transport are available, and find the route that has the highest share of rail. They then apply this share to all routes of this length where an air route exists, and quantify the carbon savings. Based on this methodology, they find that intra-EU aviation emissions would fall by 6–11% (reducing overall EU aviation emissions by 2–4%). In the case that all flights of less than 1000km were banned (including to islands which would present significant challenges, discussed in section 4), this would result in a 15% reduction in intra-EU aviation emissions.[52,53]

This figure presents the best case scenario reduction in emissions from aviation if all air routes were replaced by rail. However, it is an upper bound for the savings in emissions for several reasons. First, 1000km is a high threshold for the journey length at which rail and air are likely to be substitutable. As discussed above, the EEA and national governments have focused on distances under 500km. If we assume that the reduction in emissions from intra-EU aviation is proportional to the distance at which the shift takes place, but also take account of the higher emissions per passenger-kilometre from shorter flights, banning all flights under 500km would lead to savings of up to 3–5% of intra-EU aviation emissions, or 1–2% of total EU aviation emissions.[54] This would result in a savings of less than 1% of total EU transportation emissions and an even smaller share of overall EU emissions.[55]

The study also makes the assumption that the highest existing market share of rail on a given route can be applied across all routes. Any individual country's policy, such as a flight ban or air tax, will only affect a small proportion of routes, and therefore have a much smaller impact on intra-EU aviation emissions. In addition, the study does not consider whether there are actually rail routes that could substitute for the banned air routes. As discussed above, there are unlikely to be rail options on many of these routes and/or there may not be capacity on these routes to accommodate the shift of passengers from air. In these cases there are likely to be additional environmental impacts of encouraging a shift to rail.

Flight bans may also create carbon leakage, which occurs when emissions are shifted to other jurisdictions rather than reduced. This is a widely discussed topic on which a large body of literature exists. One study commissioned by the

[52] Transport and Environment (2020), 'Maximising air to rail journeys: Reducing intra-EU aviation emissions through modal shift to rail: limits and opportunities', July.
[53] This would lead to a smaller impact on EU aviation emissions overall and an even smaller impact on EU transportation emissions and overall EU emissions.
[54] This estimate assumes that there are approximately the same volume of intra-EU flights below 500km and above 500km, whereas in reality there are likely to be many more flights above 500km than under 500km.
[55] This is based on the fact that civil aviation in the EU accounts for roughly 13% of transportation emissions, as of 2021, see Statista (2021), 'Transportation emissions in the European Union: Statistics & Facts', 1 June, https://www.statista.com/topics/7968/transportation-emissions-in-the-eu/#:~:text=Civil%20aviation%20in%20the%20EU,fastest%2Dgrowing%20sources%20of%20emissions (last accessed 2 March 2022). The proposed ban would therefore result in a maximum of 13% * 2% = 0.3% reduction in total EU emissions from transportation. Transportation emissions accounted for 27% of EU emissions in 2017, see European Environment Agency (2017), 'Greenhouse gas emissions from transport in Europe', so the ban would result in up to a 13% * 2% * 27% = 0.07% reduction in overall EU emissions.

UK Department for Transport finds that carbon leakage associated with aviation varies significantly and leakage associated with fuel tankering—whereby an aircraft carries more fuel than required for its flight in order to reduce or avoid refuelling at the destination airport—ranges between 4% and 40%—implying the reduction in emissions is partially offset by increased emissions elsewhere.[56] Another study by Transport and Environment, looking at the potential leakage from direct long-haul flights from the EU to stop-overs at non-EU hubs, finds that there is no risk of leakage for these flights.[57]

3.3.1 Capacity constraints on Europe's rail network

On routes where air and rail may be substitutable, an additional consideration is the capacity of the existing rail network to absorb additional demand.[58] While both air and rail will require additional capacity over time due to growing demand,[59] modal shift is likely to result in a more sudden need for new rail capacity. In the short term, rail can increase passenger numbers by increasing occupancy rates and offering additional services on the existing infrastructure, where the maximum capacity and available rolling stock allows. However, a large increase in passenger numbers in a short period of time will mean that capacity has to be added by procuring additional rolling stock. Even with this additional capacity, it is likely that many rail routes will not be able to accommodate the number of passengers required—see Box 3.1 below.

Box 3.1 Case study: capacity constraints on the Munich–Berlin rail route

The route between Berlin and Munich is served by air between Munich International Airport and Berlin Airport, and by rail between Munich and Berlin central stations. While the average air travel duration is just over one hour,[60] the average train duration is nearly four hours. Once travel times to and from the airport, and time spent in the airport are included though, these journey times are likely to be more comparable. Therefore, connectivity and journey duration are not barriers to modal shift in this case.

We have calculated the potential impact on rail passenger numbers in the case of a flight ban, finding that if all current air passengers were prevented from flying from Munich to Berlin, only 26% could be accommodated on the rail network based on current timetables.[61] This leaves 22,000 passengers per week unaccommodated.

[56] Air Transportation Analytics Ltd and Clarity Ltd (2018), 'The Carbon Leakage and Competitiveness Impacts of Carbon Abatement Policy in Aviation', November.
[57] Transport and Environment (2022), 'Assessment of carbon leakage potential for European aviation: Direct flights stopping over in non-EU airports', January.
[58] European Environment Agency (2020), 'Transport and environment report 2020: Train or Plane?', March.
[59] For instance, Eurocontrol (2018) finds that the top 20 European airports, which between them account for 53% of all flights as arrivals or departures, are planning a 28% growth in capacity by 2040. Under the most likely demand scenario, overall demand for flights in Europe is expected to be 53% higher in 2040 compared to a 2017 baseline. See Eurocontrol (2018), 'Challenges of growth'.
[60] Oxera calculations of average travel time for a flight between Munich and Berlin in 2018 based on OAG data.
[61] This was calculated by comparing air passengers on the Munich–Berlin route with rail excess capacity. Air capacity numbers were obtained from OAG 2018 data, which gives the total number of seats on all flights within Europe. We estimated the average annual number of passengers from this by multiplying the figure by an occupancy assumption of 80%, and then divided by 52 to get the total weekly number of passengers travelling by air from Munich to Berlin. We then calculated the spare capacity on all rail routes between Munich and Berlin, using train timetables and data on rolling stock and number of seats. Our first scenario uses just the Deutsche Bahn trains from Munich–Berlin, which are the high-speed trains travelling the route in under four hours, and are therefore the most likely to be substitutable with air. We calculate the weekly rail capacity by multiplying the capacity of each type of train by the number of trains of this type departing per week, according the Deutsche Bahn timetables. We then calculate the spare capacity using occupancy assumptions which are available for each train on the Deutsche Bahn website. These are 'low' (which we assume to be 33% capacity utilisation), 'medium' (which the Deutsche Bahn website describes as 'over half full', so we assume to be 60% capacity utilisation), and 'high' (which the Deutsche Bahn website describes as 'nearly full', so we assume to be 90% capacity utilisation). We also calculate the spare capacity of rail under more conservative assumptions. In the second scenario, we calculate spare capacity if Deutsche

If rail services were increased from four to six trains per day during weekdays, matching the number of services that run on weekends, only 42% of passengers could be accommodated. Additionally, even under the conservative scenario where passengers who shift from air use any daytime passenger train service between Munich and Berlin, including those which take more than six hours and those which stop over at other cities, only 65% of passengers could be accommodated. This increases to 82% of passengers if Deutsche Bahn were to also increase their services.

Given that the number of air passengers exceeds the capacity of rail, some passengers may choose to travel by car instead. As discussed in section 2.3, petrol and diesel cars can have greater emissions per passenger-kilometre than aviation, especially if the car has only one individual travelling. Passengers may alternatively opt not to travel at all, which would reduce emissions, but could create social and economic impacts. Another alternative is to increase rail capacity, potentially requiring new rail lines to be built. This can come with a significant environmental cost discussed in section 3.3.2 below.

Source: Oxera.

3.3.2 Environmental costs of building new railways

Building new railway lines has a high environmental cost due to the CO_2 emissions associated with cement and steel production, and emissions from the fuel used for construction. As an example, a review of four HSR lines for the International Union of Railways (UIC) finds that the carbon footprint of constructing HSR lines ranges from 96–270tCO_2 per km of track per year.[62] This cost varies significantly with the terrain through which the line is constructed, as mountainous and island regions tend to have greater emissions per kilometre of track. According to one study, the HSR project in the Basque Country in Spain, which required a high number of tunnels and viaducts, has a footprint of 251tCO_2 per km of track per year, at the upper end of the UIC range, leading to a total carbon footprint of 2.71MtCO_2 for the whole infrastructure over its lifetime, or 45.19ktCO_2 for each year of construction.[63] Another study finds that when life cycle emissions associated with railway construction, together with low utilisation of the line, are taken into account, the environmental costs of building the Levant and Northern corridors in Spain outweigh the benefits.[64]

The CO_2 costs of building a railway therefore have to be taken into account in determining the environmental impact of a modal shift. Taking account of the CO_2 savings from using HSR instead of air travel, the UIC suggests that the payback time in CO_2 emissions from building new railways is between ten and 15 years.[65] By this point, as discussed in section 4, the gap in carbon

Bahn were to increase its services on weekdays to weekend levels, which would involve running two extra trains on Monday to Thursday. We assume additional spare capacity of having two extra empty trains on each of these days. Lastly in the third scenario, we make the conservative assumption that passengers who cannot travel by air will switch to using any daytime train, including those taking more than six hours and those with stopovers in other cities such as Nuremberg and Hannover. We similarly calculate the number of passengers on these trains, using timetables and data on rolling stock, and calculate the spare capacity on these trains using estimates on occupancy which are available on the timetables. We define daytime trains as any trains leaving between 6.30 and 19.30.

[62] International Union of Railways (2016), 'Research in Transportation Economics', June. See also Baron et al. (2011), and European Environment Agency (2020), 'Transport and environment report 2020: Train or Plane?', March.

[63] Bueno, D., Hoyes, G. and Capellán-Pérez, I. (2017), 'Evaluating the environmental performance of the high speed rail project in the Basque Country, Spain', February, in *Research in Transportation Economics* DOI 10.1016.

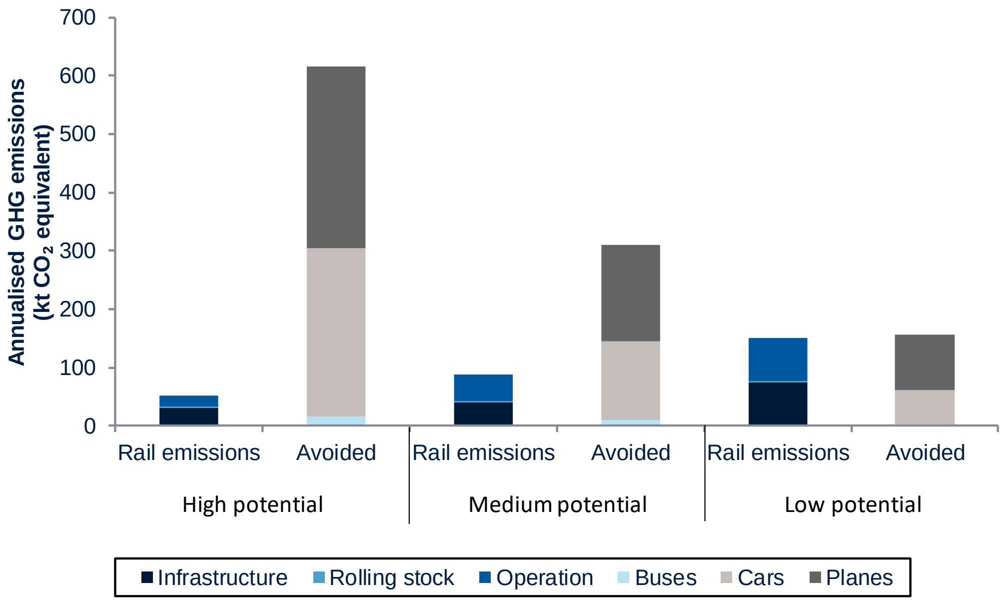
[64] Kortazar, A., Bueno, G. and Hoyos, D. (2021), 'Environmental balance of the high speed rail network in Spain: A Life Cycle Assessment approach', *Research in Transportation Economics*, **90**.

[65] International Union of Railways (2016), 'Carbon Footprint of Railway Infrastructure'. The issue of high environmental costs of building new modes of transport also applies to other modes of transport. An example of this is the hyperloop, which has been proposed as a means of transport between European cities. One

emissions between aviation and rail is likely to have reduced as both modes of transport decarbonise. Moreover, several studies find that the effectiveness of rail construction on reducing emissions varies greatly and depends on a variety of factors. The EEA finds that building new railways is most efficient when carbon costs of building the railway are low and utilisation is high—otherwise the benefits are not straightforward.[66]

The IEA additionally finds that optimal conditions for railway payback of carbon depend on the distance of the proposed railway, the affluence of the populations being connected and the availability of low-carbon electricity.[67] Figure 3.3 below illustrates the emissions of rail construction relative to not constructing the rail line over a 60-year period under three scenarios—high, medium and low potential—which have differing difficulty of rail construction, train power mixes, alternative sources of demand and train occupancies. Under the low potential scenario, which represents suboptimal conditions for carbon payback, the railway construction project only marginally reduces emissions and the carbon payback time is up to 50 years.[68] The payback for the high potential scenario is only three years.

Figure 3.3 Life cycle GHG emissions and GHG savings for a new high-speed rail line over a 60-year period



Note: A high potential rail line represents the best-case scenario for carbon payback time, with optimum conditions including just 2% of its track tunnels and 5% elevated, a well-to-wheel emission intensity of 3.2gCO_2 per passenger-kilometre, have 20% of its passengers formerly using car, 20% formerly using aviation, 5% formerly using bus and 10% newly generated, and have an occupancy of 850 people. It has a carbon payback time of just three years. A low potential rail line is difficult to construct (10% of its line is tunnels and 40% is elevated), has a well-to-wheel emission intensity of 23.5gCO_2 per passenger-kilometre, has 5% formerly in cars, 5% formerly in aviation, 1% formerly on buses, and 20% newly generated, and has an occupancy of 650. It has a carbon payback time of around 50 years.

source estimates that this would require 2,000 tonnes of steel per km, emitting 3,000 tonnes of CO_2 per kilometre. Constructing a one-way line from Amsterdam to Paris would require 1.2m tonnes of CO_2, or the same CO_2 cost as building 200 Boeing 737s.

[66] European Environment Agency (2020), 'Transport and environment report 2020: Train or Plane?', March.

[67] International Energy Agency (2019) 'The Future of Rail: Opportunities for energy and the environment', January.

[68] Ibid.

Source: International Energy Agency (2019) 'The Future of Rail: Opportunities for energy and the environment', January.

In addition to the CO_2 impacts, building new railways can have a high cost in terms of habitat damage—e.g. it can cause physical and behavioural barriers to wildlife movement, as well as disturbance to wildlife populations living nearby, due to noise, vibrations, chemical pollution and human presence (see section 2.6 above). The EEA, for instance, finds that rail is ten times more damaging to land use than aviation, resulting in a total habitat damage cost per year of €2.7bn in the then-EU28.[69] It can also take around ten years to build HSR lines. As an extreme case, construction of the UK's HS2 is expected to take 20 years.[70]

3.4 Indirect consequences on connecting flights

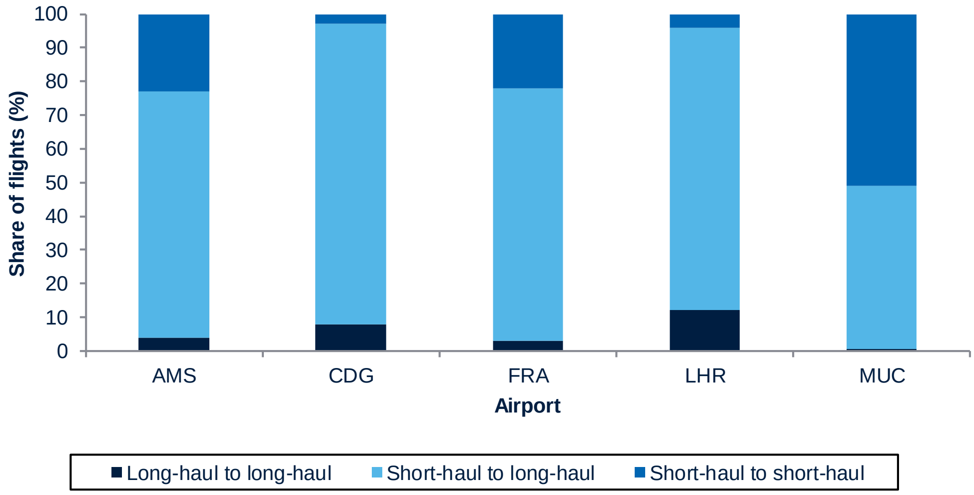
Another factor that must be taken into account in considering the effectiveness of encouraging modal shift from air to rail is the impact on connecting passengers. While passengers on connecting flights are currently excluded from France's short-haul flight ban, they may be included in the future. Additionally, Commission Vice President Timmermans has proposed that connecting flights may be included in a Europe-wide short-haul flight ban.

National or European short-haul flight bans that include connecting flights can lead to situations in which travellers opt for connecting flights to another EU hub, in some cases creating greater emissions. For example, in the context of domestic flight bans in France and Germany, a passenger travelling from Stuttgart to New York could take a connecting flight via Paris but not via Frankfurt, while a passenger travelling from Lyon to New York could fly via Stuttgart but not via Paris. Moreover a Europe-wide ban could lead to travellers opting to fly via non-EU hubs. Flight bans can therefore potentially lead to carbon leakage, and limit the emissions reductions.

Figure 3.4 below shows for a selection of European airports, the vast majority of connecting journeys are between a long-haul and short-haul flight. For some passengers a ban on the short-haul leg of connecting flights could be akin to a ban on the long-haul leg, with social and economic consequences (see section 5). For those passengers who still choose to make the trip, they will need to decide on the mode of transport to use for the short-haul leg of the journey. If passengers use rail, there will likely be a reduction in emissions, but this relies on good connectivity between air and rail. It is also possible that due to the ease of transport (e.g. especially with luggage), passengers may choose a car or taxi option, which as discussed in section 3.2, can lead to higher emissions than air travel.

[69] European Environment Agency (2020), 'Transport and environment report 2020: Train or Plane?', March.
[70] See BBC (2013), 'HS2: 20 reasons why it can take 20 years to build a railway', 29 January, https://www.bbc.co.uk/news/magazine-21231044 (last accessed 3 March 2022).

Figure 3.4 Proportion of each type of connecting flight of total connecting flights at several European airports



Source: Adapted from International Transport Forum (2018), 'Defining, measuring and improving air connectivity', May.

3.5 Summary

The key findings of this section are as follows.

- Although most sources suggest that rail has lower CO_2 emissions than air in the present context, the impact of a modal shift from air to rail on CO_2 emissions is not straightforward.
- A number of European countries are encouraging modal shift for distances of up to 500km, as these are the routes that are more likely to be substitutable between air and rail. Modal shift on distances under 500km may lead to up to a 5% effect on intra-EU aviation emissions, and a 1–2% effect on total EU aviation emissions, with a smaller effect on total EU transportation emissions and overall EU emissions.
- There is unlikely to be sufficient rail capacity to accommodate the passengers shifting from air. While capacity constraints can be mitigated through the construction of new railways, the addition of new rolling stock and upgrades to existing railways, this would come with a significant environmental impact.
- The carbon payback time of rail depends on local conditions. As the EEA notes, building a new rail line can lead to CO_2 emissions reductions, where 'the GHG intensity in the construction of the line is low […], if there is a lot of traffic diverted from more GHG-intensive modes of transport and if the occupancy rate is consistently high'.[71]
- For connecting passengers, flight bans may lead to substitution to road transport, which has a greater environmental impact than air travel with low occupancy, or to other airports, creating carbon leakage.

[71] European Environment Agency (2020), 'Transport and environment report 2020: Train or Plane?', March.

4 Decarbonisation of transport

4.1 Introduction

The above discussion focuses on the current environmental impact of air and rail. However, both modes of transport are working to significantly reduce their environmental impacts. Therefore, while much of the literature on reducing emissions from aviation focuses on a modal shift from air to rail, many researchers also note that decarbonisation of air transport is part of the solution.

There are a range of potential methods of decarbonising air transport, including improvements in Air Traffic Management (ATM) and infrastructure use, and use of advanced biokerosene and zero-CO_2 synthetic kerosene.[72] The relevant solution is likely to differ on a case-by-case basis. For example, for routes to/from an island the best solution may be to decarbonise through shifting to electric aircraft, whereas on longer journeys, alternative fuels may be a better option.[73]

4.2 Decarbonisation of aviation

Europe's aviation sector has unveiled plans to decarbonise and reach net zero emissions by 2050 through four pillars of improved aircraft and engine technology, air traffic management and aircraft operations, sustainable aviation fuels (SAF) and smart economic measures.[74]

Hybrid electric technology can be used for smaller aircraft and are already being used today for test flights.[75] Commercial use of electric or hybrid-electric passenger aircraft is expected in some regions by 2030.[76,77] SAF can be used by any aircraft and is already being used commercially. For instance, all Air France/KLM flights departing from Amsterdam use 0.5% SAF as of January 2022.[78] The EU's Fit for 55 proposals call for increased use of SAF, and at least 63% of SAF used by flights departing from all European airports by 2050.[79] Additionally synthetic jet fuel made from CO_2 is currently being developed, which would use carbon captured from the air, making it carbon

[72] Bleijenberg, Arie, Koios Strategy (2020), 'Air2Rail: Reducing CO2 from intra-European aviation by a modal shift from air to rail', March.
[73] Ibid.
[74] This will lead to a reduction in carbon emissions of 111MtCO_2 (44% of the reduction) through new hydrogen and kerosene-powered or hybrid-electric aircraft, 18MtCO_2 (7%) through improvements in air traffic management and aircraft operations, 99MtCO_2 (39%) through using drop-in sustainable aviation fuels (SAF) and 22MtCO_2 (9%) through economic measures. Airlines for Europe, Airports Council International, Aerospace and Defence Industries, European Regional Airlines Association and CANSO (2021), 'Destination 2050: a route to net-zero European aviation', February.
[75] See Airbus 'Electric flight: laying the groundwork for zero-emission aviation', https://www.airbus.com/en/innovation/zero-emission/electric-flight (last accessed 3 March 2022).
[76] See Kaminski-Morrow, D. (2020), 'Norwegian authorities aim for electric aircraft debut by 2030', *FlightGlobal*, 9 March, https://www.flightglobal.com/air-transport/norwegian-authorities-aim-for-electric-aircraft-debut-by-2030/137146.article (last accessed 3 March 2022). The first zero-emission commercial aircraft are also expected in 2026 on some routes, see electrive (2021), 'Zero-emission aviation to take off in Norway from 2026', 13 March, https://www.electrive.com/2021/03/13/zero-emission-aviation-to-take-off-in-norway-from-2026/ (last accessed 3 March 2022). More widely the European Commission's 2020 Sustainable and Smart Mobility Strategy aims for zero-emission aircraft to be largely ready by 2035, see civitas (2020), 'European Commission presents landmark Sustainable and Smart Mobility Strategy', 17 December.
[77] Notably the environmental benefits of electric aircraft will, like the benefits of electrified rail, depend on the source of the electricity. While aircraft supplied by green electricity can reach net-zero, aircraft powered by coal or gas fired electricity will still have associated emissions.
[78] KLM (2022), 'KLM further expands approach for Sustainable Aviation Fuel', 10 January, https://news.klm.com/klm-further-expands-approach-for-sustainable-aviation-fuel/ (last accessed 31 January 2022).
[79] European Union Aviation Safety Agency 'Fit for 55 and ReFuelEU Aviation', https://www.easa.europa.eu/light/topics/fit-55-and-refueleu-aviation (last accessed 4 March 2022).

neutral.[80] Some of these measures are already being used in practice—see Box 4.1 below.

Box 4.1 Case study: SAF and electrified flights in Norway

The decarbonisation of aviation is already underway in Norway. In 2016, Oslo Airport became the first international hub offering SAF on a commercial basis,[81] and in 2020 Norway was the first country to introduce a blending mandate for advanced biofuels.[82] Now the country is quickly becoming a trial ground for electric aircraft, to which it is well-suited due to its dependence on aviation and short-haul flight network.[83] Avinor, which operates most of the civil airports in Norway, has planned for the introduction of electric aircraft routes by 2030 between airports in north-western Norway, and for the electrification of all domestic aircraft by 2040.[84]

The electrification of aircraft in Norway means that aviation may become the environmentally optimal transport solution. Norway has a large supply of low carbon electricity, with around 95% of its energy coming from hydropower, and the rest made up from thermal and wind power.[85] This suggests that domestic aviation in Norway may be completely net zero by 2040. Given the planning and construction time, and ten- to 15-year carbon payback time of building new railways,[86] aviation in Norway may therefore have decarbonised by the time new rail networks are built, so any gains from a modal shift may not be realised.[87] On the contrary, shifting to rail within Norway may lead to greater carbon emissions than remaining with the current mix of transport options.

Additionally aviation in Norway has significant social and economic benefits due to the country's geography, which includes mountains and fjords.[88] Aviation is especially important for regional connectivity, linking rural areas with cities such as Oslo. While aviation saves approximately five hours for those in the west and centre of the country travelling to Oslo, it can save up to fifteen hours for those in the north of the country. With current aviation networks, just 0.3% of people are unable to get to Oslo and back within a day's journey, and the average travel time to Oslo is just 66 minutes.[89] One study that investigates the impact of Alesund airport in western Norway finds that over 50% of businesses stated that air travel supported over 60% of their business trips.[90] It also found that proximity of an airport was the fourth most important location factor for a business, coming before the quality of a road network (sixth), proximity to a harbour (tenth) and access to rail (16th).[91] Given this, aviation

[80] BBC (2019), 'Jet fuel from thin air: Aviation's hope or hype?', 1 October, https://www.bbc.co.uk/news/business-49725741 (last accessed 31 January 2022).
[81] See the Avinor website: https://www.routesonline.com/events/209/routes-europe-2022/about-the-host/ (last accessed 7 February 2022).
[82] Avinor, the Norwegian Confederation of Trade Unions (LO), the Federation of Norwegian Aviation Industries (NHO Luftfart), Norwegian, SAS and Widerøe (2020), 'Aviation in Norway: Sustainability and social benefit', 4 October.
[83] Avinor (2020), 'Norway will be the main arena for electrification of aviation', March, https://kommunikasjon.ntb.no/pressemelding/norge-skal-vaere-hovedarena-for-elektrifisering-av-luftfart?publisherId=17421123&releaseId=17880960 (last accessed 7 February 2022).
[84] See the Avinor website: https://www.routesonline.com/events/209/routes-europe-2022/about-the-host/ (last accessed 7 February 2022).
[85] International Hydropower Association (2022), 'Norway', https://www.hydropower.org/country-profiles/norway (last accessed 7 February 2022).
[86] International Union of Railways (2016), 'Carbon Footprint of Railway Infrastructure'.
[87] This is particularly the case in Norway where due to high carbon cost of building new railways and low expected railway utilisation the payback time of saved CO_2 emissions from construction can be 31–37 years. See the Norwegian Railway Directorate (2019) 'Nord-Norgebanen: Overordnet vurdering av konsekvenser for klimagassutslipp', 18 June, https://bit.ly/3KGk8lD (last accessed 11 March 2022).
[88] Avinor, LQ, NHO Luftfart, Norwegian Airlines, SAS and widerØe (2020), 'Aviation in Norway. Sustainability and social benefit', October, https://avinor.no/globalassets/_konsern/miljo-lokal/miljorapporter/aviation-in-norway-sustainability-and-social-benefit-2020.pdf (last accessed 11 March 2022).
[89] Graham, A., Adler, N., Niemeier, H.-M., Betancor, O., Antunes, A.P., Bilotkach, V., Calderón, E.J. and Martini, G. (2020), *Air Transport and Regional Development case studies*, Routledge (Oxon, UK).
[90] Ibid.
[91] Ibid.

in Norway, once decarbonised, is likely to bring substantial socioeconomic gain at minimal environmental cost.

Source: Oxera.

As evidenced by the Norway example above, short-haul intra-European air routes play an important role in the decarbonisation of aviation as the routes that are likely to decarbonise first. According to the plan to decarbonise Europe's aviation sector in 'Destination 2050', hybrid-electric aircraft will be trialled first on regional routes, bringing down CO_2 emissions by 50% per flight in that market segment.[92] Future small aircraft could then become drivers for the development of larger aircraft, meaning that maintaining air travel on short-haul routes could help reduce emissions on longer flights in the future.[93]

Short-haul flights are also most likely to reach net zero in the next few decades. Europe's aviation sector has unveiled plans for the introduction of a hydrogen-powered single-aisle aircraft on intra-European routes in 2035,[94] while Airbus is working to develop hydrogen-powered carbon-neutral aircraft for commercial use by the same year.[95] Given adequate supplies of green hydrogen, this implies carbon-neutral air travel in Europe could enter into service by the time the CO_2 savings from HSR networks which are constructed now start to be realised.[96]

4.3 Decarbonisation of rail and other transport modes

As the IEA points out, decarbonisation of aviation alone is unlikely to deliver net zero in the timescales needed to meet climate targets, and some modal shift to rail is required.[97] In addition, rail is decarbonising. In the UK, for instance, the Rail Delivery Group (RDG) plans to decarbonise the UK's rail network by 2050, and use 100% renewable electricity by the mid-2030s, saving 33m tonnes of CO_2.[98] At a European level, 45% of trains are still not electrified,[99] but the Community of European Railway and Infrastructure Companies (CER) has called on the European authorities to implement a number of policy measures for providing full rail decarbonisation by 2050.[100]

However, in some cases where rail lines do not currently exist or will need to be updated, it is unclear whether the construction of new rail lines or decarbonisation of aviation will enable net-zero emissions more quickly. It is likely that in some cases aviation will have reached net-zero before a rail network is completed, or that the carbon costs of building a new rail line will outweigh the benefits given the decarbonisation of aviation.

As noted above, some individuals shifting away from aviation may also shift to car. Electric cars, which represent a small but growing share of road transport,

[92] Airlines for Europe, Airports Council International, Aerospace and Defence Industries, European Regional Airlines Association and CANSO (2021), 'Destination 2050: a route to net-zero European aviation', February.
[93] Ibid.
[94] Ibid.
[95] See Airbus (2022), 'ZEROe: Towards the world's first zero-emissions commercial aircraft', https://www.airbus.com/en/innovation/zero-emission/hydrogen/zeroe (last accessed 4 March 2022).
[96] International Union of Railways (2016), 'Carbon Footprint of Railway Infrastructure'.
[97] International Energy Agency (2017), 'Energy technology perspectives 2017'.
[98] Rail Delivery Group (2021), 'Catalysing a green recovery: Creating jobs by building Britain's net zero railway', October.
[99] Mediarail (2021), 'Decarbonisation of transport: options and challenges for railways', 14 November, https://mediarail.wordpress.com/decarbonisation-of-transport-options-and-challenges-for-railways/ (last accessed 31 January 2022).
[100] Railtech (2019), 'CER calls for full decarbonisation of EU railways by 2050', 13 November, https://www.railtech.com/policy/2019/11/13/cer-calls-for-full-decarbonisation-of-eu-railways-by-2050/?gdpr=accept (last accessed 31 January 2022).

have significantly lower emissions.[101] In 2021 electric cars represented close to 9% of the global car market,[102] and electric vehicles are expected to reach price parity with petrol and diesel vehicles by 2027.[103] The sale of new petrol cars will be effectively banned in the EU by 2035 by the 'Fit for 55' proposals that target a 100% reduction in emissions from cars by that year.[104]

In addition, ferries may be an option for short-haul journeys to/from islands, though there are similar issues with capacity as for rail and the decarbonisation potential is not clear. This is important as island communities are likely to be particularly dependent upon aviation, with long travel times to and from the mainland in the absence of air—see Box 4.2 below.

Box 4.2 Case study: substitutability between air travel and ferries between Athens and Crete

The Athens–Crete route is commonly travelled by both air (with 950,000 passengers traveling annually from Athens to Crete's three airports) and ferry (between Piraeus in Athens and either Heraklion or Chania in Crete). While the average flight time from Athens to Crete is under one hour, the ferry between Piraeus and Heraklion takes around eight hours and 30 minutes.[105] The long duration of the ferry is likely to be especially important for business travellers, and for other passengers who would be unable to make the return journey in a day.

If a flight ban were pursued, an additional consideration is the capacity of ferries. If all current air passengers travelling from Athens to Crete shifted to ferries, only around 43% of passengers could be accommodated, leaving 8,000 passengers per week without transport options.[106] Under a more conservative occupancy assumption, there would still be 1,755 passengers left without transport options per week. This implies that to continue to meet demand, additional ferries would have to be run, with additional carbon and financial costs.

Compared to a shift to from air to rail, a shift from air to ferry is likely to come with smaller environmental benefits. Ferries, while having lower emissions than aviation, have higher emissions than rail at approximately 61gCO_2 per passenger-kilometre (compared to 33g per passenger-kilometre for rail).[107] They also have non-CO_2 environmental impacts, with maritime transport being responsible for 13% of global sulphur dioxide emissions, causing acid rain and respiratory disease.[108] Studies have also suggested that ferries emit more PM than road transport on a passenger-kilometre basis. As emissions from ferries, including air pollution, CO, NOx and PM, are concentrated in local waterways, they can have large local effects.[109] Studies

[101] See European Environment Agency (2020), 'Transport and environment report 2020: Train or Plane?', March, p. 6.
[102] IEA (2022), 'Electric cars fend off supply challenges to more than double global sales', January.
[103] Transport and Environment (2021), 'EVs will be cheaper than petrol cars in all segments by 2027, BNEF analysis finds', 10 May, https://www.transportenvironment.org/discover/evs-will-be-cheaper-than-petrol-cars-in-all-segments-by-2027-bnef-analysis-finds/ (last accessed 9 March 2022).
[104] See Carey, N. and Steitz, C. (2021), 'EU proposes effective ban for new fossil-fuel cars from 2035', *Reuters*, 14 July, accessible here https://www.reuters.com/business/retail-consumer/eu-proposes-effective-ban-new-fossil-fuel-car-sales-2035-2021-07-14/ (last accessed 9 March 2021).
[105] See the Direct Ferries site: https://www.directferries.ie/piraeus_heraklion_ferry.htm (last accessed 4 February 2022).
[106] To calculate this, we compared the weekly air passengers between Athens and Crete with the spare capacity of ferries along the same route. Air passengers between Athens and Crete were obtained from the OAG data, as described above. Ferry spare capacity was calculated by applying an occupancy assumption to the ferry weekly capacities, which was estimated using the ferry timetables for all routes between Athens and Crete together with capacity data for the ferry types used. While no data was available on occupancy for ferries along this route, several sources that the capacity of Greek ferries is often upwards of 80%. See *GTP* (2020), 'Ferries in Greece are Now Allowed to Carry More Passengers', 2 August, https://news.gtp.gr/2020/08/02/ferries-greece-now-allowed-carry-more-passengers/ (last accessed 11 March 2022).
[107] EEA (2021), 'Briefing: Rail and waterborne — best for low-carbon motorised transport', March.
[108] European Commission (2018), 'Electric ferries and joined-up shipping to turn sea travel green', April, https://bit.ly/3KCC5kV (last accessed 7 February 2022).
[109] Corbett, J. and Farrell, A. (2002), 'Mitigating air pollution impacts of passenger ferries', May, Transportation Research Part D 7 197–21.

have found that because of this, ferry emissions are ‘a new and important issue for air quality management’.[110]

Additionally, while both air and rail are decarbonising, decarbonisation of ferries remains a challenge. Ferries are difficult to electrify due to large volumes of energy needing to be stored. The most advanced electric ferries have a maximum range of 40 nautical miles (74km).[111]

Source: Oxera.

4.4 Summary

The key findings regarding the decarbonisation of air and other modes of transport are as follows:

- Both the aviation and rail industries are working to improve their environmental and CO_2 footprint.
- The European aviation industry is working towards carbon neutrality by 2050, through a combination of new technology, improved ATM and smart economic measures including offsets.[112]
- Hybrid electric aircraft have been used for test flights and the first hybrid-electric aircraft are expected to enter commercial routes by 2030, becoming more widespread by 2040.[113] The first hydrogen aircraft are expected to operate on commercial routes by 2035.[114]
- Short-haul flights are likely to reach net zero before long-haul flights because hybrid-electric aircraft are at present only practical for shorter journeys. Small aircraft could later become drivers of decarbonisation for larger hybrid-electric aircraft that could travel longer distances.
- The rail industry is also decarbonising. The Community of European Railway and Infrastructure Companies (CER) has called on the European authorities to implement a number of policy measures for providing full rail decarbonisation by 2050.[115]

[110] Ibid.
[111] Kane, M. (2020), ‘Meet The World's Fastest Electric Ferry With A Massive 2 MWh Battery’, *InsideEVs*, 10 June, https://insideevs.com/news/428001/world-fastest-all-electric-rygerelektra-ferry/#:~:text=42%2Dmeters%20long%2C%20carbon%20fiber,mph%3B%2031.5%20km%2Fh (last accessed 7 February 2022).
[112] Airlines for Europe, Airports Council International, Aerospace and Defence Industries, European Regional Airlines Association and CANSO (2021), ‘Destination 2050: a route to net-zero European aviation’, February.
[113] See the Avinor website: https://www.routesonline.com/events/209/routes-europe-2022/about-the-host/ (last accessed 7 February 2022).
[114] Airlines for Europe, Airports Council International, Aerospace and Defence Industries, European Regional Airlines Association and CANSO (2021), ‘Destination 2050: a route to net-zero European aviation’, February.
[115] Railtech (2019), ‘CER calls for full decarbonisation of EU railways by 2050’, 13 November, https://www.railtech.com/policy/2019/11/13/cer-calls-for-full-decarbonisation-of-eu-railways-by-2050/?gdpr=accept (last accessed 31 January 2022).

5 Social and economic impacts

In addition to the environmental impacts discussed in sections 2–4, it is important to consider the social and economic impacts of air and rail transport in order to undertake a holistic assessment.

According to a recent Commission-funded project, regional airports are crucial in regional economic development, as they ensure local economies can access economic centres.[116] A large body of literature also finds social benefits of airports, with several studies using econometric analysis to show that regional aviation is socially beneficial.[117] According to the International Transport Forum, governments 'recognise that air connectivity plays a crucial role in enhancing economic growth by facilitating tourism and inward foreign direct investment and supporting trade in goods and services'.[118] In particular air connectivity 'supports a country's integration into the global economy'.[119] The French Senate, for instance, cites several studies and finds that a 10% increase in air transport is linked to an average increase of 0.1–0.5% in gross domestic product (GDP), a 4.7% increase in foreign direct investment (FDI), a 0.3–0.7% increase in wages, and a 3.9% increase in local demography.[120] The European Parliament estimates that the aviation sector supports around 5m jobs and contributes €110bn to European GDP per year.[121] If indirect effects are included, these numbers rise to 12m jobs and at least €700bn in GDP.[122]

Moreover, evidence suggests that aviation delivers especially large benefits when serving provincial areas that are not otherwise well-connected. The French Senate notes that there has been a shift in France towards wealth being concentrated in the cities and highlights that this 'has been accentuated by the high-speed rail network', which has considerably reduced travel times along the rail lines but left large parts of France uncovered, in particular the North-West (Normandy) and a vast 'centre-south' zone located between the South-East and South-Atlantic lines.[123] An example of an area relying on air for its connectivity is Limoges, near Bordeaux, which is not served by the Train à Grande Vitesse (TGV) network but by a regional airport. The Senate has suggested that air transport is a 'lever for economic development and rebalancing territorial inequalities'.[124] They find that a 'mix' of transport modes is necessary to 'ensure the opening up of territories'.[125]

[116] Seaplane (Sustainable and Efficient Air Transport - Platform for Linked Analysis of the North Sea Air Transport Environment), http://archive.northsearegion.eu/files/user/File/Project%20Book/1-16-31-7-533-02.pdf (last accessed 21 January 2022).
[117] See, for example, Sun, X., Zhang, Y. and Wandelt, S. (2017), 'Air Transport versus High-Speed Rail: An Overview and Research Agenda', *Journal of Advanced Transportation*, May, https://doi.org/10.1155/2017/8426926 (last accessed 11 March 2022), and Ha, H.-K., Yoshida, Y. and Zhang, A. (2011), 'Social efficiency benchmarking of Japanese domestic transport services: a comparison of rail and air,' in *Transportation Research Part D: Transport and Environment*, **16**:7, pp. 554–61.
[118] International Transport Forum (2018), 'Defining, measuring and improving air connectivity', May.
[119] Ibid.
[120] French Senate (2022), 'Contribution du transport aérien au désenclavement et à la cohésion des territoires', 21 January, http://www.senat.fr/rap/r18-734/r18-7344.html#toc62 (last accessed 21 January 2022), translated by Google translate.
[121] Erbach, G. (2018), 'CO2 emissions from aviation', European Parliament, European Parliamentary Research Service, https://www.europarl.europa.eu/RegData/etudes/BRIE/2017/603925/EPRS_BRI(2017)603925_EN.pdf (last accessed 11 March 2022).
[122] Air Transport Action Group, (2019), 'Aviation Benefits Report 2019'.
[123] French Senate (2022), 'Contribution du transport aérien au désenclavement et à la cohésion des territoires', 21 January, http://www.senat.fr/rap/r18-734/r18-7344.html#toc62 (last accessed 21 January 2022), translated by Google translate.
[124] Ibid.
[125] Ibid.

Moreover, it is worth noting that the connectivity benefits of air transport rely on the whole air network, as well as the individual lines. Each flight removed from the air transport network results not only in the loss of connectivity from that flight alone but the loss of several onward flight connections due to the interconnected nature of air travel.[126] This is illustrated by the effects of the COVID-19 pandemic, from which the European air network had recovered 64% of its direct connectivity but only 31% of its indirect connectivity by October 2021.[127]

It is also important to consider the economic implications of air and rail in the context of a modal shift. As discussed in section 3, significant additions to the European rail network may be needed to accommodate a modal shift due to connectivity and capacity constraints of the current network. As well as the environmental costs discussed, this would likely come with economic costs. As noted by the ECA, HSR infrastructure is expensive, costing around €25m per kilometre, which does not take into account the more expensive tunnelling projects.[128] Moreover, as some studies note, the construction of new rail lines create large economic costs, sometimes combined with low carbon savings. One study, based on an assessment of HSR lines in France, finds that 'the gain in greenhouse gas emissions of all the HSR projects is minimal compared to the level of investment: 2 to 3 MteqCO2 avoided per year, i.e. 150 MteqCO2 avoided over the 50-year lifespan of the infrastructure, for an investment of more than €240 billion'.[129]

Finally, there are also likely to be time and cost implications of a shift to rail for passengers. On most routes, air delivers time savings for passengers relative to rail, and this increases with the distance travelled.[130] Air can also be less expensive than rail on certain routes. A modal shift to rail is therefore likely to increase travel costs for some passengers, with the burden falling on those on lower incomes or else requiring subsidisation from government.

[126] ACI Europe (2021), 'Airport Industry Connectivity Report 2021', October.
[127] Direct connectivity refers to the passenger flows from A to B in European airports, while indirect connectivity refers to passenger flows that go via A or B, where this is not their final destination.
[128] European Court of Auditors (2018), 'A European high-speed rail network: not a reality but an ineffective patchwork'.
[129] Cour des Comptes (2014), 'La Grande Vitesse Ferrovaire: Un Modele Porte Au-Dela De Sa Pertinence', October.
[130] Bleijenberg, Arie, Koios Strategy (2020), 'Air2Rail: Reducing CO2 from intra-European aviation by a modal shift from air to rail', March.

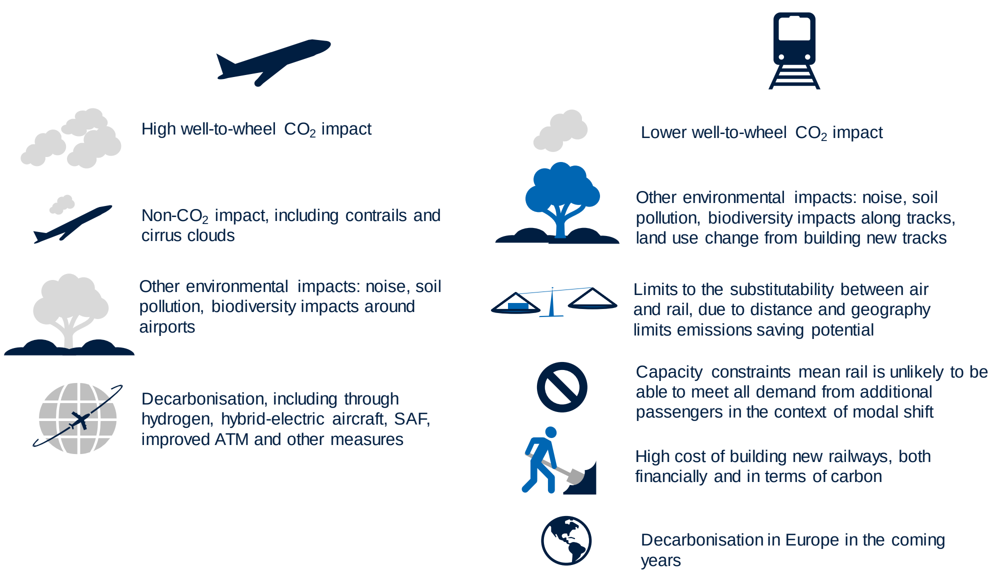
6 Conclusion

Modal shift from air to rail has been proposed as part of the solution to decarbonise transport in the EU, and has been encouraged through recent proposals for flight bans in Europe on distances up to 500km. On these distances, air and rail are likely to be most substitutable, and rail tends to have lower emissions and a lower environmental footprint than aviation per passenger-kilometre. The EEA finds that the environmental impact of a modal shift to rail above this distance is 'not straightforward' for a number of reasons, including that passengers are less likely to consider air and rail as substitutable at these distances.[131]

However, even when considering the implications of a modal shift from air to rail on short-haul routes, it is important to determine the practicalities of this shift. A significant increase in the number of passengers on the rail network is likely to exceed the capacities of existing railways in many cases, and may require the construction of additional rail infrastructure with large CO_2 costs and significant carbon payback times. Other indirect consequences include a possible shift to road, which can have higher emissions than air travel, as well as carbon leakage if passengers on connecting flights use airports outside the EU instead.

At the same time, as both the rail and aviation sectors decarbonise, the gap between air and rail CO_2 emissions will reduce. Any investment in a modal shift towards rail is therefore likely to lead to lower future returns in terms of carbon payback. Additionally, aviation can bring large social and economic benefits, including connectivity gains to rural areas, and facilitating tourism and FDI. These factors, set out in Figure 6.1 below, all need to be taken into account in deciding on the optimal policy for short-haul aviation in Europe. Overall, providing a range of transport options and encouraging intermodality between them is likely to offer the best solution from a social, economic and environmental perspective.

Figure 6.1 Summary table



Source: Oxera.

[131] European Environment Agency (2020), 'Transport and environment report 2020: Train or Plane?', March.

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