Plane and train: Getting the balance right

Urgent action is needed to curb climate change and reduce transport emissions, and the aviation industry recognises the need to 'go green' and achieve carbon neutrality by 2050, as per the ambitious goals of the European Green Deal. In parallel, many commentators have hypothesised that some air routes should rather be operated by high-speed trains or sleeper trains. This Think Paper aims to assess the practicality of an increased shift to rail, and the environmental, economic and societal implications that this would have as part of a wider green, smart and affordable mobility approach.

The paper reviews the latest literature comparing air and rail sustainability, assesses whether shifting from air to rail across Europe is a realistic option, and identifies areas where air and rail could be complementary, rather than mutually exclusive. To do so, it seeks to answer the following questions:

- What would be the impact of shifting from air to rail – and how feasible is this?
- What are the trade-offs necessary to get the air-rail balance right?
- In which circumstances would air-rail complementarity work better?

The paper concludes that transportation decarbonisation is more complex than simply planning to shift to rail for travel below 1,000 km. The positive impact on the climate this would have is limited, but it will generate a range of drawbacks. However, it finds that air and rail have a natural complementarity that should be capitalised on, and recommends that investment be balanced with a view to developing multimodal solutions.

Main Findings

1. **High-speed rail (HSR) has the greatest potential to replace air in the below 500 km category, but this segment, while responsible for 24.1% of European flights, only accounts for 3.8% of aviation emissions – and for geographical reasons, not all of this saving is achievable.** In the 500-1,000 km sector, however, HSR has much less ability to substitute successfully for air.

2. **By the time it takes to put new HSR infrastructure into operation** (18-26 years on average), **aviation will be well on track towards reaching net zero emissions by 2050 on its own**, in particular with upscaled Sustainable Aviation Fuel (SAF) use, and new propulsion technologies. Transport investment should therefore be carefully balanced between both industries, particularly **as aviation decarbonisation will benefit all aviation distance ranges all over Europe**, whereas HSR can only realistically impact shorter distances.

3. **Studies proposing an air-rail shift underestimate or fail to factor in the significant economic and environmental impacts that a massive expansion of HSR lines would entail**, including total lifecycle emissions. This impedes a **level playing-field assessment** as data on the rail market and infrastructure are missing. Even if the **10,000 km** of envisaged new HSR lines[1] were to be built, HSR will still not be able to match air in terms of connectivity, despite a potential infrastructure investment of **around €250 billion[2]**. Massive HSR expansion would also entail significant **socioeconomic and biodiversity loss impacts** compared to aviation, which has limited new infrastructure needs.

4. **Rail simply cannot substitute for air in many circumstances, e.g. islands and regions that are remote or face particular geographic barriers – and for which connectivity is vital to economic survival.**

5. **Multimodal solutions that combine air and rail are highly attractive in terms of optimising sustainability and improving connectivity**, particularly in dense metropolitan areas where HSR infrastructure is already in place. In this sense, both are complementary ways towards meeting emission reduction goals, making the optimal solution more "plane and train" rather than "plane vs train".

The challenge of the European Green Deal: how to reduce transport emissions

The European Green Deal[3] sets an ambitious course for the EU: to become the first continent with no net emissions of greenhouse gases (GHG) by 2050. For transport, it calls for a "90% reduction in greenhouse gas emissions by 2050 (from 1990 level), while also working towards a zero-pollution ambition". **Aviation**, as Figure 1 shows, accounts for **13.9%** of those GHG emissions –far higher than **rail**, which accounts for a tiny fraction at **less than 1%**; comparable to **maritime (13.4%)**; but massively below **road** transport, which provides over two-thirds of GHG at **71.7%**.

FIGURE 1: SHARE OF TRANSPORT GREENHOUSE GAS EMISSIONS IN EU-28 IN 2018

Railways 0.5% Other 0.5%
Aviation 13.9%
Maritime 13.4%
Road 71.7%
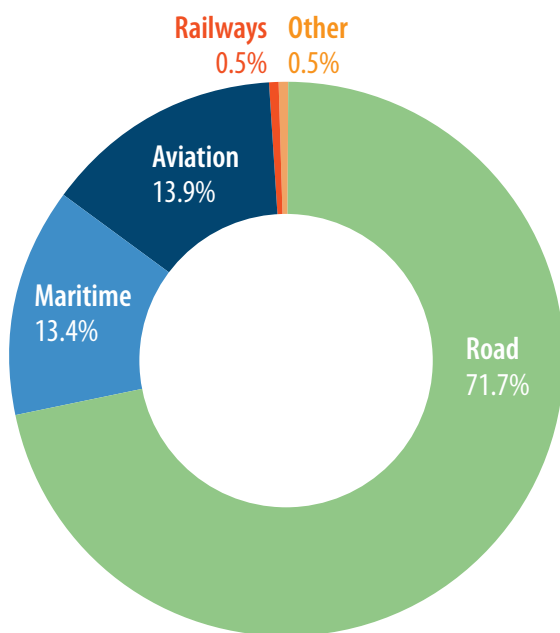
Source: EEA[4]

Although road transport accounts for over 5 times the emissions of air and over 140 times that of rail, paradoxically much recent public debate has centred on the possibility of switching from air to rail, not advocating road to rail concepts. Numerous studies have argued the desirability of an air to rail shift, and this is having an impact on policymaking at State level[5]. Rail is in any case clearly highly attractive in terms of emissions, and the EU's Sustainable and Smart Mobility Strateg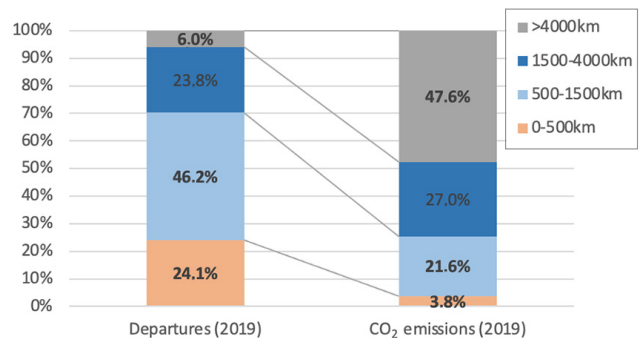y (SSMS)[6] grants a prominent role to the sector in the transition towards zero-emission mobility, arguing for a doubling of HSR traffic in the next decade, and a tripling by 2050, partly at the expense of air.

But would a shift from air to rail really have the desired effect on emissions?

The "plane vs train" debate is centred on two distance categories: up to 500 km, and 500-1,000 km. Of these, clearly the first is a more realistic goal in terms of passenger journey time, with the European Environment Agency (EEA) "Train or Plane?" report 2020[7] concluding that for the latter category, "it is not straightforward [to determine] what a future shift from air to rail can bring" in terms of reduced emissions and total environmental impact.

This would target the 24.1% of European flights that are under 500 km (which, during a pandemic that has impacted long-haul travel the most, even rose to 30.6% in 2020[8]). However, such flights were only responsible for 3.8% of aviation's gross CO_2 emissions in 2019, as EUROCONTROL Think Paper #10[9] underlines.

FIGURE 2: % OF FLIGHT VERSUS CO_2 EMISSIONS IN 2019

>4000km
1500-4000km
500-1500km
0-500km

Departures (2019): 6.0%, 23.8%, 46.2%, 24.1%
CO_2 emissions (2019): 47.6%, 27.0%, 21.6%, 3.8%

Source: EUROCONTROL

And **even if it were possible to aim for a blanket substitution of all flights for rail in this category, it would still be impossible to realise the full 3.8% CO_2 saving cap on total emissions**, owing to terrain, travel time considerations or higher fares, which would kill the business case for rail connection (arguments confirmed in the 2020 Eurobarometer[10] survey, which found that most travellers are only prepared to switch to more environmentally-friendly modes of transport if costs and speed are comparable).

"24.1% of European flights are under 500 km - but account for only 3.8% of aviation's gross CO_2 emissions"

HSR is also highly reliant on low carbon electricity to realise the greatest benefits, but this is not widely available: whereas France, which has the densest HSR infrastructure of +2,700 km[11], benefits from the third-lowest carbon rate in Europe at 0.047 kg CO_2e emissions per kWh, average electricity generation elsewhere in Europe is over seven times greater at 0.339kg CO_2e emissions per kWh[12].

Even when considering journeys up to 1,000 km, and assuming high-speed connections were established between all major European cities, **a shift towards rail would not deliver more than 2-4% gross CO_2 emissions savings**, according to the Transport & Environment "Maximising air to rail journeys" briefing[13].

HSR's environmental and socioeconomic impacts should not be underestimated

When comparing transport modes, total lifecycle emissions must be considered, including each stage of energy production and use, and the environmental and economic impact of transport infrastructure. **While the EEA "Train or Plane?" Report excludes infrastructure aspects from its analysis, citing a lack of data on the intra-European rail market and infrastructure, in fact railways entail significant negative impacts. Not factoring in these** impacts skews the analysis and impedes a level playing-field assessment, to the clear detriment of air.

HSR costs twice as much as air when adding up external costs and infrastructure, a European Commission study[14] finds (see Figure 3), and HSR infrastructure alone costs 5 times more. The EEA[15] also reports that rail is **10 times more damaging to land use**, resulting in a total habitat damage cost of **€2.7 billion** per year in the then-EU28. For aviation, the equivalent total costs per year at 33 selected major airports were estimated at **€0.05 billion**. Even if this cost were multiplied by 5 to extrapolate it to all airports in the then-EU28, **the resulting total habitat damage caused by aviation is still 10 times lower on an annual basis than that for rail**. Airport infrastructure investment is also typically funded by the airports themselves, whereas the cost of HSR is largely paid out of public taxes[16].

Data are also much more complete for air usage as opposed to rail usage, with data on train occupancy rates, additional rail tracks required to absorb demand, associated costs/lifecycle greenhouse gas emissions, etc. not readily available. This can be contrasted unfavourably to aviation, where extensive studies are available tracking emissions, passenger data, flows, forecasts and demand predictions. **All of this puts air at a distinct disadvantage when seeking to make a balanced comparison**.

FIGURE 3: AVERAGE EXTERNAL AND INFRASTRUCTURE COSTS FOR PASSENGER TRANSPORT (€-CENT/PKM)
Road & rail for EU28; Aviation for selected 33 airports
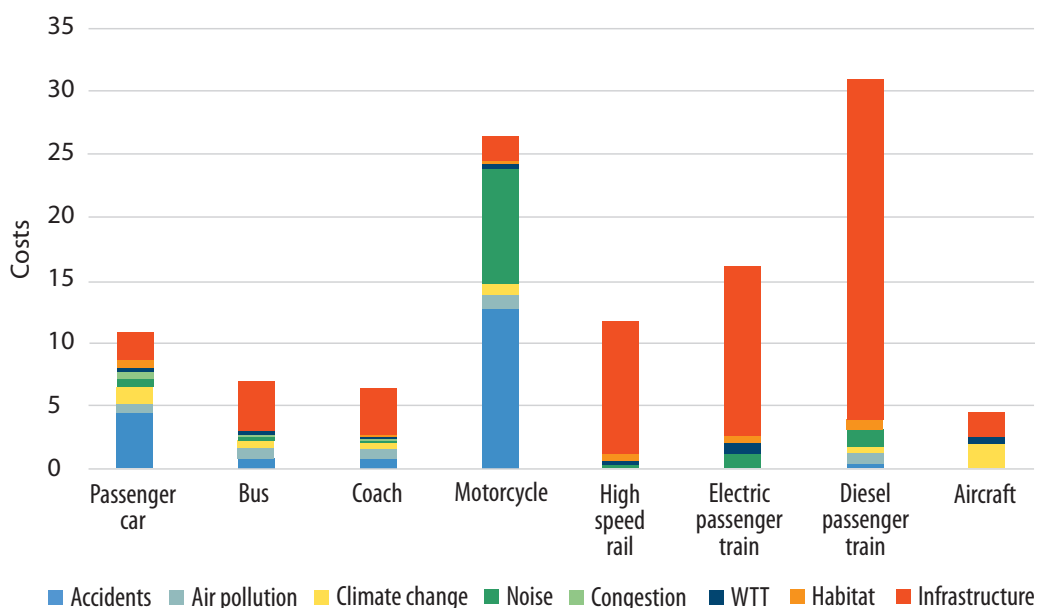
Source: EC/CE DELFT STUDY – State of play of Internalisation in the European Transport Sector- 2019[17]

"HSR costs twice as much as air when adding up external costs and infrastructure, HSR infrastructure costs 5 times more, and is 10 times more damaging to land use"

The UIC publication 'High Speed Lines in the World 2020'[18] reports on the HSR extensions currently planned in Europe, which amount to 10,000 km of new lines. The study does not however specify if these investments would be sufficient to meet the ambitions of the SSMS of doubling/tripling HSR traffic by 2030/2050. Using the calculation that 3 hectares of land are used for each km of additional HSR track, this would result in **30,000 hectares of biodiversity loss** (new rail lines fragment existing land) and **add up to €1 bn in additional costs per year**[19].

Community support is also far from a given for massive land-use change, or for the noise impacts. Communities living in the vicinity of HSR lines are, like those living close to airports, majorly affected – in fact, **5 times more people are impacted by HSR noise than by air**, as the SSMS notes, estimating that "around 100 million people in the EU are exposed to average sound levels of 55 dB or higher during the day, evening and night for road traffic noise, 20 million for railway noise and 4 million for aircraft noise."[20]

HSR investment vs. aviation decarbonisation: Which will be quicker to deliver?

Building 10,000 km of new HSR lines would cost around €250 bn, and each new line tends to take anywhere between 18 and 26 years to build[21]. This may make it **difficult to achieve the SSMS goal of doubling the available traffic by 2030, rather than later in the decade**. HSR is thus far from being a rapid way of meeting climate goals. HSR-air substitution is also, as we have seen, largely only practical in the under 500 km segment.

While aviation generates more emissions now, it will generate significantly less in the coming decades, as EUROCONTROL Think Paper #10 shows. A major upscaling of sustainable aviation fuels (SAF) has the potential to lower rapidly emissions across all flight distance categories, not just the ones that HSR could aim to substitute for air, while new propulsion technologies such as electric, hydrogen or hybrid aircraft are expected to enter the market in the next decade, with zero-emissions aircraft steadily replacing conventionally-powered ones.

A new HSR route commissioned now, and which by its nature can only link several cities, therefore risks entering into operation after the first zero-emission airliners have been brought to market on multiple shorter-haul routes across Europe[22]. HSR and aviation decarbonisation initiatives are certainly complementary, but **replacing air by HSR is not the silver bullet needed to achieve transport climate neutrality by 2050**.

FIGURE 4: COMPARISON OF AIR & HSR CONNECTIVITY IN WESTERN EUROPE

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

Source: X. Sun, Yu Zhang, S. Wandelt (2017), Air Transport vs . High Speed Rail : An Overview and Research Agenda (2017)

HSR can complement air connectivity but hardly replace it

HSR routes are fixed and take years to build, whereas air routes are only constrained by the existence of airports, can adapt easily to changes in demand, and crucially require lower investment (upgrading of infrastructure rather than the wholescale creation of new infrastructure that new HSR lines require).

Multimodality: Improving sustainability now without huge investment

While the ability of HSR to substitute comprehensively for air in short-haul sectors is limited in terms of cost, construction time and connectivity, **HSR does have a key role to play in the development of multimodal transport solutions, where significant advantages can be achieved in terms of the environment, connectivity and profitability**. As the SSMS states, "where high-speed rail services can be linked to form an attractive offer with long distance flights... this could not only reduce CO_2 emissions... but also... avoid maintaining unprofitable air routes".

This would "require investment into improving the access of high-speed rail to airports", which is an area that has been increasingly explored in recent years, from the Rail Baltica project to connect the capitals of the three Baltic States, to the growing number of air-rail alliances across Europe. Lufthansa has teamed up with Deutsche Bahn to create new services to Frankfurt from Hamburg, Munich, Berlin, Bremen and Münster; Austria has switched to rail all flights between Graz, Linz and Salzburg to Vienna Airport; Switzerland's "Airtrain" links Geneva, Basel and Lugano to Zurich Airport; and Schiphol benefits from comprehensive national and international rail links (with international services between Amsterdam and Brussels increasingly switching to rail links for passengers catching connecting flights to intercontinental destinations at the airport).

"HSR has a key role to play in the development of multimodal transport solutions, bringing significant advantages in terms of the environment, connectivity and profitability"

There is also **potential for exploring further multimodality solutions around airports, by focusing on travellers' door-to-door needs, and by assessing the full environmental impact of the traveller's journey**. For instance, connecting airports by rail would allow passengers to travel to the airport by train instead of by car, a key advantage given that car journeys overall generate the highest carbon footprint of all transportation modes.

To achieve this potential, passengers will need more information on the sustainability of travel alternatives, based on independent comparison methods; new ticketing systems will also need to be developed to facilitate access.

Conclusions

Overall, therefore, we can conclude that the case for an air-rail shift, either on up to 500 km or 500-1,000 km routes, is far from convincing, even if improving the HSR network per se will clearly improve choice and connectivity. In terms of emissions, rail has clear advantages now over air, but new HSR will take decades to put into place – and by that time, aviation decarbonisation will be well underway. It is also important to factor in properly HSR's far greater socioeconomic and land/biodiversity constraints than air, which studies tend to underestimate massively, and be aware that HSR cannot match the flexibility and connectivity of air, which remains vital to the European economy. However, where rail does have a major role to play is in further developing multimodal solutions – less "plane vs train", and rather "plane and train".

Austrian Airlines and ÖBB (Austrian Federal Railways) innovative AIRail intermodal transport concept with Railjet services

Main Findings

1. **High-speed rail (HSR) has the greatest potential to replace air in the below 500 km category, but this segment, while responsible for 24.1% of European flights, only accounts for 3.8% of aviation emissions – and for geographical reasons, not all of this saving is achievable.** HSR has much less ability to substitute successfully for air in the 500-1,000 km sector, however.

2. **By the time it takes to put new HSR infrastructure into operation** (18-26 years on average), **aviation will be well on track towards reaching net zero emissions by 2050 on its own,** in particular with upscaled Sustainable Aviation Fuel (SAF) use and new propulsion technologies. Transport investment should therefore be carefully balanced between both industries, particularly as aviation decarbonisation will benefit all aviation distance ranges all over Europe, whereas HSR can only impact shorter distances.

3. In the studies comparing air and rail sustainability, **a level playing-field assessment is not achievable** since data on the rail market and infrastructure are missing, which penalises aviation. **If the 10,000 km of new HSR lines planned by the UIC were to be built, and assuming that this would meet the SSMS goals of doubling rail traffic by 2030 and tripling it by 2050, this would cost approximately €250 billion using the calculation methodology provided in the Handbook on the External Costs of Transport – 2019**. Air, on the other hand, has very limited new infrastructure needs – and despite all that investment, HSR would still not be able to match air in terms of connectivity. Moreover, it would entail significant **socioeconomic and biodiversity loss impacts** compared to aviation which all available studies underestimate.

4. **Rail simply cannot substitute for air in many circumstances, e.g. islands and regions that are remote or face particular geographic barriers – and for which connectivity is vital to economic survival.**

5. **Multimodal solutions that combine air and rail are highly attractive in terms of optimising sustainability and improving connectivity**, particularly in dense metropolitan areas where HSR infrastructure is already in place. In this sense, both are complementary ways towards meeting emission reduction goals, making the optimal solution more "plane and train" rather than "plane vs train".

1- **International Union of Railways (UIC):** https://uic.org/IMG/pdf/20200227_high_speed_lines_in_the_world.pdf

2- **ECA Special report 19/2018:** A European high-speed rail network: not a reality but an ineffective patchwork. On average, 28/16 years from start of planning/construction to opening for selected HSR lines (study covering 50% of the HSR network), and the average cost of a new HSR line in 2017 was €25M/km. https://www.eca.europa.eu/Lists/ECADocuments/SR18_19/SR_HIGH_SPEED_RAIL_EN.pdf

3- **EEA:** https://www.eea.europa.eu/data-and-maps/daviz/share-of-transport-ghg-emissions-2#tab-googlechartid_chart_13

4- **EEA:** https://www.eea.europa.eu/publications/transport-and-environment-report-2020 – 24 Mar 2021.

5- **Loi climat-résilience:** https://www.ecologie.gouv.fr/loi-climat-resilience. The Law aims to ban flights where rail services of under 2½ hours exist, excluding flights mostly taken by connecting passengers.

6- **SSMS:** https://ec.europa.eu/transport/themes/mobilitystrategy_en

7- **EEA:** https://www.eea.europa.eu/publications/transport-and-environment-report-2020

8- **EUROCONTROL Data Snapshot 4**, March 2021. https://www.eurocontrol.int/publication/eurocontrol-data-snapshot-CO_2-emissions-flight-distance. Short-haul flights accounted for 4.3% of total emissions in 2020 owing to their increased share, slightly up on 2019 data.

9- **EUROCONTROL:** https://www.eurocontrol.int/publication/eurocontrol-think-paper-10-flying-perfect-green-flight

10- **Eurobarometer on Mobility and Transport**, June 2020: https://data.europa.eu/data/datasets/s2226_92_1_495_eng?locale=en

11- **UIC:** https://uic.org/IMG/pdf/20200227_high_speed_lines_in_the_world.pdf

12- **Carbon Footprint:** https://www.carbonfootprint.com/docs/2019_06_emissions_factors_sources_for_2019_electricity.pdf

13- **T&E:** https://www.transportenvironment.org/sites/te/files/publications/2020_07_Air2Rail_Briefing_paper.pdf

14- **European Commission:** State of play of internalisation in the European transport sector - Publications Office of the EU (europa.eu), p.44. https://cedelft.eu/publications/state-of-play-of-internalisation-in-the-european-transport-sector/

15- **EEA:** https://www.eea.europa.eu/publications/transport-and-environment-report-2020, p. 37.

16- **European Commission:** https://cedelft.eu/wp-content/uploads/sites/2/2021/03/CE_Delft_4K83_Overview_transport_infrastructure_expenditures_costs_Final.pdf. Appendix F: " the private investment [in road and rail] reached at best of times 10-15% of the total investments."

17- **Publications Office of the EU:** https://op.europa.eu/en/publication-detail/-/publication/696d402f-a45a-11e9-9d01-01aa75ed71a1

18- **UIC:** https://uic.org/IMG/pdf/20200227_high_speed_lines_in_the_world.pdf

19- **Handbook on the External Costs of Transport - 2019:** https://op.europa.eu/en/publication-detail/-/publication/9781f65f-8448-11ea-bf12-01aa75ed71a1, which calculates that the external environmental cost of this additional land occupancy is on average €84,500 per km per year.

20- **SSMS:** https://ec.europa.eu/transport/themes/mobilitystrategy_en

21- **ECA Special report n° 19/2018:** A European high-speed rail network: not a reality but an ineffective patchwork. https://www.eca.europa.eu/Lists/ECADocuments/SR18_19/SR_HIGH_SPEED_RAIL_EN.pdf

22- **Airbus:** Hydrogen - Zero emission https://www.airbus.com/innovation/zero-emission/hydrogen.html

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