Greening of Railway Infrastructure: Designing a timely and orderly Transition

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Greening trains and railway infrastructure assets will provide enormous benefits for society at large. However, Infrastructure Managers need to follow a progressive approach: actions need to be deployed over time in the most cost-effective way, depending on the portfolio of clean technologies available and of the life cycle of assets.

Railways are broadly perceived as the most sustainable form of mass transport for both passengers and freight. Compared to other modes, railways generate low CO_2 emissions and air pollutants, save energy and space, thus reducing the pressure on natural resources, habitat and biodiversity.

When considering external transport costs, a recent EC study shows that overall rail traffic scores better for both passenger and freight transport than road and air traffic. According to the *Handbook on the external costs of transport (EC, 2019a)*, external costs linked to greenhouse gas emissions, local air pollution, noise, habitat damage and biodiversity, as well as the costs of congestion and crashes, sum up in the EU to almost €900 billion annually, or the equivalent of almost 7% of EU GDP. These external costs vary greatly depending on the transport mode: Road transport accounts for 83% of such negative externalities, whereas the contribution of rail is smaller than 2%.

Nonetheless, the environmental impact of railways must still be improved for three different reasons:

- Business: Railways must demonstrate to their passengers and freight clients that they are fully engaged in the decarbonisation of transport;
- Acceptability: Railway systems run through urban areas, providing a wide range of benefits. Nonetheless, noise emerges as a public health and political concern in some Member States and generates substantial opposition to increases in rail freight. Noise emissions, therefore, need to be reduced in order for increased traffic to be accepted by the public, especially for freight and high-speed lines;
- Regulation: Railways must demonstrate that they are committed to complying with more stringent European and national regulations concerning soil, water pollution, vegetation management and protection of habitat and biodiversity and, more generally, to reduce the environmental footprint of works.

In this context, rail infrastructure managers (IMs) can "green" railways by providing a decarbonised and silent infrastructure to railway undertakings (part I), increasing the capacity of their networks (specifically where there is a potential for further modal shift (part II)) and by reducing the environmental footprint of infrastructure works (part III).

These actions can bring considerable environmental benefits for society at large. However, three main obstacles need to be overcome: some clean technologies are not mature enough or are unavailable; some measures come at a relatively high cost, making the case for investment more difficult. Moreover, the high cost must not endanger the competitiveness of the railways, otherwise, the benefits of the railways in terms of sustainability may be outweighed.

Here lies the main challenge for IMs: finding the right balance between environmental benefits and costs. Providing green assets yields huge benefits for society at large, but IMs need to follow a progressive approach based on the merit order of greening actions: starting with the low-hanging fruit; defining a trajectory of actions considering the life cycle of assets, minimising the cost of retrofitting, and fostering innovation when technologies (e.g., hydrogen) are not mature enough to be deployed.

Greener assets

IMs are both asset managers and traffic managers: they maintain the infrastructure, provide train paths and

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manage rail traffic. They can contribute to the railway system's greening by acting on the two residual external costs of railway infrastructure in operation: carbon emissions resulting from powering trains and noise.

A low carbon infrastructure

The European Green Deal (EC, 2019b) calls for a reduction of 90% in transport CO_2 emissions, in order for the EU to become a climate-neutral economy by 2050.

In 2018, rail accounted for only 0.4% of transport CO_2 emissions and 2% of transport energy consumption in EU27. Moreover, rail is the only transport mode to have reduced its CO_2 emissions almost continuously since 1990, while carrying about 11,2% of freight and 6,6% of passengers on all modes (EC, 2020a).

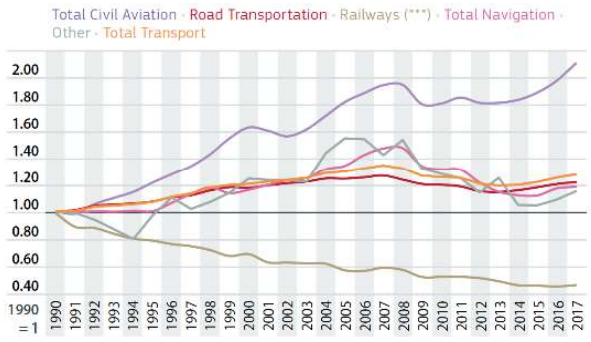

Figure 1: Evolution of greenhouse gas emissions by transport mode in the EU

Source: European Commission (2019): EU Transport in Figures. Statistical Pocketbook 2019.

It should be remembered that railways were not originally climate-friendly: they appeared during the industrial revolution and were heavy users of coal. The progressive greening of railway infrastructure comes from two fundamental trends: electrification and development of low carbon sources of electricity while also showing the highest energy efficiency among all transport modes.

The total length of the EU27 rail network in 2018 was around 201 000-line km. About 56% of the lines carrying 80% of traffic are electrified, which practically means that all mass transit lines are electrified. Electrified trains, however, are not necessarily green by default, depending on the electricity generation mix in the specific country of operation. In some countries where electricity generation is very carbon-intensive, it may be misleading to claim that electrified trains have zero operating CO_2 emissions. In other countries where electricity is sourced from nuclear power or natural sources, such as wind or solar energy, operating CO_2 emissions will be significantly lower. However, with the EU's long-term energy strategy in mind, the electricity generation mix in Europe is expected to become greener.

This leaves the issue of diesel trains open. Their elimination raises important economic and financial questions. Electrifying existing lines is a very costly way to decarbonise the transport system: it requires huge investment and further maintenance costs while providing limited additional revenues as the electrification does not increase the capacity on the network per se. New technologies such as batteries are emerging, which allow for partial electrification of a line for short distances and the use of hydrogen for long distances.

Infrastructure will need to adapt progressively following the merit order of actions:

- the area of relevance of traditional electrification should be limited to freight lines with a high potential of traffic;
- partial electrification using batteries to avoid the high cost of electrification for forward-stations and tunnel sections is a viable alternative, but only for short and medium distances given available technologies;
- for longer distance electrification based on hydrogen should be considered in the coming decades. Some promising pilot-tests have already been carried out in Germany and the Netherlands. However, the deployment costs are still too high when taking into account production, distribution costs (e.g., hydrogen refueling stations) and retrofitting costs of rolling stocks.

Silent routes

Railways are rightly considered as one of the greenest modes of public transport and benefit as such from the support of the public. However, they face growing concerns from local communities concerning noise emissions. This paradox is particularly true in urban or specific geographic areas (e.g., Rhine Valley in Germany): although the benefits of railways in those areas are sig-

nificant in reducing air pollution and congestion, noise emerges as a major obstacle to the development of traffic.

Noise could historically be considered a pure NIMBY (*Not in my backyard*) issue: the opposition of people living geographically close to infrastructure, which delivers more significant benefits for society at large. Historically, local opposition could be dealt with using a mix of state prerogatives and compensation for damages and losses in land values. Still, the issue nowadays is much broader: railways are more and more a mass transit system, running intensively through urban and noise-sensitive areas, thereby increasing the number of people exposed to noise. According to the latest data reported under the Environmental Noise Directive, around 100 million people in the EU are exposed to average sound levels of 55 decibels (dB) or higher during the day, evening and night from road traffic noise. Railways are the second most important source of noise, with a total of nearly 20 million people exposed (EU, 2017).

Although modern electric passenger trains running on well-maintained tracks are relatively quiet, older freight wagons equipped with cast iron brake blocks can pose a significant noise issue, as many freight services are operated at night. Here again, the environmental benefits of noise reduction come at a cost that needs to be minimised and efficiently shared between the infrastructure and the rolling stock: finding an optimal combination of track components (e.g., soft rail pads) and improved rolling stock, retrofitting freight wagons with less noisy brakes. The reduction of noise at the source (trains) is a more efficient and less intrusive way of addressing the matter than adapting the infrastructure (e.g., erecting noise barriers). Furthermore, noise barriers sometimes create a visibility barrier for rail passengers as well as nearby residents and can attract vandalism and graffiti. The revised *Noise Technical Specification* for Interoperability has defined an efficient compromise with the banning of "noisy" freight wagons from some of the busiest rail freight routes as of December 2024.

Increasing capacity to allow for a modal shift in favour of rail

To meet the objectives of the European Green Deal, rail will have to take up a bigger share of passenger and freight transport. As detailed in the ProRail policy paper (2019), an ambitious policy agenda will be needed. This calls for careful cost-benefit analysis as rail infrastructure implies high fixed costs.

The case for cost-benefit analysis

Cost-Benefit Analysis (CBA) allows the selection of relevant options by assessing the socio-economic value added by projects or public policies and ranking them. The practice of CBA has a long-standing history, dating back from the end of the 19th century. It needs, however, to play a bigger role in the policymaking process of climate action.

In the context of climate action, the key parameters are the value of time and the so-called shadow price of carbon, which reflects the value put by society on measures aimed at avoiding the emission of one ton of CO_2. Whereas a market price is based on the trading price for a service or a product, a shadow price is the price that reflects the full value to society. In France, a first set of values for the shadow price of carbon was defined by a specific commission on this topic (Quinet, 2008), with a recommendation of €100/t CO_2 in 2030. Given the new objective of carbon neutrality, a second commission (Quinet, 2019) recommended considering a shadow price of carbon of €250/t CO_2 in 2030. This means that all actions which deliver an abatement cost below this reference should be considered as they efficiently contribute to the net-zero emissions target. Actions that deliver abatement costs above this reference should be considered as relevant to fight climate change (but may be justified by other considerations).

A portfolio of cost-effective actions

A modal shift from road or air to rail requires both an improvement in cost-competitiveness and an increase in the capacity offered by the railway network. This needs to be cost-effective: there is no need to increase capacity everywhere, hoping for an increase in demand. One should instead focus on congested areas and lines: In 2018, the EU27 network had an intensity of use of 18.2 thousand train kilometres per line kilometre. The most intensively used networks in 2018 were those in western Europe, particularly the Netherlands, which has an intensity of use of 50.6 thousand train kilometres per line kilometre. The total length of track that was declared to be congested in EU27 affected 2 261 kilometres, including 1 339 kilometres along rail freight corridors (EC, 2021).

In this context, it may be, at times, necessary to build new lines. This may be the case when a high-speed line between two metropolitan areas can induce a significant shift from

road and air to rail or when a new freight line is needed to bypass a metropolitan area. In these cases, maximising the environmental benefit goes hand in hand with maximising the commercial and financial objectives: the more traffic you capture, the more environmental benefits you get.

Looking at the socio-economic advantages of a development project, a wide range of benefits need to be considered because a costly new line cannot be justified simply on the ground of climate benefits. In this respect, a distinction needs to be drawn between passenger and freight traffic.

The high investment costs of a new high-speed line (about 25 Million € per km) cannot be justified by climate benefits alone, and broader socio-economic benefits need to be considered. Time savings remain the principal advantage as they provide a 'double dividend': a welfare benefit as well as climate benefits when they deliver a shift from air and road to rail. Overall, the climate benefits of an HSL project account for about 10% of the investment costs.

The picture appears to be more favourable for freight transport for two reasons: investment costs for new freight lines are significantly lower than for new high-speed lines (5 million €/km compared to 25 million €/km for a high-speed line) and decarbonising freight transport delivers larger climate benefits because the emissions from a freight train are superior to the emissions from a passenger train and freight trains frequently operate on long distances.

In most cases, entirely new infrastructure is not a cost-effective choice. A portfolio of alternative options is available to increase traffic thanks to digitalisation and better interoperability:

- Digital technologies can increase both punctuality and infrastructure capacity on existing lines. For instance, in France, the number of train paths between Paris and Lyon will increase from 13 to 17 per hour thanks to the retrofit of the high-speed line with ERTMS level 2;

- More than half of total rail freight is across borders, making the competitiveness of rail freight very sensitive to interoperability and operational difficulties between national rail networks. Passenger traffic is still mostly domestic, with only 7% of it crossing borders in 2018. The interoperability of technologies, traffic management systems and timetabling, with priority given to international trains, can play a key role in fostering long-distance traffic for both passengers and freight across European countries.

The case for carbon pricing

A transport network is and will always be multimodal. But modal shift in favour of rail is necessary to decarbonise mobility. Where passengers are concerned, modal shift can come from a time gain of an HSL between big cities or road congestion within urban areas, but for other types of traffic on conventional lines, the time gains are less relevant. Carbon pricing - or regulation dedicated to reducing air pollution - are essential to sustain the competitiveness of railways compared to other modes.

Despite longstanding policy commitments for efficient carbon pricing in transport progress has been limited. As flagged in the communication on Sustainable and Smart Mobility Strategy (EU, 2020b), the "polluter-pays" principle needs to be implemented in all transport modes. Enlarging the scope of the European Emissions Trading Scheme (ETS) to transport or implementing an EU-wide eco-tax on trucks would be the most efficient way to level the playing field and to reap the carbon benefits of rail, and notably rail freight.

Reducing the environmental footprint of infrastructure works

In the context of the urgent need to decarbonise our transport systems, rail is expected to expand its reach and capacity. Across Europe, existing lines are predicted to get busier and new lines are planned, and with this growth, there is a risk to biodiversity.

Track maintenance and works carried out by IMs impact the environment globally and locally. For a significant part of day to day activities, IMs don't have clean options that are nearly as cheap as their polluting counterparts. Reducing the environmental footprint of activities and notably of works requires a long-term strategy.

The carbon footprint of works

Besides the CO_2 emissions from powering trains, IMs carbon emissions come from a wide range of business activities. These include direct emissions stemming from road fleet vehicles and buildings (scope 1 and 2 emissions) and indirect emissions generated by the supply

chain (scope 3 emissions). Indirect emissions include 'embodied carbon' in products (for example, from the energy required to extract raw materials, manufacture the materials into a product, and transport the product to the site), and onsite contractors using machinery and equipment to design, build, maintain and renew the assets. A specific feature of IMs is that the indirect emissions represent a major part of total emissions.

The construction of a new line is indeed responsible for massive CO_2 emissions, especially in certain circumstances such as large tunnel sections. This is also the case, to a lesser extent, with renewal investments. In the first place, it should be recognised that a large part of these emissions is inevitable given the lack of carbon-free technologies to produce materials such as cement and steel.

Most importantly, the reference to scenarios to assess the impact of works needs to be carefully designed to avoid misleading conclusions. True, the 'payback' period in which lower carbon emissions delivered by a modal shift once a new line is in operation offset the higher carbon emissions during the construction period can be long (depending on the traffic), but the relevant question is to consider the alternative scenarios: should we inflict congestion costs to passengers in dense areas, build a road or reinforce urban sprawl rather than density?

Nonetheless, reducing the carbon footprint of infrastructure works is a requirement. It should be based on a two-pronged approach:

- The companies which supply materials for work and projects are critical. IMs spend billions of euros each year buying materials. Environmental considerations need to be addressed in the early stages of procurement and given a high priority and appropriate weighting in the assessment of tenders.

- A life cycle approach implementing circular economy, focusing on the reuse and recycling of materials (tracks, ballast, crossings), is a very cost-effective way to reduce both maintenance costs and carbon emissions.

The local footprint of infrastructure works

The biodiversity challenge is distinct from the climate challenge. Increased traffic provides climate benefits but can degrade ecosystems through land consumption, landscape fragmentation, barrier effects, soil pollution and waste. These can threaten the viability of sensitive populations and alter ecosystem dynamics. Moreover, biodiversity impacts are diffuse and are more difficult to quantify and monetise, thus harder to incorporate in a cost-benefit analysis.

IMs understand that railway infrastructure should be part of the natural landscape, becoming a 'green network' integrating vegetation management, protection of habitat and biodiversity. While the focus was traditionally on the environmental impact of large-scale greenfield projects, IMs are now seeking comprehensive solutions that can halt and reverse the loss of biodiversity.

The most promising avenues concern:

- the eco-design of renewal and development projects, based on a comprehensive assessment of the infrastructure's life cycle, from construction and use through to maintenance;

- a more circular economy, where the railway extracts fewer virgin resources from the planet, keeps materials and resources in circulation and waste to an absolute minimum;

- The transition from herbicide based to non-herbicide-based vegetation control.

Carrying out these policy actions should not be based only on compliance with stringent norms and regulations but include an environmental management system to support the rise of awareness among the organisation's staff on environmental protection and local-level concertation to design specific solutions.

Conclusion

Greening trains and railway infrastructure assets requires actions which need to be deployed over time in the most cost-effective way depending on the portfolio of clean technologies available and of the life cycle of assets to minimise retrofitting costs.

Greening trains and railway infrastructure assets are and will be a team effort. IMs must work with passenger and freight operating companies that run their services as investments must be coordinated between IMs and Railway Undertakings. The teamwork extends into collaborative planning with municipalities and other providers of passenger transport (such as cities) as well as

freight buyers. IMs must work with their supply chain as a major part of CO_2 emissions come from materials.

All these efforts carried out for the benefits of society at large need to be sustained by public regulation: selecting the policy actions with the best cost-benefit ratio and putting a price on carbon emissions are key to deliver a smooth and efficient transition to sustainable rail networks.

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