TRENDS
RAIL

Heatwaves pushing the sector off its rails

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While rail is one of the least polluting modes of transport, it is also one of the most vulnerable to climate change. 2022 and its succession of heat waves around the world put railways under stress, even though the issue has been studied for a long time. While there are ways to adapt, including nature-based solutions, their uptake to date has not been rapid, with current responses more geared to short-term crisis management than to longer-term adaptation.

DATA OVERVIEW

The electrification of railways charts it course around the world

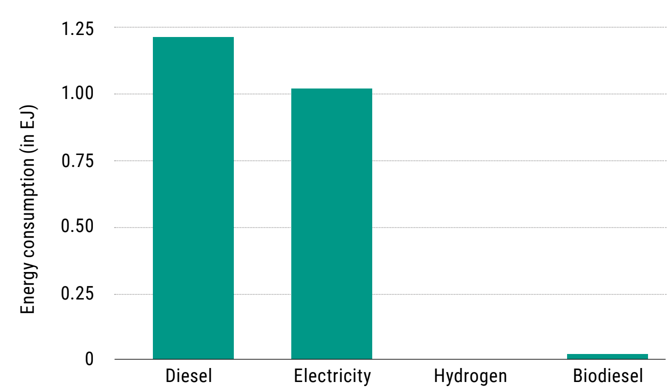
Rail transportation is among the means of passenger transport that emit the least greenhouse gases (GHG): with a carbon intensity of about 15 gCO_2e[1] per passenger-kilometre,[a] which is less than a tenth of that of large cars or aircraft.[2] It also has about the same efficiency when transporting goods. While it represents about 9% of the global transport of passengers and 7% of global freight,[3] rail transport only accounted for 2.2% of the total energy consumption of the transport sector in 2021,[4] and no more than 1.5% of the sector's direct CO_2 emissions.[5] In 2021, total direct worldwide emissions from the railway sector amounted to 96.8 $MtCO_2$, on the rise compared to 2020 (89.91 $MtCO_2$, an increase of 7%), but well below the peak reached in 2019 (104.22 $MtCO_2$).[6] With the annual increase since 2019 in diesel rail operations being less than 1%, and electric rail not directly emitting CO_2, emissions from the sector are not expected to reach 2019 levels again.[7]

In the face of limited options for increasing the efficiency of rolling stock, the decarbonisation strategies of actors in the railway sector essentially seek the electrification of rail lines, a trend that has already seen progress in recent years; the worldwide share of electrified railway tracks increased from 36.7% in 2015 to 40.2% in 2019.[8] Rail electrification percentages for passenger and freight transport differ significantly from each other: electric rail accounts for about 80% of passenger transportation, and about half of all freight traffic. As a result, the final energy consumption for rail transport in 2021 is almost equally split between electricity and diesel, with biodiesel accounting for only a tiny share, while developments in fuel cell (hydrogen) trains are not yet substantial enough[9] (**FIG. 1**).

FIGURE 1

FINAL ENERGY MIX OF RAIL TRANSPORT IN 2021

Source: IEA, 2022



Yet regional and intra-regional variations in the rates of rail electrification persist. While a substantial part of European rail networks is already electrified (more than 60% of main lines),[10] it is in Western Europe that electrification is highest. According to data from the European Commission and the German Ministry of Transport and Digital Infrastructure, compiled by the NGO Pro-Rail Alliance, Switzerland leads with an electrification percentage of 100%, ahead of Belgium with 86%. The Netherlands, Sweden, Austria, Italy, Poland, and Spain follow, while Germany is placed at 61%—having increased railway electrification by no more than 2% between 2009 and 2019,[11] and France at 58%—having increased by 0.22% since 2014 and by 4% since 2019.[12] The Deutsche Bahn, the German railway company announced its 2040 climate neutrality goals in 2021, bringing them forward by 10 years compared to its previous target. The company has also committed itself to supplying its factories, offices, and stations with 100% renewable energy by 2025. To this end, it signed renewable energy purchasing agreements with Statkraft

a The passenger-kilometre, which corresponds to transporting a passenger over a distance of 1 kilometre, is the unit of reference for measuring the volume of passenger transport. In the same way, the tonne-kilometre corresponds to the transportation of a tonne of goods over a distance of 1 kilometre. These units therefore depend on the carbon footprint of the means of transport used as well as on their capacity (in goods or passengers).

and RWE[13] in 2021. To free low-traffic smaller regional lines ("*petites lignes*") from diesel, the SNCF in France has targeted a strategy known as "frugal electrification", which is based on the development of battery-powered trains, particularly for sections of railway that would be difficult to electrify – as seen in the pilot project using battery-powered trains on the Aix-Marseille line. This strategy also involves taking into consideration the specific needs of each line, whether mostly used by passengers or freight, and choosing electrification options accordingly—catenary or other.[14]

Throughout Europe, efforts are underway to electrify more lines or develop greener alternatives to diesel trains. In Lithuania, ABB won a contract for the electrification of the Vilnius-Klaipėda line within the framework of a larger programme aiming to electrify 39% of the country's railway lines (currently, only 8% are electrified), and to ensure better interoperability with the European network.[15] Alstom and Avax will work on the modernisation of the Thessaloniki-Idomeni line in northern Greece. This line is part of the pan-European X corridor which connects Thessaloniki to Budapest, passing through North Macedonia, Serbia and Hungary—one of the main freight corridors in Central and Eastern Europe.[16] Hungary is targeting hybrid trains in order make its network greener,[17] and recently strengthened its collaboration with Alstom, with the signing of a cooperation agreement to develop both the national rail sector and the manufacture of rolling stock at Alstom production sites in the country.[18]

Alongside electrification processes, the European energy crisis led to the issue of overall energy saving being added as a rail sector priority. Major operators have been taking steps to reduce their energy consumption: the SNCF is working to reduce the energy consumption of its trains by regulating their speed using more efficient traction technology, switching off the motor during stops, and reducing the energy consumption of its buildings and its heating.[19] Deutsche Bahn proposed an energy consumption reduction incentive to employees,[20] while the Swiss Federal Railways is reducing the speed of its trains, the temperature inside the trains, and the lighting in stations.[21]

In the United States, where the rail network is used more for freight than for passengers, the electrification percentage is below 1%.[22] Its future growth and profitability remain uncertain.[23] The Association of American Railroads states that electrification of the network using overhead lines is "unfeasible", while touting investments in battery-powered electric trains.[24] On the other side of the world, in Asia, electrification is in full swing. By March 2022, India had electrified almost 80% of its network,[25] while Pakistan and Bangladesh were also modernising their networks.[26] Southeast Asia has made progress in both electrification and the construction of high-speed lines, as evidenced by the development of the Jakarta-Bandung line in Indonesia (expected opening in 2023) or the construction works for the Bangkok-Nong Khai line in Thailand.[27]

As electrification progresses, the source of the electricity used to power the trains has without doubt an effect on the ultimate carbon footprint of rail transport—a concern that is being taken into account on the African continent,[28] as new rail projects are emerging in Senegal, Nigeria, Kenya, Guinea, and elsewhere. While rail electrification on the continent is currently at 15%, new projects are being developed, in particular those financed by the Chinese Belt and Road initiative,[b] or by way of competing European investments through the Global Gateway initiative.[29]

THE OBSERVATORY'S LENS

Adapting rail transport to global warming in order to stay on track

While rail transport has been identified as the least vulnerable to liability and transition risks[c] due to its relatively low share of emissions, they are relatively more exposed to physical risks. The modal share of rail transport for passengers and freight could be affected by an increase in traffic in years to come as current incentives materialise (such as those which are part of the EU's Sustainable and Smart Mobility Strategy, or the Green Deal, for example, or even national and local policies).[30, 31] In this context, rail operators should be better prepared to manage this additional traffic, given that they are exposed to physical risks associated with the impacts of climate change.

Little flexibility and high vulnerability

The greatest challenge for railways in the face of climate change comes from the low flexibility of their infrastructure and operations. These are very vulnerable to extremes of temperature and intense weather events. Failure of a single component may entail high replacement costs and long service interruptions.[32, 33] Extremes in temperature and amounts of rainfall, as well as storms, can all have an effect on various components of rail infrastructure, including the tracks themselves, railway signalling systems, overhead power lines, track-carrying infrastructure (such as bridges, tunnels, viaducts, etc.) and trackside structures (embankments, drainage, and vegetation) (**FIG. 2**).

High temperatures can, for example, directly affect the tracks, with thermal expansion and buckling of the rails, or electrical equipment, with sagging overhead cables. In most countries, rails are designed to operate within a range of 45 °C, depending on local conditions. In Great Britain, for example, rails are resistance-tested at temperatures up to 27 °C—a threshold that would undoubtedly be higher in a warmer climate—beyond which they remain vulnerable.[34] Forest fires may also affect the rails or obstruct them when vegetation alongside the tracks burns. High winds may cause overhead lines, trees, or

b See Observatory of Non-State Climate Action. (2021). Global Synthesis Report on Climate Action by Sector. *Climate Chance*.

c As proposed by Mark Carney, former Governor of the Bank of England, the risks faced by companies usually fall into 3 categories: "physical risks" resulting from the unpredictable effects of climate change on our environment; "transition risks" resulting from the effects of imposing a low-carbon economic model on economic actors; "liability risks" resulting from legal action initiated against the financial actors when they are held accountable for climate inaction.

objects to fall on tracks. Heavy and light rainfall may affect surrounding infrastructure such as slopes and embankments through landslides and flooding, or cause water damage to equipment.

The most recent examples of these effects occurred in 2022 when a heat wave severely hampered infrastructure and train routes across Europe. During last summer in France, problems with power lines and track-side fires interrupted train services in Brittany, and power cuts as a result of the heatwave led to a suspension of train traffic in Hauts-de-France. After calculating the temperature of the rails, the SNCF, and the RATP in Paris, imposed much lower speed limits on the trains and metros they operate, owing to the risk of rail deformation due to heat.[35] Similarly, in the UK, train speed was restricted as part of the red extreme heat warning,[36] two main line closures occurred, damage was caused to overhead power lines, and fires also spread to the tracks.[37]

UK operator Network Rail also reported the need to rebuild embankment infrastructure following landslides, and increasing pressure on drainage systems.[38] This problem is particularly acute in Europe and North America, where a lot of railway infrastructure is in places up to a century and a half old, and are therefore even less resilient to climate change.[39, 40] In 2018, a landslide caused a derailment in Catalonia, Spain, leading to one death and several injuries.[41] In 2020, heavy rainfall caused a derailment in Scotland, the first fatal railway accident in the UK in over 10 years. The 2021 floods in Belgium and Germany caused €1.3 billion in damage to railways, with damage to level crossings, bridges and signalling and electricity masts.[42]

The financial costs of these incidents increase each year, shifting their status from "*inconveniences*" to "*serious threats affecting every aspect of a rail operator's cost structure*".[43] In 2021, the Lava and Dixie fires in the United States caused serious damage to the infrastructure of freight giant Union Pacific, costing 100 million dollars. This was compounded by the chaos rampant throughout the network because trains needed to be rerouted, taking detours which quadrupled the duration of the journeys, and the need for additional manpower and resources.[44]

Around the world, rail operators must also adapt their operations to climate effects, whether by rerouting or rescheduling trains, or reassessing transport priorities. In the north of India, the 2022 summer heat wave forced Indian Railways to cancel more than 1,100 passenger and mail trains in order to make way for trains transporting coal to the country's power stations.[45] While timetables are being altered due to delays, operators are also asking passengers to limit their train travel,[46] or to prepare for higher temperatures.[47]

"Grey" and "green" solutions to adapting infrastructure

"Grey" or "hard" solutions in the context of adaptation (mainly coastal adaptation until now) refer to engineered solutions that involve artificial constructions. In contrast, "green" or "soft" solutions refer to using nature through smaller-scale initiatives, and may even complement "grey" solutions.[48, 49] In the context of railways, the majority of adapted solutions so far have been grey solutions, while the use of green solutions has been very limited, with very few studies on them.[50]

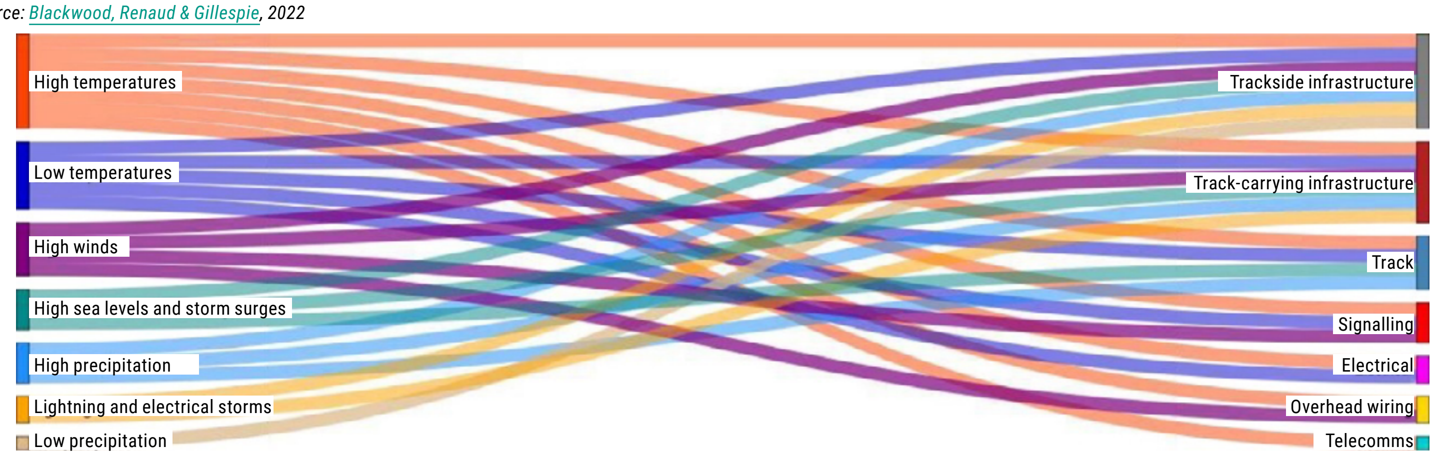
In the event of high temperatures directly affecting rails, an example of a commonly adopted solution is to paint the rails white in areas where they are directly exposed to the sun and therefore at risk of expansion—this has already been done in Germany, Italy,[51] Switzerland[52] and the UK,[53] among others. At the same time, the effectiveness of this method has been questioned, with calls for better anticipation and preparation for rail expansion and buckling by using composite materials or rail expansion joints that leave enough space.[54, 55] Network Rail has also resorted to using concrete to lay tracks rather than the traditional sleepers or gravel, since concrete can withstand greater forces.[56]

Overhead electrical cables can be adapted to higher temperatures by installing them with weights or springs to compen-

FIGURE 2

HYDRO-METEOROLOGICAL RISKS AFFECTING RAIL INFRASTRUCTURE

Source: Blackwood, Renaud & Gillespie, 2022



sate for sagging or, in the case of older cables, by adjusting their height and tension.[57] While slowing down trains is also an option, it carries the risk of traffic disruption and of potential losses for the operator. Generally, with infrastructure like bridges or overpasses, the most common protection against overheating is the use of automatic water sprinklers, or replacing existing infrastructure with heat-resistant infrastructure.[58]

In response to flooding and rising sea levels, grey options include raising the level of stations, installing dikes and pumps, and stabilising hillsides and slopes. Although all of these options have been put in practice at varying scales, a common problem often encountered by older railway networks is related to land use restrictions, since land surrounding the tracks is often not owned by the operators, which leads to extremely steep slopes along railway lines, for example. This remains a limiting factor that prevents many operators from taking action, as does the overall age of the rail network.[59, 60]

This is one of the advantages that green solutions could have, being relatively cost effective and requiring less extensive work. In addition, whereas grey infrastructure degrades over time, vegetation grows stronger as trees and plants take root.[61] Green corridors and vegetation for shade have been identified as ways to reduce direct sun exposure, although careful selection of specific species and vegetation management is crucial to ensure that the trees and plants do not become a hindrance or block the rails. Windbreaks, biotechnical stabilisation and bioengineering[d] of embankments and slopes are potential solutions to turning grey infrastructure green.[62]

Although limited, there are examples of the use of such solutions, such as the net positive biodiversity policy of the Thameslink upgrade and extension programme, which involved the construction of embankments on either side of the railway in London by planting wild native flower species to reduce runoff.[63] The Adelaide-Seaford line in Australia completed a project to green the corridor by planting trees along the line, but these were eventually uprooted in order to carry out the electrification of the line, thereby highlighting the potential conflicts between the mitigation and adaptation strategies in the sector. Although other projects have been proposed and vegetation planting initiatives have been carried out, there is insufficient information on the relevant benefits of these initiatives.[64]

Adaptation specific to the region in question is also to be considered, because railways face different challenges in different geographic areas.[65] In Egypt, for example, sandstorms cause problems on railway lines, with sand accumulating and settling on the tracks. Since 1999, Egyptian National Railways has studied wind patterns and topology to make aerodynamic modifications to the slopes of embankments in order to protect the Abou Tartour – Qena freight line.[66]

In various projects in emerging countries, adaptation is integrated into new rail projects from the outset. Incorporating adaptation as a criterion at the design phase is also less costly.[67] In India, the Dedicated Freight Corridor development project takes proactive adaptation measures against fog (advanced communication between track signals and the train cabin), temperature variations (definition of thresholds, development of early warning systems and sensors on the rails), and floods (definition of thresholds and integration of climatic provisions in construction standards).[68] In China, the Railway Design Corporation is developing measures to keep high-speed lines running under conditions of extreme cold, such as “freeze-thaw” embankments, antifreeze materials for bridges and other civil engineering structures, switches to melt ice and snow, etc. In 2017, 2,659 km of tracks were built using these technologies and an additional 2,572 km were under construction during this period.[69] In 2021, the country successfully tested the Fuxing high-speed train, which is capable of withstanding blizzards and temperatures down to -40 °C.[70]

Adaptation at the institutional level: a matter of taking ownership of issues

At the transnational level, especially in Europe, various initiatives have been launched to study the impact of extreme meteorological conditions and climate change on rail transport and related infrastructure. In 2009, the International Union of Railways (UIC) launched the Adaptation of Railway Infrastructure to Climate Change (ARISCC)[71] project, with the aim of establishing cooperation between professional sectors and fields, meteorologists and climatologists working with railway experts to improve preparedness.[72] The findings and case studies resulting from the programme were then made available on the dedicated website. The UIC also has a framework document—RAIL ADAPT—to help rail companies adapt to climate change and support national climate commitments.[73]

Various initiatives have also been launched at the European level, such as those financed by the European Commission, with programmes that include FP7 EWENT, FP7 WEATHER, FP7 SMART RAIL, MOWE-IT, or the Horizon2020 Destination RAIL project, all of which have produced results and recommendations on topics such as the impacts, consequences, and costs of extreme weather on rail networks, risk modelling, and the best practices for the effective management and maintenance of such infrastructure.[74] There are also research initiatives at the national level, often led by governments in partnership with rail operators and relevant stakeholders—such as the TRaCCA (Tomorrow’s Railway and Climate Change Adaptation)[75] project in the UK. In Spain, a government initiative[76] working with all major transport stakeholders (including Renfe, the national railway company) studied the vulnerability of infrastructure to climate change in order to understand requirements in terms of adaptation.

d Bioengineering and biotechnical stabilisation involves the use of vegetation to maintain stability and reduce the risk of erosion and runoff—instead of using gabions or soil nails, for example.

Building on this knowledge and working within national institutional adaptation frameworks, rail operators have adopted various adaptation strategies, taking ownership of adaptation actions to varying degrees. In the United States, several operators are working under Federal Railway Administration programmes to bolster the resilience of the sector.[77] The SNCF carries out annual inspections in order to assess adaptation measures each summer, and is currently working on its adaptation roadmap as part of the national adaptation plan.[78] In Canada, as part of the development of the first National Adaptation Strategy, the Rail Climate Change Adaptation Program will contribute up to 2.2 million dollars of funding to Canadian railways to share the costs of research on improving their resilience.[79] Network Rail is working on its network based on findings from TRaCCA and its own Weather Resilience and Climate Change Adaptation plans (WRCCA).[80, 81] In response to the 2022 heat wave, Network Rail also launched its resilience task force made up of independent experts.[82]

Therefore, while most railway operators, nationalised or not, have set up a strategy for adapting to climate change, the manifestation of these strategies varies, ranging from dispersed actions or a wider adoption of national strategies, to detailed and documented operator strategies. Among the factors influencing the effectiveness of adaptation strategies are the organisational values of operators, knowledge of the vulnerabilities to climate change and the integration of this knowledge into daily operational practice, and the simultaneous consideration of adaptation and mitigation actions.[83]

KEY TAKEAWAYS

Rail is currently among the relatively green modes of transport for both freight and passengers, and is on the way to becoming more so as rail electrification progresses—although rates vary according to region, and the benefits of this process must be assessed while taking the electricity mix into account. However, with the effects of climate change becoming apparent, the rail sector is left vulnerable to costly disruption and damage to infrastructure. While short-term "grey" solutions are adopted in immediate response to crises, railway operators are already considering longer-term options, such as using more natural "green" solutions. The incorporation of adaptation criteria in the design of projects prior to their launch is emerging in developing countries. While knowledge of rail transport adaptation issues is growing, the implementation of the relevant recommendations is hindered by a number of factors, such as land ownership and the lack of ownership of adaptation issues within national institutional frameworks.

TRANSPORT

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