Report
Rail Resilience to Climate Change
Impact of extreme weather events on the European railway system

EUROPEAN UNION AGENCY FOR RAILWAYS

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ERA would also like to thank all the stakeholders which have contributed to the different surveys and interviews organised being infrastructure managers, representative bodies, national safety authorities (NSAs) and ERA staff from different units who shared knowledge and experience to improve the quality of this report.

Welcome Message from Director-General for Mobility and Transport at the European Commission (DG MOVE)

The transport sector is the largest source of greenhouse gas emissions in the European Union with around 25% of total EU greenhouse gas emissions and has shown little progress in emission reduction in recent decades. Reducing emissions is one of the greatest challenges in achieving a sustainable transformation of the EU's mobility systems and mitigate the climate change consequences.

Rail is playing a crucial role in this mitigation transport policy with the lowest greenhouse gas emissions of all mass transport modes and the highest degree of energy independence and efficiency. However, mitigation alone is not enough to limit the impact of climate change, it goes in pair with adaptation.

The work done by ERA is an important step as it gives a comprehensive view on the impact of extreme weather events on the European rail system. It is a necessary blocking stone to build sound adaptation policies and better target the investment needs to make our railway network more resilient. In December, we published a study on climate adaptation and cross-border investment needs of the TEN-T network. According to this assessment the costs for the rail networks to adapt to the climate conditions predicted for around 2050 is expected to be 27.4 billion EUR.

A resilient transport system should go beyond the immediate emergency response to the adverse consequences of climate change. It should include foresight thinking with adaptation at its core so that it is able to withstand higher and more severe risks and in particular floods, windstorms, landslides and wildfires.

As this report demonstrates the need to take action in the rail sector, the Commission is fully committed to reinforce our resilience and is therefore preparing a European Integrated Framework for Climate Resilience, an agenda of support to build resilience by design and which is expected to be adopted during the second half of 2026. The Commission will continue to work in cooperation with the European Union Agency for Railways and other relevant partners to ensure a coordinated and effective response across the rail sector.

Magda Kopczyńska, Director-General for Mobility and Transport, European Commission

Welcome Message from EEA Executive Director

Resilient railways in a warming Europe

Railways play an essential role in low-carbon and sustainable transport, conveying passengers and goods with far lower energy use and greenhouse gas emissions per kilometre than road or air transport. Railways are also wonderfully romantic. They hold immense cultural and societal value, and shape how people experience distance, time and connection. Over the years they have influenced literature, film, music, art, architecture and everyday life, and have helped to forge a sense of collective European identity.

We need to protect this vital social and cultural asset in the face of climate change. With Europe warming faster than any other continent, it is vital that we maintain our rail networks and prepare them for the increasing impacts of extreme weather.

Climate change is already affecting the railway system through heatwaves, heavy rainfall, and flooding, leading to operational disruptions and economic losses. Risk assessments are essential to understand impacts and to identify the best adaptation measures to strengthen the resilience of the railway system. Knowing what lies ahead is the best way to avoid the worst effects.

In 2024, the European Environment Agency published the first European Climate Risk Assessment (EUCRA). This report identifies 36 major climate risks with the potential for severe consequences. They are grouped into five broad clusters: ecosystems, food, health, infrastructure (including railways), and economy and finance.

EUCRA highlights the main impact drivers that can disrupt or damage long-term assets like rail lines, bridges and tunnels. They are: extreme heat; prolonged drought; intense precipitation; flooding; sea-level rise; and cascading or compound events. These impact drivers affect all European regions, with hotspots in Southern Europe and low-lying coastal zones. To maintain the continuity of Europe's rail infrastructure, adaptation measures will be needed in many different places.

Among rail network owners and operators, some frontrunners are already taking action. This is evidenced by several case studies published on the knowledge-sharing platform, Climate-ADAPT. One such example is railway modernisation in Slovakia, which is tackling climate risks through technical, management and early-warning measures.

Over the past twenty years, the European Union Agency for Railways (ERA) has played a key role in supporting the development of rail as a sustainable transport mode by promoting railway safety, interoperability and harmonisation across European rail systems.

This timely report helps to develop a much-needed systemic approach to improving rail resilience. It also provides a baseline to better understand the impacts of extreme weather on rail infrastructure and operators.

I am proud of the European Environment Agency's contribution to this work, which strengthens the shared knowledge base needed to inform action, guide investment and support effective adaptation across Europe's rail sector. This collective effort must now translate into concrete action to strengthen the resilience of our rail networks and, by extension, the resilience of European society. The time to act is now.

Leena Ylä-Mononen, Executive Director, European Environment Agency

Welcome Message from ERA Executive Director

Climate change is among the top three pressing issues in most of EU Member States and 81% of European citizens support the EU goal of reaching climate neutrality by 2050. If the level of concern regarding climate change and the level of support to the European actions in this field are so high, it is because **climate change is a non-contestable reality**. Indeed, 38% of European citizens already feel personally exposed to climate-related risks and it can go up to more than half of the citizens in certain Member States, especially in Southern Europe. All economic sectors are confronted to this reality.

The aim of this study is to better understand the impact of climate change on the railway sector and the conclusions are clear: the railway system is exposed to extreme weather events, whose frequency and intensity are increasing with climate change. Two thirds of rail infrastructure managers reported **clear impact of extreme weather events** on their networks across Europe.

With this report, a better view on the impact of climate change on the railway system has been developed. Although this is very important, it is far from being sufficient. Climate resilience is a topic that has rapidly moved from long-term strategic reflection to an urgent operational priority, and all of us in the rail system should now accelerate the transition **from a reactive approach to a more pro-active and systematic one**.

The increasing frequency and intensity of extreme weather events directly affect the reliability, availability, and performance of the railway network and its level of safety. Strengthening resilience is not only an environmental or infrastructural concern; it is **a core requirement for railway safety and interoperability**.

Several areas can be improved to ensure this move can happen. As a starting point, **structuring data collection** and harmonising data terminology, together with **vulnerability and risk assessments**, should allow to take more informed decision on adaptation measures to be implemented. Equally important is the **systematic monitoring and evaluation of adaptation measures** once deployed, to ensure they deliver the expected level of resilience and to enable continuous improvement over time, while sharing this information with other interested stakeholders. Using climate projections to embed resilience considerations by design in the existing construction rules and existing funding instruments is also key to ensure that **in-built resilience measures** are adopted at an early stage when planning investments.

Investment needs on the railway network are increasing to maintain and improve the safety level, to enhance interoperability and capacity, to develop the European high-speed network, to facilitate military mobility or to adapt to the climate change challenge. While those investments might be perceived as competing with each other, they must be considered holistically and prioritised with the aim of improving the performance of the European railway system, of completing the Single European Railway Area, while reflecting long-term climate risks. Developing this global view on **investments synergies and prioritisation** needs to be accompanied by **smart regulations**, allowing to address those challenges without creating additional obstacles on stakeholders.

I share the pride feeling of Leena Ylä-Mononen on the work achieved, and the **excellent cooperation with the European Environment Agency**. Cooperation is also needed at broader scale between all railway stakeholders and European organisations to build a coordinated approach on the regulatory framework and to foster the adaptation investments to be made. ***Cooperation is therefore not just desirable; it is indispensable for achieving all our shared objectives and for building a resilient, future-proof European railway system***.

Oana Gherghinescu, Executive Director, European Union Agency for Railways

1. Executive summary

In the Summer 2024 the European Commission requested the European Union Agency for Railways to perform a study on climate resilience of the railway system within the Technical Specifications for Interoperability revision request 2024-2030+. One of the aims of this study is to have a better understanding of the trends of extreme weather events and their consequences on rail infrastructure and operations[1]

The European Union Agency for Railways has prepared a questionnaire to collect data from the main infrastructure managers on the frequency of those events and the severity of their impact over the period 2005-2024 in the European Union plus Norway, Switzerland and the United Kingdom (the latter for benchmarking purposes). Only the events having as an impact at least EUR 2 million of damage and/or traffic disruption of at least six hours have been considered in the scope of the study. In parallel to this data collection, the European Union Agency for Railways organised bilateral meetings with all the main infrastructure managers covering topics such as data collection and monitoring of data, climate risks and vulnerability assessments, adaptation measures and plan or evolution of the European legal framework.

The railway system is particularly sensitive to the following climate hazards: heavy precipitation and floods (coastal, pluvial, fluvial, ground water), landslides, snowstorms and cold waves, heatwaves and wildfires and windstorms. The study is focusing on those climate hazards although the infrastructure managers have been given the possibility to identify other extreme weather events. Based on their own criteria infrastructure managers have identified floods, windstorms and landslides as the main climate hazards affecting rail infrastructure and operations.

70% of the EU infrastructure managers (i.e. 19 infrastructure managers in 27 Member States, representing 79% of the EU network in track-km) and Network Rail in the United Kingdom perceived an increase of the weather events' impact on rail operation and infrastructure. This perception is corroborated by the data gathered as the yearly number of events shows a notable increase between 2017 and 2018, peaking in 2018. Following a decline in 2019 and 2020, the number of events stabilizes between 2021 and 2023, with moderate fluctuations. Although a slight decrease is observed in 2024 compared to previous years, the value remains broadly consistent with the lower range recorded in previous years confirming an increasing trend over the past decade.

Economic losses due to extreme weather events are increasing over the last decades at EU level all sectors combined. For the railway sector, although data gathered were not sufficient and needed a deeper data cleaning / validation to establish trends, most of the infrastructure managers (23 out EU27 and Network Rail) stated that they faced extreme weather event(s) that have severely impacted their rail system over the last 5 years. In addition, it was possible to analyse the total annual railway delays (in hours) across the European Union caused by extreme weather events from 2015 through 2024. The delay fluctuations reflect the uneven but intensifying impact of extreme weather on rail operations over the past decade.

Climate-proof assets should be designed according to climate projections. However, only 37% of the infrastructure managers and Network Rail are using climate projections and Intergovernmental Panel on Climate Change's scenarios to design new assets. In addition, a bit less than half of the infrastructure managers has developed an adaptation plan. Infrastructure managers which do not have an adaptation plan are still usually taking adap-

([1]) The original EC request regarding Climate resilience states: "*Activities including, but not limited to: i) Assessing and if relevant, proposing changes in the technical legal framework that could contribute to increased resilience of the railway system, an ii)–Taking the environmental impact of the proposed resilience measures into account.*"

tation measures. However, those measures are more targeting a specific risk in a specific geographical area and are not encompassed in a global strategy at the level of the infrastructure manager and with a long-term strategy.

Finally, the European Union Agency for Railways, as requested by the European Commission, has developed 6 proposals to improve the European technical legal framework regarding the resilience of the railway system to climate change. These proposals cover the areas of data collection, climate risk assessment, contingency arrangements, evolution of requirements, standards and norms, role of the authorities and cooperation among railway stakeholders.

2. Introduction

Extreme weather events have impacted the railway system heavily in the 2020's with particularly a series of important floods with dramatic consequences going much beyond the railway sector only. Although it is difficult to link single events with climate change, climate change increases the severity and frequency of extreme weather events. However, no overview has been developed on the increased frequency and severity – or not – of extreme weather events on the railway system. Following a request from the European Commission to ERA in Summer 2024, this study is a first attempt to build a better understanding on the trends of extreme weather events and their consequences on rail infrastructure and operations.

ERA has first analysed the sensitivity of the railway system to climate change (chapter 4.1) mostly based on the European Climate Risk Assessment developed by the European Environment Agency in 2024 and constant exchanges with this Agency. ERA has gathered data on extreme weather events from the main infrastructure managers in the EU and Norway, Switzerland and the United Kingdom and organised bilateral interviews to be able to establish the mentioned trends (chapter 4.2). Based on those data, ERA has analysed the economic consequences of those events on the railway system (chapter 4.3). ERA has identified the long-term climate trends based on the Intergovernmental Panel on Climate Change (IPCC) work which should influence future railway developments and adaptation measures to be put in place for the existing infrastructure (chapter 4.4).

Based on the qualitative interviews with the infrastructure managers, ERA identified the measures put in place to respond to the climate change challenge (chapter 5.1) and some best practices (chapter 5.2). An on-line questionnaire was also sent to the NSAs to better understand their role in ensuring a resilient rail system and their answers have been analysed (chapter 5.3).

During the bilateral interviews, infrastructure managers have put forward some proposals to improve the resilience of the railway system (chapter 6.1) and ITF has identified some high-level recommendations on this topic (chapter 6.2). These proposals and recommendations have served as inputs to develop proposals to improve the European technical legal framework aimed at enhancing the resilience of the railway system (chapter 6.3).

Finally, the annexes give additional information to facilitate the reading of the report (Annex 1 on abbreviations, Annex 2 on definitions and Annex 3 on resources) and provide the details on the contributors to the various surveys (Annex 4 on data collection, Annex 5 on bilateral interviews and Annex 6 on NSAs' contribution). A conference has been organised in June 2025 on rail resilience to climate and minutes of the conference has been drafted (Annex 7). This report has been subject to review by the relevant stakeholders and a workshop has been organised in November 2025 to discuss the various comments received (Annex 8). Finally, the data gathered from Network Rail in the United Kingdom have been used as a benchmark (Annex 9).

3. Methodology of the study

ERA published its first Rail Environmental Report in July 2024[2]. The last chapter of this report focused on rail resilience and occurrences for which weather was a direct cause or a contributing factor. However, this report was also an opportunity to acknowledge that there was no overall data at European level on the frequency and consequences of extreme weather events on rail infrastructure and operations. This lack of European overview on the recalled events impedes a comprehensive analysis of their trends.

While the topic of rail resilience to climate change gains more importance at all levels, developing a more structured approach to improve rail resilience to climate change at European level has been identified as a necessity. In the Summer 2024 the European Commission requested ERA to perform a study on climate resilience of the railway system within the Technical Specifications for Interoperability (TSIs) revision request 2024-2030+. ERA has organised a series of bilateral meetings with targeted organisations in September-October 2024 to define the scope of the present study in more details.

One of the aims of this study is to have a better understanding of the trends of extreme weather events and their consequences on rail infrastructure and operations. To do so, ERA has prepared a questionnaire to collect data from the main infrastructure managers on the frequency of those events and the severity of their impact. This questionnaire focused on extreme weather events (heavy precipitation, floods and landslides, snowstorm and cold waves, heatwaves and wildfires, high winds and hurricanes), their frequency and the severity of their consequences on the rail infrastructure and operation over the period 2005-2024 in the European Union plus Norway, Switzerland and the United Kingdom. Considering the potential high number of events and to give a threshold for the events to be reported, it was decided to use criteria coming from the Railway Safety Directive[3] and to consider only the events having the following impact:

- At least EUR 2 million of damage which is considered in the definition of 'serious accident' as 'extensive damage'. Estimated or real costs were requested to infrastructure managers for each single event in three categories: infrastructure, rolling stock and operational; and/or
- Traffic disruption of at least six hours which is considered in the common definitions for the Common Safety Indicators (CSIs) as 'extensive disruptions to traffic'. It was decided to also add situation in which railway traffic is stopped as a preventive measure to reduce inconveniences and safety risks due to a meteorological alert. In some cases, answers were received with cumulated train delays.

Annex 4 lists the contribution received from the infrastructure managers. 22 out of 27 IMs plus Network Rail in the UK replied to the quantitative data and 19 out of 22 IMs plus Network Rail in the UK provided data.

In parallel to this data collection, ERA organised bilateral meetings with the main infrastructure managers in each of the countries in the scope of the study to exchange on some qualitative aspects having also the objectives of identifying best practices currently in place in tackling climate risks. The topics were among others:

- Data collection and monitoring of data;
- Description of specific extreme weather events;
- Impact of extreme weather events and climate projections;
- Methodology used to determine the impact;
- Climate risks and vulnerability assessments;
- Vulnerable equipments and geographical areas;
- Adaptation measures and plan;
- Maintenance;

(2) Rail & Environnement | European Union Agency for Railways
(3) Directive–2016/798–EN–railway safety–EUR-Lex

- Crisis management;
- Evolution of norms and standards;
- Cooperation with other organisations;
- Competence Management System;
- Evolution of the European legal framework.

Annex 5 lists the interviews organised and their dates. All targeted infrastructure managers have participated to these interviews.

To complete the picture, ERA also developed a short survey to better understand the role that the (NSAs may have in ensuring a higher degree of resilience to climate change. The survey considered the following aspects:

- Monitoring weather events' impact on rail infrastructure and operation;
- Climate risks and contingency arrangements addressing extreme weather conditions as part of Single Safety Certificate and Safety Authorisation assessments;
- National rules, evolution of norms and standards for the authorisation for placing in service of fixed installations.

Annex 6 provides an overview of the contributions. 56% of the NSAs from EU Member States (MS) replied to this questionnaire and NSAs from CH, NO and UK.

As part of the Polish Presidency to the European Union (EU), ERA, in cooperation with the European Commission and the Polish NSA (UTK), organised a conference on rail resilience to climate change[4] on the 16th of June 2025 in Warsaw. The presentations and discussions during the conference also served as an input to the study.

Annex 7 provides the programme of the conference and summarises the interventions of the different speakers.

Following the distribution of the draft report and the comments received, a workshop was organised on the 13th of November 2025 where representative bodies, NSAs, National Investigation Bodies (NIBs) and the IMs who participated to the study were invited. Its aim was to present formally the results of the study with a specific focus on the proposals made to improve the European legal framework and to discuss the comments received and potential further proposals made.

Annex 8 contains information on the comments received and the minutes of this meeting.

Finally, it was clear from the very beginning that the aim of the study would not be to assess the damage related to the increasing intensity/frequency of extreme weather events due to climate change. This aspect is not part of the scope of the study. Although climate change is a reality that most of the railway operators are already confronted with, it is very difficult to establish a direct correlation between a specific weather event and climate change.

This study considered Directive (EU) 2022/2557[5] on the resilience of critical entities which states that each Member State shall identify the critical entities for different sector, including the rail sector, by the 17th of July 2026. It also considered to a minor extent the importance given to military mobility in the current geopolitical context. The study largely focuses on the impact of past extreme weather events on the infrastructure and operation given the magnitude of this impact compared to the one on rolling stock. In addition, the on-going FP4-Rail4Earth project under Europe's Rail programme is dedicated, among other aspects, to research on the impact to rolling stock[6].

(4) Conference on Rail Resilience to Climate Change | European Union Agency for Railways
(5) Directive–2022/2557–FR–CER–EUR-Lex
(6) Flagship Project 4: RAIL4EARTH–A sustainable and green rail system–Europe's Rail

Table 1: Timeline of the study

Scope of work	Timeline
Desk research and targeted bilateral interviews (DZSF, EEA, EIB, Belgian Ministry of Transport, ITF, CER/EIM, Europe's Rail) to improve the scope of the study and work on questionnaires.	September–December 2024
Data collection from IMs	December 2024 – May 2025[7]
Bilateral interviews with IMs	January – May 2025
Survey to NSAs	April 2025 – June 2025
European Commission-ERA-UTK conference on rail resilience to climate change	16 June 2025
ERA internal consultation	June 2025
Draft report including internal consultation and consultation with the European Commission	May – September 2025
External consultation	October 2025
Workshop	13 November 2025
Final report sent to the European Commission	December 2025
Final report publicly available	1st quarter 2026 and webinar to present the results of the report

(7) Additional contributions were received in October and November 2025.

4. Climate change impact on the European railway system

4.1. Sensitivity of the European railway system to climate change

Globally, 2024 was the warmest year ever recorded and the first year with a global average temperature exceeding 1.5°C above the pre-industrial level[8]. While higher temperatures increase the likelihood of extreme weather events such as heatwaves and heavy rainfall, the relationship varies by region and season. That year, Europe saw both record warmth in the East and the most extensive flooding since 2013, driven by prolonged and intense rainfall episodes.

In 2024, the European Environment Agency published the first European Climate Risk Assessment[9] in which 36 climate risks have been identified which could negatively affect Europeans' lifestyle including increased mortality, exacerbate crisis and impact the European economy while substantially varying across European countries and regions. On top of the necessary mitigation measures aimed at reducing greenhouse gas emissions, adaptation measures also need to be implemented depending on the risk levels of the different sectors and geographical areas.

Climate change represents a challenge for the railway system, especially in terms of safety and regularity, as well as for other modes of transport and economic sectors. While the railway transport is the mode of transport with the lowest level of greenhouse gases emissions, it is facing some specific vulnerabilities compared to other modes of transport and needs to plan to be fit for the future. In addition, infrastructures are highly interconnected meaning that a disruption in one sector, such as electricity distribution, can affect others, such as train operations. Similarly, climate hazards can also interact in compound or sequential ways, for example, drought followed by heavy rainfall can increase the risk of flood. Indeed, damage to the built environment from extreme weather events is projected to increase up to 10-fold by the end of the 21st century due to climate change alone with the most significant increases in impacts expected in the energy and transport sectors.

Figure 1: Climate risks identified for 'infrastructure' cluster, European Climate Risk Assessment, European Environment Agency, 2024

Climate risks for 'Infrastructure' cluster	Urgency to act	Risk severity			Policy characteristics		
		Current	Mid-century	Late century (low/high warming scenario)	Policy horizon	Policy readiness	Risk ownership
Pluvial and fluvial flooding		+++	+++	++	Long	Medium	Co-owned
Coastal flooding		+++	+++	+++	Long	Advanced	Co-owned
Damage to infrastructure and buildings (*)		++	++	++	Long	Medium	Co-owned
Energy disruption due to heat and drought (hotspot region: southern Europe)		++	++	++	Medium	Medium	Co-owned
Energy disruption due to heat and drought		++	++	+	Medium	Medium	Co-owned
Energy disruption due to flooding		++	++	++	Long	Advanced	Co-owned
Marine transport		++	++	++	Medium	Medium	Co-owned
Land-based transport		++	++	++	Medium	Medium	Co-owned

Legends and notes

Urgency to act
- Urgent action needed
- More action needed
- Further investigation
- Sustain current action
- Watching brief

Risk severity
- Catastrophic
- Critical
- Substantial
- Limited

Confidence
Low: +
Medium: ++
High: +++

(*) Urgency based on high warming scenario (late century)

(8) Copernicus Climate Change Service (C3S) and World Meteorological Organization (WMO), 2025: European State of the Climate 2024, climate.copernicus.eu/ESOTC/2024, doi.org/10.24381/14j9-s541
(9) European Climate Risk Assessment, European Environment Agency, 2024

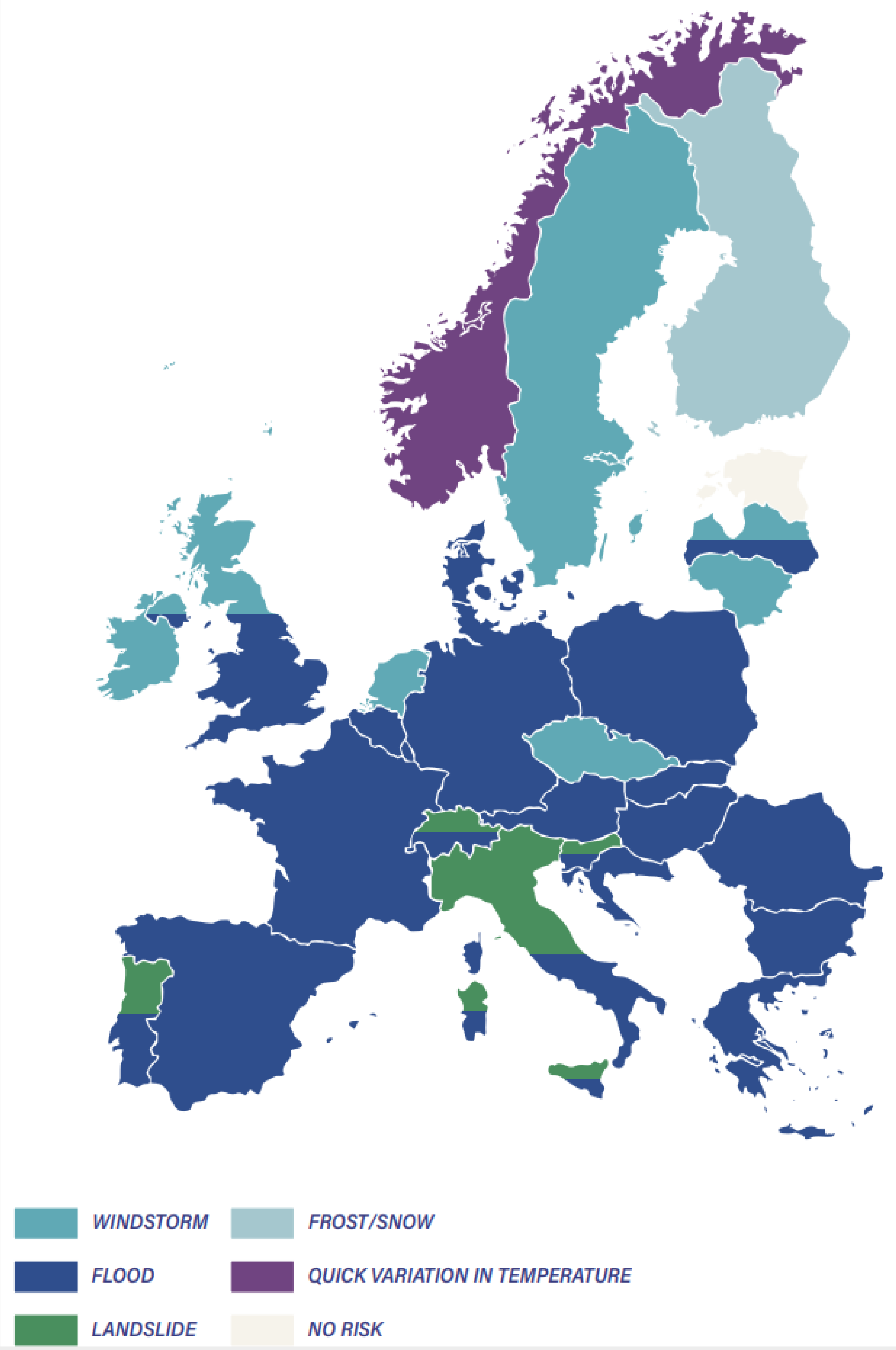
Among the 7 risks identified within the infrastructure cluster, pluvial and fluvial floods are the risks with the highest probability of severe consequences. As most economic losses are caused by fluvial flooding, this area should be a priority. The urgency to act is particularly valid for the critical infrastructures[10] which are essential for the European economy, the European transport system (TEN-T) and/or crucial for military mobility.

Coherently with the climate risk assessment made by EEA, the flood risk has been identified as the most important one by a large majority of the infrastructure managers (20 out of 27 IMs mentioned the flood risk as the main one). This risk materialised in recent years with catastrophic events heavily impacting the railway system and with consequences much beyond it. The floods which caused the greatest economic damage in recent years are:

- in July 2021 in Germany, Belgium and the Netherlands;
- in May 2023 in Italy;
- in August 2023 in Slovenia;
- in September 2023 in Greece;
- in September 2024 in Central Europe and in particular in Austria, Poland and Czechia;
- in October 2024 in Spain.

([10]) Directive (EU) 2022/2557 of the European Parliament and of the Council of 14 December 2022 on the resilience of critical entities and repealing Council Directive 2008/114/EC

Figure 2: Main climate hazards identified by the main infrastructure manager per country during the interviews, European Union Agency for Railways, 2025



Note: When a country is represented with two colours, it means that the main infrastructure manager of that country identified two main climate hazards at national level. It is not to be intended as regional differences within the country.

Based on their own criterion (e.g. most devastating economic consequences, most extensive operational restrictions, frequency of the events), IMs have identified floods, windstorms and landslides as the main climate hazards affecting rail infrastructure and operations. As the risk of flood is the main one for most of the IMs, most of the efforts are made to identify risk areas and the percentage of the network exposed to HQ100 and HQ300[11]. Vulnerability assessments are carried out for specific equipment (in particular bridges and embankments) or for specific geographical locations. The most exposed and vulnerable to flooding are the structural "infrastructure" and "energy" subsystems. For instance, in Belgium, the flood risk is higher in Wallonia compared to Flanders because of topographical reasons and a lot of railway tracks are along the rivers. In Ireland, the Dublin Area Rapid Transport (DART) in Dublin area needs to be more protected to the sea level rise as the line is along the coast. In Germany, the main IM has identified Upper Rhine Valley and Brandenburg regions as the most affected ones.

For EU co-funded projects, climate proofing is generally a mandatory requirement for funding[12], although the extent and quality of its application can very between projects. In addition, almost all IMs are closely connected with their national meteorological office with sharing of information on short-term meteorological forecasted events and, for some of them, also on longer term predictions.

To better understand the impact of extreme weather events, it was necessary to define the climate hazards integrated in the scope of the study. The climate hazards as classified in the Commission Delegated Regulation (EU) 2021/2139[13] were used in the first place as an established list of climate hazards.

Table 2: Appendix A on Classification of climate-related hazards, Commission Delegated Regulation (EU) 2021/2139, 2021

#	Temperature-related	Wind-related	Water-related	Solid mass-related
Chronic	• Changing temperature (air, freshwater, marine water) • Heat stress • Temperature variability • Permafrost thawing	• Changing wind patterns	• Changing precipitation patterns and types (rain, hail, snow/ice) • Precipitation or hydrological variability • Ocean acidification • Saline intrusion • Sea level rise • Water stress	• Coastal erosion • Soil degradation • Soil erosion • Solifluction
Acute	• Heatwave • Cold wave/frost • Wildfire	• Cyclone, hurricane, typhoon • Storm (including blizzards, dust and sandstorms) • Tornado	• Drought • Heavy precipitation (rain, hail, snow/ice) • Flood (coastal, fluvial, pluvial, ground water) • Glacial lake outburst	• Avalanche • Landslide • Subsidence

As a second step, EEA defined in its European Climate Risk Assessment the sensitivity of the railway system to climate hazards in Europe as follows:

(11) Hundred-year flood — European Environment Agency: Flood hazard is clustered into different mean recurrence intervals in the range of frequent to very rare. HQ100 defines a flood statistically happening every 100 years while HQ300 every 300 years.
(12) This is a requirement for Recovery and Resilience Facility funding and for European Regional Development Fund but not yet for Connecting Europe Facility funding.
(13) Commission Delegated Regulation (EU) 2021/2139 of 4 June 2021 supplementing Regulation (EU) 2020/852 of the European Parliament and of the Council by establishing the technical screening criteria for determining the conditions under which an economic activity qualifies as contributing substantially to climate change mitigation or climate change adaptation and for determining whether that economic activity causes no significant harm to any of the other environmental objectives, OJ L 442 9.12.2021, p. 1, ELI: https://eur-lex.europa.eu/eli/reg_del/2021/2139/2025-01-08.

Table 3: Sensitivity of the railway system to climate hazards in Europe, European Climate Risk Assessment, European Environment Agency, 2024

Heatwaves	Cold waves	Droughts[14]	Wildfires	River and coastal floods	Windstorms
Medium	Medium	No	Medium	High	Low

Based on those inputs, it was possible to define the scope of the extreme weather events covered by this study and for which data have been gathered. The study is focusing on the following climate hazards:

- Heavy precipitation and floods (coastal, pluvial, fluvial, ground water);
- Landslides;
- Snowstorms and cold waves;
- Heatwaves and wildfires;
- Windstorms.

Droughts were excluded from the scope of this study. Although droughts might be an indirect cause of floods due to the lower capacity of the soil to absorb the precipitations, railway is not considered to be directly affected by droughts. However, the respondents to the questionnaire had the opportunity to add climate hazards in their answers. For instance, lightning has been mentioned as a climate hazard which impacted several infrastructure managers.

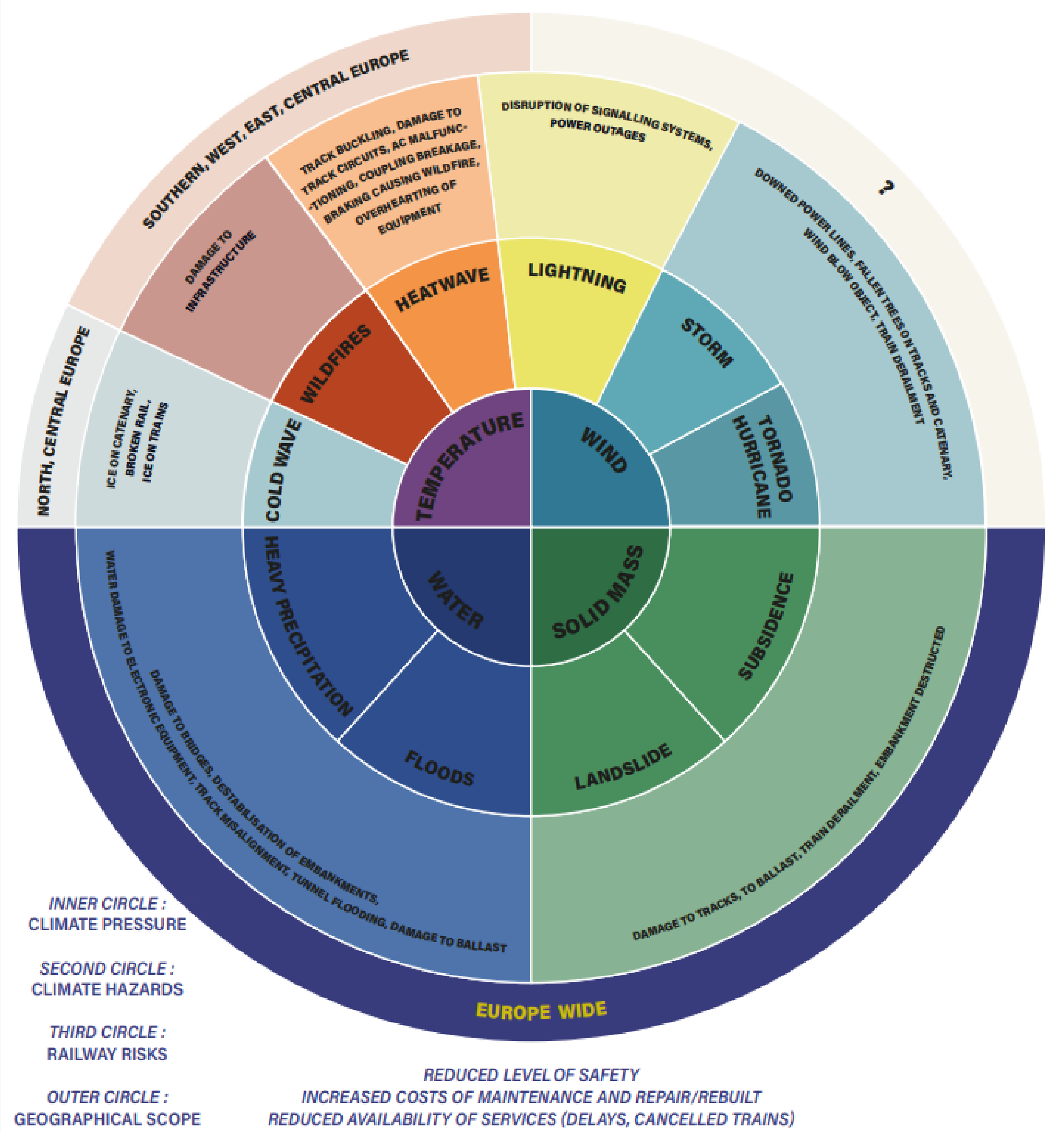
Based on all this information, ERA developed a climate railway risks wheel in figure 3 which synthetises:

- The *climate pressures*:
  - higher temperatures with the 10 last years being the warmest 10 years on record according to the European State of the Climate 2024[15].
  - Stronger winds with the 1990s and 2000s having generally above-average wind speeds, while the 2010s and 2020s saw both large positive and negative anomalies.
  - Heavier precipitations with the railway sector facing double to triple flood risk under different global warming level scenarios, potentially leading to substantial public expenditure increases (Bubeck et al., 2019).
  - and effects on the solid mass;
- The correlated *climate hazards* identified above[16];
- The *railway risks* linked to the climate hazards from track buckling and destabilisation of embankments to destruction of structural subsystems; and, finally,
- The *geographical areas* where those risks are becoming more important with the exceptions of cold waves which should be less frequent and intense with a reduced period of the length of the snowfall season and far fewer winter snow days than average. The wind projections have no clear trend, and it is, at this stage, not clear how they might evolve in the future.

Eventually, those railway risks, if not well controlled, can impact negatively the level of railway safety, increase the costs of maintenance and repairing/rebuilding of assets and, finally, reduce the level of availability of train services with more delays and cancelled trains.

(14) Droughts may have an impact on the railway system as a drought with clay soils can lead to subsidence of the tracks as well as platforms. It can also increase the risk in case of subsequent heavy precipitation with the soil not having the same ability to absorb water. The sensitivity of the railway system to drought could be reclassified as "low" instead of "no".
(15) European State of the Climate 2024 | Copernicus
(16) Lightning has been added to the wheel considering that several IMs have reported events linked to lightning.

Figure 3: Climate railways risks wheel, European Union Agency for Railways, 2025



The level of climate change risk is commonly defined by combining the magnitude of a climate hazard with the levels of exposure and vulnerability of a system to that hazard. Exposure is defined by the IPCC as 'the presence of people; livelihoods; species or ecosystems; environmental functions, services and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected' (Intergovernmental Panel on Climate Change (IPCC), 2022a). Vulnerability is a term used in various ways in the literature, but in the context of risk as defined by the IPCC it refers to 'the propensity or predisposition to be adversely affected', encapsulating concepts such as sensitivity, susceptibility and lack of capacity to cope (IPCC, 2022a).

The railway system is exposed to climate change risks but the level of its exposure and its vulnerability needs to be assessed in a more systematic way. With this study, ERA aimed at understanding its level of exposure and vulnerability at macro-level with an analysis of the extreme weather events having affected negatively the European rail infrastructure and operations over the last 20 years over the period 2005-2024[17]. However, most of the infrastructure managers were able to provide information only on the last 10 years over the period 2015-2024. Although a 10-year period is short from a climate analysis perspective, it was still possible to establish some trends on the impact of extreme weather events on the rail system providing good indication of the current situation.

4.2. Frequency and trends of extreme weather events affecting the European rail infrastructure

70% of the IMs (19/27) representing 79% of the network covered in track km[18] and Network Rail in the UK perceived an increase of the weather events' impact on rail operation and infrastructure as expressed during the bilateral interviews. This perception was supported by various indicators, including increases in train delays and cancellations caused by meteorological conditions, as well as higher exceptional maintenance costs.

Additional data were collected through a survey conducted to gather information from 28 IMs across the EU and NO, CH, and UK, with responses received between the 10th of January and the 19th of May 2025. With an approximate response rate of 89%, **24 IMs replied to the data request.** Among these, one (EE) confirmed that no event met the specified criteria, three (AT, SE, NO) respondents were unable to provide relevant data due to limitation in data availability or collection capacity and two (FR, EL) provided data which were either not usable (limited time range covered and classified by event and not by year) or data were submitted too late to be integrated, resulting in usable datasets covering approximately 75% of the European rail network. The remaining three IMs (DK, IE, LT) did not submit any contribution (further details in Annex 4 of this report).

Data submissions–mostly spanning from 2015 onwards–followed the ERA template (in Excel format), with the sole exception of the one country, which supplied its records in an alternative format to reduce reporting burden. To further reduce the reporting burden, IMs were given the option to submit raw data directly as extracted from their internal IT systems, without pre-filtering for the specific characteristics of extreme weather events. As a result, substantial and necessary data filtering and cleaning processes were carried out to isolate and validate the relevant records.

In total, 224.531 raw extreme weather event records for the 2005-2024 time period were collected after scope filtering and data cleaning, 13.469 events remained, representing roughly 6% of the original dataset[19]. Data submitted by top 5 IMs (UK, DE, HU, NL, ES) accounts for 97% of the total dataset collected, considering the extended EU scope which includes CH, and UK. Notably, the UK alone represents 49% of the entire dataset.

In countries with the highest number of reported events, part of the elevated count may be attributed not only to the frequency of extreme weather, but also to the way events are recorded within national infrastructure systems. In some cases, a single event affecting multiple railway lines may be logged as separate entries, reflecting both the widespread impact of the phenomenon and methodological differences in how IMs document disruptions.

The figure below displays the **trend in Europe** (including CH) **of extreme weather events recorded annually from 2005 to 2024** (Figure 4). The data shows a notable increase in events between 2017 and 2018, peaking in 2018. Following a decline in 2019, the number of events stabilizes between 2020 and 2023, with moderate fluctuations. Although a decrease is observed in 2024 compared to the previous year, the value remains

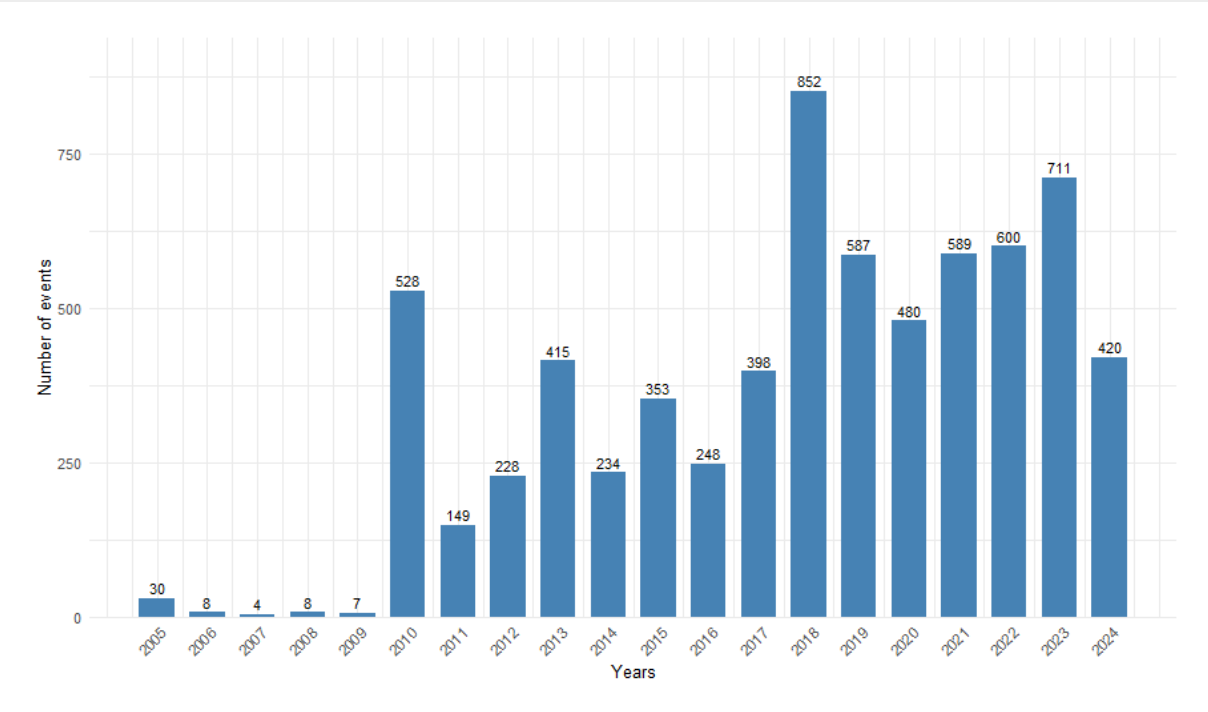
(17) The study only covered the last 20 years but climate change already had impacts before 2005.
(18) Based on statistical pocketbook 2024 : Statistical pocketbook 2024–Mobility and Transport–European Commission
(19) Scope filtering involved retaining only those events that fell within the defined thresholds of the study; data cleaning included the exclusion of incomplete entries and the removal of duplicates.

broadly consistent with the lower range recorded in previous years. The number of events recorded in the UK is presented in Annex 9 of this report.

Considering the 20-year timeframe under review, the concentration of data in the last decade appears reasonable and may reflect increased awareness among IMs of the importance of climate change impacts on their assets resulting in improvements in data collection, management, and analysis systems. Several IMs were not able to report data before 2015 which explains also the lower number of events reported in the earlier years.

A similar trend was found depicted in Figure 53 of the first Rail Environmental report (ERA, 2024)[20], based on a much smaller sample of events, specifically limited to accidents investigated by NIBs. This narrow scope highlighted the need for a broader analysis that also considers less severe occurrences and near misses, to capture a more comprehensive picture of the impact of extreme weather on the rail system.

Figure 4: Number of extreme weather events affecting the EU railway system per year (EU+CH; 2005-2024), European Union Agency for Railways[21]



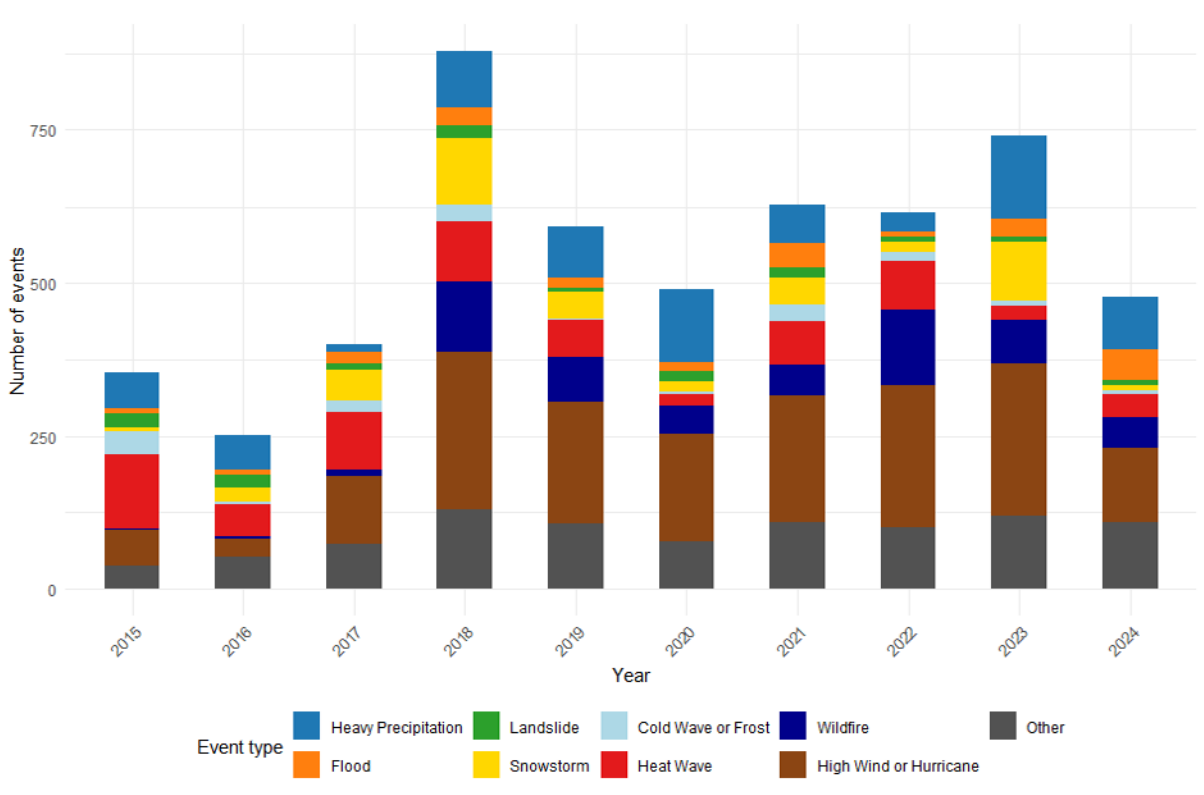
The annual distribution of the **number of extreme weather events by type of climate hazard** affecting the European railway system (including CH) from 2015 to 2024 is reported in Figure 5. Events are categorised by type, including heavy precipitation, flood, landslide, snowstorm, cold wave/frost, heatwave, wildfire, and high wind/hurricane. The events categorised as others are mostly lightning and subsidence.

What clearly stands out in the mentioned figure is the increasing trend over the past decade. This rise is not only due to the actual frequency of events but also reflects improved awareness and more systematic data collection over time. In particular, a marked increase is observed between 2017 and 2018, with a peak in 2018 with approximately 878 recorded events. This surge is primarily driven by a rise in high wind and hurricane (including storm), heavy precipitations and floods. The last two mentioned events align with insights from

(20) ERA, 2024, Rail Environmental Report, available at: Report. Rail Environmental Report, access: 24/07/2025.
(21) SNCF Réseau provided data on the 30th of October 2025. However, those data could not be integrated into the figure because the data were provided from 2020 to 2024 and were aggregated per type of event without discriminating them per date/year.

qualitative interviews and previous presentations (such as those from the EEA and IPCC report). Also, heatwaves recorded a significant share. From 2019 onward, the total number of events stabilizes and slightly increasing over time, fluctuating moderately across years. As mentioned, although a decrease is observed in 2024 compared to the previous year, the value remains broadly consistent with the lower range recorded in previous years. The number of events recorded in the United Kingdom is presented in Annex 9 of this report.

Figure 5: Trend of extreme weather events affecting the European railway system (EU+CH; 2015-2024), European Union Agency for Railways.



Note: Due to the terminology used in the answers, some events have been reclassified by climate hazards for some countries (e.g. 'storm' is reclassified as 'high wind').

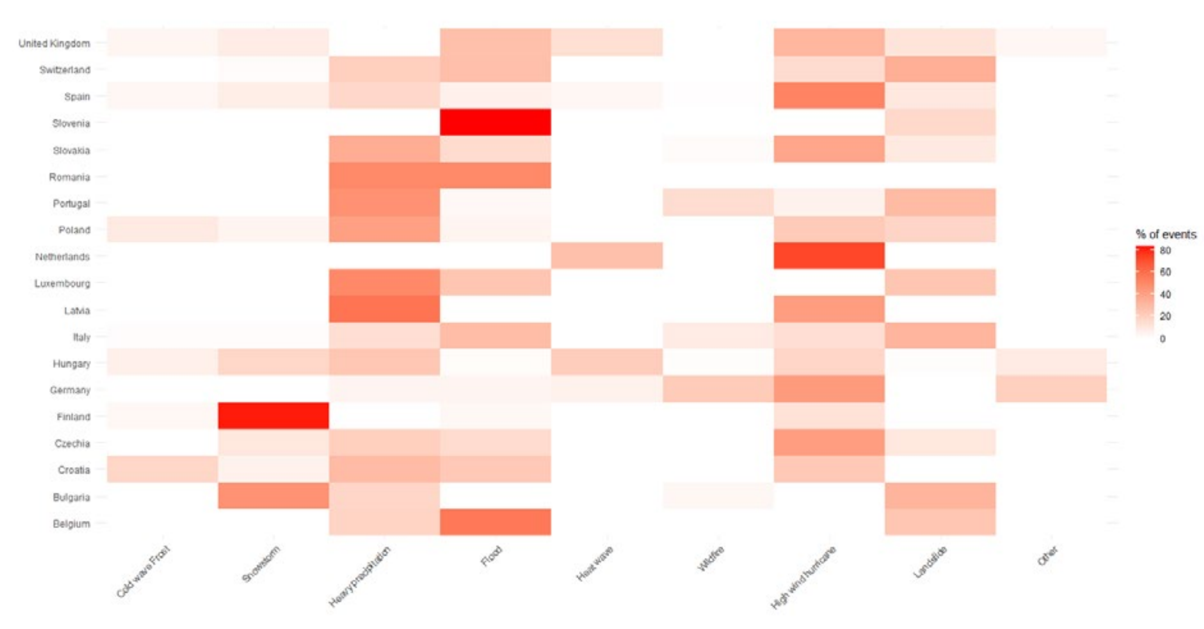
The **distribution of extreme weather event types across 19 European countries for which data have been reported**, including CH and UK, highlights MS-related variability in the types of extreme weather events affecting the railway infrastructure, revealing diversity of hazard profiles across Europe's railway networks (Figure 6). This variability reflects both climatic differences and possibly national reporting practices. For instance:

- Floods and heavy precipitation are consistently present, making them the most universally disruptive event types across Europe;
- Wind events are consistently present in Europe and more prevalent in countries like the NL, ES and DE;
- Cold-related events dominate in Northern and Eastern regions;
- Wildfires are more prevalent in Mediterranean countries.

The different combinations of extreme weather events by country emphasize that:

- Each country faces a unique mix of climatic threats, requiring context-specific adaptation strategies (they vary in terms of both types of events and number of climate hazards suffered by country);
- The number of hazards varies significantly between the countries, suggesting differences in exposure, vulnerability, and possibly reporting practices;
- Floods and heavy precipitation are the most universally disruptive events, while heatwaves, wildfires, and wind events show strong regional clustering.

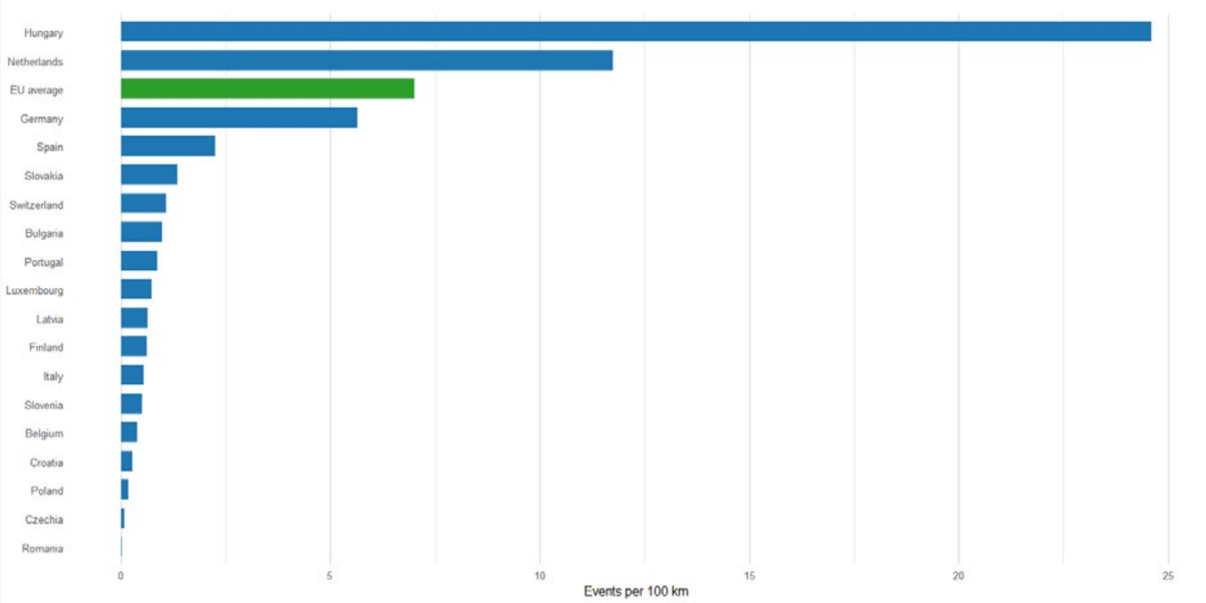
Figure 6: Extreme weather events by country (EU+CH+UK; 2015-2024), European Union Agency for Railways[22]



To ensure comparability across countries with different railway network sizes, the previous indicator was calculated as the number of extreme weather events per 100km of infrastructure over the past ten years. The indicator represents the **average number of extreme weather events per 100km of railway infrastructure** over the past ten years. It does not imply that each 100km segment experienced that exact number of events but rather reflects a national average density. For reference, the European average is around 3 events per 100km, serving as a benchmark to identify countries with higher or lower climate-related disruption intensity. This normalization highlights areas of concentrated climate vulnerability, regardless of total network length; it prevents large countries with extensive networks from appearing more vulnerable simply due to size, and it helps identify high-density climate risk areas, even in smaller countries.

(22) Events categorised as others are mostly lightning.

Figure 7: Density of extreme weather events per 100km of railway network (EU+CH+UK; 2015-2024), European Union Agency for Railways



The results reveal significant disparities across Europe:

- HU (24.61), the NL (11.74), and DE (5.64) show notably high densities, suggesting substantial climate-related impacts but which may also reflect a more robust reporting system;
- Intermediate values are observed in ES (2.25), SK (1.35) and CH (1.07);
- Most other countries report densities below 1.0, including: Bulgaria (0.99), Portugal (0.87), LU (0.74), LV (0.64), FI (0.61), IT (0.54), SI (0.50), BE (0.39), HR (0.27), PL (0.17), and CZ (0.08);
- RO presents the lowest density, with only 0.02 events per 100km, which may reflect lower exposure or the existence of limitations in detection and reporting.

This indicator may reflect a range of underlying factors, including:

- Actual higher exposure to extreme weather events, such as heavy precipitation, flood, landslides, or heatwaves;
- Greater vulnerability of the railway infrastructure, due to geographic, structural, age of infrastructure or maintenance-related conditions;
- More intensive monitoring and reporting systems, which may lead to a higher number of recorded events;
- Stricter classification criteria, where even moderate disruptions are systematically logged as extreme events;
- Variations in data availability or transparency, which can influence the completeness of event records.

Of the approximately 5 900 **rail stations reported as affected by at least one extreme weather event**[23], HU and DE account for the largest proportions, with 61% and 37% of stations impacted, respectively (see Table 4 below). Specifically, the German IM reported

(23) The station count presented in the chart derives from a preliminary data cleaning process conducted on an original dataset comprising around 6 000 rail stations. For more in-depth analysis, it is advisable to conduct further validation and verification of the data provided.

around 2 190 affected stations, while the Hungarian IM reported around 3 620 stations impacted by extreme climate events[24].

Table 4 presents a breakdown of rail stations across several European MSs, listing both the number of stations and their names. It highlights the geographic distribution of selected stations, following a data cleaning process from a larger dataset.

Key insights:

- PT features 12 stations, representing the highest counts in this selection (after Germany and Hungary);
- BE and IT each feature 11 stations
- SK follows with 7 stations, while PL lists 5;
- FI includes 3 stations, with Helsinki appearing multiple times (noted as "Helsinki (4)");
- HR, LV, LU and SI have between 1 and 2 stations each, indicating more limited representation.

Table 4: Railway stations in Europe affected by extreme weather events (EU; 2015-2024)

Country	Number of stations affected by extreme weather events	Number of stations reported in RINF[25]	List of stations
Belgium	11	424	Neufchateau, Marbehan, Dolhain-Gileppe, Trooz, Assesse, Tilly, Duffel, Luttre, Nossegem, Anseremme, Vise
Croatia	2	214	Kupjak, Botovo
Germany	2190	7279	-
Finland	3	111	Helsinki (4), Vihanti, Tampere
Hungary	3620[26]	950	-
Italy	11	584	Palermo Brancaccio, Genova Nervi, Reggio Calabria Centrale, Prasco Cremolino, Genova Marittima, Rossiglione, Genova Vesima, Crotone, Mosciano Sant'Angelo, Mantova, Cagliari Elmas
Latvia	1	23	Jelgava
Luxembourg	1	32	Bettembourg-Marchandises
Poland	5	1859	Poznan Głowny (2), Warszawa Wschodnia (2), Chmielów, Sedziszow, Warszawa Zachodnia
Portugal	12	274	Luso, Trezói, Entroncamento, Mouriscas-A, Fratel, Praia Do Ribatejo, Braço Prata, Marujal, Fornos De Algodres, Aregos, Alcântara-T, Santarém
Slovenia	1	121	Zagorje
Slovakia	7	287	Pusté Pole, Slančík, Matejovce Pri Poprade (3), Cífer (2), Studený Potok, Kuchyňa, Nové Zámky

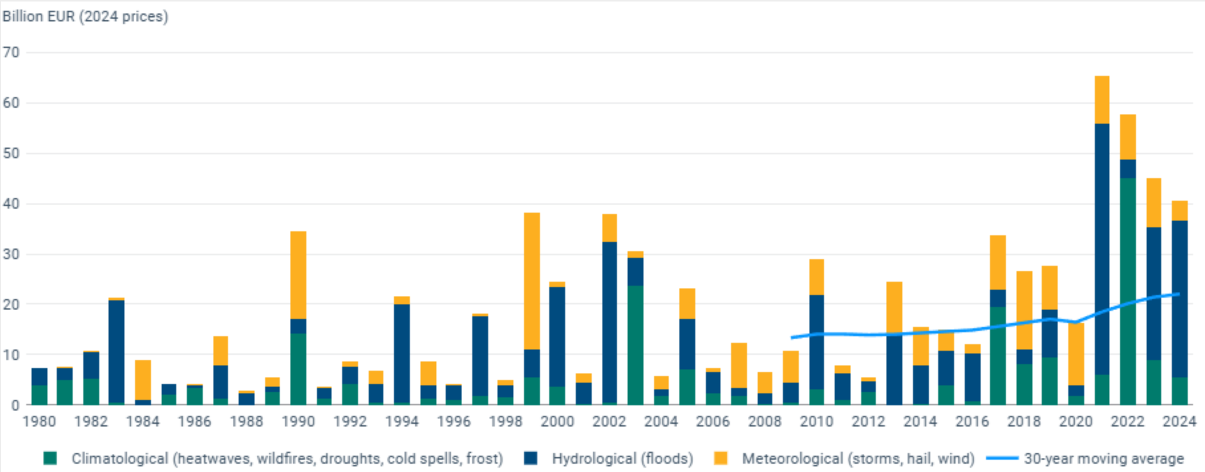
Notes: 1) Data from DE and HU are not included; 2) The number in parentheses next to the station indicates how many times that station was mentioned in connection with extreme climate events; 3) Events generically referring to multiple stations have been excluded unless the affected stations were explicitly identified; in cases where a railway line is mentioned without specific station names, and no individual stations could be confirmed, these records were not considered.

(24) The HU and DE data have undergone a basic and initial cleaning process to ensure minimal consistency. For more in-depth analysis, it is advisable to conduct further validation and verification of the data provided.
(25) Data extracted from Register of infrastructure (RINF) on 06/10/2025.
(26) This value should be further validated with an additional data cleaning activity to be coherent with the RINF value.

4.3. Economic and operational consequences of extreme weather events on the European rail infrastructure

Economic losses due to extreme weather events are increasing over the last decades at EU level all sectors combined.

Figure 8: Annual economic losses caused by weather-and climate-related extreme events in the EU Member States, European Environment Agency, 2025



Between 1980 and 2023, extreme weather events have caused 738 billion of economic losses in constant 2023-euro prices and 482 billion of economic losses between 2005 and 2024, the period studied in this report. Three of the five years with the highest annual values are very recent (2021, 2022 and 2023). Data for 2024 were not yet complete but considering the floods in Spain and Central Europe, 2024 will also rank very high and potentially, also in the top 5. Floods (44% of the losses), storms (29%) and heatwaves (19%) are the most impactful events and, although there is no data specific for rail, it is assumed that the situation is similar for the rail sector only[27].

This assumption needed to be confirmed with this study with order of magnitude of economic consequences of extreme weather events on the rail system. However, out of 19 EU IMs and Network Rail who provided data on the frequency of extreme weather events and their operational consequences, only 10 IMs and Network Rail provided data on the economic impact of those events. In addition, most of the economic data (clustered as infrastructure costs, operational costs and rolling stock costs, if available) were not complete so that a precise trend cannot be determined at this stage but only assumed.

Despite this incomplete data, during the bilateral interviews, most of the IMs (23 out 27 + UK) stated that they faced extreme weather event(s) that have severely impacted their rail system over the last 5 years.

In **July 2021**, very intense precipitations led to catastrophic floods in Belgium and Germany impacting also Luxembourg and the Netherlands. In Belgium, the financial consequences for the railway sector have been estimated to over **65 million euros** with bridges that have been temporarily repaired but still need to be rebuilt. The most damaged bridge in Pepinster has recently been rebuilt.In Germany, the estimation is up to **1.4 billion euros** with 300 level crossings, 80 signal boxes, more than 200 overhead lines, 700 km of railway tracks, 80 stations, 120 switches, 10 tunnels, 200 bridges destroyed or

(27) Economic losses from weather- and climate-related extremes in Europe | European Environment Agency's home page

severely damaged. The consequences are still visible as the Ahr valley is a big construction site and the trains should be running again only by the end of 2025. In the Netherlands, the provinces of Limburg and Noord-Brabant were affected by the heavy precipitations but the consequences on the rail infrastructure were more limited compared to Belgium and Germany.

Figure 9: Flood in the Ahr valley, DB InfraGO AG, 2021

In **September 2022**, severe floods in the Plovdiv region in Bulgaria, affected very badly the transport infrastructure (both rail and road) leaving some villages isolated due to additional landslides following the heavy rainfall. Some reconstructions are still on-going in the area.

In **May 2023**, a significant flood has impacted the region of Emilia-Romagna in Italy with several lines that have seen their traffic interrupted (e.g. Bologna-Rimini for a week, Faenza-Firenze for 6 months while the smaller line between Faenza and Lavezzola has not been reactivated). The repair and modernisation costs have reached at least **150 million euros**[28].

In the beginning of **August 2023**, major floods happened in large part of Slovenia and especially the Goriška region in the West part of Slovenia with the busiest passenger railway lines and three rail freight corridors heavily impacted. This storm also impacted continental Croatia with very strong winds which have removed tracks and catenary on some lines in the Zagreb region leading to the closure of the traffic for almost 2 months.

(28) ConvenzioneRFI OMISSIS.pdf

Figure 10: Flood in Botovo, HŽ INFRASTRUKTURA d.o.o., 2023

In the end of **August 2023**, a landslide in Maurienne area in the French Alps damaged heavily the line between Saint-Michel-de-Maurienne and Modane. The traffic between France and Italy in this area has been fully interrupted for 19 months to excavate the rocks and secure the area for direct cost of **13.5 million euros** and **3 million euros** to repair the line. However, the indirect costs are even higher as **30 to 35 million euros** of track access charges have been lost. In addition, in Summer 2025, the rail freight traffic on this line was still well below the level before the landslide.

In **September 2023**, two storms in less than two weeks, Daniel and Elias, heavily hit Greece with floods badly affecting the railway system (100km of double track, signalling system, electrical system completely damaged) and especially the critical line of Athens-Thessaloniki which needs to be fully restored for a cost of about **450 million euros**.

2024 was the rainiest year ever recorded in Denmark since records started in 1874 which has entailed lots of flood on smaller lines, landslides and damages on dams.

In **July 2024**, the storm Kirsti was the strongest in Latvia during Summer season with high winds observed in the capital Riga, Jurmala and Jelgava. Two electrified lines in the central part of Latvia were very much affected (Jelgava and Tukums lines, the busiest rail passenger transport links between Riga and the nearest populated areas). Direct damages were evaluated to **378.000 euros**.

Figure 11: Storm damage in Latvia, Latvijas dzelzceļš, 2024

In **September 2024**, the most important route in the Austrian rail system was severely damaged due to heavy precipitation while the infrastructure was built to sustain a HQ100 flood. Some tracks, tunnels, train stations and electricity systems needed to be repaired. For example, one problem identified which led to high consequences was an overwhelmed drainage system in combination with a nearby burst dam. On the side of the costs, no official data have been shared yet, but it is estimated at "**three-digit million euros**" on the and the loss of revenue due to cancelled trains. This extreme weather event also impacted Czech Republic as one railway line was flooded, and some days were needed to operate trains in normal conditions. Poland was also affected with some stations and lines flooded.

Figure 12: Flood in Lower Austria, ÖBB/Mayer, 2024

In **October 2024**, a DANA hit the Valencia Region in Spain with heavy rains damaging severely roads and railway infrastructure. In some areas up to 720 l/m² were collected in just twelve hours, which is almost as much as it can rain as an average in a whole year. Costs of **212 million euros** were incurred for emergency works alone (not including the cost of maintenance contracts themselves).

The conventional railway network, and specifically the commuter network, three lines C1, C2 and C3 were strongly damaged at several points, destroying 80km of platform, being track and facilities needed to be rebuilt from scratch. The most affected line was the C3 non-electrified line, with 45 km completely destroyed. As for the Madrid-Levante High-Speed network, much more modern, designed with parameters in accordance with the TSIs and inaugurated in 2010, the effects were milder, being mainly affected at two points:

- Chiva Tunnel. Double track tunnel on ballast, which has been damaged both inside the tunnel (631 m) and at the entrance and exits of the tunnel (300 m on each side);
- Torrent Tunnel. A double-track, slab tunnel almost 3km long that was completely flooded.

Figure 13: Flood in Valencia, ADIF, 2024

The last 4 years have been particularly damaging to the transport infrastructures and the rail sector. Looking at the expected damage to critical infrastructure assets (not only rail infrastructure), the situation will not improve in the near future so that on top of mitigation measures, the rail system needs to be adapted to be fit for the future.

In addition to collecting trend data about extreme weather events (section A), the survey of IMs also aimed to capture the impacts of extreme weather events, including:

- Delay hours directly attributable to climate-related disruptions (e.g., storms, floods, landslides); and
- Economic damages to infrastructure, rolling stock, and operational systems.

Among the consequences of the event, the **duration of the traffic disruption** (in hours) was specifically requested. The results are as follows:

- Data availability and scope: 16 EU IMs offered continuous records, confirming a broad commitment to tracking weather impacts on rail operations. Only RO reports no data, while CZ has supplied figures that will require further validation before they can be used for analysis;

- Reporting format and precision: IMs employ at least four primary formats to express interruption duration:
  - Exact hours of interruption (BG, IT, SK, ES, SI, HR, LV, HU, DE, LU, PL, PT);
  - Minute precision, requiring conversion to hours for consistency (NL);
  - Threshold flags ("over 6 hours") reserved for one-off or exceptionally severe incidents (BE, select FI events), or range of dates of events (HR);
  - Cumulated delays of train services (UK).

These variations reflect differing national practices, with some IMs opting for the simplicity of categorical thresholds when facing disruptions, while others maintain full numeric precision.

With regard to commonalities among EU IMs, it is worth to mention the widespread use of exact-hour metrics underscores a de facto EU standard for representing service interruptions. However, also the selective threshold reporting is used by some IMs.

Figure 14 illustrates **total annual railway delays (in hours) across the EU** caused by extreme weather events from 2015 through 2024. After relatively low disruptions in 2015–2017, delay hours increase sharply in 2018, dip slightly in 2019–2020, and then peak dramatically in 2021. Although still elevated in 2022, the trend shows a gradual increase in 2023 and a return to comparatively lower values by 2024.

These delay fluctuations reflect the uneven but intensifying impact of extreme weather on rail operations over the past decade. Notably, the cumulative effect of weather-related disruptions (in terms of hours of delay) across the European railway network results in a substantial loss of operational time. When aggregated across all affected routes and services (by year), the total /cumulated amount of railway delay correspond to an estimated reduction equivalent to **between 1 to 3 full years of service annually for Europe**. This figure reflects the total downtime caused by delays due to adverse weather conditions for the period 2015-2024.

Figure 14: Railway total delay in hours due to extreme weather events (EU; 2015-2024), European Union Agency for Railways

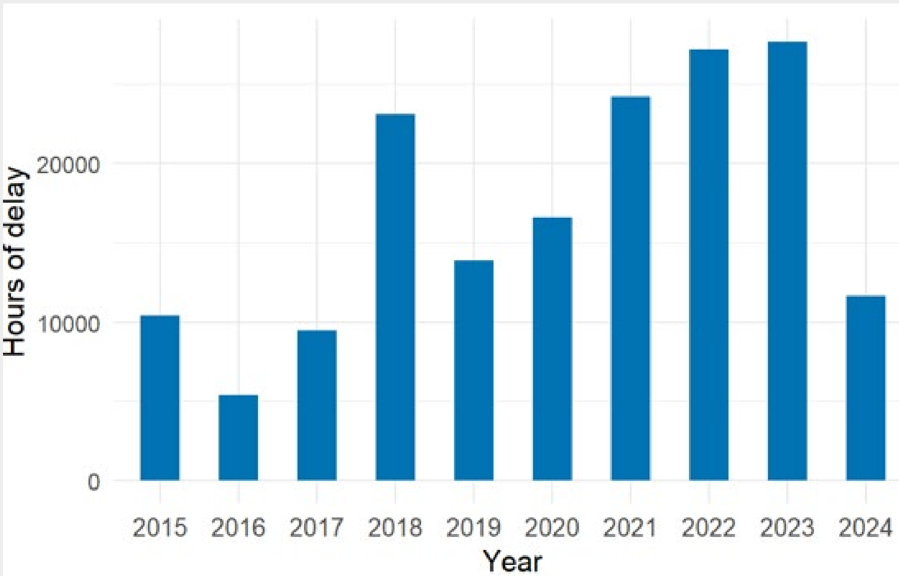
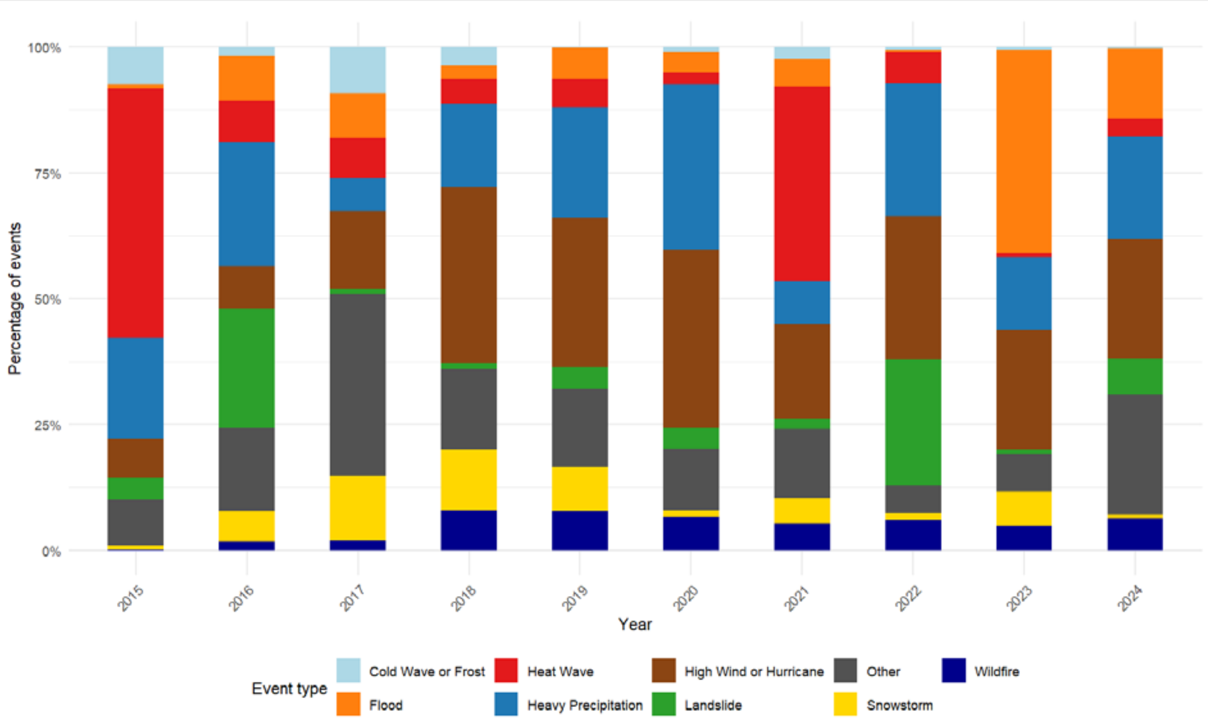


Figure 15 presents the **percentage of railway traffic disruption per type of extreme weather event** across the European Union from 2015 to 2024. Each bar represents a year and is segmented to show the relative contribution of different hazards–such as heavy precipitations, floods, landslides, snowstorms, frost, heatwaves, wildfires, high winds, and other phenomena–to total delay hours.

The main results can be summarised as follows:

- Heavy precipitation and floods consistently account for a substantial share of delays across all years, often forming the largest combined segment;
- Also, high wind and hurricane events show a significant impact, especially in recent years, highlighting increasing vulnerability to wind-related disruptions such as fallen trees and damaged infrastructure;
- Landslides and heatwaves show variable but notable presence, particularly in years with elevated total delays;
- Snowstorms and frost appear more prominently in colder years, while wildfires gain visibility in later years, possibly reflecting shifting climate patterns.

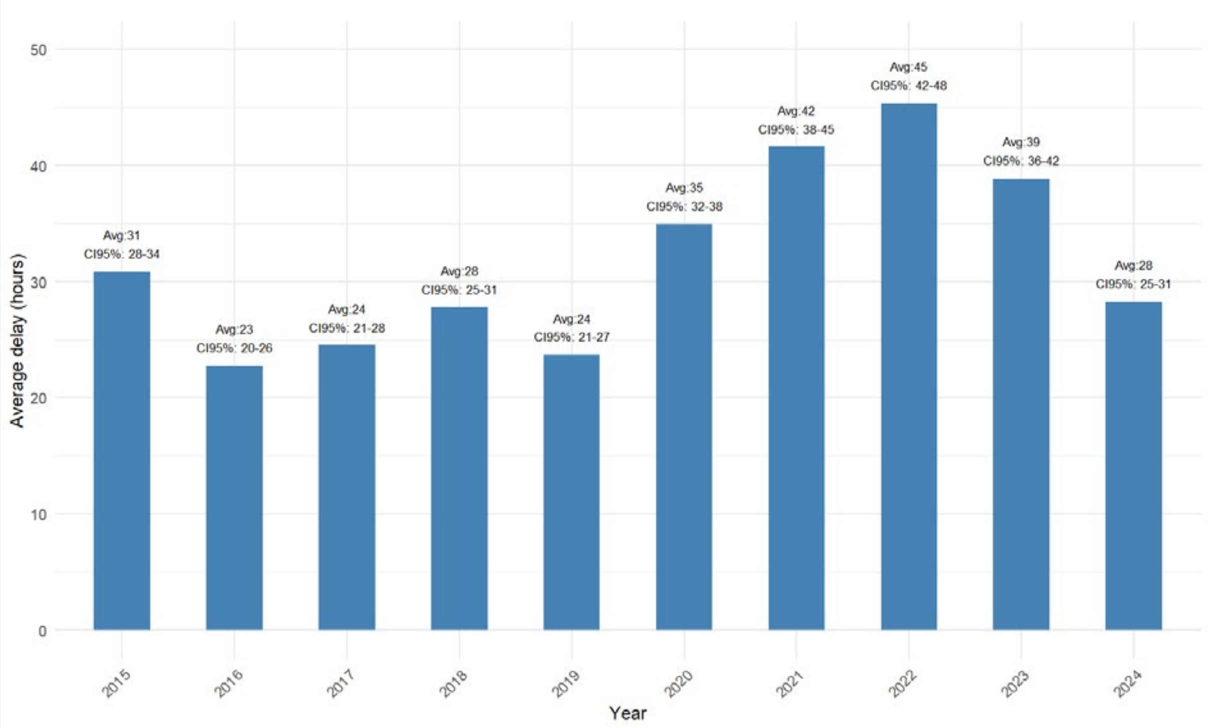
Figure 15: Railway delay linked to extreme weather events (EU; 2015-2024), European Union Agency for Railways



The following figure tracks how much disruption–measured in average delay hours–extreme weather events have caused to EU railway systems over the past decade. Rather than showing the total delay hours, it focuses on the **average delay per event**, giving indication of how intense each incident has been.

From 2016 to 2019, the average delay per event remained relatively stable, fluctuating between 23 and 28 hours. But starting in 2020, the impact of individual events began to grow noticeably. Delays jumped to 35 hours in 2020, climbed even higher in 2021, and peaked in 2022 at around 45 hours per event, suggesting that weather disruptions were not only more frequent but also more severe. Interestingly, the trend begins to reverse in 2023 and 2024, with average delays dropping to 39 and then 28 hours. This could point to improved resilience in railway infrastructure, better emergency protocols, or simply a shift in the nature of the events themselves.

Figure 16: Railway average delay in hours per extreme weather event (EU; 2015-2024); European Union Agency for Railways



Note: CI95%–95% Confidence Intervals[29]

Figure 17 illustrates the **cumulative railway traffic disruption** across the EU from 2015 to 2024, categorized **by climate hazard**. It included complex events involving multiple climate hazards, capturing their combined impact on railway disruptions; "multiple hazard" events include only those disruptions where at least two distinct hazard types were recorded simultaneously, reflecting their compounded impact (represented in orange in the figure). The data highlights that heavy precipitation caused the most significant disruptions, followed by landslides. In contrast, heatwaves and wildfire were never recorded in combination with other climate hazards. The mentioned figure also isolates the **effect of individual hazards**, offering a more direct assessment of each hazard's standalone impact; "single hazards" refer to events attributed exclusively to one hazard type, without overlap (represented in blue in the figure). The data shows that high wind/hurricane remains the most disruptive, with delays exceeding 40,000 hours, followed by other and heatwave. Hazards such as cold wave/frost, landslides, and snowstorm result in significantly lower delays. Some hazards, like high wind / hurricanes, floods or snowstorms, appear less impactful in this figure, suggesting their disruptive potential often arises in combination with other hazards.

([29]) CI 95% helps communicate the statistical reliability of the indicator because it shows uncertainty with the range of values within which the true average delay is likely to fall (reflecting natural variability and measurement errors), and improve transparency rather than presenting a single number, the CI shows how precise that number is, avoiding misleading conclusions on point values alone.

Figure 17: Total railway traffic disruption by climate hazard (EU, 2015-2024), single and multiple-hazard events, European Union Agency for Railways

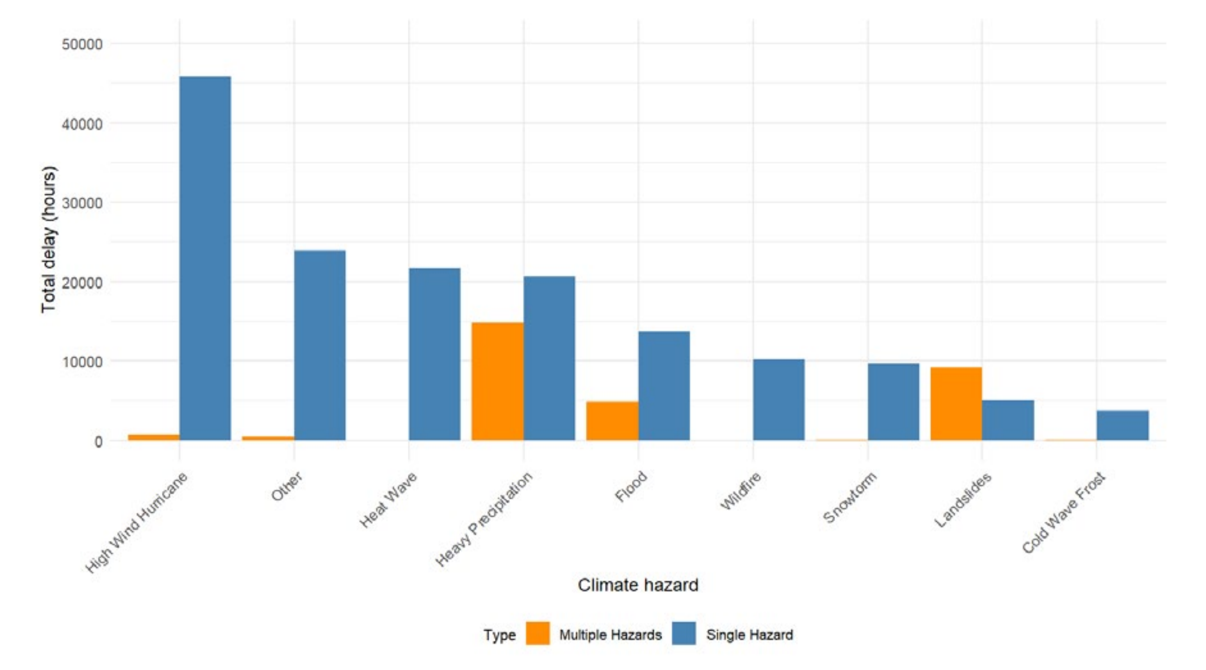
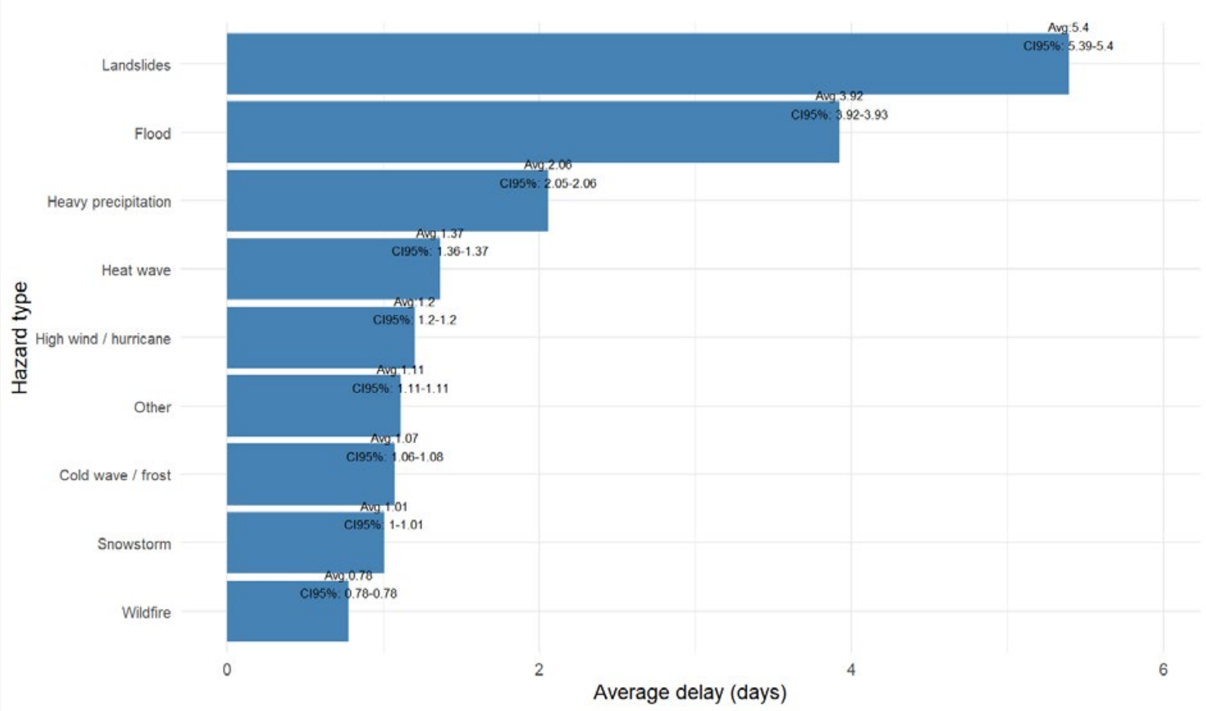


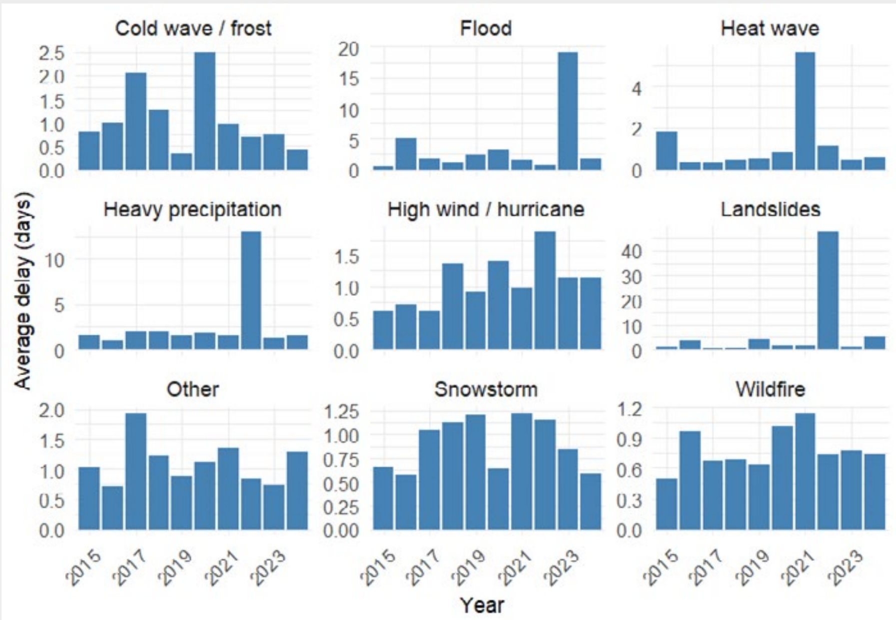
Figure 18 illustrates the **average delay per event (in days) caused by different climate hazards** affecting railway traffic in the EU from 2015 to 2024. The data reveals that landslides lead to the longest average delays per incident, followed by floods and heavy precipitation. On the other end of the spectrum, wildfires, snowstorms, and cold waves/ frost result in the shortest average delays. This figure shifts the focus from total disruption to event-level severity, helping identify which hazards, though possibly less frequent, cause the most significant delays when they occur. It complements previous figures by highlighting the intensity of individual hazard events rather than their cumulative impact.

Figure 18: Average delay per event and per climate hazard (EU, 2015-2024), European Union Agency for Railways



While the above Figure offered a static snapshot of average delays per hazard over the full period, the Figure below adds a temporal dimension, revealing how the severity of each hazard fluctuates year by year. Figure 19 presents the **average delay per event (in days) across different climate hazards and years** within the EU railway sector.

Figure 19: Average delay (days) per year and per climate hazard (EU, 2015-2024), European Union Agency for Railways



Regarding the **economic damage** caused by extreme weather events, the analysis of cost data provided by IMs across 17 European countries for the entire 20-year period included various elements, such as types of costs, currency and values, and number of events in the last 10 or 20 years. The overall results are reported as follow:

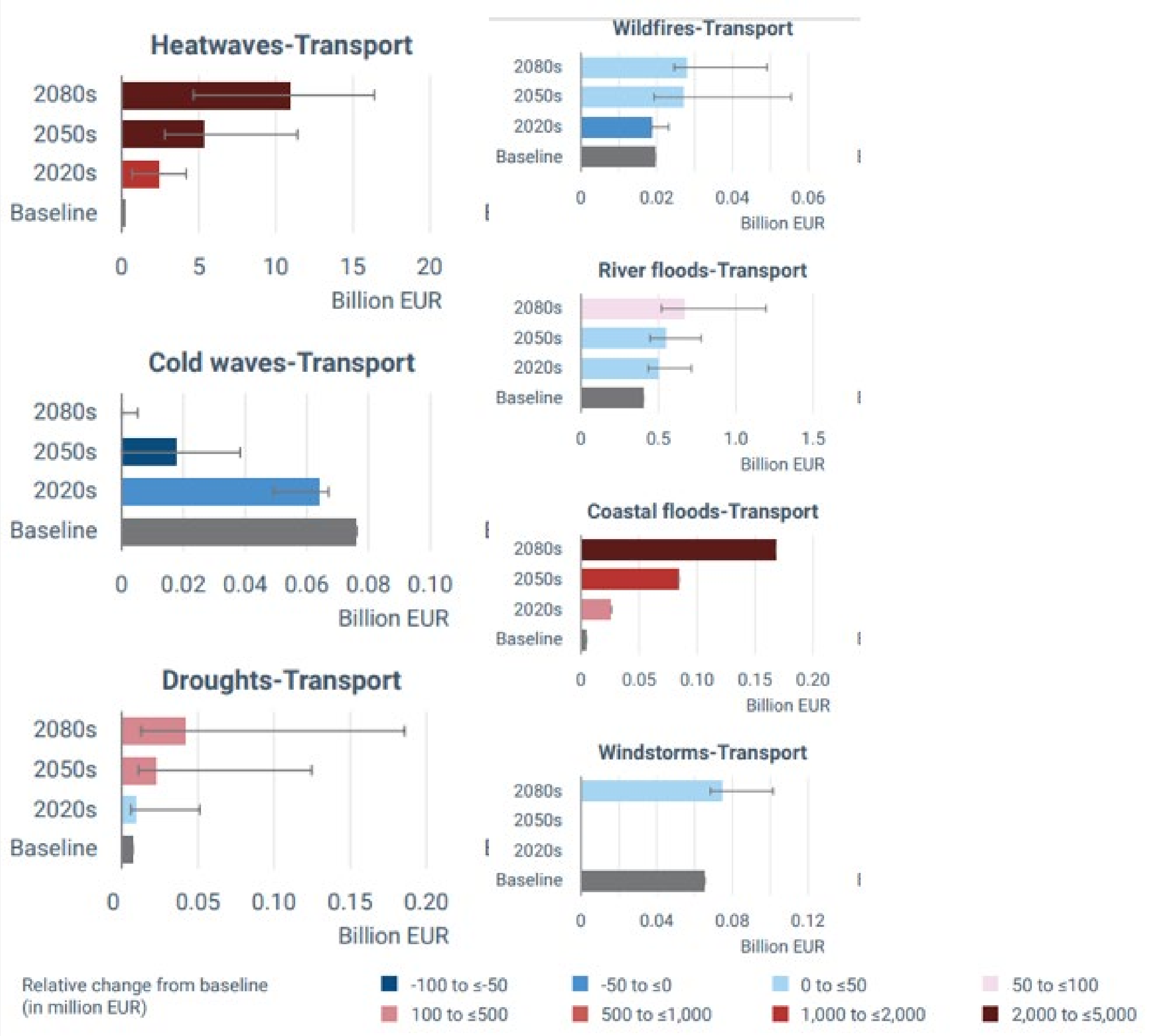
- Data availability: cost data were provided by 12 IMs. Additional 5 IMs (ES, DE, LU, FI, and NL) did not submit any data for inclusion;
- Type of cost data: most countries reported infrastructure-related costs, with some also including operational and rolling stock expenses. However, in several cases, the categorisation requires clarifications;
- Currency and cost values: several entries raise concerns about the accuracy or interpretation of monetary values. As requested, the majority of countries reported costs in thousands of euro, but differences exist providing cost figures with an unclear value (thousand vs million / billion; euro vs. national currency);
- Temporal coverage: overall, it is observed that when cost data is available, it typically spans a long temporal range, often extending over the past 20 years.

It was also observed that for a limited number of specific and particularly extreme events (those with the most catastrophic consequences) the data related to costs (as well as other information, such as the duration of traffic disruption) tend to be more accurate and comprehensive.

As highlighted above, the cost data reveals a high variability in cost data availability and consistency across European IMs. While some IMs provide detailed cost breakdowns–including infrastructure, rolling stock, and operational impacts–others offer only partial data or figures which need to be further investigated. This inconsistency poses challenges (especially in terms of time) for cross-country comparisons and for drawing robust conclusions about climate-related financial risks[30].

([30]) EEA is developing terms of reference for countries on how to report on their economic losses.

Figure 20: Expected annual damage to critical infrastructure assets, European Climate Risk Assessment, European Environment Agency, 2024

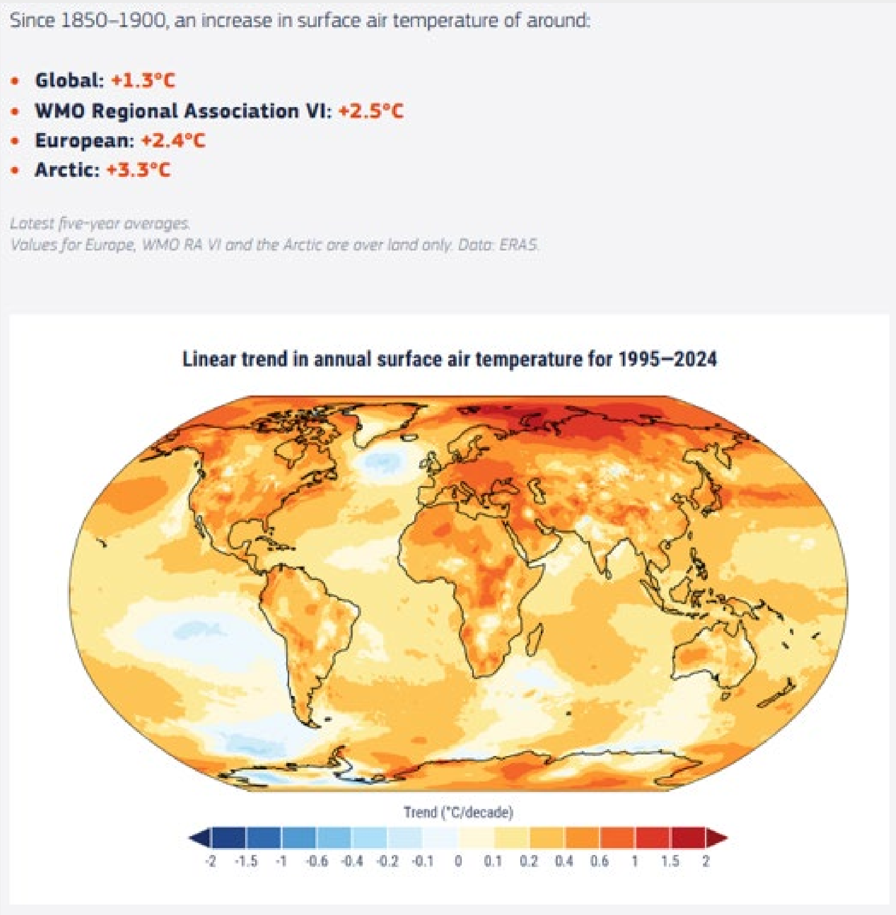


While past climatic data (e.g. for flood) are used to design new infrastructure, this is most probably not sufficient considering the economic consequences of climate change and climate projections need to be used to build climate resilient infrastructures. The expected annual damage to critical infrastructure assets – all transport modes included (figure 20)– are foreseen to increase in the decades to come compared to today especially due to heatwaves and floods.

4.4. Climate projections

Based on climate indicators, it is possible to analyse long-term trends and especially the global average temperature which is aimed at 'holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels' according to the Paris Agreement[31]. However, global average temperatures have already increased significantly compared to the pre-industrial levels by around 1.3°C. European land temperatures have increased even faster by around 2.2-2.4°C[32].

Figure 21: Trend in annual surface air temperature (°C/decade) for 1995-2024, Copernicus Climate Change Service (C3S) and World Meteorological Organization (WMO), 2025: European State of the Climate 2024, climate.copernicus.eu/ESOTC/2024, doi.org/10.24381/14j9-s5



Trends in global average temperature are linked to CO_2 emissions mostly related to human activities. The Intergovernmental Panel on Climate Change has developed different climate change scenarios (SSP for Shared Socioeconomic Pathways) based on the evolution of CO_2 emissions in this century.

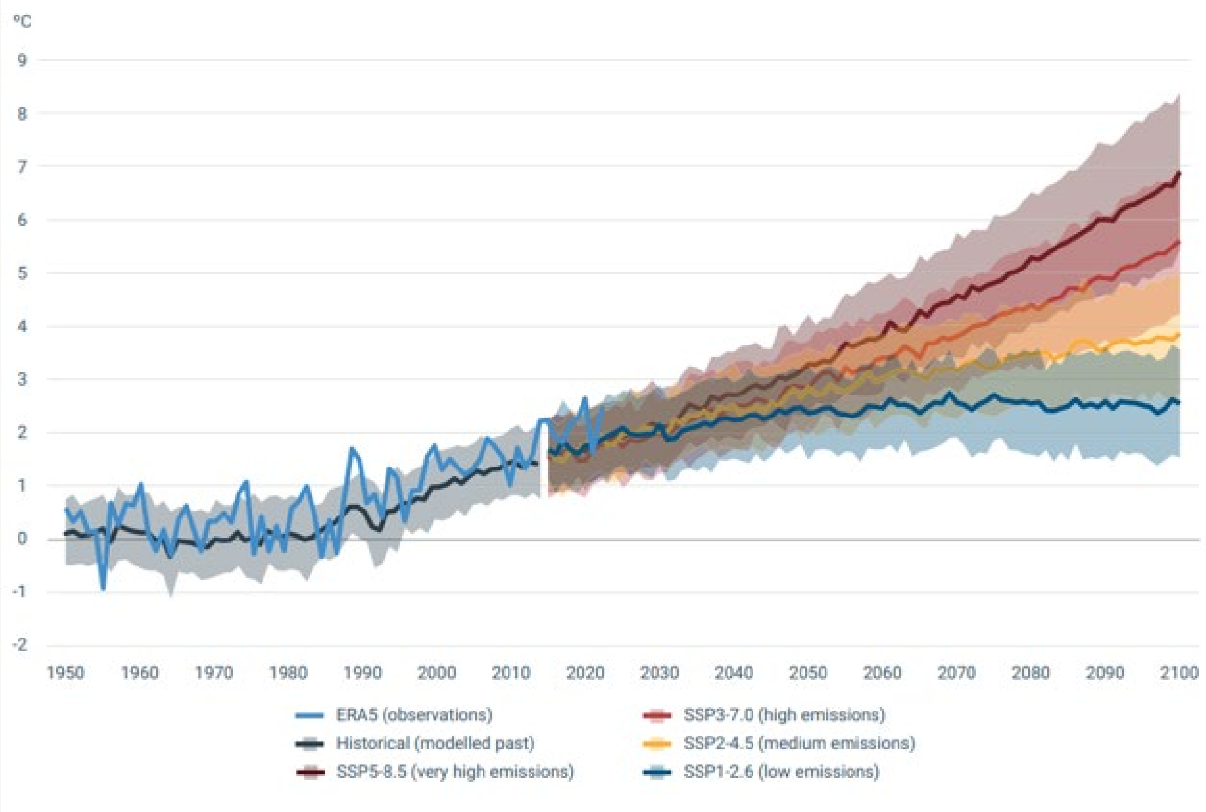
(31) Paris Agreement English
(32) Global and European temperatures | Indicators | European Environment Agency (EEA)

Table 5: IPCC scenarios in IPCC sixth assessment report on climate change, 2021

IPCC Scenario	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Title	Sustainability	Middle of the road	Regional rivalry	Inequality	Fossil-fuelled development
Change in temperature	1.5°C by 2050	1.8°C by 2100	2.7°C by 2100	3.6°C by 2100	4.4°C by 2100
Evolution in CO_2 emissions	CO_2 emissions are cut to net zero around 2050	CO_2 emissions are cut severely, reaching net zero after 2050	CO_2 emissions remain around current levels before starting to fall mid-century, do not reach net zero by 2100	CO_2 emissions rise steadily and roughly double from current levels by 2100	CO_2 emissions levels roughly double by 2050

Those scenarios have been linked to the observations made by C3S.

Figure 22: Observed and projected temperature increase over European land area, European Climate Risk Assessment, European Environment Agency, 2024



Notes: Temperatures are expressed relative to pre-industrial levels. The model projections show the mean and uncertainty interval. The two scenarios assessed are SSP1-2.6: low warming, and SSP3-7.0: high warming.

Finally, based on the European geographical areas and the scenario retained, the European Environment Agency has projected the changes in the climate impact drivers. Those climate impact drivers are essential elements which can support railway stakeholders when making a climate risk assessment on their network and operations.

Figure 23: Projected change in climate impact drivers in Europe, European Climate Risk Assessment, European Environment Agency, 2024

		Northern Europe		Western Europe		Central-eastern Europe		Southern Europe	
		SSP1-2.6 (low emissions)	SSP3-7.0 (high emissions)	SSP1-2.6 (low emissions)	SSP3-7.0 (high emissions)	SSP1-2.6 (low emissions)	SSP3-7.0 (high emissions)	SSP1-2.6 (low emissions)	SSP3-7.0 (high emissions)
Heat and cold	Mean temperature	↑	↑↑	↑	↑↑	↑	↑↑	↑↑↑	↑↑↑
	Cooling degree days	↑	↑↑	↑↑	↑↑↑	↑↑	↑↑↑	↑↑↑	↑↑↑
	Heating degree days	↓	↓↓	↓	↓↓	↓	↓↓	↓↓	↓↓↓
	Frost days	↓	↓↓↓	↘	↓	↓	↓	↓	↓↓
	Daily minimum temperature	↑	↑↑↑	↑↑	↑↑↑	↑	↑↑	↑↑↑	↑↑↑
	Daily maximum temperature	↑	↑↑	↑	↑↑	↑	↑↑	↑↑↑	↑↑↑
	Heatwave days	↑↑↑	↑↑↑	↑↑	↑↑↑	↑↑↑	↑↑↑	↑↑↑	↑↑↑
Wet and dry	Total precipitation	↗	↗	⤨	⤨	⤨	⤨	↘	↘
	Heavy precipitation (1 day)	↗	↑	↗	↑	↗	↗	↗	↗
	Heavy precipitation (5 days)	↗	↗	↗	↗	↗	↗	⤨	⤨
	Consecutive dry days	⤨	↗	↗	↗	↗	↗	↗	↗
	Meteorological drought	↘	↘	⤨	⤨	⤨	↘	↗	↗
	Agricultural drought	⤨	↘	↗	↗	↗	↗	↑	↑
Wind	Mean wind speed	↘	↘	↓	↘	↓	↓	↘	↘
Snow and ice	Snowfall	↓	↓	↘	↓	↘	↓	↘	↓

High agreement: at least 80% of models of each ensemble show a positive change

Low agreement: at least 50% of models of each ensemble show a positive change

No agreement: ensembles disagree on the direction of change

Low agreement: at least 50% of models of each ensemble show a negative change

High agreement: at least 80% of models of each ensemble show a negative change

↑↑↑ increase above 3 standard deviations
↑↑ increase above 2 standard deviations
↑ increase above 1 standard deviation
↗ increase above 0.25 standard deviations
⤨ limited change between 0.25-0.25 standard deviations
↘ decrease below -0.25 standard deviations
↓ decrease below 1 standard deviation
↓↓ decrease below 2 standard deviations
↓↓↓ decrease below 3 standard deviations

ERA questioned the infrastructure managers during the bilateral interviews on the current impact of extreme weather events and their use of climate projections to prepare their assets to be fit for the future. 30% of the IMs are basing the design of their constructions on historical data and have not yet considered the integration of climate projection data.

33% of the IMs have either:

- Adapted some elements of their infrastructure such as the design for the drainage or the embankments based on climate projections; and/or
- Performed climate risk assessment to identify weakest points and to map the geographical differences within the country; and/or
- Used ISO 14091 and 14092 to perform vulnerability assessments; and/or
- Have indicated the lines with higher risks in this context as part of their emergency procedures.

37% of the IMs and Network Rail are using climate projections and many of those IMs are using IPCC's scenarios although in a different manner. Some are using the average scenario (SSP2-4.5), some others the most pessimistic scenario (SSP5-8.5) and some are using both. The time horizon covered is also differently defined by IMs ranging from 2050 to 2100. All of those who are making climate projections consider a review, usually every 4 years. Most IMs were wondering in this context which was the best scenario to be used and the most relevant time horizon to be retained. Indeed, considering the life span of railway assets, decisions taken today will have influence on several decades. Consequently, many of those IMs were also wondering whether it is more appropriate to already prepare the railway assets for 2100 considering the different scenarios or to prepare them for 2050 with a certain degree of modularity considering the potential evolution and refinement of the scenarios in the years to come.

Finally, considering that the risk of flood is increasing due to climate change (with a high degree of confidence according to IPCC), Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks[33] which obliges Member States to assess all areas where significant floods could take place is considered essential in managing the risk of floods by all IMs. Indeed, thanks to this Directive, it is possible for the IMs to map quite precisely the flood risk over their network.

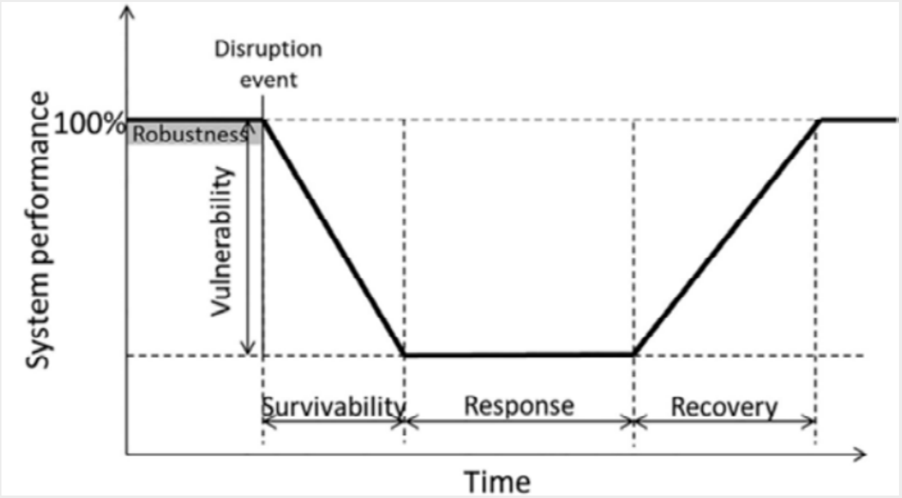
([33]) Directive–2007/60–EN–EUR-Lex

5. Resilience of the European railway system to climate change

On top of climate change, the EU is also facing a situation characterized by an ongoing military conflict at its borders and economic uncertainty so that the resilience of transport and rail infrastructure is not solely important for climate change but also to ensure well-functioning military mobility and preserve the railway system from cyberattacks.

The United Nations Office for Disaster Risk Reduction defines resilience as 'the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management'[34]. A resilient system would be less subject to disruption and, in case of an event, would trigger the appropriate and timely response and ensure a quick recovery of the activities as shown in the below graph.

Figure 24: Resilience of rail transport systems: vulnerability, survivability, response and recovery, Bešinović, N. (2020), 'Resilience in railway transport systems: A literature review and research agenda', Transport Reviews, Vol. 40, No 4, pp. 457–478.



Weather is rarely a direct cause of a railway accident. Indeed, using the accident investigation reports notified/sent to ERA, it is possible to provide an overview of weather-related rail accidents/incidents investigated by the NIBs. In total, 100 accident investigations following weather-related occurrences from 2007 to 2023 have been reported[35]; in 27 cases, weather conditions are indicated as direct causes, while for the other 73 occurrences they are considered contributing factors. So, weather contributed to or was a direct cause of 3 to 13 accidents investigated each year. However, weather and, especially extreme weather events, is impacting more and more railway services availability, punctuality and entails increased economic losses on railway operators (ERA, 2024[36]).

Most of the IMs are taking measures to adapt to this situation. Adaptive capacity is defined by the IPCC as 'the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities or to respond to consequences' (IPCC, 2022a). The level of maturity is however very different among the IMs. Two factors have been identified which increased IMs' level of maturity:

- A reactive factor: having been exposed to an extreme weather event with catastrophic consequences has raised awareness on the importance to take measures for such an event not to happen again.

(34) United Nations Office for Disaster Risk Reduction (UNDRR). 2017. The Sendai Framework Terminology on Disaster Risk Reduction. "Resilience". https://www.undrr.org/terminology/resilience.
(35) Out of 3197 investigations reported for EU and CH, NO and UK and 2762 for EU only.
(36) Report. Rail Environmental Report (ERA, 2024).

- A pro-active factor: receiving support from EU institutions (e.g. EIB, climate proofing obligation with EU grants) in building competence and knowledge on climate risk and vulnerability assessments with the development of new or modernization of infrastructure. Competences and knowledge being then re-used for other projects which are not necessarily supported by EU institutions and/or to develop a more systematic methodology to tackle climate risk assessment.

According to Chapter 13.6 on adaptation for cities, settlements and key infrastructure of IPCC 6th assessment report, 'adaptation actions do not consider enough long-term transition paths embedded in mitigation, while mitigation strategies are often not assessed under future climate scenarios'[37]. In addition, there is a data gap as 'empirical data on the damage of transport infrastructure (e.g., railways) covering different European countries have not been systematically collected, and indirect economic effects of interruptions of transport networks have not been well studied'[38]. This data gap is still valid despite this study as mentioned in chapter 1.C of this report as no exhaustive overview on economic impact of extreme weather events could be determined with the collected data but only estimates and extrapolations.

At national level, national climate risk assessments are increasingly used, and adaptation plans are developed with a minority of countries which have not yet done it[39]. For the railway sector, adaptation strategies and adaptation plans are still not broadly used. IMs have identified different challenges depending on their level of maturity to take the subsequent step(s).

Table 6: Challenges faced by European infrastructure managers in relation to resilience to climate change

IM's country of origin	Challenges faced
AT, BE, DK, LT, PL, SK	Reliable data and big data management at IM and EU level
AT, EL, HU, PT, RO	Budget constraint and validation of the expenditures. Matching the financial constraint and the time constraint[40]
IE	Consistent and replicable methodology for risk assessment for critical infrastructure including scenario(s) to be used
LV, LU	Lack of predictive tools
AT, DK, FR, LU, NL, PL, ES	Heavy process for organisational change management/internal coordination and decision-making on the relevant measures to be prioritised considering the time constraint
DK, FR	Lack of awareness
HU, LU, CH	Lack of staff
PT	Implementation of a geotechnical strategy[41]
SE	Short maintenance period due to cold climate
CZ	Environmental legislation (in particular forestry Law)

(37) Aparicio, Á., 2017: Transport adaptation policies in Europe: from incremental actions to long-term visions. *Transp. Res. Procedia*, 25, 3529–3537, doi:10.1016/j.trpro.2017.05.277.
(38) Bubeck, P., et al., 2019: Global warming to increase flood risk on European railways. Clim. Change, 155 (1), 19–36, doi:10.1007/s10584-019-02434-5.
(39) Climate-ADAPT country Profiles
(40) Greece received EU funds to install modern signalling and electrify a railway line. However, after receiving the funds, the line has been partially destroyed by a flood. The line needs thus to be rebuilt before the other subsystems can be deployed.
(41) Analysis of soil and rock's properties and conditions to improve railway construction.

5.1. Infrastructure Managers' measures to resist climate change

The measures have been clustered based on the different elements ensuring the resilience of the railway system.

5.1.1. Robustness and vulnerability

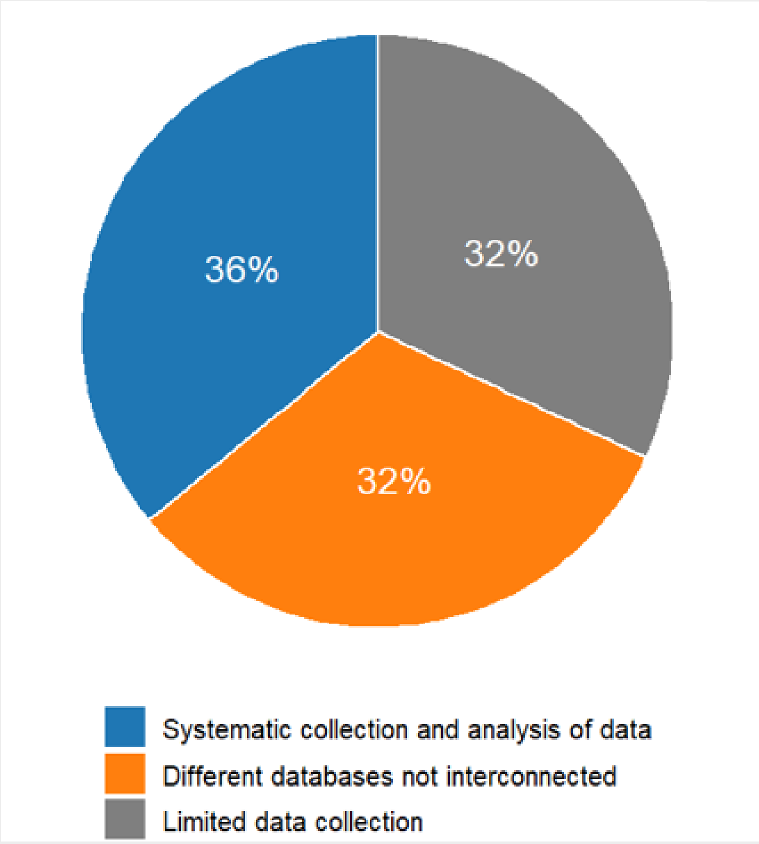
The preventive measures are the measures that reduce the probability of a disruptive event to take place while knowing and understanding where the system's vulnerabilities are.

Data collection and Monitoring of data

Collecting and analysing data is of outmost importance to understand the magnitude of a problem and many IMs identified getting reliable data on one hand and managing big data on the other hand as a challenge. Among the 28 IMs who were in the scope of our study, not all the infrastructure managers have a systematic and structured monitoring system of occurrences caused by weather events and when they have, it is not always possible to link a specific occurrence to its original cause. Some infrastructure managers have a more structured way of collecting data but originating from different organisational units or systems which are not interconnected impeding them to establish a sound analysis. For some IMs, it is even the opposite, so many data are collected that it is difficult to consolidate all the information gathered into a single reporting system.

The infrastructure managers are gathering data on train delays (traffic management perspective) but the data on traffic disruption i.e. when trains cannot be operated on a specific line because of a weather event are often lacking. In addition, the economic losses, whether direct or indirect, due to extreme weather events are also largely not fully integrated in IMs' analysis as asset manager and often not directly linked to the related extreme weather event. This is an important gap which impedes IM to take grasp of the effect of climate change on rail operation and rail infrastructure.

Figure 25: IMs' data collection and monitoring of data linked to extreme weather events, 2025, European Union Agency for Railways



Conclusion:

Improvements are largely needed in the field of data collection, data standardisation, monitoring and systematic analysis of data and linkage of databases.

Competence Management system

To tackle the topic of climate change within the railway sector, it is essential to develop specific competences combining climate expertise and railway expertise to mix the knowledge and experience in these two fields to finally adopt the right mindset. However, most of the IMs indicated that adaptation has not yet really been incorporated into engineers' education and training. Some IMs are trying to bridge this gap by strengthening the awareness of engineers, designers and project managers to include adaptation measures into their projects, by developing training on managing big data and by integrating climate risk assessment and vulnerability assessment into the more comprehensive risk management process. Some others, however, are struggling to recruit experts in sustainability especially because with the adoption of the Corporate Sustainability Reporting Directive (CSRD)[42], the specialists are in high-demand. In this situation, several IMs are contracting external expertise among public organisations in the Member State or private companies. Finally, most of the IMs pointed out the importance of sharing experience with other IMs. It was especially mentioned that IMs in Western and Central Europe could benefit from the experience of IMs in the Mediterranean area in managing heatwaves.

(42) Directive–2022/2464–EN–CSRD Directive–EUR-Lex

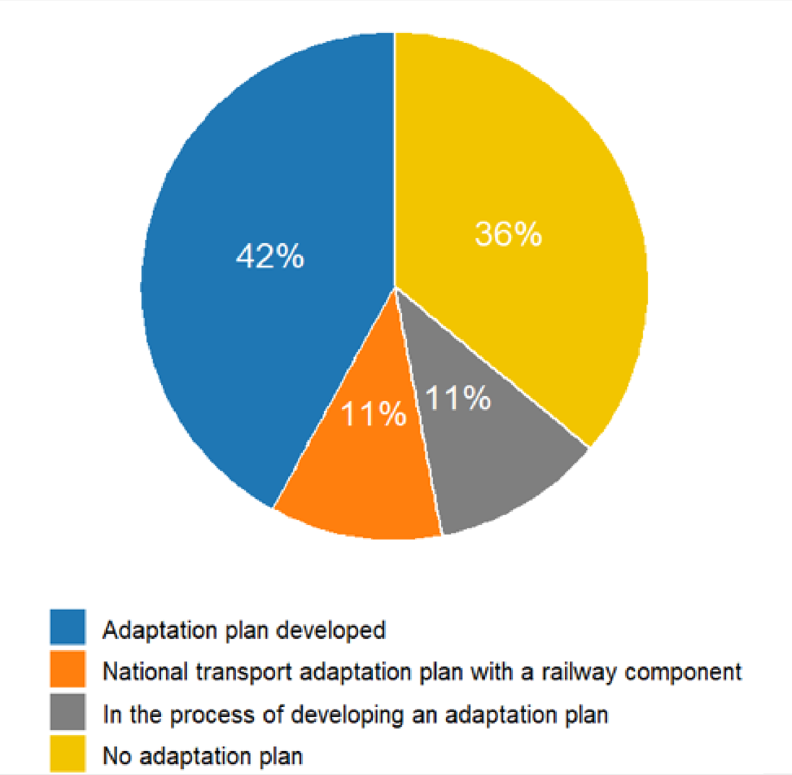
Conclusion:

Climate and adaptation expertise is not yet commonly spread within the IMs although knowledge and experience are being more and more built whether internally or through external support.

Adaptation measures

A bit less than half of the IMs have developed an adaptation plan. IMs which do not have an adaptation plan are still usually taking adaptation measures. However, those measures are more targeting a specific risk in a specific geographical area and are not encompassed in a global strategy at the level of the IM and with a long-term vision.

Figure 26: infrastructure managers and adaptation plan, 2025, European Union Agency for Railways



The most commonly adaptation measures to specific hazards are reported in the table below:

Table 7: Most frequent adaptation measures put in place by infrastructure managers per climate hazard

Climate hazard	Adaptation measure
Cold wave	Electrical heating on the switches.
Wildfires	Cameras near the tracks in dedicated areas to alert in case of start of fire.
Heatwave	Painting in white boxes containing electronic equipment. More resistant electronic system to high temperatures. Human supervision of the tracks in case of heatwave to verify their state. Welding temperature of the rail adapted to be less vulnerable to high temperatures. Air conditioning in operational centers.
Heavy precipitations and floods	Flood monitoring system. Increase drainage capacity. Increase the freeboard of bridges to avoid debris blocking the flow of water. Avoid pillar in the middle of the river with new bridges. Electronic equipment positioned higher. Monitoring devices in transversal drainage (e.g. culverts) works that generate warnings at the control centre. Drones for monitoring water levels. Increasing the level (elevation) of the placement of the rails, by resizing the embankment in areas at risk of flooding, in the case of new construction or rehabilitation/modernization works.
Storm, tornado, hurricane	Digital weather stations giving precise information on wind speed. Reduction of speed in case of strong wind. Preventive closure of a line in case of extreme situation. Side wind detectors. List of tree types to avoid along the railway tracks because they are not ready for climate change.
Landslide, avalanche and subsidence	Monitoring systems along the track for avalanches and landslides. Artificial Intelligence cameras on the most exposed slopes. Protective vegetation to the track from landslide/avalanche. Increased use of coring in pre-building study to have a better understanding of soil stability.

On top of these specific measures, even if almost all the IMs are receiving warnings from their national meteorological office, it must be noted that several IMs have their own weather stations in dedicated areas because the weather stations from the national meteorological office are not necessarily located in the vicinity of the railway network and their forecast might not be sufficiently precise to anticipate some climate risks for railway operation.

As part of their climate adaptation strategy, some IMs have identified critical parts of their infrastructure (e.g. the most important signal boxes, some tunnels, data centres) for which a climate proofing will be made and back up signal boxes defined to ensure continuity of the service. Partial redundancy of the electrical network is also foreseen in one case so that in case of black-out, there is a back-up solution. On top of drainage capacity, embankments are also very often prioritised depending on the criticality of the line. In addition, several IMs are developing toolbox of measures for specific hazard and specific equipment based on a review of best practices to replicate them on a larger scope of their network.

In addition, one IM has the project to centralise all the information related to the railway infrastructure in a Railway Infrastructure Monitoring Centre.

For new projects and, usually, for modernisation projects as well, climate and resilience studies are foreseen which contain mitigation and adaptation measures.

Conclusion:

Almost all IMs are taking adaptation measures even if not necessarily coherently coordinated into an adaptation plan. Sharing experience between railway stakeholders is essential to disseminate best practices.

Evolution of standards and norms

One adaptation measure which is quite broadly used or envisaged is to review the standards and norms of construction to integrate the more recent climate data. 15 IMs, so 53,5% of the respondents, have reviewed some standards to adapt them to future climate conditions or are in the process of reviewing them.

At this stage, most of the IMs are still building according to the current rules based on historical data but most of them are setting working groups to review internal regulations and standards. The prioritised standard to be reviewed is very often the standard on drainage capacity. For instance, in Belgium, a HQ20heavy rain should not impact the rail foundations and a HQ100 heavy rain should not flood the ballast. However, with changes in heavy precipitation patterns, what used to be a HQ20 heavy rain has changed and this change must be considered and integrated in standards. Infrabel foresees the involvement of an independent assessor to have a second opinion on the change (with the plan to finalise the work in 2025). In addition, for the past three years, higher rail temperatures have been considered and adaptations have been made. Summer rail temperatures of up to 60°C and winter rail temperatures of up to -20°C are now assumed. Additional adjustments may be made depending on further effective temperature changes. Design standards on bridges are also reviewed regarding erosion of pillars and increased water flow capacity and the slopes of the embankments are also reviewed. One IM is working with its national meteorological institute to develop a set of updated standards which should cover until 2100. Some IMs considered that this work on updating standards should be part of TSIs. Indeed, they consider that if IMs cannot cope with extreme weather events in the same way in the EU, interoperability will be eventually hindered.

Greater climate resilience can be achieved through the modernization of existing railway infrastructure in accordance with updated standards. For example, the new strategy in Germany is to renovate high traffic lines by closing them for the traffic for a long period ensuring continuous works instead of renovating the line on a long period with intermittent works, e.g. in 2024 the traffic was blocked for 6 months between Frankfurt and Mannheim to fully renovate it, and higher standards were used in that case.

Finally, in some Member States, national rules must also be considered when developing a new infrastructure project (e.g. law on water management, nature protection, environmental impact assessment, waste management, etc.). However, IMs considered that the missing element is the target system and how much resilient the railway system must be, especially when considering the needs of military mobility.

Conclusion:

Approximately half of the IMs are active in reviewing standard to be future climate proof with a priority on drainage capacity, embankment and civil engineering structures. It must be assessed whether some of the effort to review standards which are currently done at individual level should be more efficient at European level or not.

Maintenance

Most of the IMs have seasonal plans implementing preventive actions (e.g. to manage leave falls, lubrication, anti-icing agents) and/or to ensure coordination between the needs in maintenance and traffic management in case of storm events (e.g. VÄYLÄ) but very few IMs have integrated climate risks in their maintenance plans whether annual or multiannual. However, some IMs are reviewing their maintenance pattern to include the impact of weather events (e.g. Správa železnic with an increase in preventive cleaning due to more frequent heavy rains). According to Banedanmark, the end goal on asset management system standard (ISO 55001) is to integrate climate adaptation measures into the maintenance planning especially as many assets are old and risk assessment is mostly made on assets. The idea is to have a climate action plan that is modular so to design a railway system that is resilient all the way through with a certain level modularity i.e. to be adapted to the climate projection in 2050 and keeping the potential to enhance the robustness for 2100 depending on the evolution of climate projections when they are reviewed. As such, when there is a renewal of assets, climate risks are more systematically considered e.g. increase the culverts' capacity based on the flood data map.

Maintenance is a mix between preventive and reactive actions. The Swedish Transport Administration works to risk-assess and document the sites and assets that need both extra supervision, monitoring while awaiting action, but also as a basis for future action planning. This work is directly linked to strengthening the rail network and making it more resilient. CFL, in case of higher temperature or heavy rain, will deploy more frequent inspection of civil engineering structures and ADIF is reviewing its General Maintenance Criteria as soon as some new risks are detected. For maintenance, Network Rail has an asset degradation model and on lifecycle, climate change is decreasing assets, and the end goal is to determine how to manage those extra risks. Finally, SBB considers the lack of redundancy within infrastructure systems, or insufficient redundancy, as an element that will heighten the criticality of a component: individual infrastructure components become more critical, as their failure would be more disruptive to essential services so that redundancy is an essential way of increasing resilience of a system.

Conclusion:

Very few IMs have reviewed their maintenance pattern to integrate climate adaptation measures. This could have some potential safety and availability consequences on the long-term as the higher maintenance needs due to more frequent intense weather events are not necessarily properly considered at this point.

Financial resources and extra costs of adaptation measures

The aim of all the works mentioned in the paragraphs above (in particular, data collection, developing adaptation measures based on risk/vulnerability assessments, evolution of standards and norms) is to build well prioritised investment plans based on the limited financial resources available i.e. making all euros spent in making the rail network more resilient in the most efficient way possible by encompassing the view that today's investments are the benefits of the future losses avoided.

In terms of financial resources available, IMs have generally a multiannual investment plan negotiated between the infrastructure manager itself and the Member State. Several IMs have a dedicated budget line in this plan for climate actions and adaptation measures.

EU funds (e.g. Connecting Europe Facility, regional fund, EU Recovery and Resilience Facility) and EIB loans are considered by many IMs as key financing instruments to increase the resilience of their network to climate change. Indeed, when EU funds are allocated, climate proofing and adaptation measures must generally be foreseen. This allows IMs to gain experience and knowledge in vulnerability assessment, climate proofing and development of adaptation measures from these EU funded projects. This experience and knowledge can then be used to replicate it in non-EU funded projects. In addition, in at least one

Member State, budget lines from the Defence Ministry are used to enhance rail resilience, with the view that the rail network is a strategic asset for military mobility.

Conclusion:

Financial resources are limited, and rail assets have long lifecycles. infrastructure managers therefore needs to prioritise investments across competing projects, with improving the resilience of critical parts of the network being a key objective.. To support this, Member States should ensure adequate funding is made available, and EU funding are crucial to build up knowledge and experience in climate proofing. The new Multiannual Financial Framework should create new opportunities to find financial solutions to invest into the resilience of their network.

5.1.2. Survivability and response

Crisis management

In case of crisis, whether linked to extreme weather events or not, most of the IMs set up a crisis board to take quick decisions. Depending on the size of the network and the severity of the event (some IMs like SNCF Réseau use a scoring system from 0 to 6 to determine the seriousness of the crisis), the crisis will be either managed locally or centrally and with different potential levels (e.g. strategic, tactical and/or operational). The organisational structure and composition of this board will greatly vary from IM to IM.

In addition, most of the IMs have also developed seasonal plans (e.g. for the leaves in autumn etc.) and contingency plans which includes action plans in the case of heavy precipitation, wind, snowstorms, establishing the levels of impact and the traffic conditions to be applied in each case.

When the crisis is cross-border, coordination between IMs is essential. When different Member States were for instance hit by a flood in September 2024, notifications were exchanged between the IMs from Czech Republic, Austria, Hungary and Poland. However, some IMs also noted that this cooperation is still not yet optimal and could be further improved.

Conclusion:

All the IMs have procedures to manage crisis situations which can also include extreme weather events. While contingency plans should be developed by the IMs in coordination with the RUs operating on their network and the neighbouring IMs, this coordination is not always effective and could be further improved.

Cooperation with other organisations

Apart from one IM, all the IMs work with their respective national meteorological institute or equivalent to get real time information on the weather forecast which are then provided to the traffic management centre. In addition, when an event does occur and a crisis needs to be managed, IMs are usually working with local authorities, fire fighters, civil protection and neighbouring IMs, if relevant.

IMs are very often working in close collaboration with their respective national institute of hydrology or equivalent to build up knowledge on the flood risks (sharing risk maps, evolution of pluviometry, etc.) and some IMs are even sharing data from their own water management monitoring system.

Lots of IM are also closely connected to the forestry managers to analyse and prevent the risk of fallen trees on their network. However, the actual management of this risk is very heterogeneous between Member States due to their national legal framework and some IMs have different constraints to prevent this risk (e.g. usually linked to the organisation of negotiations with the owners of the land where the tree is rooted).

At international level, many IMs are also actively participating to the RERA (Resilient Railways facing Climate Change[43]) project led by UIC and in other workstreams such as the environment subgroup of the platform PRIME. CER and EIM also have dedicated working group on this topic which are following by various IMs and several IMs are also participating to the UN expert group on climate adaptation on rail, road and harbour. This cooperation can also be done at a more targeted level. For instance a working group set up between DB InfraGO AG, ÖBB-Infrastruktur AG and SBB Infrastructure is active on many topics in relation to climate change.

The IMs are also closely connected to their respective Ministry of Transport which can organise dedicated networks to exchange on the resilience topic. For instance, in Germany, an expert network has been created to structure the exchange between the different infrastructure managers with a multimodal perspective. In some cases, this can also include the electricity network manager considering the close link between the railway and the electricity networks.

Finally, several IMs have recognised the importance of cooperating with the academic world on specific resilience projects like VÄYLÄ in Finland with the University of Tampere on frost and track buckling.

Conclusion:

IMs cooperate with a multitude of organisations, the national meteorological institute being the most frequent one, and in very various formats (bilateral, small groups, sector organisations, international organisations). Despite all these fora to exchange experience and knowledge and share best practices, most of the IMs were eager to structure even more the cooperation.

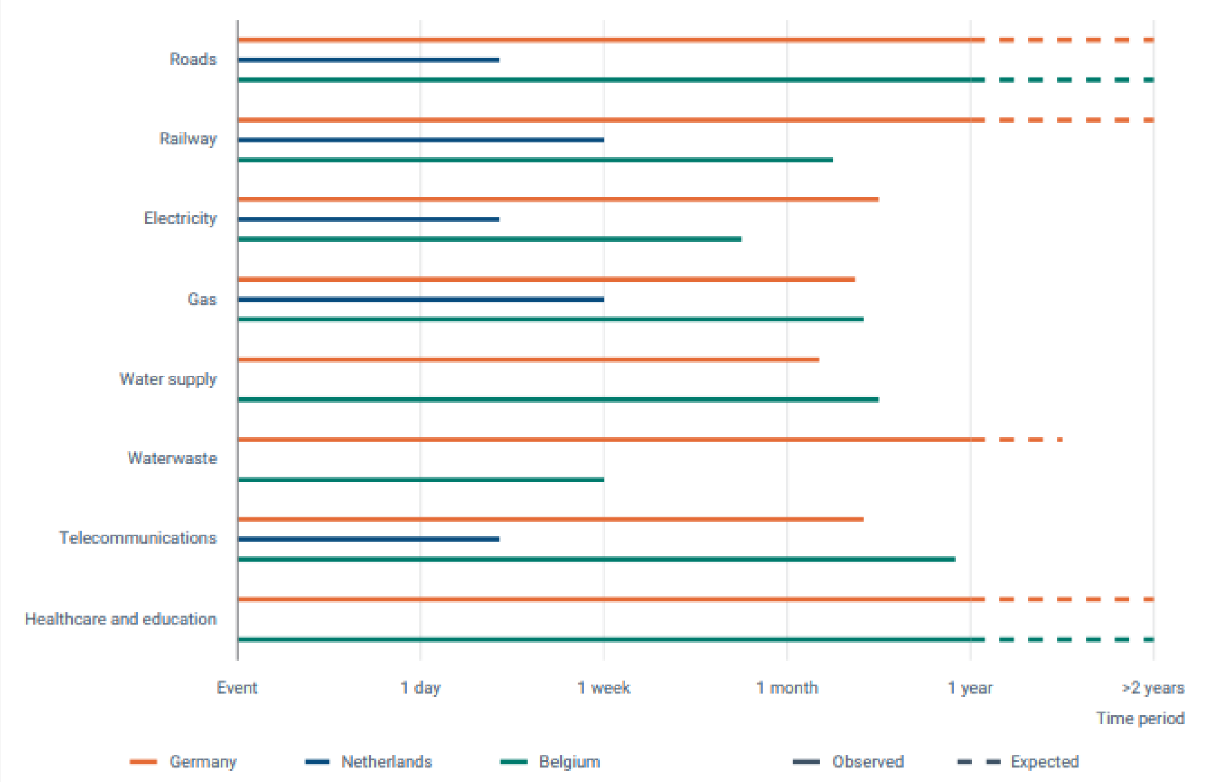
The role of national meteorological institutes is critical and the integration of their data into early warning systems and operational decision-making is fundamental.

5.1.3. Recovery

The recovery time to restore the traffic to its nominal situation will highly depend on the severity of the consequences of the extreme weather event. In the worst-case scenario, the damages are so substantial that it leads to the decision to abandon the restoration of a line shrinking thus the length of the railway network. However, the recovery time will also depend on the initial robustness of the system. Indeed, for several extreme weather events analysed (e.g. flood in Emilia-Romagna in 2023 or Valencia region in 2024), the local and regional lines have been affected more severely than the high-speed lines built with more modern standards.

(43) UIC led two projects: resilient railways facing Rain and resilient railway facing high temperatures. A new permanent group, RERA task force/knowledge hub, has been set up.

Figure 27: Recovery time of several critical infrastructure systems after 2021 flood in Belgium, Germany and the Netherlands, European Climate Risk Assessment based on Koks et al., European Environment Agency, 2024



5.2. Identification of best practices

During the bilateral interviews held with the IMs, many adaptation measures have been presented with different impact levels on reinforcing the robustness of the railway system and a wide range of financial intensity (from painting to decision of relocating a part of the infrastructure). Many measures are tailored to the local situation, but other measures can be replicated at a broader scale. What is important to consider is to apply a range of climate change scenarios and stress tests for high value investments. In addition, data monitoring, vulnerability and risk assessments, analysing the consequences and costs of inaction and use of adaptation plans are essential to decide on the right investments to be made. Finally, adaptation measures must as far as possible be modified as conditions change.

The adaptation measures can be multidimensional i.e. to prevent an event to happen by increasing the robustness of the system and limiting its vulnerability (e.g. improving drainage systems to increase capacity) or to prepare the system so that it can better respond and recover sooner to an adverse situation (e.g. real time weather monitoring system with emergency procedures linked to specific situations). The type of measures can also very much differ from hard investments (e.g. elevation of track bed) to competence enhancement through trainings and simulations, adaptation of protective clothing of workers and operational measures such as speed restrictions.

Many IMs are developing their own catalogue of adaptation measures that can be replicated on their network and are participating to international fora (e.g. UIC, UN) to exchange experience and knowledge. Some cross-sectoral information is also made available by EEA on its platform CLIMATE ADAPT[44] in which a reference is made to the UIC work RAIL ADAPT.

Some best practices are identified in this chapter as they are considered cost-efficient, relatively cheap with immediate effect, to mitigate a specific hazard and/or were commonly adopted by several IMs. However, developing a more exhaustive catalogue would require more analysis.

Following the catastrophic flood of 2021 in Belgium, Germany and the Netherlands, both DB InfraGo AG and Infrabel have taken the decision to rebuild the railway bridges with slimmer and higher structure and with piers outside the riverbed to increase the capacity of water flows and avoid debris blocking the flows. In addition, water basins have been added to absorb more volume of water in the affected areas. Water level monitoring systems are also considered essential and cost-efficient by several IMs and, in particular, Banedanmark is in the process of installing 1200 sensors to get real time information on water level including an alert system in case thresholds are overpassed. Banedanmark have also taken the decision to publicly share those data so that they can be used by researchers. ADIF has also implemented systems that sends alerts to the command post.

For high temperatures, DB InfraGO AG started using insulating white paint to protect heat-sensitive switching technology. Following an analysis of the average number of technical issues on switching technology on hot days (> 30° C) leading to delays, different options have been analysed. The most cost-effective solution retained has been the special painting which allows to reduce the average temperature in the switchgear buildings by up to 10° C with additional co-benefits such as lowered heating costs in winter and lower temperature fluctuation with a positive impact on battery life. In addition, many IMs are adapting the rail welding with higher neutral temperature.

In Spain, ADIF is implementing in various phases a plan to protect the network against thunderstorm, since a large part of its elements are vulnerable to electrical damage. To this end, new self-valving lightning conductors and voltage limiters are being installed at

(44) EEA, Climate-ADAPT

stations, at different points along the network and at tunnel mouths, as well as additional elements like catenary protectors, overpass visors and earthing systems.

As a conclusion, most of the IMs explained that a well-maintained infrastructure with built-in redundancy is less likely to fail during an extreme weather event than an ageing infrastructure that was already at its limit under past climate conditions.

5.3. NSAs' role in ensuring a resilient rail system

NSAs have a role to play in ensuring a more resilient rail system to climate change. Indeed, as part of their Safety Management Systems (SMS), IMs and RUs must have a risk assessment and risk management procedures which should cover different types of risks including the risks entailed from weather conditions. In addition, IMs must also develop contingency arrangements addressing extreme weather conditions in coordination with RUs and neighbouring IMs as required in point 4.2.3.6.3 of TSI operation and traffic management. When issuing Single Safety Certificates for RUs and Safety Authorisation for IMs, NSAs should assess whether those requirements are complied with by railway stakeholders. ERA also has a role when it is the authorising entity for Single Safety Certificates.

Additionally, NSAs are also in charge of authorising for placing in service of fixed installations. For these projects, design practices/standards are evolving to integrate further climate change effects and, in addition, some national rules integrating climate risks which need to be complied with might exist and NSAs must verify that those requirements are well respected when issuing an authorisation for placing in service.

Finally, NSAs also have a key role in supervising railway stakeholders' activities using the results of their assessments. As part of their supervision strategy and activities, NSAs might decide to include how IMs and RUs are integrating into their risk assessment procedures the specific risks linked to weather conditions (e.g. early warning system in case of predicted extreme weather event) or how contingency arrangements are tested.

A survey was launched in April 2025 to the NSAs to better understand how active NSAs are in this field leaving approximately 6 weeks to answer. Only 14 NSAs out of 25 replied to the survey representing 56% of the total number of NSAs. In addition, 3 NSAs outside the European Union answered.

Most of the responding NSAs (56%) do not have a monitoring system in place to gather information on weather events having an impact on rail infrastructure and/or rail traffic. However, 44% of the responding NSAs either cooperate with the national meteorological service and receive the information bulletins with weather forecasts and warnings in case of extreme weather phenomena forecasted or are aware that the main IM in the Member State has a traffic control centre that coordinates with the national meteorological service. In case of an occurrence, weather conditions existing at the time of the event are also indicated with, in some cases, a catalogue of the direct cause of the occurrence in the category of natural disaster (e.g. flood, landslide, snowstorm, windstorm, high temperatures).

When assessing the risk assessment procedure of the IMs/RUs following the submission of an application for Single Safety Certificate (SSC) or Safety Authorisation (SA), very few NSAs (19%) are considering climate risks as being in the scope of assessment and the vast majority (81%) are not assessing how climate risks are integrated into this procedure. The rate of NSAs checking whether IMs are performing vulnerability assessments of its network to climate change is very low as only 12.5% do this check while 87.5% do not look at this aspect. Compliance with point 4.2.3.6.3 of TSI OPE on contingency arrangements addressing extreme weather conditions is verified in a more systematic manner (44% of the responding NSAs) usually through the crisis management plan of the IM and its dedicated chapter on extreme weather conditions covering both preventive measures and procedures to be followed in the event of traffic disruption due to extreme weather events. This requirement from TSI OPE is generally linked with CSM on SMS point 5.5 on emergency management and covers also operational procedures (closure of lines, emergency timetables, deviations from the planned route for instance). In addition, one NSA has also been appointed as the Competent Authority under Directive (EU) 2022/2557 of 14 December 2022 on the resilience of critical entities and will therefore have a separate regulatory function which will also address extreme weather conditions from 2026.

Only 44% of the NSAs have incorporated into their supervision activities/strategy how IMs and RUs are integrating climate risks into their risk management procedure with topics such as evacuation of passengers in specific conditions (shared risk between IM and RU), questions raised on analysis of past events, instructions for the prevention and control of flood, snow accumulation on railway lines, power shutdown, fire prevention, asset management from a climate change perspective, including impact of climate change on maintenance (e.g. coastal erosion, embankments stability). 44% of the NSAs are also supervising how IMs are coordinating their contingency arrangements with RUs mostly through the supervision of emergency tests or simulations not necessarily linked to the case of extreme weather events. The ratio of NSAs having incorporated into their supervision activities/strategy early warning system to mitigate risks in case of forecasted extreme weather event is even lower with only 37.5% of the responding NSAs are supervising this aspect. Those NSAs active on this topic are supervising for instance deployment of operational hazard detection systems for monitoring operational processes and environmental conditions, risk ranking method for specific assets (e.g. embankments, drainage systems), use of weather alert system of the national meteorological service.

On the modification of standards and design practices:

- 44% of the responding NSAs indicated that there were projects or current works to update standards aiming at integrating climate change impact (e.g. changed influence of wind and temperature on the dimensioning of bridges);
- 12% that there was no project in that direction; and
- 44% who did not know if such project existed.

31% of the responding NSAs also indicated that there were national rules integrating climate risks to be complied with for new infrastructure and/or modernization projects although, for some of them, they have not yet been specified in recognized national technical rules. 44% indicated that there was not and 25% did not know.

Several NSAs mentioned their contribution to the transport adaptation plan elaborated at national level. Finally, some NSAs are actively involved in research projects (e.g. EBA with DZSF) with for instance the development and provision of hazard indication maps providing large scale indications of possible climate influence and climate hazards and potential risks areas on the rail network to optimize resource allocation for adaptation measures. One research focus is the development of these maps to assess climate related hazards along the rail network, including embankment fires, flood, and landslides events influenced by factors, such as temperature, rainfall, and wind. A reactive adaptation measure was also investigated with regard to the risk of storm damage. The usage of high-resolution radar satellites for the identification of treefalls in near-real-time was tested and carried out as an example.

In addition to these measures, investigations into possible changes to regulations are also being initiated. Currently, a detailed and structured overview of the regulations, guidelines, and standards of transport infrastructure, for which it would be useful to consider potential changes due to climate change, is in development at German level. As part of the Horizon 2020 project "NATURE-DEMO: Nature-based solutions for climate-resilient critical infrastructure"[45], the DZSF is working together with other NSAs. The fundamental aim of the project is to develop scientifically sound and practically applicable solutions to make critical infrastructures climate resilient. Nature-based Solutions are to be established as an integral part of planning processes in the long term to make infrastructure more resilient to climate-related hazards and at the same time achieve ecological, economic, and social benefits. The project is carried out by an international research consortium of 23 European partners and funded by the European Union.

(45) NATURE-DEMO–Nature-Based Solutions for Demonstrating Climate-Resilient Critical Infrastructure

6. Closing the gap: proposals to reinforce the European legal framework for railway resilience

Based on the gathered information, data collected and bilateral exchanges, ERA has identified some areas where potential improvements could be made to reinforce the resilience of the railway system. Those potential improvements are not detailed proposal of legal change but areas for which further reflections would be needed with different options. Before developing those proposals, ERA also asked during the bilateral interviews the opinion of infrastructure managers on what could be done to improve the resilience of the rail system.

6.1. Infrastructure Managers' proposals

First, most of the IMs agreed to say that doing nothing was not an option considering the trends of the impact of climate change on the railway system. In addition, while some IMs made quite detailed proposals other remained more general. Some of the proposals made by the IMs have been considered by ERA in its proposals while others are very specific/very general or out of the scope of ERA's activities. If a proposal has not been considered by ERA, it does not mean that this proposal does not need to be further analysed. For instance, the idea of a Landslide Directive following the model of the Floods Directive 2007/60/EC which has been very often quoted as an important legal instrument to assess and manage flood risks across Member States, could prove beneficial.

Table 8: IMs proposals to reinforce the resilience of the railway system to climate change

IM's country of origin	Measure proposed	ERA proposal n°
BE, ES, HU, IE, LU, PT, SI	More financial support with global investments to be designed based on climate projections and which network/parts of the network will be mostly impacted by climate change.	
AT, ES, LU, PT, SK	Common methodology to demonstrate the extra cost of inaction VS cost of inadaptation/adaptation and to quantify the economic impact of extreme weather events. Guidelines on the estimation of financial impact of climate change.	2
ES, PT	Establish indicators common to all IMS to assess the impact of extreme weather events, such as minutes of delays, rail traffic cuts (which are not included in the minutes of delay)	
ES, PT, SK	Standardize the methodology for recording and categorizing extreme weather events that allows for a comparison between countries.	1
CZ, PT	Resilience should be tackled with a holistic approach including military aspects, defence and cybersecurity.	
CH, PT	Essential to ensure redundancy in transport system to increase resilience.	
HR, ES, PT	Common rules/guidelines on integrating climate risks into projects from the planning phase until the maintenance and common requirements on mapping risks and prioritise the projects to be financed. Risk assessment should be supplemented with vulnerability assessment to help developing strategic planning feeding the asset management strategy.	2
LV, PT	Common guidelines supporting the decision-making process on when to suspend operation based on forecasted extreme weather events.	3
NL, PT	Increase coordination between IMs during crisis management because of cascading effect.	3
LU, PT	Setting-up a more user-friendly tool than Copernicus Interactive Climate Atlas to get a view on climate hazards' probability in different time horizon (e.g. DRIAS[46] in France considered easier to use).	
DK, DE, PT	Building resilience metrics which would help to define the level of robustness needed and eventually increase the understanding of what a resilient railway is.	2
DK, ES, PT, SK	Agreeing on the use of specific IPCC scenario and time horizon to make climate projections to have a comparable approach, even if it is not the same for all countries or regions. UN is promoting the use of the average scenario (SSP2-4.5) with stress test for the most pessimistic scenarios.	2
ES, IT, LU, PT	Harmonised standards where climate risks are integrated for specific equipment, especially the resistance threshold of equipment to some climate hazards. Adaptation measures should be in European legislation to have more restrictive and conservative dimensioning criteria and measures in projects and maintenance.	4
FI, FR, DE, HU, LT, LU, NO, PL, PT	Develop a catalogue of best practices to extend knowledge on innovative solutions for building infrastructure. Best practices are currently mostly shared at bilateral level. A network dedicated to share knowledge/experience on those aspects could prove useful.	4 + 6
IT, PT	Simplification of the authorisation for placing in service of fixed installations procedure when adaptation measures are implemented as those measures should not be considered as additional/new elements.	
CZ, PT, SE	Increase the coordination between the funding calls and the resilience requirements.	
IT, PT	Considering the positive experience with the flood Directive and its effect on harmonising practices in managing the flood risk, a landslide Directive would prove beneficial to harmonise practices in managing the landslide risk.	
BG, CZ, FR, IT, PT	Common rules on vegetation management in areas which are outside the remit of the IM. While the vegetation management is mostly based on national rules, those rules are rooted in European environmental legal framework (e.g. protection of biodiversity) which can encompass contradictory objectives. A clearance zone could be defined to protect the infrastructure from fallen trees.	4

(46) French project which acronym means « Donner accès aux scénarios climatiques Régionalisés français pour l'Impact et l'Adaptation de nos Sociétés et environnement ».

6.2. ITF's top recommendations

In its ITF Roundtable n°194 on Transport System Resilience[47], ITF has put forward the following top recommendations:

Incorporate resilience into transport policy and planning systematically: Resilience shall be an integral part of transport policies, strategic planning and transport-related indicators among others.

Develop tools that help reduce uncertainty about future disruptions of transport systems: development and deployment of methods such as horizon scanning, risk assessment and prediction of vulnerabilities via analysis of network characteristics, digital twins or transport modelling should be stimulated.

Develop guidance on which resilience measures for transport systems should be applied when and how: The focus should be put on best practices on robustness and recovery. Estimating costs of disruption, mitigation and adaptation in different circumstances is also essential.

Improve global coordination mechanisms to deal with the impacts of transport system disruptions: Crisis can cascade and have regional or even global impacts and ability to react at the sole national level can be limited so that coordination between different stakeholders must be enhanced with collateral positive effect on learning curve on dealing with disruptions.

([47]) ITF (2024), Transport System Resilience: Summary and Conclusions, ITF Roundtable Reports, No. 194, OECD Publishing, Paris.

6.3. ERA's proposals

ERA's proposals have used the inputs from the different IMs and try to respond to the ITF's recommendations.

ERA proposal n°1: Common Safety Method for Assessing the Safety Level and the Safety Performance of railway operators at national and Union level (CSM ASLP)

Problem definition

This study is the first attempt to develop an exhaustive view on the impact of extreme weather events – whether linked or not to climate change–on the rail system. Despite the large amount of data collected and the efforts put to involve all the main IMs in EU Member States, it was not possible to get an exhaustive and fully accurate view of the situation. It was possible though to determine trends on the number of events and order of magnitude of their consequences at European scale.

Objective

Considering those trends and consequences of those events, it seems necessary to develop a more systemic, structured and harmonised approach to data collection and analysis. This would enhance the comprehension of the impact of climate change on the railway system and allow the railway stakeholders and policy makers to take more appropriate and targeted adaptation measures.

Means

The European Commission is currently processing the adoption of the Commission Delegated Regulation establishing Common Safety Methods for Assessing the Safety Level and the Safety Performance of railway operators at national and Union level (CSM ASLP) which could be adopted in 2025/2026. The overall purpose of these common safety methods is to help the railway undertakings and infrastructure managers for improving their safety management and to ensure that they can achieve their business objectives in a continuously improved safe manner. The methods should also support decision-making of Member States regarding the achievement of common safety targets referred to in Article 7 of Directive (EU) 2016/798 on railway safety (RSD), by providing evidence and information on the evolution of safety performance and safety levels at national and Union level. Eventually, CSM ASLP should enable the sharing of data and reporting of accidents and incidents in a harmonised manner through a common taxonomy considering that data collection will be mandatory.

Article 3 (12) of RSD gives a definition of 'serious accident' as follows: "*any train collision or derailment of trains resulting in the death of at least one person or serious injuries to five or more persons or extensive damage to rolling stock, the infrastructure or the environment, and any other accident with the same consequences which has an obvious impact on railway safety regulation or the management of safety; 'extensive damage' means damage that can be immediately assessed by the investigating body to cost at least EUR 2 million in total*".

The current application of this definition seems to be interpreted in various ways and seems to be restricted to the railway sphere excluding thus the extreme weather events which are causing extensive damage to the railway system or its environment. Unless weather events are the direct cause or a contributing factor of an accident, extreme weather events extensively damaging rolling stock, infrastructure or the environment are not reported.

'Accident' is defined in article 3 (11) of RSD as *follows "an unwanted or unintended sudden event or a specific chain of such events which have harmful consequences; accidents are di-*

vided into the following categories: collisions; derailments; level crossing accidents; accidents to persons involving rolling stock in motion; fires and others". Extreme weather events could potentially fall in the category of "fires and others".

The CSM ASLP already foresees to collect the reporting of any accidents and incidents included those caused by weather related conditions. In this future context, extreme weather events will fall in the scope of 'Other' accidents as soon as they result in harmful consequence, as well as in 'Other' incidents, potentially causing those accidents.

Note: in the CSM ASLP context, harmful consequence is to be understood in broad meaning, including accidents with victims and damages, or only victims or only damages.

Data properties related to weather conditions are included in the CSM ASLP proposal, as a starting point, in the reference taxonomy. The starting taxonomy might not yet be fully exhaustive and can be updated when needed according to the CSM ASLP maintenance processes, considering the experience learnt for the future reported record.

Note: in full regime, it is expected to collect around 1 million records per year in Europe gathering accidents/incidents records, with a share of them potentially linked to weather conditions.

The events taxonomy of the future CSM ASLP are clustered into 3 categories:

Accidents	Direct causes	Indirect causes
Any accident directly resulting in fatality, injury or damage.	Incident with the potential to directly cause an accident.	Incident with the potential to directly or indirectly cause a direct cause.

For each occurrence reported, the context of the occurrence shall be determined including the weather conditions with the ambient conditions (e.g. air temperature, rain, storm) and the track surface conditions (e.g. slippery, leaves, ice). However, at this stage, the initial list of direct causes only includes "Other direct cause" (B4) and "Fire in proximity of the infrastructure" (B4.1) while category C events include some weather events (e.g. flood, landslide). C2.1 to C2.7 list the weather events considered.

The CSM ASLP should then offer the right reporting environment to cover the reporting of weather-related accidents and incidents.

Implementing actions

Ensure that the initial taxonomy of the CSM ASLP is updated and improved, where needed, to fully satisfy the reporting of weather-related accidents and incidents.

- Option 1: Use the future CSM ASLP Delegated Regulation to collect weather related occurrences and introduce guidance on how best use and improve the harmonised CSM ASLP taxonomy to report those type of events. In the meantime, ERA should start gathering information on extreme weather events with the initial CSM ALSP taxonomy and propose potential improvements in coordination with the sector, in the context of the ISS Pilot.
- Option 2: Option 1 + until CSM ASLP is fully implemented, ERA should continue its work in gathering data on impact of extreme weather events on the railway system. The next edition of the rail environmental report foreseen in 2027 could be used to integrate the newly collected information with the information collected for the sake of this report. In addition, the potential to link ISS information to meteorological data (with potential support of artificial intelligence) in order to assess the link between extreme weather events and occurrences should be further analysed.

Preferred option

Option 2 is the preferred option as it would allow to improve CSM ASLP taxonomy and data collection while in parallel giving ERA the possibility to continue analysing the evolution of extreme weather events' impact on the European railway system.

ERA proposal n°2: Common Safety Method for Risk Evaluation and Assessment (CSM RA)

Problem definition

Commission Implementing Regulation (EU) No 402/2013 on the common safety method for risk evaluation and assessment[48] has been adopted in 2013 to harmonise the methods used for identifying and managing risks and the methods for demonstrating that the railway system in the territory of the Union conforms to safety requirements. This Commission Implementing Regulation focuses on the assessment of technical, operational or organisational changes, that are initiated by a proposer, to the railway system in a Member State and their significance. Climate risks are not considered in this Implementing Regulation as the concept of proposer is absent. However, safety risks associated with physical assets should be managed throughout their lifecycle as stated in criteria 5.2 of the CSM on Safety Management System[49], Commission Delegated Regulation (EU) 2018/762. Climate change has an impact on existing infrastructure and, as such, risk assessment should also cover climate risks linked to activity risk management.

Objective

At this stage, railway stakeholders which are performing climate risk assessments are either using their own methods or are using:

- ISO 14091:2021 on Adaptation to climate change — Guidelines on vulnerability, impacts and risk assessment[50]. This standard focuses on hazard, the exposure of a given system to the hazard, the sensitivity of the system to the hazard, the potential impact without adaptation measure(s) and the risk with adaptation measure(s) adopted.
- JASPERS-Guidance Note "The Basics of Climate Change Adaptation Vulnerability and Risk Assessment" (Version 1) June 2017[51].
- Commission Notice–Technical guidance on the climate proofing of infrastructure in the period 2021-2027 (2021/C 373/01)[52]. Climate proofing is divided into two pillars (climate neutrality/mitigation of climate change and climate resilience/adaptation to climate change) and two phases (screening and detailed analysis). Climate risk assessment is a key aspect of the second pillar on climate resilience leading to the definition of the necessary adaptation measures. In the first phase, a climate sensitivity, exposure and vulnerability analysis shall be carried out (similarly as what is recommended in ISO 14091:2021 standard) and, if significant climate risks are identified, the second phase should start. During this phase, a climate risk assessment must be carried out including the likelihood and impact analyses. This assessment can consider different IPCC scenarios and time horizon based on design working life of the asset. For instance, the design working life of a bridge is considered to be 100 years so that a bridge designed in 2025 will have to be resilient to the climate conditions and extreme events expected up to 2125.

In addition, climate risks assessments are aimed at directing the necessary investments to protect an asset so it should be complemented by a criticality assessment to enhance the prioritisation of the investments.

(48) Implementing regulation–402/2013–EN–EUR-Lex
(49) Delegated regulation–2018/762–EN–EUR-Lex
(50) ISO 14091:2021–Adaptation to climate change — Guidelines on vulnerability, impacts and risk assessment
(51) the-basics-of-climate-change.pdf
(52) EUR-Lex–52021XC0916(03)–EN–EUR-Lex

The current CSM RA method is aligned to a certain extent with the second phase (detailed analysis) of the technical guidance on the climate proofing of infrastructure. However, for climate risks, a preliminary screening phase is necessary to assess not only the likelihood and impact but also the vulnerability of the system to a specific climate hazard through an exposure and sensitivity analysis. In addition, during the detailed analysis phase, climate projections need to be used to integrate in the assessment probable future conditions.

Note that one of the deliverables of the JNS Normal Procedure[53] "Crosswind" that took place from January 2024 to December 2025 is the development of a methodology on holistic risk assessment of freight transport on crosswind sensitive infrastructure. This methodology aims at guiding IM through the risk assessment process as described in CSM RA for the specific case of crosswind. Similar methodologies could be developed for other climate-related hazards (such as flood, extreme temperatures, etc.).

The aim would be to have a common approach for the railway stakeholders to tackle climate risks.

Means

ERA has recently produced a CSMs review vision document and discussions are on-going on evaluating the criteria to assess the significance of a change and on extending the scope of CSM RA to additional risks (e.g. climate, cyber).

Implementing actions

Ensure that climate risks are considered in a common way by railway stakeholders when performing risk assessment.

<u>Option 1</u>: CSM RA's application guide has not been reviewed since 2009. During the general revision of the CSMs, this application guide should be further revised to include among other a specific annex on how to tackle climate risk assessment.

<u>Option 2</u>: CSM RA Implementing Regulation should be revised to integrate climate risks into its scope and when and how to apply it. In particular, the vulnerability assessment (exposure and sensitivity analyses) should be included into the process for the climate risk assessment following the ISO 14901:2021 standard and the technical guidance on the climate proofing of infrastructure[54].

<u>Option 3</u>: Option 2 + CSM RA's application guide should contain elements in relation to:
- Evaluation of the potential impact of a specific climate hazard on the railway system without adaptation measure(s) i.e. guidance on how to evaluate the inaction/inadaptation costs versus the benefits of adopting the appropriate adaptation measures.
- Development of resilience metrics i.e. guidance on how to assess the resilience of a system based on its robustness and its response/recovery time.

Preferred option

Option 3 is the preferred option as it encompasses the main proposals made by the IMs and is the key instrument to have a holistic approach of climate risks on the railway system.

(53) Joint Network Secretariat (JNS) | European Union Agency for Railways
(54) In this technical guidance on the climate proofing of infrastructure, it is specified that it may be complemented with sectoral considerations and guidance.

ERA proposal n°3: Technical Specifications for Interoperability relating to the operation and traffic management (TSI OPE) and Contingency plans/Crisis management

Problem description

While most of the IMs have seasonal plans and all of them have developed contingency plans and internal processes on how to manage crisis, those plans are not systematically defined in conjunction with all the RUs operating on the infrastructure and with the neighbouring infrastructure managers. In addition, only less than half of the NSAs are assessing the plans and how they are elaborated when delivering the safety authorisation to the IM and the same proportion of NSAs are incorporating those aspects into their supervision activities.

Objective

Considering the climate pressure, having strong methods and means of coordination between railway stakeholders is necessary.

Rail Net Europe has developed the first edition of its Handbook for International Contingency Management[55] in 2018 following the Rastatt incident which occurred in 2017 in the Rhine Valley in Germany. This handbook has been revised most recently in December 2024 and aims at structuring cooperation in case of international disruptions of railway traffic by, for instance, defining roles and responsibilities, elaborating pre-defined procedures and listing best practices.

Means

Commission Implementing Regulation (EU) 2019/773 of 16 May 2019 on the technical specification for interoperability relating to the operation and traffic management subsystem of the rail system within the European Union requires in point 4.2.3.6.3 on Contingency arrangements that "*the infrastructure manager in conjunction with all the railway undertakings operating over its infrastructure, and neighbouring infrastructure managers as appropriate, shall define, publish and make available appropriate contingency measures and assign responsibilities based on the requirement to reduce any negative impact as a result of degraded operation.*

The planning requirements and the response to such events shall be proportional to the nature and potential severity of the degradation.

These measures, which shall as a minimum include plans for recovering the network to 'normal' status, may also address:

[…]

- *Extreme weather conditions*".

In addition, the proposed capacity management Regulation which would amend Directive 2012/34/EU establishing a single European railway area[56] would also introduce obligations concerning disruption management and crisis management and cross-border coordination on these issues.

Implementing actions

Ensure higher level of coordination between railway stakeholders in managing crisis linked to extreme weather events.

Option 1: TSI OPE application guide should be complemented with additional guidance on the development of contingency arrangements for managing extreme weather con-

(55) RNE-ICM-Handbook_v3.0.pdf
(56) Directive–2012/34–EN–EUR-Lex

ditions and in particular how coordination with RUs operating on the network and neighbouring IMs should be organised.

Option 2: Option 1 + Acceptable Means of Compliance (AMOC) should be developed to cover TSI OPE's requirement on contingency arrangements including extreme weather conditions and potentially condition to suspend operations. RNE's handbook for international contingency management could be used as an input for this AMOC[57].

Preferred option

Option 2 is the preferred option as an AMOC would give more relevance on how to be compliant to the requirements of point 4.2.3.6.3 of TSI OPE.

ERA proposal n°4: Structural TSIs and evolution of standards and norms

Problem description

Structural TSIs can consider the resilience of the railway system to climate change just to the extent necessary to achieve interoperability.

Regarding rolling stock subsystem, point 4.2.6.1 of TSI LOC&PAS and point 4.2.5 of TSI WAG have general requirements indicating that the design of the unit, as well as its constituents shall consider the environmental conditions to which this rolling stock will be subject to. In TSI LOC&PAS application guide, a reference is made to complete EN50125-1:2014 that could be used as guidance for environmental parameters not specified in the TSI. The standard covers environmental conditions for RST and onboard equipment such as altitude, temperature, humidity, air movement, rain, snow, ice, solar radiation, pollution, etc.

The main aspects mandated by the TSIs are the temperature range and winter conditions with a reference to EN 50125-1:2014 on Environmental conditions in TSIs WAG and LOC&PAS. Measures to tackle crosswinds' risk effect are also foreseen in point 4.2.6.2.4 of TSI LOC&PAS with also a reference to EN 14067-6:2018 on Railway applications–Aerodynamics–Part 6: Requirements and test procedures for crosswind assessment and in point 4.2.10.2 of TSI INF[58]. In 2025, the WAG TSI was amended to include requirements in point 4.2.2.4 for devices to secure semi-trailers on pocket wagons. These requirements were developed during the JNS procedure "crosswind" as a measure against the hazard of crosswind.

In addition, as a side product of the development of the holistic methodology for the assessment of the risk freight traffic on crosswind sensitive infrastructure, requirements for the WAG TSI are envisaged for the minimum crosswind stability of freight wagons. Corresponding requirements will be proposed for the INF TSI that the IM shall respect to control the risk of overturning rolling stock due to crosswind.

Point 4.2.8.2.5 of TSI LOC&PAS also has requirements for maximum current usable from the overhead contact line (catenary) by the train pantograph in standstill situation, with special provisions for trains equipped with electric energy storage for traction purpose (battery trains). The objective is to facilitate the place into service of alternative fuel trains (e.g. battery trains, hydrogen trains) in line with European Commission objectives for energy efficiency and resilience to climate change. In addition, as for TSI LOC&PAS, the current revision of the Energy TSI, in the context of the EC mandate to ERA, also considers further possible improvements for the use of alternative fuels, in line with European commission objectives for energy efficiency and resilience to climate change.

([57]) In addition, a draft standard is being developed and could be also used as input for developing this AMOC. Draft ISO 22083 on "railway applications – Concepts and basic requirements for the planning of railway operation in the events of predictable natural hazards".
([58]) These risk control measures were developed within the JNS Normal Procedure "Crosswind", Subgroup AMOC along with an impact analysis.

Regarding TSIs related to fixed installation, point 4.2.10.2 of the Infrastructure TSI specifies that the effects of crosswinds must be assessed under the most critical operational conditions to ensure compliance with safety requirements. If safety cannot be guaranteed without mitigation, the infrastructure manager must implement the necessary measures to maintain safe operation (for example, by locally reducing train speeds). The demonstration of safety lies outside the scope of this TSI and shall be carried out by the infrastructure manager, in cooperation with the railway undertaking where necessary.

Regarding the Control Command and Signalling (CCS) subsystem: several points of TSI CCS require that this equipment shall be able of being operated under the climatic and physical conditions of the area of use (see points 3.2.3.1.1, 4.2.16).

TSIs are thus not yet fully adapted to tackle the topic of resilience to climate change. TSIs are developed to meet essential requirements for interoperability of the Union rail system such as safety and reliability and availability.

Feedback from IM on existing practice

The most shared proposal made by the IMs is to at least develop a catalogue of best practices to enhance the resilience of the railway system and even, for some IMs, to integrate targeted adaptation measures into the European legislation. In addition, climate risk assessment, when not already foreseen (e.g. Directive 2022/2557 on the resilience of critical entities), could be made mandatory for new infrastructure projects and for modernisation projects based on defined criteria such as operational and economic relevance, passenger/freight volume, existence of alternative routes.

On top of individual IMs, different organisations such as UIC, EEA or EIB[59], have already developed non-exhaustive lists of best practices which could serve as basis for the definition of adaptation measures aiming at improving the resilience of the railway system.

Finally, most of the IMs have mentioned fallen trees on the track as a frequent problem which is generating delays and several IMs would like to have a clearance zone (often between 6 to 10 meters) along the track for vegetation management to be specified in a TSI. However, vegetation and trees can also be a stability factor so that solution should be tailored to the situation.

Means

The relevant structural TSIs would be an appropriate legal tool to tackle this problem. In addition, there is a request in the updated mandate M591 to the European Committee for Standardization (CEN) and the European Committee for electronical standardization (CENELEC) with a generic requirement to consider future climatic conditions to draft the standards and specific requirements for EN 50125-1 and 50125-2 and 3 for which the standard shall define the environmental and climate conditions for rolling stock and on-board equipment

Implementing actions

Ensure that TSIs are adapted to face the challenge of resilience to climate change.

Option 1: ERA should make a general review of structural TSIs' requirements against the climate risks identified and identify the potential gaps which would need the development of new requirements. This should include request to CEN for revising relevant EN standards as EN50125-1 or EN14067.

Option 2: option 1 + Develop a catalogue of best practices and adaptation measures which have proven their efficiency to be added in the application guides of the dedicated TSIs.

([59]) jaspers-climate-resilience-sectoral-guidance-nov2024.pdf p.179-182

Option 3: option 2 + provided that an essential requirement on resilience is added and considering the trends of the impact of extreme weather events on the railway system and the need it entails to have climate-proof design for new structures and retrofitting and reinforcement of existing installations, additional requirements could be developed in TSIs with specific attention to be paid to the following items:

- *Drainage systems.* Most of the IMs which have been severely affected by flood recently are reviewing their drainage standards. Based on their experience, the possibility to add requirements in TSI could be studied.
- *Bridges and culverts*. Similarly as for the drainage systems, following floods, the design of bridges and culverts has been reviewed to increase the water flow capacity and avoid the potential accumulation of debris on to the bridge.
- *Stability of embankment.* Several hazards can impair embankments' stability (e.g. heavy precipitation, landslide, subsidence) and they are very often prioritised in IMs' vulnerability assessments.

Preferred option

Option 3 is the preferred option as it would allow to develop a comprehensive action list which would still need to be prioritized.

ERA proposal n°5: NSAs and ERA's role in improving the rail resilience to climate change

Problem description

Few NSAs have integrated the topic of rail resilience to climate change into their tasks while they have a critical role to ensure that railway undertakings and infrastructure managers are taking the necessary measures to improve the resilience of their assets and processes.

Objective

ERA can act on the resilience of the railway system when delivering SSCs and NSAs can act on the resilience of the railway system when delivering SSCs/SAs which gives them the opportunity to verify how RUs and IMs are organising, for instance, their risk assessment process, their maintenance procedures or their contingency plans. Through their supervision activities, NSAs also have the possibility to verify how SMS procedures are implemented in practice.

Means

ERA through its role of coordinating the NSA network and its monitoring role could enhance the capabilities of the NSAs to act on the resilience of the railway system to climate change. ERA should also advocate such idea at the level of its Management Board and Network of Representative Bodies to raise awareness at Member State and sector's level.

Implementing actions

Option 1: ERA should raise awareness on the topic of rail resilience through the NSA Network. ERA's guidance for certification and supervision on SMS requirements for safety certification or safety authorisation could be further developed to include elements in relation to resilience and especially in the paragraphs related to risk management, asset management and emergency management. Finally, ERA could develop some dedicated training tools/programmes on the topic of resilience to climate change.

Option 2: Option 1 + NSA Monitoring assessment criteria should integrate the topic of resilience when looking at how NSAs deal with SSC/SA, supervision and Authorisation for placing in service of fixed installations.

Preferred option

Option 2 is the preferred option as it would allow to act at different level to strengthen the role of NSAs on rail resilience to climate change.

ERA proposal n°6: Reinforcing cooperation in the railway sector on the resilience to climate change

Different fora already exist to facilitate the exchange and sharing of experience between railway stakeholders (e.g. UN group of experts, UIC, RNE, PRIME among others). Despite all these possibilities, many IMs considered that building a network dedicated to share knowledge/experience on rail resilience to climate change would be useful. This is maybe due to that the fact that there is a lack of clear leadership and fragmented responsibilities in terms of investments, planning and adaptation measures to be taken. In addition, transport being a system, cooperation across modes of transport is also needed.

An option could be to ensure a better coordination between those different networks and working groups to avoid duplication of efforts and stronger synergies among stakeholders.

7. Conclusions

2024 was the warmest year in global temperature records going back to 1850and before that 2023 was the warmest year recorded. Higher temperatures are already having effect to the society with among other heatwaves and heavy precipitations and floods and eventually economic losses. Climate change is a non-contestable reality and already affects the railway system through more frequent and more severe weather events. More than two thirds of the infrastructure managers reported clear impact of extreme weather events on their networks across Europe.

Thanks to this study, it is possible to analyse trends of these events at European scale. However, to better understand the magnitude of the impact of climate change, data collection and analysis should be more structured at European level. This would allow to enhance decision-making on adaptation measures increasing thus the level of resilience of the railway system and to better direct the investment needs. It would also permit railway stakeholders to move from a reactive approach to a more pro-active one.

Climate risk assessment is essential to increase our understanding of the climate change consequences and to take the necessary adaptation measures to make the railway system, and more globally our society, more resilient. Capabilities to perform vulnerability assessments, climate risk assessments should be reinforced among the railway stakeholders. The railway sector is facing specific vulnerabilities, and they need to be assessed to build adequate adaptation measures and adaptation plan to be fit for the future with in-built resilience in investments being key. The EU has a key role in supporting those investments and helping railway stakeholders to increase their know-how to face this challenge. It was interesting to note that the railway stakeholders who received the support from the EIB generally have a higher degree of maturity in tackling climate risks.

Damage to the built environment from extreme weather events is projected to increase up to 10-fold by the end of the 21st century due to climate change alone with the most significant increases in impacts expected in the energy and transport sectors. Being able to use climate projections when planning investments for upgrade or new infrastructure is also key to increase their resilience as the historical data used for the design of assets can rapidly be outdated due to climate change.

Finally, infrastructure managers cannot deal with one climate hazard without thinking on how to deal with the other ones as climate hazards can interact in compound or sequential ways. Infrastructures are also highly interconnected meaning that a disruption in one sector, such as electricity distribution, can affect others, such as train operations. Cooperation between infrastructure managers and with other relevant partners such as meteorological institutes is crucial to develop a coordinated approach and to build economies of scale together with safeguarding interoperability.

ERA is committed to continue working on the topic resilience to climate change and to monitor the trends of the impact of extreme weather events to the European railway system.

Annexes

Annex 1: Abbreviations

°C	Degree Celsius
AMOC	Acceptable Means of Compliance
ASLP	Assessing the Safety Level and the Safety Performance of railway operators at national and Union level
C3S	Copernicus Climate Change Service
CCS	Control Command and Signalling
CEN	European Committee for Standardization
CENELEC	European Committee for electronical standardization
CER	Community of European Railway and Infrastructure Companies
CFL	Société Nationale des Chemins de Fer Luxembourgeois
CO_2	Carbon dioxide
CSI	Common Safety Indicators
CSM	Common Safety Methods
CSRD	Corporate Sustainability Reporting Directive
DANA	Depresión Aislada en Niveles Altos – Cold drop in English
DZSF	Deutsche Zentrum für Schienenverkehrsforschung
EBA	Eisenbahn-Bundesamt
EC	European Commission
EEA	European Environment Agency
EIB	European Investment Bank
EIM	European Rail Infrastructure Managers
EN	European Norm
ERA	European Union Agency for Railways
ESOTC	European State of the Climate
EU	European Union
HQ100	100-year flood
IM	Infrastructure manager
INF	Infrastructure
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardisation
ITF	International Transport Forum

JASPERS	Joint Assistance to Support Projects in European Regions
LOC&PAS	Locomotives and Passenger rolling stock
MS	Member State
NIB	National Investigation Body
NSA	National Safety Authority
OECD	Organisation for Economic Cooperation and Development
OPE	Operation and Traffic Management
PRIME	Platform of Rail Infrastructure Managers in Europe
RA	Risk Evaluation and Assessment
RINF	Register of Infrastructure
RNE	Rail Net Europe
RSD	Railway Safety Directive
RST	Rolling stock
RU	Railway Undertaking
SA	Safety Authorisation
SMS	Safety Management System
SPF Mobilité	Service Public Fédéral Mobilité et Transports
SSC	Single Safety Certificate
SSP	Shared Socioeconomics Pathways
TEN-T	Trans-European Transport Network
TSI	Technical Specifications for Interoperability
UIC	Union Internationale des Chemins de Fer
UN	United Nations
UTK	Urząd Transportu Kolejowego
WAG	Wagon
WMO	World Meteorological Organisation

Annex 2: Definitions[60]

Adaptation measure: Actions to reduce vulnerability to the current or expected impacts of climate change.

Adaptation plan: Comprehensive medium and long-term strategies that outline how an organisation will adapt to the changing climate and reduce its vulnerability to climate-related risks.

Climate change: Term used to describe changes in the state of the climate that can be identified by changes in the average and/or the variability of its properties and that persists for an extended period, typically decades or longer.

Climate hazard: Potential occurrence of climate-related physical events or trends that may cause damage and loss.

Climate projection: Simulated response of the climate system to a scenario of future emissions or concentrations of greenhouse gases (GHGs) and aerosols and changes in land use, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socio-economic and technological developments that may or may not be realised.

Climate risk: In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards.

Cold wave: A period where the maximum temperature falls below the 10th percentile of the monthly distribution for at least two days.

Contingency arrangements: Measures and definition of responsibilities to reduce any negative impact as a result of degraded rail operation.

Drought: An exceptional period of water shortage for existing ecosystems and the human population (due to low rainfall, high temperature and/or wind).

Exposure: Presence of assets, services, resources and infrastructure that could be adversely affected by climate hazard.

Extreme weather event: Weather event at a particular place and time of year, with unusual characteristics in terms of magnitude, location, timing, or extent. The characteristics of what is called extreme weather may vary from place to place in an absolute sense. In this study, extreme weather events are events which caused at least EUR 2 million of damage and/or traffic disruption of at least six hours[61].

Flood: The overflowing of the normal confines of a stream or other water body, or the accumulation of water over areas that are not normally submerged. Floods can be caused by unusually heavy rain, for example, during storms and cyclones. Floods include river (fluvial) floods, flash floods, urban floods, rain (pluvial) floods, sewer floods, coastal floods, and glacial lake outburst floods.

Heatwave: A period where the maximum apparent and the minimum temperature are over the 90th percentile of the monthly distribution for at least two days.

([60]) European legislation, European Environment Agency and IPCC sources have been used to establish the definitions of terms. In particular, IPCC Glossary Search has been used as main reference.
([61]) Using definitions in the Railway Safety Directive.

Heavy precipitation: An extreme/heavy precipitation event is an event that is of very high magnitude with a very rare occurrence at a particular place. Types of extreme precipitation may vary depending on its duration, hourly, daily or multi-days (e.g., 5 days), though all of them qualitatively represent high magnitude. The intensity of such events may be defined with block maxima approach such as annual maxima or with peak over threshold approach, such as rainfall above 95th or 99th percentile at a particular space.

Landslide: Gravitational movement of a mass of rock, earth or debris down a slope. Landslides are usually classified based on the material involved (rock, debris, earth, mud) and the type of movement (fall, topple, avalanche, slide, flow, spread). Thus, the generic term landslide also refers to mass movements such as rock falls, mudslides and debris flows.

Resilience: The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and/or transformation.

Subsidence: Downward vertical movement of the Earth's surface, which can be caused by both natural processes and human activities.

Vulnerability: Propensity or predisposition to be adversely affected by climate hazard.

Wildfires: Uncontrolled fires that occur in nature or at the wildland urban interface and are often exacerbated by climatic conditions.

Windstorm: The extreme wind speed days index counts the number of days with daily maximum wind speeds above the 98th percentile, computed over the reference period. Variants of the index can adopt different percentile-based thresholds for identifying the extreme conditions.

Annex 3: Resources

ADIF, Metodologia para el analisi de la vulnerabilided, riesgo y adaptacion a los efectors del cambio climatico – segunda edicion, 2024

Commission Delegated Regulation (EU) 2021/2139 of 4 June 2021 supplementing Regulation (EU) 2020/852 of the European Parliament and of the Council by establishing the technical screening criteria for determining the conditions under which an economic activity qualifies as contributing substantially to climate change mitigation or climate change adaptation and for determining whether that economic activity causes no significant harm to any of the other environmental objectives

Commission Notice–Technical guidance on the climate proofing of infrastructure in the period 2021-2027 (2021/C 373/01)

Contrat de performance 2023-2032 entre l'État belge et Infrabel

Cour des Comptes, l'adaptation du réseau ferroviaire national au changement climatique, 2023

Directive (EU) 2016/798 of the European Parliament and of the Council of 11 May 2016 on railway safety

Directive (EU) 2022/2557 of the European Parliament and of the Council of 14 December 2022 on the resilience of critical entities

EPSF, Étude d'impact des risques liés au changement climatique sur l'exploitation ferroviaire – précurseurs, méthodes et premiers résultats, 2024

European Commission: Directorate-General for Mobility and Transport, EU transport in figures – Statistical pocketbook 2024, Publications Office of the European Union, 2024

European Environment Agency, European Climate Risk Assessment, 2024

European Union Agency for Railways, Rail Environmental Report, 2024

ITF, Transport System Resilience: Summary and Conclusions, ITF Roundtable Reports, No. 194, OECD Publishing, 2024

JASPERS-Guidance Note "The Basics of Climate Change Adaptation Vulnerability and Risk Assessment", 2017

Network Rail, Third adaptation report, 2021

ORR, Resilience of rail infrastructure, 2021

Paris Agreement

RNE, Handbook for international contingency management, 2024

SNCF Réseau, Adaptation au changement climatique, stratégie de SNCF Réseau, 2024

UIC, Global rail sustainability report, 2023

UIC, RERA-RAIN

UIC, RERA-TEMP

World Meteorological Organization and European Union, represented by the European Centre for Medium-Range Weather Forecasts (ECMWF), European State of the Climate report 2024, 2025

Annex 4: Contributions to the data collection

Country	Infrastructure Managers	Contribution received	Time span covered	Size of railway network in km at country level[62]
Austria	ÖBB-Infrastruktur AG	No data	/	5 575
Belgium	Infrabel	10 March 2025	2005-2024	3 619
Bulgaria	National Railway Infrastructure Company	3 April 2025	2005-2024	4 029
Croatia	HZ Infrastruktura	19 May 2025	2013-2024	2 617
Czechia	Správa Železnic	29 April 2025	2016-2024	9 521
Denmark	Banedanmark	**No contribution received**	/	2 448
Estonia	Eesti Raudtee	7 February 2025	No event reported in the covered period	1 175
Finland	VÄYLÄ	3 June 2025	2005-2024	5 918
France	SNCF Réseau	30 October 2025	2020-2024[63]	27 812
Germany	DB InfraGO AG	1 May 2025	2015-2024	38 836
Greece	OSE	21 November 2025	2017-2024[64]	1 990
Hungary	MAV	29 April 2025	2009-2024	7 907
Ireland	Irish Rail	**No contribution received**	/	2 045
Italy	RFI	15 May 2025	2005-2024	16 829
Latvia	LDZ Infrastruktura	19 May 2025	2013-2024	1 865
Lithuania	LTG Infra	**No contribution received**	/	1 919
Luxembourg	CFL Infra	6 May 2025	2015-2024	271
Netherlands	ProRail	28 April 2025	2012-2024	3 041
Poland	PKP PLK	6 May 2025	2019-2025	19 355
Portugal	IP	28 May 2025	2005-2024	2 527
Romania	CFR SA	26 March 2025	2005-2024	10 615
Slovakia	Zeleznice Slovenskej Republiky	29 April 2025	2005-2024	3 626
Slovenia	SZ-Infrastruktura	24 April 2025	2014-2024	1 208
Spain	ADIF	30 April 2025	2013-2024	16 468
Sweden	Trafikverket	No data	/	10 914
Norway	Bane NOR	No data	/	3 907
Switzerland	SBB Infrastructure	30 April 2025	2013-2024	5 332
United Kingdom	Network Rail	10 January 2025	2015-2024	16 430

(62) Length of lines in use in 2022 according to EU transport in figures, statistical pocketbook 2024.
(63) Data sent by SNCF Réseau on the 30th of October 2025 covered the events by type over the period 2020-2024 (e.g. 22 floods between 2020 and 2024) and not by type and by year. This data could not be included as such in the analysis.
(64) Data sent by OSE on the 21st of November 2025 covered the events over the period 2017-2025 and ERA template to provide the data was used. This data will be analysed and integrated in the follow-up actions considering the time constraint to release the report.

Annex 5: Bilateral interviews with infrastructure managers

Country	Infrastructure Managers	Date of the interview
Austria	ÖBB-Infrastruktur AG	8 April 2025
Belgium	Infrabel	22 April 2025
Bulgaria	National Railway Infrastructure Company	7 May 2025
Croatia	HZ Infrastruktura	15 May 2025
Czechia	Správa Železnic	25 March 2025
Denmark	Banedanmark	5 May 2025
Estonia	Eesti Raudtee	6 February 2025 (written contribution)
Finland	VÄYLÄ	14 March 2025
France	SNCF Réseau	8 April 2025
	LISEA	18 June 2025
Germany	DB InfraGO AG	13 May 2025
Greece	OSE	23 July 2025
Hungary	MAV	28 March 2025
Ireland	Irish Rail	25 March 2025
Italy	RFI	15 May 2025
Latvia	LDZ Infrastruktura	14 February 2025 (written contribution)
Lithuania	LTG Infra	19 February 2025
Luxembourg	CFL Infra	28 March 2025
Netherlands	ProRail	29 April 2025
Poland	PKP PLK	11 April 2025
Portugal	IP	28 May 2025
Romania	CFR SA	10 June 2025 (written contribution)
Slovakia	Zeleznice Slovenskej Republiky	11 June 2025
Slovenia	SZ-Infrastruktura	20 May 2025
Spain	ADIF	15 April (written contribution)
Sweden	Trafikverket	23 May 2025 (written contribution)
Norway	Bane NOR	27 March 2025
Switzerland	SBB Infrastructure	8 May 2025
United Kingdom	Network Rail	7 March 2025

Annex 6: Contributions to NSAs' survey

ERA launched an EU survey to the NSAs on the 29th of April 2025 on their role related to rail resilience to climate change. The survey contained 5 questions with, for some of them, subquestions to better understand the role of the NSAs in:

- Monitoring weather events impacting rail infrastructure and/or rail traffic;
- SSC/SA assessment;
- Supervision activities;
- Authorisation for placing in service of fixed installations;
- Any other actions in the field of rail resilience to climate change.

NSAs were given until the 16th of June 2025 to answer the survey.

The following NSAs replied to the survey:

- In the European Union, 14 NSAs replied:
  - Austria;
  - Belgium;
  - Croatia;
  - Denmark;
  - Germany;
  - Greece;
  - Hungary;
  - Ireland;
  - Luxembourg;
  - Poland;
  - Romania;
  - Slovakia;
  - Slovenia;
  - Sweden.
- Outside the European Union, 3 NSAs replied:
  - Norway;
  - Switzerland;
  - United Kingdom.

Annex 7: Programme and summary of the conference on rail resilience to climate change

The conference on rail resilience to climate change[65] was organised by the European Commission, ERA and UTK as part of the Polish Presidency to the European Union in Warsaw, Poland, on the 16th of June 2025.

09:30-10:00	Opening speeches	**Ignacy Góra**, President of the Office of Rail Transport (UTK) **Joachim Lücking**, Head of Rail Safety and Interoperability Unit, European Commission **Oana Gherghinescu**, Executive Director of the European Union Agency for Railways (ERA)
10:00-11:30	Setting the scene	Moderation: **Idriss Pagand**, ERA 1) Data and Climate Event Modeling, **Julie Berckmans**, Climate Risk & Environment Expert, European Environmental Agency (EEA) 2) Resilient Railways Facing Climate Change (RERA) Project, **Lucie Anderton / Francisco Cabrera Jeronimo**, UIC 3) Mitigation and Adaptation, **Lisa Constable**, Head of Climate Change Resilience and Adaptation, Network Rail 4) Heavy Precipitation Events and Pluvial Flood, **Sonja Szymczak**, Scientific Desk Officer, German Centre for Rail Traffic Research (DZSF) 5) Climate Adaptation Needs on the TEN-T Network, **Nevena Gavalyugova-Bolsi**, Policy Officer European Commission, DG Mobility and Transport Presentation of initial results of ERA's study, **Eva Valeri**, ERA

(65) Video recording and presentations are available here: Conference on Rail Resilience to Climate Change | European Union Agency for Railways

11:45-12:45	Experts' panel I–Rail Resilience in the EU – Status Quo, Knowledge Sharing, and Best Practice	Moderation: **Miriam Graute**, Policy Officer European Commission, DG Mobility and Transport **Lene Bøgebjerg Bøgvad**, Climate Adaptation Manager, Banedanmark **Violeta González Aleñar**, Technical Manager for European Funds and Project Finance, ADIF **Anthony Holmes**, Manager Sustainability & Environment, Deutsche Bahn AG **Michelle Ochsner**, University of Lund **Andreas Schirmer**, Coordinator Standardisation, Joint Network Secretariat ERA
14:00-15:30	Experts' panel II–Innovation for Rail Resilience	Moderation: **Nicolas Furio**, Head of Innovation Pillar, Europe's Rail **Alexandre Anfriani**, Chief of Modeling and Risk Management Division EPSF **Luca Beccastrini**, FS Research Centre **Zbigniew Jancewicz**, Project Director PKP / Rail4Earth Project **Peter Schmidt**, Standards and Regulations Director, Alstom Group / UNIFE **Elisabet Vila Jordà**, Transport Specialist European Investment Bank (EIB) / JASPERS
15:30-16:00	Conclusions	**Joachim Lücking**, Head of Rail Safety and Interoperability Unit, European Commission **Oana Gherghinescu**, European Union Agency for Railways (ERA)

Opening speeches

Ignacy Góra, President of the Office of Rail Transport (UTK), reminded that the railway sector has proven its resistance to various threats many times – not only climate – and this is making rail a key element of national security of any country. He added that "*in the face of growing climate and geopolitical challenges, European railways must adopt a holistic approach to building resilience that combines advanced technologies with international cooperation and long-term strategic planning*". The Polish Presidency of the Council of the European Union was considered as a unique opportunity to strengthen European cooperation in the field of railway adaptation to climate change by using the experience from all over the continent.

Joachim Lücking, Head of Rail Safety and Interoperability Unit (DG MOVE) at the European Commission, reminded that 90% of the European citizens consider climate change as a serious problem or a fairly serious problem while the transport sector produces 25% of all the greenhouse gases emissions produced by the European Union. He also pointed out that rail is the transport with the lowest greenhouse gases emissions and external costs, the highest degree of energy independence, energy efficiency, land take efficiency and the most durable assets. The objectives of the Sustainable and Smart Mobility Strategy have been reminded and especially the modal shift to rail goal. However, the railway system is also more exposed to natural disasters which frequency increases with climate change. Investment needs on the railway network to adapt it are thus also increasing.

Oana Gherghinescu, Executive Director of the European Union Agency for Railways, pointed out that "*climate change is a non-contestable reality*" with two thirds of IMs reporting clear impact of extreme weather events on their networks across Europe. Currently, climate change in railways is mainly measured through the frequency and the size of the negative consequences and the plea is to move from the reactive approach to a pro-active one, through early-stage data collection. Such data collection and analysis should be more structured and allow decision-making on adaptation measures. In terms of regulation and investments, rather than having earmarked provisions and funding schemes in response to climate incidents, it would be very important to embed resilience considerations by design in the existing frameworks and funding instruments. This can also ensure that regulation is smartly used to embrace climate change and not create additional obstacles on stakeholders. Finally, cooperation between IMs is crucial to have a coordinated approach e.g. on the TEN-T corridors, in order to build economies of scale and safeguard interoperability.

Setting the scene

Julie Berckmans, Climate Risk & Environment Expert, European Environmental Agency (EEA), presented the first European Climate Risk Assessment that EEA published in 2024. She reminded that "*2024 was the warmest year recorded and before that 2023 was the warmest year recorded*" based on data from Copernicus. These increased temperatures are already having effect to the railway system with among other heatwaves and heavy precipitations and floods and eventually economic losses. Climate risk assessment is essential to increase our understanding of the climate change consequences and to take the necessary adaptation measures to make the railway system, and more globally our society, more resilient.

Lucie Anderton, Director for Sustainability, and **Francisco Cabrera Jeronimo**, Deputy Head of Operations and Safety, UIC, informed that in the last years weather events are generated more disruptions and delays on the railway network. In the last 5 years, UIC is working on the RERA (Resilient Railways facing Climate Change) programme on different climate hazards such as temperature, rain, wind. Transport being a system, "*the system is only strong as the weakest point in it*", which is why UIC is also collaborating with other transport modes' organisations to understand cascading effects across transport modes. RERA rain was then presented in more details with a particular focus on climate impact analysis, vulnerability, risk and criticality assessment and the adaptation planning. It was particularly pointed that "*the historical data are not valid anymore*" for the design of assets with the example of the Valencia flood in 2024.

Lisa Constable, Head of Climate Change Resilience and Adaptation, Network Rail, has shared the experience of Network Rail in managing the impact of climate change. Delays cost 100-120M euros/year to Network Rail as a results of different weather events. The main question is to define the level of resilience expected for the network and to have a well-adapted railway system that is flexible, reliable, operates safely and is responsive to a changing climate. Network Rail has built a strategy for greener railways around six key themes: Weather and adaptation planning, Resilient Assets, Resilience in processes, Climate intelligence, Adaptive capability and Operational weather response.

Sonja Szymczak, Scientific Desk Officer, German Centre for Rail Traffic Research (DZSF), focused her intervention on the impact of heavy precipitations and fluvial and pluvial floods on the German rail network. The distinction was made between fluvial flood which can be predicted in terms of time of occurrence, spatial extent and magnitude and, on the contrary, pluvial flood which is more difficult to predict. A flood indicator is being developed to better understand the pluvial flood risk. Adaptation measures which are being implemented following the flood in 2021 have been presented with, for instance, adaptation of culverts' dimensions, relocation of tracks, slimmer bridges structures and relocate the piers outside the riverbed if possible.

Nevena Gavalyugova-Bolsi, Policy Officer, DG Mobility and Transport, European Commission, presented the support study on the climate adaptation and cross-border investment needs to realise the TEN-T network. The objectives of this study were to identify past climate impacts and their costs, future climate risks on the TEN-T network, adaptation measures and the investment needs, in particular, the cross-border investment gaps on the TEN-T core and extended core network. Heatwaves and fluvial floods will increase quite significantly. A transport vulnerability index has been developed to map the vulnerability across Member States. A gap of approximately 70 EUR billion until 2035 of investments has been identified for the hazards examined in the study.

Eva Valeri, Economic Evaluation Officer at ERA, presented the preliminary results of this study and particularly its chapter 4.2.

Experts' panel I–Rail Resilience in the EU – Status Quo, Knowledge Sharing, and Best Practice moderated by Miriam Graute from the European Commission

Michelle Ochsner, University of Lund, is studying the impact of climate change on railway operations and infrastructure in Sweden. Winder conditions and high winds are the two main climate hazards impacting the railway system in Sweden but with climate change heavier precipitations are expected. The responsibilities relate to adaptation measures are fragmented especially for the financing of projects.

Violeta González Aleñar, Technical Manager for European Funds and Project Finance, ADIF, presented ADIF's master plan to combat climate change. ERDF funds 2014-2020 was the beginning to assess climate change impact on the rail network. ADIF started to work with JASPERS from EIB to build competences and knowledge on climate risk assessment, adaptation strategy. Initially, the focus was on project co-funded by ERDF. By 2026, 70% of the network will be assessed with the objective to have a full assessment by 2030. ADIF published the first standard on its methodology of vulnerability and risk assessments and adaptation in 2020 and its has been reviewed once since. The result of all these assessments is to build a well-planned investment plan.

Lene Bøgebjerg Bøgvad, Climate Adaptation Manager, Banedanmark, presented the work of the UN's group of experts on assessment of climate change impacts and adaptation for inland transport she is participating to. New guidelines to support climate impact assessment will be published next year as a result of this work. In Denmark, 2024 was the rainiest year ever recorded with for instance the highest number of landslides and dam closures while spring 2025 was the driest in 52 years which resulted in wildfires along the track. IMs cannot deal with one climate hazard without thinking on how to deal with the other ones. BDK made a vulnerability assessment of its infrastructure and based on the data gathered, put in a GIS model, which allowed to determine high risk areas. Sensors are installed to monitor those risky areas.

Anthony Holmes, Manager Sustainability & Environment, Deutsche Bahn AG, informed that DB is aiming at becoming climate neutral in 2040 which is also an important measure to reduce the long term of climate change since mitigation and adaptation must be tackled in parallel. DB has cooperated with the Postdam institute for climate impact research and trends have been determined for heat days (more than 30°C)–increasing, frost days–decreasing, heavy rainfall (more than 20mm/day) and storm days (more than 17m/s or wind category 8). For these two, no clear trend has been identified but intensity of events will increase. One example of quick win has been presented with insulating paint as a cost-effective and sustainable way of protecting heat-sensitive switching technology.

Andreas Schirmer, Coordinator Standardisation, Joint Network Secretariat – ERA, started by presenting the role of JNS which is a task force of experts chaired by ERA with the task to solve railway specific issues of EU relevance. He then presented the Great Belt bridge accident on the 2nd of January 2019 and the incident on the 13th of January 2021 both cause by crosswinds. A JNS "crosswind" has been created which resulted in the development of an acceptable means of compliance published in December 2024 for loading and securing semi-trailers and WAG TSI requirements on devices to secure semi-trailers.

Experts' panel II–Innovation for Rail Resilience moderated by Nicolas Furio from Europe's Rail

Elisabet Vila Jordà, Transport Specialist, European Investment Bank (EIB) / JASPERS, explained that EIB is the financing arm of the EU, one of the largest lender and borrower in the world and provides expertise in projects. EIB has advisory support on climate change on adaptation and climate resilience plans and has helped several IMs (IP, ADIF, RFI). She presented the support provided on the development of the climate change resilience plan of Infraestructuras de Portugal.

Luca Beccastrini, FS Research Centre, defined resilience as the system's capacity to deal with, adapt and recover from disruptions. A system is resilient based on its level of robustness and its capacity to restore the traffic to its nominal situation quickly. FS is working on innovative projects on all the different stages that make a system resilient. 4 projects have been presented: two on the prevention stage with rain radar to better predict the conditions for landslides and the acoustic technologies for infrastructure monitoring aimed at detecting anomalies in concrete beams of the bridges. The other two projects are on the respond and recover stages with the use of drones to verify the conditions of the tracks (unmanned railway vehicle and drone for aerial operations).

Zbigniew Jancewicz, Project Director PKP / Rail4Earth Project, presented the Rail4Earth project which is financed by Europe's Rail which main objective is to provide new innovative products and services to minimize the overall energy consumption and environmental impact f the railway system and to provide resilience measures to climate change with six focus areas: alternative to diesel energy solutions for rolling stock, energy in rail infrastructure and stations, sustainability and resilience of the rail system, electro-mechanical components and subsystems for rolling stock, healthier and safer rail system and train attractiveness.

Alexandre Anfriani, Chief of Modeling and Risk Management Division EPSF, presented the Datathon organized by EPSF in May 2025 focused on safety impact of climate hazards with the use of EPSF's database on national safety events. The aim was to develop predictive models to facilitate the supervision activities of the NSA and Railway stakeholders

Peter Schmidt, Standards and Regulations Director, Alstom Group / UNIFE, presented the methodology to make evolve the standards by explaining the standards governance and how these changes are triggered. The relevant standards (ISO 14090, ISO 14091, ISO 31000, EN 50125, EN 13129 and EN 50155) have been presented with a specific focus on EN 50125 on Environmental conditions.

Conclusions

Joachim Lücking, Head of Rail Safety and Interoperability Unit, DG MOVE, European Commission, concluded this conference a lot of work and money are needed to increase the resilience of the railway system. ERA report will support the Commission in deciding on policy developments. Adaptation must become an indispensable element of the developments of railway infrastructure and prioritization will have to be made. This conference is not a one-off event but a topic which will be subject to continuous works in the years to come.

Oana Gherghinescu, Executive Director of the European Union Agency for Railways, focused its conclusions on key words. Data collection needs to be structured and harmonized in terms of data terminology. The use of the data which is not counting ex-post but also being pro-active with predictive analysis for proper decision-making when it comes to climate events. Vulnerability assessments and maturity of the organisations are key elements to tailor the adaptation measures to be adopted, in-built resilience in investments is key.

Annex 8: Statistics on comments received to the draft report and minutes of ERA workshop held on the 13th of November 2025

ERA held a workshop on the 13th of November 2025 from 09:30 to 16:00 to exchange on the draft report. NSAs, NIBs, Representative Bodies, IMs involved in the study and relevant other organisations (EC, Europe's Rail, EEA, EIB, UIC, DZSF) were invited to participate.

The following organisations participated to the workshop:

Type of organisation	Organisations represented
European institutions	European Commission European Environment Agency European Union Agency for Railways Europe's Rail
IMs	ADIF (ES) DB Infrago (DE) Network Rail (UK) OBB Infra (AT) OSE (EL) Prorail (NL) RFI (IT) SNCF Réseau (FR) SZ (CZ) SZ-INFRASTRUKTURA (SI) ZSR (SK)
International organisation	UIC
NIBs	BEATT (FR) RAIB (UK)

Type of organisation	Organisations represented
NSAs	ACF (LU) AESF (ES) AZP (SI) CRR (IE) EBA (DE) EKM (HU) EPSF (FR) ORR (UK) SSICF/DVIS (BE) Traficom (FI) Transportstyrelsen (SE) UTK (PL)
Representative Bodies	AERRL CER EIM ERFA UNIFE
Research institute	DZSF

The morning session was dedicated to discuss the comments received to the draft report. A total of 282 comments were received from 21 organisations:

- 135 comments (**48%**) **have been integrated into the report** in track changes and 41 **(14%) were noted without change** either because the comment was a general statement or it was duplicating another comment for which changes were already introduced.
- 67 comments (**24%**) **have been discussed during the workshop**. Clusters of comments by themes/figures have been developed to manage discussions during the workshop. Clarifications have been brought during the workshop and changes to the draft report have been introduced to improve its quality.

The afternoon session was dedicated to discuss the comments received on the proposals. 39 comments (14% of the comments received) were related to ERA's proposals. Several general comments have been received on the need to further assess the proposals. ERA reminded that the results of ERA's work is incorporated into a study and not a recommendation and that the European Commission will then have to assess ERA proposals and decide whether or not these proposals (or some of them) will need further work and be included in a potential future ERA recommendation.

Proposal n°1 was well received and one organisation stated that use of new technologies such as artificial intelligence should be assessed.

Proposal n°2 triggered discussions on the scope of the CSM on risk assessment. While some organisations consider that external risks to the railway system are not covered by CSM on risk assessment, some other organisations stated that new risks like those linked to climate change should be covered. This shows the need to clarify the scope of this CSM to ensure that there is a common understanding among the relevant stakeholders.

Proposal n°3 was also well received and one organization added that ERA should also have a role in facilitating cross-border contingency workshops.

Proposal n°4 received mixed feedback especially from the rail industry considering that additional requirements were considered as a potential factor reducing the attractiveness of the rail sector.

Proposal n°5 did not receive any comment on the content of the proposal itself.

UIC reacted on proposal n°6 to inform on the launch of a UIC permanent group RERA hub in 2026.

Annex 9: Analysis of extreme weather events based on data provided by Network Rail in the UK–for benchmark purposes

Figure 28: Number of extreme weather events per year; ERA based on Network Rail data, 2025 – NB: for 2024, data are partial as only the first quarter of the year was covered.

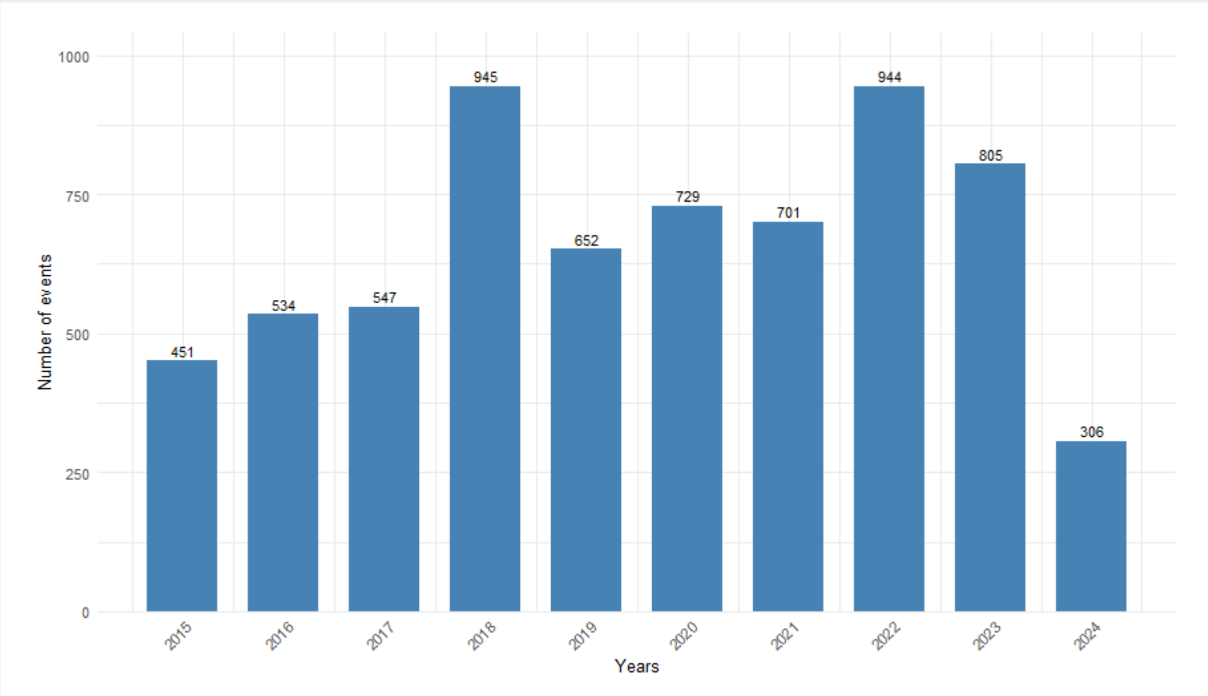
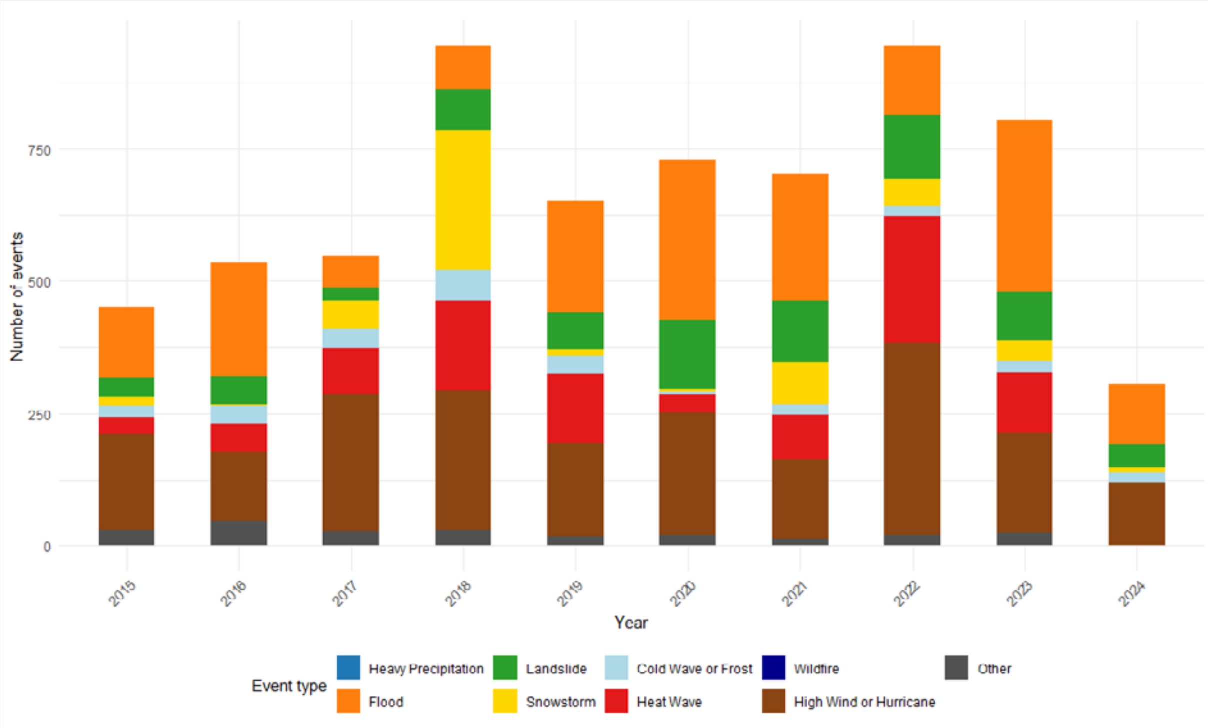


Figure 29: Trend of extreme weather events affecting UK per climate hazard; ERA based on Network Rail data, 2025 – NB: for 2024, data are partial as only the first quarter of the year was covered.



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