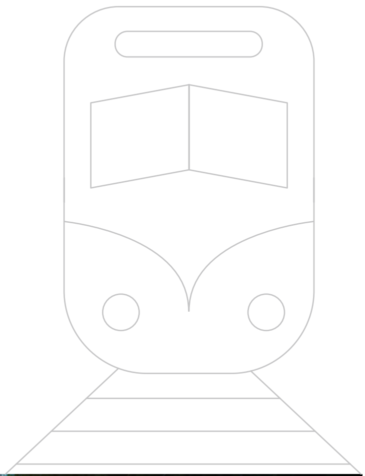
epsf

établissement public de sécurité ferroviaire

IMPACT STUDY

on climate change risks to rail operations - precursors, methods and initial results

IMPACT
STUDY



CONTENTS

Table of contents P4

Glossary P5

Introduction P6

I. Anticipating changes to the railway system in response to the risks associated with climate change - the need to adapt P14

II. Initiatives by specialists in the rail sector P28

III. Risk summary P42

Conclusion P55

Appendices P56

Acknowledgements P62

TABLE OF CONTENTS

Glossary 5

Introduction 6

I • Anticipating changes to the railway system in response to the risks associated with climate change – the need to adapt 14

1 • Combining the climate data available to initiate a risk analysis for rail operations 16

1a • Studies on the changing global climate 16

1b • Organisations specialising in French climate studies 18

2 • Climate hazards identified as having a major impact on the rail sector 21

2a • Climate hazards identified as having a potential impact on the rail system 21

2b • Identifying short-term climate trends 24

2c • Identifying long-term climate trends 24

3 • Methods for studying and reconciling the data available 25

3a • Preliminary steps for risk analysis 25

3b • Risk analysis 27

II • Initiatives by specialists in the rail sector 28

1 • Initiatives by Infrastructure Managers 30

1a • The South-East Atlantic high-speed line 30

1b • The Nîmes and Montpellier bypass line 32

1c • The historic manager in France 33

2 • Initiatives by Railway Undertakings 35

2a • Freight transport: FRET SNCF 35

2b • Passenger transport: RENFE 36

3 • EPSF initiatives 37

4 • Experience and initiatives from other European countries 38

4a • The NSA Network survey 38

4b • The Network Rail study 41

III • Risk summary 42

1 • The major risks identified and their consequences 43

2 • Recommendations 54

Conclusion 55

APPENDIX 1: Concept definitions 56

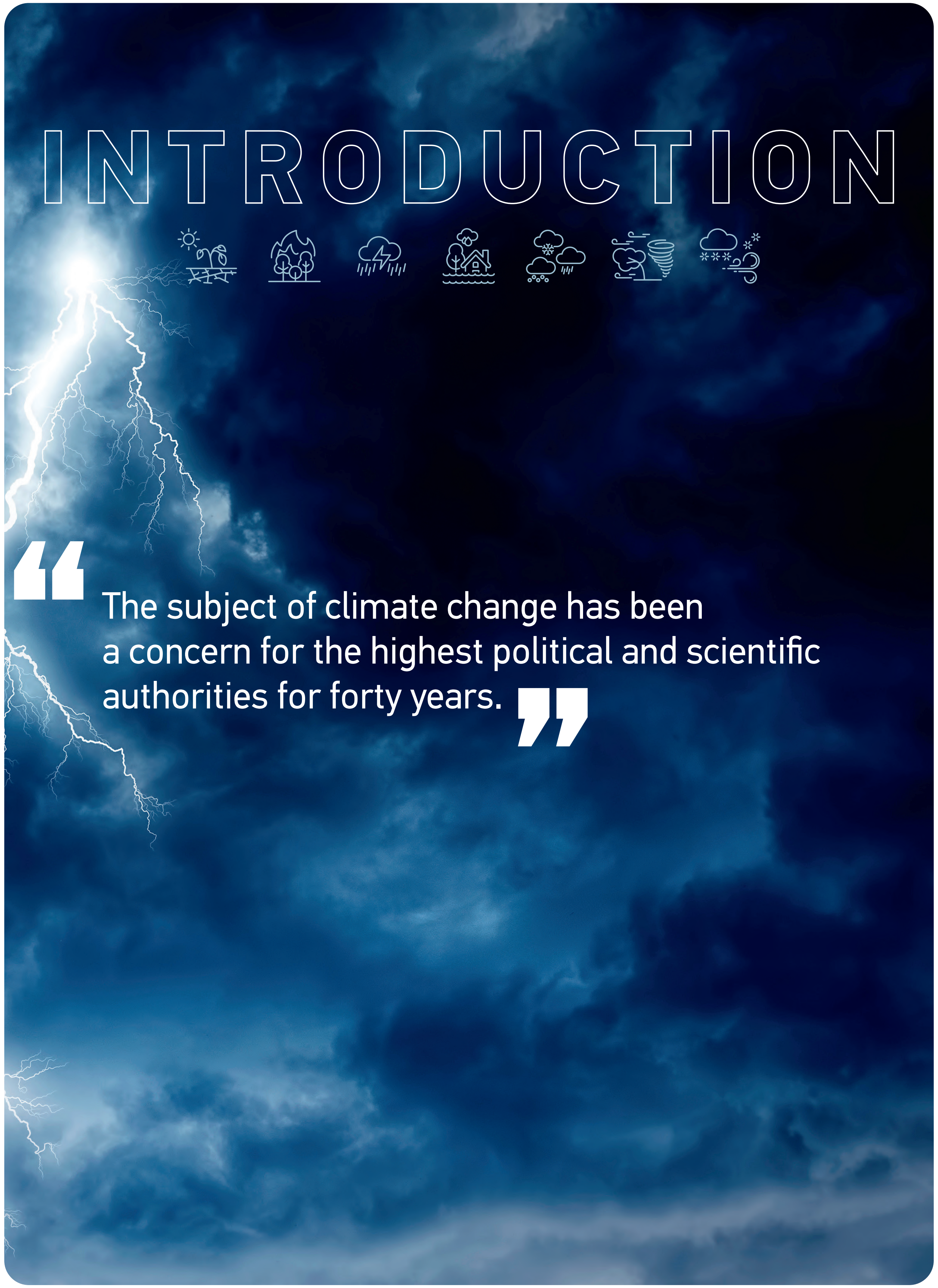
APPENDIX 2: Bibliography 58

APPENDIX 3: NSA research sources 60

Acknowledgements 62

GLOSSARY

ANS	National safety authority
BEA-TT	Land Transport Accident Investigation Bureau
CCNUCC	United Nations Framework Convention on Climate Change
CEREMA	Centre for Studies and Expertise on Risks, the Environment, Mobility and Development
CERFACS	European Centre for Advanced Research and Training in Scientific Computing
CNRM	National Centre for Meteorological Research
COP	Conference of the Parties
DRIAS	Providing access to regionalised French climate scenarios on impact and the adaptation of our societies and environment
EF	Railway undertaking
EPSF	Public rail safety institution
ERA	European Union Agency for Railways
GES	Greenhouse gas
GI	Infrastructure manager
GIEC	Intergovernmental Panel on Climate Change
IPSL	Institut Pierre-Simon Laplace
LISEA	Public-private partnership IM for the South-East Atlantic high-speed line
LTV	Temporary speed restriction
OC'VIA	Public-private partnership IM for the Nîmes-Montpellier bypass high-speed line
ONU	United Nations
SFN	National rail network
SNCF	French national railway company
TER	Regional express train
TGV	High-speed train



INTRODUCTION

> The subject of climate change has been a concern for the highest political and scientific authorities for forty years.

▶ Climate initiatives and discussions began in 1979 in Geneva with a global conference organised by the United Nations (UN). Thirteen years later, in 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was born. In 1997, the members of the Conference of the Parties (COP) signed the Kyoto Protocol, which set the first global target for reducing greenhouse gas (GHG) emissions. Then, in 2016, came the Paris Agreements, which set an ambitious new target: to keep global warming below 2°C.

▶ Alongside these global political bodies, the scientific community has been trying to demonstrate the effects of global warming for over forty years. The mission of the Intergovernmental Panel on Climate Change (IPCC) is to synthesise knowledge about global climate change, its impacts and ways of mitigating and adapting to them. As part of its work, the IPCC has drawn up an assessment of the risks in the medium and long term:

- the worsening of current climate phenomena in terms of the frequency, intensity, geographical distribution and duration of extreme weather events (storms, floods, droughts);
- the extinction of 20 to 30% of animal and plant species;
- rising sea levels: by 2050, one billion people living at an altitude of less than 10 metres could be affected by sea levels rising by 15 millimetres a year[(1)];
- the loss of agricultural yields pushing more than 100 million people into extreme poverty. Nearly 600 million people could suffer from malnutrition and 140 million people could be forced to migrate.

▶ The impacts of climate change may vary greatly from one region to another, but they affect the whole planet.

A closer look at the effects of climate change shows that France is the country in Europe with the second-highest impact from natural disasters. Almost 120 very serious natural events have been recorded since 1950. Extreme events are characterised by low frequency but high severity. Many natural hazards threaten French territory: flooding, marine submersion, coastal erosion, storms, cyclones, but also landslides, forest fires, avalanches and earthquakes. Their unpredictable nature makes it impossible to anticipate how devastating the consequences may be for society as a whole over the long term.

▶ The frequency of natural events has quadrupled in France over the last twenty years, from one exceptional event a year between 1950 and 1996 to almost four events a year between 1997 and 2017. Two thirds of these events are caused by flooding. A total of 17.1 million people are exposed to the various consequences of flooding. Almost 1.4 million people are exposed to the risk of marine submersion. More than nine million jobs are exposed to river flooding and over 850,000 to marine submersion[(2)]. The seriousness of these events is all the greater in the context of what is at stake in each area (population, economic activities, heritage etc.)[(3)].

(1) According to the worst-case scenario considered by the IPCC. The various scenarios are set out later in the report.

(2) Rida, E (2023). Généralités sur le risque inondation en France. Ministères Écologie Énergie Territoires. https://www.ecologie.gouv.fr/generalites-sur-risque-inondation-en-france

(3) Notre-environnement. (2023, 17 April). Les risques naturels majeurs en France – Notre-environnement. https://www.notre-environnement.gouv.fr/themes/risques/les-mouvements-de-terrain-et-les-erosions-cotieres-ressources/article/les-risques-naturels-majeurs-en-france

INTRODUCTION

▶ Like any other economic sector, the rail industry is not immune to the need to adapt to climate change. Adaptation is a process of adjustment to the climate and its effects. An adaptation strategy aims to limit damage in order to maintain a level of quality and transport service that meets the population's needs. The number of safety incidents linked to climatic hazards has been rising steadily for several years. In Europe, several significant events with far-reaching consequences have taken place over the last decade.

▶ In France, the number of significant rail accidents linked to climatic hazards tripled over the period 2015-2022. There was one such event in 2015, compared with nine in 2019[4]. Analysis by the Land Transport Accident Investigation Bureau (BEA-TT) recognises the influence of climate causes for these accidents, which resulted in traffic disruptions of more than six hours, damage to equipment in excess of €150,000 and, above all, serious human consequences.

Among the most serious incidents was the event that took place on 8 February 2014 in Alpes-de-Haute-Provence. A railcar was hit by a boulder of approximately 15 m³ that rolled down the slope for 130 metres before hitting the first carriage of the train, which derailed and fell into the ravine. This event, which took place outside the NRN, killed two passengers. The BEA-TT investigation revealed that heavy rainfall and unseasonably warm temperatures contributed to the accident.

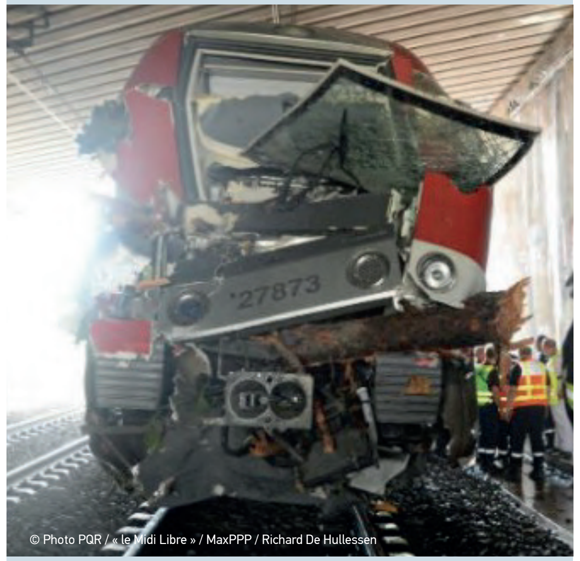
© https://www.bea-tt.developpement-durable.gouv.fr/IMG/pdf/Rapport_BEATT_2014-003.pdf


© Olivier Anrigo/Reuters

In October 2015, torrential rain drowned Cannes station under three metres of water. The sheer quantity of water tore out a five-metre-wide chasm beneath the ballast, bringing traffic to a complete standstill. When it resumed, traffic remained disrupted: speed was limited to 30 km/h and the electric signals that usually regulate traffic were replaced by visual checks.

In 2016, in Hérault, a TER driver collided with a tree that had fallen on to the tracks after heavy thunderstorms. There was extensive damage to rolling stock and infrastructure. One passenger was seriously injured, while seven others suffered minor injuries. The BEA-TT investigation revealed that the top of the tree had been broken off by the strong wind. The upper section, around fifteen to twenty metres long, was blown by the wind towards the railway and fell on to the tracks just as the TER was arriving.


© Photo PQR / « le Midi Libre » / MaxPPP / Richard De Hullessen


© Photo PQR / « le Midi Libre » / MaxPPP / Richard De Hullessen

In 2020, Storm Alex caused major damage to railway lines in the Roya and Vésubie valleys. Landslides, trees on the tracks, rockfalls and slope failures caused enormous damage to railway infrastructure. It took two years of work to restore the infrastructure to operating condition.


© NGE

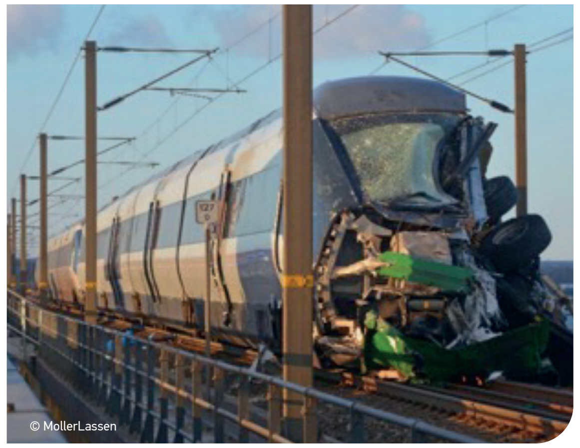
(4) Figure based on feedback from EPSF events

INTRODUCTION

On 14 July 2022, during a period of drought, wildfires spread near Graveson in Bouches-du-Rhône. These fires appear to have been caused by sparks flying from a brake being applied on a wagon carrying dangerous goods (DG). The damage caused to the environment was extensive (1,500 hectares of forest burnt). This accident required the intervention of over a thousand firefighters.

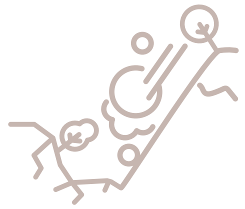
© SDIS33 Tous droits réservés

Elsewhere in Europe, on 2 January 2019, a passenger train collided with a freight train on Denmark's Great Belt Bridge. A semi-trailer that had not been properly secured to a wagon broke loose and crashed into the front carriage. High winds were a contributing factor in the accident, which killed eight people and seriously injured four others.



© MollerLassen

© https://mx-schroeder.medium.com/blown-away-the-2019-great-belt-bridge-freight-collision-e94a91d5d01a



In August 2020, at Stonehaven in Scotland, a passenger train reversed after being warned of a landslide by an IM employee. The train ran into another landslide. All the carriages derailed, killing three passengers and seriously injuring six others.

© RAIB

In March 2023, in the canton of Berne in Switzerland, two trains derailed a few dozen kilometres apart due to strong gusts of wind measured at over 130 km/h. The first derailment, near Lüscherz, caused three minor injuries. The second, near Büren am Hof, injured twelve people, one of them seriously. The damage was estimated at over two million Swiss francs[5] *for both accidents.*

© MAXPPP - MANUEL LOPEZ

(5) Approximately two million euros

INTRODUCTION

Even more recently, on Sunday 27 August 2023, a landslide occurred between Saint-Michel-de-Maurienne and Modane, in Savoie. Around 12,000 m³ of boulders broke loose from the mountain. No-one was injured, but the landslide caused the closure of the railway line between France and Italy, and at the time of writing rail traffic had still not resumed. It is accepted that this phenomenon, generated by the thawing of the permafrost, is accelerating rapidly. There were more than 200 such landslides in 2022, and none at all in the 1990s.

© Photo AFP

© Tom Pham Van Suu / MAXPPP

▶ **Rail infrastructure and rolling stock are designed to last over time.** Design and construction rules are based on often empirical weather data of varying age, so the vulnerabilities of infrastructure and materials have evolved, are evolving and will continue to evolve as the climate changes. Regions will have to deal with new problems: network disruptions, more frequent damage to infrastructure and destruction on a larger scale.

▶ **Natural hazards and the risks associated with climate change must be taken into account to ensure the durability and resilience of rail infrastructure and rolling stock.** Resilience has become the watchword in managing these new challenges. It is defined as the ability of a system to cope successfully with risk situations, to adapt and to develop successfully despite unfavourable circumstances. It is therefore vital for every organisation to prepare to face the potential climate risks by establishing an adaptation strategy to ensure this resilience.

Although climate change is more harmful than beneficial overall, there are certain positive effects. For example, less damage will be caused to railway tracks by the cold, and energy costs for heating will be lower.

▶ **Identifying the network's strengths and its vulnerabilities to climate change will make it easier to monitor the state of the rail system's components and how they are changing.** Initiating a risk analysis should make it possible to identify areas of fragility that could contribute to the implementation of a climate strategy. It also enables at-risk components to be identified in rolling stock, for example, as well as scenarios for network operation that can be put in place in response to change and potential disruption. Risk analysis helps to improve crisis management by anticipating possible developments.

On a larger scale, bringing together the results of risk analysis specific to each activity in the area will underpin spatial planning policy, which must now take account of the vulnerabilities identified in the region.

▶ **This report is the first step in taking climate change into account across all rail activities and the interaction of all the players involved in France.** Its aim is to provide some initial thoughts on the impact of climate change on the country's mainland rail system. This thinking has been developed on the basis of the climate studies already available to help identify the climate hazards faced by the railways. A risk analysis method is also presented. This method was developed by public bodies and has proved its worth on French transport infrastructure networks. Finally, this preliminary report is also a record of experience from various public, private, national and international players.

This report therefore addresses the following issue:

how can we initiate a study of the impact of climate change risks on rail operations?

Anticipating changes to the railway system in response to the risks associated with climate change - the need to adapt

I.

The regulatory environment in France and Europe encourages companies to begin the energy transition. Transport is one of the main levers that has been identified to reduce our greenhouse gas emissions. The policies governing the transport sector, including the railways, encourage energy sobriety, the transition to cleaner sources of energy and the resilience of transport systems. To satisfy the priorities of public policy, the rail sector must guarantee a level of reliability that is compatible with a modal shift in favour of rail. Rail transport is a strategic element in sustainable regional development and in achieving the objectives of the Paris Agreement.

Initiating a study into the resilience of the rail system to climate change is a first step. Identifying the risks generated by climate change will make it possible to adapt the rail system by introducing technical, operational or organisational changes. European and national regulations already provide tools for analysing these changes and the risks they entail. Once they have analysed the risks associated with climate change, railway operators will be able to apply Implementing Regulation (EU) 402/2013 on the common safety method for risk evaluation and assessment.

That's why this first chapter is designed to provide a few keys to help rail operators protect themselves against the risks associated with climate change. The aim is to raise awareness and bring together the information available and the studies already carried out about our society and, more specifically, our infrastructure. These are global impact studies that go beyond the rail sector and provide a broader understanding of the risks.

I.

1 • Combining the climate data available to initiate a risk analysis for rail operations

▶ To understand the changes we will have to face, a number of organisations have carried out studies, with alarming conclusions.

Like the IPCC, several organisations are working to model climate change for the 21st century. These models and datasets, made available to the public, should help us to prepare for climate change as effectively as possible. Identifying the natural risks we could face will make it easier to adapt to the challenges of today and tomorrow.

Knowledge, and access to existing databases describing expected climate trends, are already available. Data on today's natural hazards should also be cross-referenced with past climatic events. This will make it possible to understand how hazards are evolving, on one hand, and to characterise the ones that should be fed into a strategy to deal with climate risk, on the other. Several databases and their possible uses for risk analysis are presented in this chapter.

This list of datasets is not exhaustive.

1a • Studies on the changing global climate

▶ The IPCC, a non-governmental body of scientists responsible for assessing climate change, regularly publishes its studies, which anyone can access. In its 2021 report[6], the IPCC set out five new scenarios for climate change over the 21st century based on GHG emissions. By using these different scenarios, it is possible to establish the major potential directions human societies could take and their influences on the climate. These scenarios are not intended to predict the future, and no levels of probability are assigned to them. The aim is to take into account the uncertainties associated with future human activities and to inform decision-making.

The five scenarios are based on reference socioeconomic trajectories known as "Shared Socioeconomic Pathways" (SSP), which were developed to provide a common framework for thinking about the challenges of climate change. These five scenarios describe possible social, economic, political and technological developments between now and the end of the century.

The models, from the most optimistic to the most pessimistic, map out a wide range of plausible futures. The most optimistic scenario describes a world in which CO_2 emissions fall drastically to reach carbon neutrality around 2050 and become negative in the second half of the century (SSP1-1.9). The most pessimistic scenario, meanwhile, describes a world in which CO_2 emissions continue to rise sharply until 2050, reaching a level twice as high as today and more than three times higher by 2100 (SSP5-8.5) (see Figure 1).

(6) Lee, J-Y, J Marotzke, G Bala, L Cao, S Corti, JP Dunne, F Engelbrecht, E Fischer, JC Fyfe, C Jones, A Maycock, J Mutemi, O Ndiaye, S Panickal and T Zhou, 2021: Future Global Climate: Scenario-Based Projections and Near-Term Information. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V, P Zhai, A Pirani, SL Connors, C Péan, S Berger, N Caud, Y Chen, L Goldfarb, MI Gomis, M Huang, K Leitzell, E Lonnoy, JBR Matthews, TK Maycock, T Waterfield, O Yelekçi, R Yu and B Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 553-672, doi:10.1017/9781009157896.006.

▶ The five scenarios considered by the IPCC are:

- SSP1-1.9: very ambitious scenario representing the 1.5°C target of the Paris Agreement
- SSP1-2.6: sustainable development scenario
- SSP2-4.5: intermediate scenario
- SSP3-7.0: regional rivalry scenario
- SSP5-8.5: development based on fossil fuels

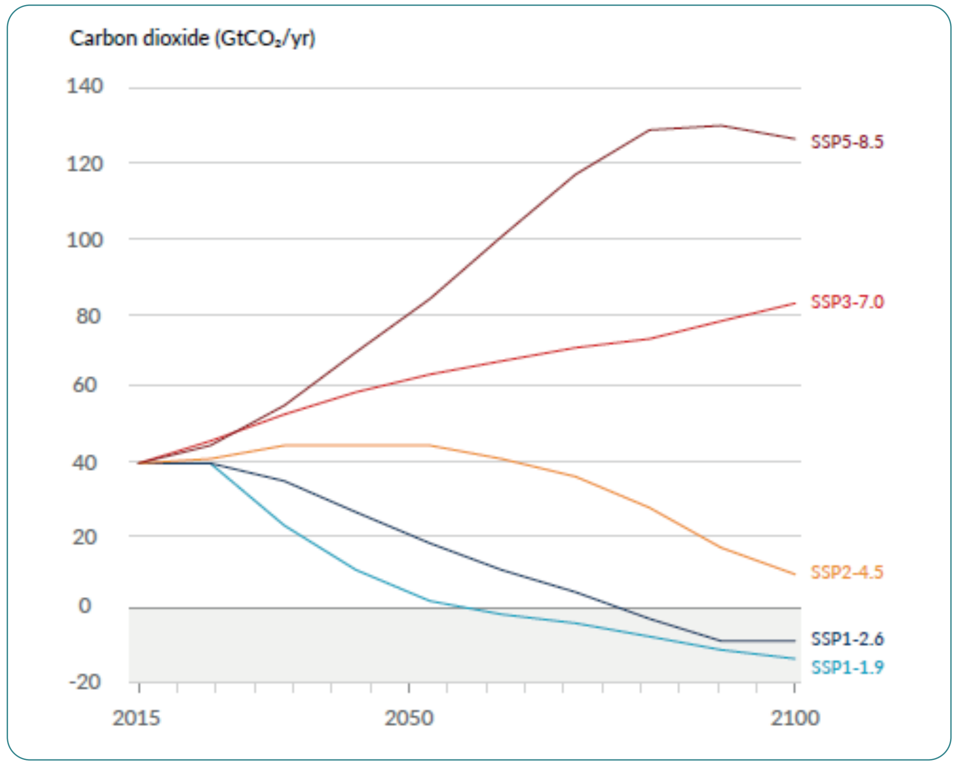


Figure 1: Future CO_2 emissions in the five illustrative scenarios

The report is accompanied by an interactive online atlas[7] that allows users to explore the evolution of observed or simulated climate variables according to the scenarios on different geographical and time scales. This visualisation makes the changes caused by climate change more tangible and usable.

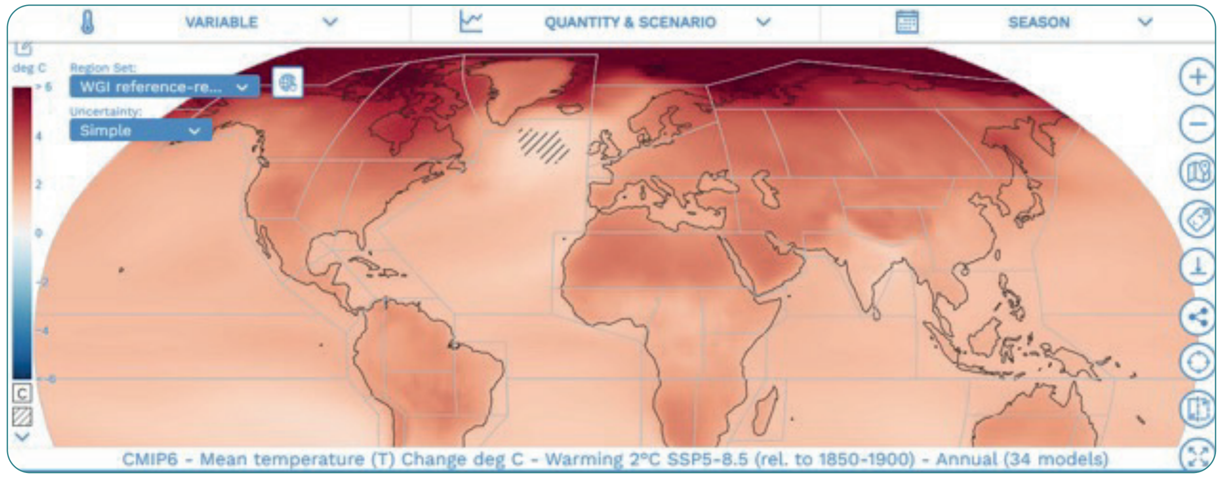


Figure 2: Simulation of temperature trends

(7) IPCC AR6-WGI Atlas. (n.d.). https://interactive-atlas.ipcc.ch/

I.

▶ **In policy terms and in the context of the studies carried out by the IPCC, mitigation refers to a policy implemented with the aim of reducing the impact of human activities on climate change. The term adaptation, on the other hand, accepts that some climate change is inevitable despite all the efforts made to mitigate GHG emissions. It will therefore be necessary to adapt to the new situation.**

The IPCC concludes that it is now more urgent than ever to take action on adaptation and mitigation. All the scenarios show temperature rises in excess of the 1.5°C set by the Paris Agreement over the next twenty years. Immediate action is needed to adapt, and the IPCC is helping to identify the inevitable changes in climate so that we can better prepare for them.

In March 2023[8], the IPCC's synthesis report was published, concluding the sixth reporting cycle launched in 2021. Following this publication, the French government published a summary of this sixth cycle[9]. It makes a number of alarming observations, particularly concerning the policies in place at the end of 2020, which would lead to global warming of 2.4 to 3.5°C by the end of the century compared with the pre-industrial era.

▶ **However, the government is providing a number of answers and solutions involving policies on adaptation, resilient development, systemic transformation and consideration of the links between these different concepts, which affect all sectors of society, including the transport sector[10].**

1b • Organisations specialising in French climate studies

▶ **Following the example of the IPCC, which studies global climate change, a number of bodies are tasked with studying climate change in France. Their results are copyright-free and can be used to develop local projections of climate change.**

For example, the DRIAS portal is a data platform provided by the French Ministry of the Ecological Transition. This platform delivers region-specific climate projections produced by French climate modelling laboratories (IPSL, CERFACS, CNRM). Climate information is provided in a variety of graphical and numerical formats. The latest DRIAS report dates from 2020[11] and the projections are based on data from the fifth IPCC assessment cycle: the RCP scenarios[12].

(8) The interactive atlas is available at the following address: https://report.ipcc.ch/ar6syr/pdf/IPCC_AR6_SYR_LongerReport.pdf

(9) Climat : un nouveau rapport alarmant du GIEC sur un réchauffement global de la planète. (2023, 21 March). Vie publique au coeur du débat public. https://www.vie-publique.fr/en-bref/288687-rechauffement-climatique-un-nouveau-rapport-alarmant-du-giec

(10) Ce qu'il faut retenir du 6e rapport d'évaluation du GIEC. (n.d.). In Gouvernement. https://www.ecologie.gouv.fr/sites/default/files/20250_4pages-GIEC-2.pdf

(11) Les Nouvelles Projections Climatiques de Référence DRIAS 2020 pour la métropole. (2020). In http://www.drias-climat.fr/document/rapport-DRIAS-2020-red3-2.pdf

(12) Representative Concentration Pathway

To illustrate this work, an extract is presented below based on a projection for the near future (2035) of forest fires throughout the country. It is also possible to break down this search by region, refine the time interval and choose a GHG emissions scenario.

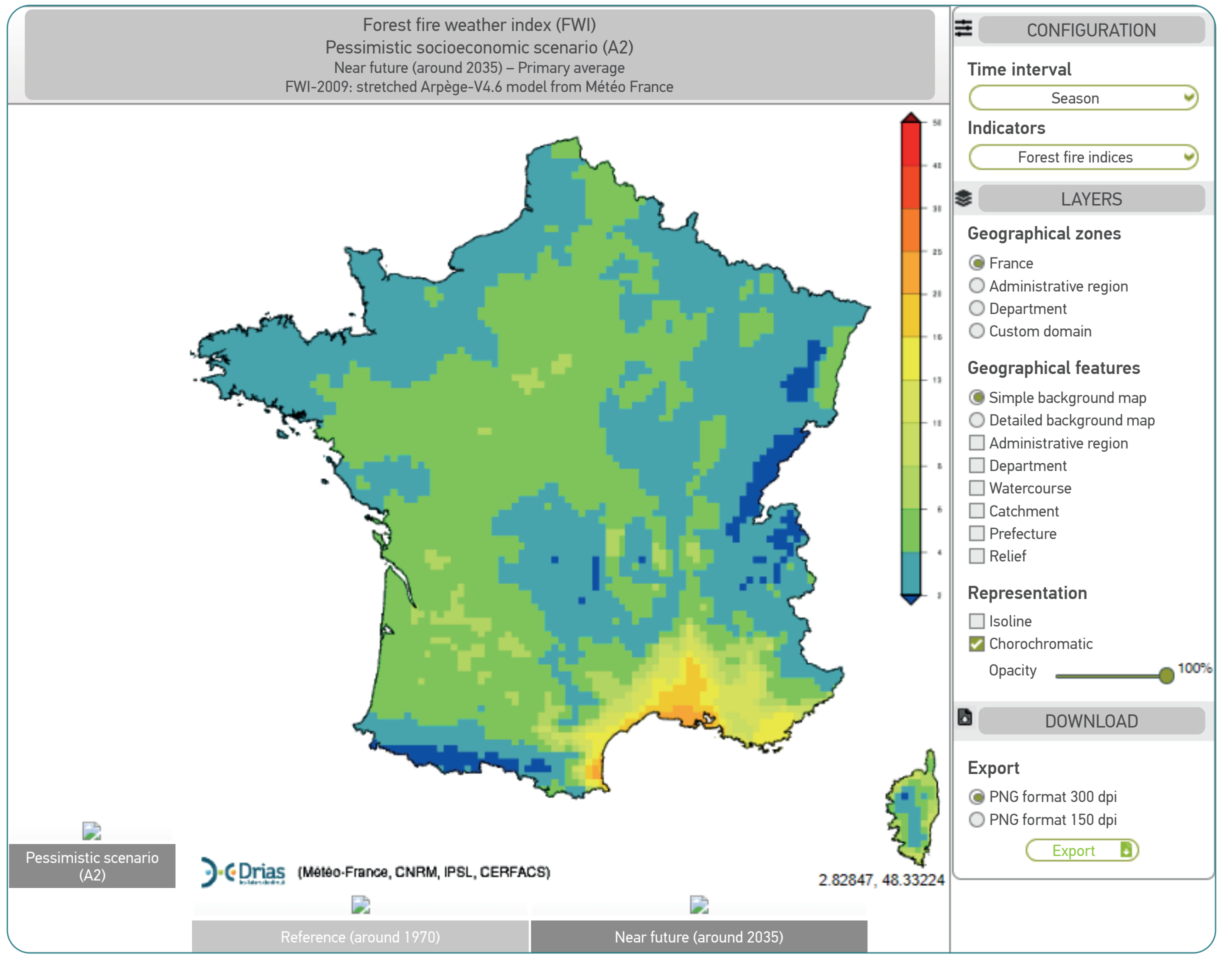


Figure 3:
Forest fire weather index for a pessimistic socioeconomic development scenario for 2035 with spring averages

▶ **Climat HD[13], a platform provided by Météo France, offers an integrated view of past and future climate trends at national and regional level.** This internet platform summarises the latest work by scientists and climatologists, highlighting key messages and illustrated data to help people better understand climate change and its impacts.

The following extract is an example: cumulative winter precipitation by 2100 under the IPCC's most pessimistic scenario. This result is accompanied by an explanatory comment.

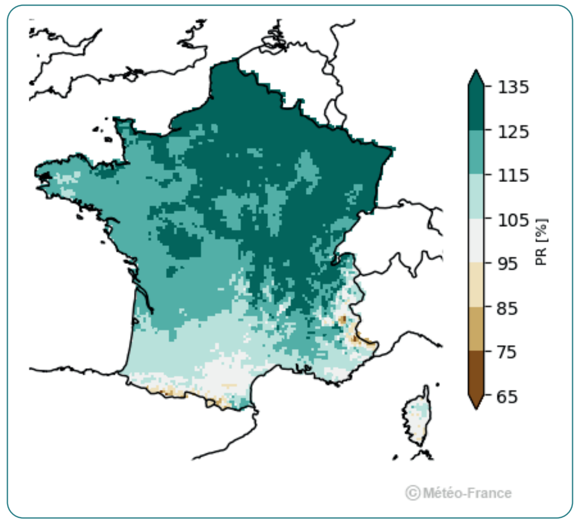


Figure 4:
Cumulative winter precipitation: relationship (%) to 1976-2005 baseline for the long term (2071-2100), heavy precipitation scenario (RCP8.5)

(13) CLIMAT HD by Météo-France. (n.d.). https://meteofrance.com/climathd

▶ **Météo France also offers a self-diagnosis tool, Climadiag Entreprise. This tool enables players in the business world to test their sensitivity to the future climate and prepare for it.** The tool is available free of charge on the Météo France website[14]. Like Climat HD, run by Météo France, other portals make climate data available to the public, such as Pluies Extrêmes and Tempêtes Extrêmes.

Other institutions have produced studies that are accessible to all: the Centre for Studies and Expertise on Risks, the Environment, Mobility and Development (CEREMA), the Environment and Energy Management Agency (ADEME), the Regional Climate, Air and Energy Observatories (ORCAE) and the National Observatory on the Effects of Global Warming (ONERC).

▶ **CEREMA is a public body. Its mission is to provide expertise and support to central and local government in the development of public planning and transport policies.** CEREMA's work is accessible to the public via its website.

▶ **ADEME has seven main missions, one of which is to make available all the data it collects in the course of its work.** Others are to support and mobilise stakeholders in response to climate change, to share its expertise and to support research.

▶ **ORCAE has four observation missions, including helping to draw up integrated local "climate, air and energy" diagnostics.** ORCAE is also a forum for discussion between players (representatives of the state and public bodies, research and observation organisations, local authorities, socioeconomic players and associations).

▶ **ONERC's main mission is to collect and disseminate information on the risks associated with global warming, to make** recommendations on adaptation measures to limit the impact of climate change and to liaise with the IPCC.

(14) Climadiag Entreprise can be accessed at https://meteofrance.com/climadiag-entreprise

(15) L'adaptation au changement climatique dans la taxonomie européenne | Carbone 4. (n.d.). https://www.carbone4.com/analyse-adaptation-climat-taxonomie-europeenne?mc_cid=87e49bd788&mc_eid=305c502099

(16) Notre-environnement. (2023b, April 17). Les risques naturels majeurs en France – Notre-environnement. https://www.notre-environnement.gouv.fr/themes/risques/les-mouvements-de-terrain-et-les-erosions-cotieres-ressources/article/les-risques-naturels-majeurs-en-france

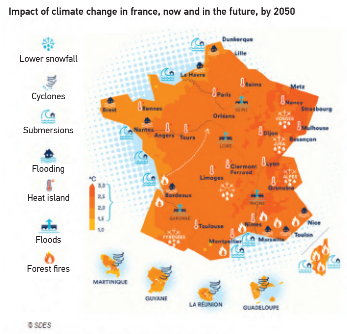
(17) Comprendre le PNACC2. (2018) - https://www.ecologie.gouv.fr/sites/default/files/2018.12.20_Comprendre_le_PNACC2_0.pdf

(18) Plan National d'Adaptation au Changement Climatique, volet infrastructures et systèmes de transport | Analyse des risques liés aux événements climatiques extrêmes sur les infrastructures, systèmes et services de transport | Recueil de concepts. Rapport d'étape (2015). Cerema.

2• Climate hazards identified as having a major impact on the rail sector

2a • Climate hazards identified as having a potential impact on the rail system

To identify the climate hazards that the rail system is likely to face in the coming years, we can draw on studies already carried out by experts on the subject.



Firstly, at European level, the Commission has defined a taxonomy that constitutes a "classification system" for economic activities. The taxonomy is designed to identify activities that make a "substantial" positive contribution to preserving the environment. This classification work has been orchestrated by the European Commission since 2018.

There are a number of key points in the taxonomy, including an analysis of climate risks and vulnerabilities disrupting the operation of economic activities. To produce this, they defined all the hazards according to different aspects of the climate, based on their frequency and intensity. They identified no fewer than 28 risks[15] linked to climate change. This definition can be used as a basis for identifying the climate hazards the rail sector could face in the future.

In the same vein, the French Ministry of the Ecological Transition has conducted a study of major natural hazards in France[16]. This study also provides a database for identifying climate hazards. Taken from this study, the graph below shows the most common hazards that have occurred in France over the last century. Flooding accounts for around two-thirds of all damaging weather events in France.

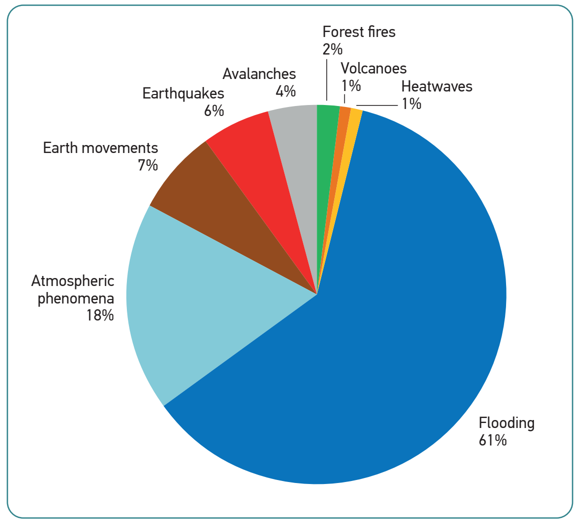


Figure 5:
Proportion of damaging natural events by risk type between 1900 and 2017 (sources: MTES/DGPR/SRNH and BARPI, Gaspar database, latest decrees taken into account, published in the French Official Journal on 24/09/2017. AFP, CCR, FFSA/GEMA,

▶ **France is exposed to other natural hazards that are less frequent but can be extremely damaging, such as earthquakes, volcanic eruptions and cyclones.** Nonetheless, however damaging they may be, earthquakes and volcanic eruptions are extremely rare events in mainland France, so they will not be addressed in this study.

To complete the identification of climate hazards, version 2 of the National Climate Change Adaptation Plan (PNACC), published in 2018, identifies the ten major impacts of climate hazards and informs thinking about the climate hazards impacting the rail system[17]. The aim of this plan is to build resilience to climate change in the main sectors of the economy.

▶ **Finally, CEREMA, in its work to define a general methodology for risk analysis, also identifies a list of climate hazards relevant to the transport sector[18].**

Drawing on this work, the climate hazards considered to be a major threat to the French rail system and its activities are as follows:

This list of hazards is not exhaustive and may be supplemented as part of the risk analysis specific to each player in the rail sector.

Primary climate hazards	Secondary climate hazards	Justification of potential impacts on the rail system	Key figures
Temperature-related climate hazards	Increasing periods of drought	Accounts for the impact of hot weather without rain	An extreme temperature event that occurred once every ten years in 1900 is likely to occur four times every ten years with +1.5°C warming and nine to ten times with +4°C warming.
	Increase in extreme temperature values	Accounts for the impact of extreme heat on a one-off basis (unlike the item above, which refers to a period)	Rails are made of steel, a material that is sensitive to temperature variations. During hot spells, if the temperature is 37°C, the temperature of the rail can exceed 55°C
	Heatwave	Accounts for the impact of hot weather during both day and night	Train speed can be limited due to heat waves, dropping from a commercial speed of 160 km/h to 100 km/h and causing many delays
	Forest fires	Accounts for the impact of fires on the network (including the surrounding area)	By 2050, 50% of natural areas will be at risk from fire[16]
	Cold snap/frost	Accounts for the impact of very cold sub-zero temperatures	
	Storm	Accounts for lightning strikes	
Water-related climate hazards	Changes in precipitation patterns (rain, snow, hail)	Accounts for the impact of heavy precipitation	
	Flooding	Accounts for the impact of surface water flooding, which does not necessarily affect the same areas as marine submersion or rising groundwater levels	76 mm of rain in 90 minutes: in London in July 2021, heavy rainfall caused flash flooding, resulting in a fire at an electricity substation and the suspension of traffic for seven hours [19]
	Marine submersion	Accounts for the impacts of rising sea levels and the risks of corrosion, which do not necessarily affect the same areas as flooding or rising groundwater levels	The PNACC predicts that almost 2,000 km of railway line will be submerged by the end of the century with a one-metre rise in sea level[20]
Wind-related climate hazards	Strong winds (tornadoes, cyclones)	Accounts for the impact of strong gusts of wind	In Switzerland, two derailments were caused by high winds in March 2023
	Snowstorm	Accounts for the impact of strong gusts of wind, cold and snow	
	Sandstorm	Accounts for the impact of strong gusts of wind and grains of sand (rolling stock)	
Climate hazards linked to solid masses	Avalanche	The most common hazards in France, which may themselves be caused by a climate hazard linked to temperature, water, wind or other factors	In 2022, an avalanche caused the derailment of a train near Villars in Switzerland, although the area was not considered to be at risk
	Landslide	The most common hazards in France, which may themselves be caused by a climate hazard linked to temperature, water, wind or other factors	A landslide in Switzerland in 2014 caused the derailment of a passenger train: seven seriously injured and one dead
	Landslide	The most common hazards in France, which may themselves be caused by a climate hazard linked to temperature, water, wind or other factors	On 27 August 2023, a 700 m3 landslide interrupted train traffic between France and Italy in the Maurienne valley and closed the A43 motorway
	Mudslide	The most common hazards in France, which may themselves be caused by a climate hazard linked to temperature, water, wind or other factors	
	Falling rocks	The most common hazards in France, which may themselves be caused by a climate hazard linked to temperature, water, wind or other factors	In Switzerland in 2012, falling rocks led to the death of a passenger
	Subsidence	The most common hazards in France, which may themselves be caused by a climate hazard linked to temperature, water, wind or other factors	

Figure 6: Summary table of major climate hazards in mainland France

(16) Notre-environnement. (2023b, April 17). Les risques naturels majeurs en France – Notre-environnement. https://www.notre-environnement.gouv.fr/themes/risques/les-mouvements-de-terrain-et-les-erosions-cotieres-ressources/article/les-risques-naturels-majeurs-en-france

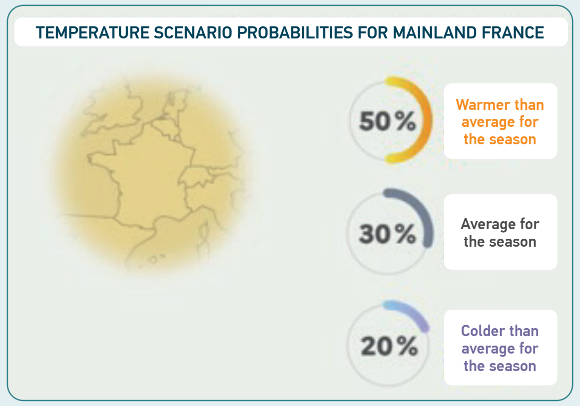
(19) Third Adaptation Report. Network Rail (December 2021). https://www.networkrail.co.uk/wp-content/uploads/2022/01/Network-Rail-Third-Adaptation-Report-December-2021.pdf

(20) Comprendre le PNACC2. (2018). https://www.ecologie.gouv.fr/sites/default/files/2018.12.20_Comprendre_le_PNACC2_0.pdf

2b • Identifying short-term climate trends

▶ **To provide the best possible protection against climate change, Météo France has created a special platform to identify three-month climate trends[21].** This platform sets out several scenarios for temperature and precipitation trends. Each scenario is weighted by a probability for an area of around 1000 km². These forecasts can be used to identify the most likely scenario for the region in question: close to, below or above normal. The results are presented in the form of a "hot", "normal" or "cold" scenario for temperature and a "wet", "normal" or "dry" scenario for precipitation.

The aim is not to predict the weather conditions over the coming months, but to determine the trends expected on average over the quarter. These forecasts are an average over the season and cannot identify a specific, one-off event lasting several days or weeks.



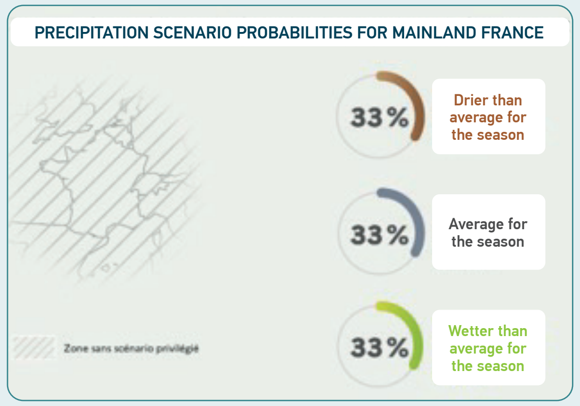


Figure 7: illustrations of two temperature and precipitation scenarios for mainland France

2c • Identifying long-term climate trends

▶ **To end this section, climate trends for the end of the century have been the subject of numerous studies by various bodies.** By cross-referencing these data, we can identify a trend up to the year 2100.

The trends observed at the beginning of the century are likely to become more pronounced, with:

- a sharp rise in average temperatures for some scenarios: from 0.9°C to 1.3°C for the scenario with the lowest greenhouse gas emissions according to the IPCC, up to 2.6°C to 5.3°C in summer for the IPCC's most pessimistic scenario;
- for the most pessimistic scenario, an increase in the number of days with heat waves exceeding 20 days in the south-east of the country;
- milder periods of extreme cold;
- an increase in drought in most of the south of the country;
- an increase in extreme precipitation[22].

These trends apply to the whole of France. More region-specific climate trends can also be identified, as explained earlier in this report. It is important to know about past climate trends in order to better understand future developments, as Climat HD has done.

(21) Les tendances à trois mois | Météo-France les dernières prévisions saisonnières. (n.d.). https://meteofrance.fr/actualite/publications/les-tendances-climatiques-trois-mois

(22) Nouvelles simulations du climat : quel réchauffement en 2100 ? | Météo-France. (n.d.). https://meteofrance.com/changement-climatique/quel-climat-futur/nouvelles-simulations-du-climat-quel-rechauffement-en-2100 - Le climat futur en France | Météo-France. (n.d.). https://meteofrance.com/changement-climatique/quel-climat-futur/le-climat-futur-en-france

3• Methods for studying and reconciling the data available

▶ **The remainder of this section sets out a method for analysing the data from the sample of sources mentioned above. This step provides a specific result for each player in the rail industry and each type of activity. Analysing the data should lead to a result that can be used to make decisions. These decisions should then enable us to develop resilient systems.**

3a • Preliminary steps for risk analysis

CEREMA has set out its method for analysing the vulnerability of transport infrastructure to climate change and how it is likely to evolve in several reports[23].

The first step is to define the scope and objectives of the analysis. This involves defining the infrastructure to be analysed. This initial thinking determines the duration and cost of the study, the people who will need to be involved in carrying it out and the data required.

- 1 - Vulnerability study

This step is devoted to assessing infrastructure vulnerabilities. Broadly speaking, the rail system is broken down into assets, which can themselves be broken down even further. The aim is to break down the railway system into individual systems.

At this stage, a good knowledge of the assets and the actual condition of the infrastructure is important (existing damage, traffic levels, feedback on past events, etc.).

Two types of vulnerability are considered: physical and functional. Physical vulnerability represents the vulnerability of the subsystem and depends on the infrastructure components, their strength and behaviour, etc. Functional vulnerability represents the vulnerability of the infrastructure network and depends on its functional characteristics: capacity, coverage, etc. Physical vulnerability analysis means determining the vulnerability of each subsystem that may suffer significant damage, based on its characteristics. Characterising the vulnerability of system components requires a list of factors to be drawn up. The priority vulnerability factors to be taken into account in risk analyses may include the following:

- the age of the infrastructure;
- the planned lifetime of the subsystem;
- design rules;
- the materials used;
- existing maintenance and inspection procedures;
- feedback data;
- the topographical situation of the infrastructure (in relation to sea level);
- network capacity;
- coverage.

Existing data can be used to establish the vulnerability of the infrastructure. In the case of engineering structures, for example, there is a database[24] that provides indicators about their condition. Statistical or historical studies, models, etc. are also available.

(23) Vulnérabilités et risques : les infrastructures de transport face au climat. In the "Connaissances" collection (2019). Cerema.- Changement climatique Les réseaux de transport aussi sont vulnérables ! In the "Le P'tit Essentiel" collection (November, 2018). Cerema - Plan National d'Adaptation au Changement Climatique, volet infrastructures et systèmes de transport | Analyse des risques liés aux événements climatiques extrêmes sur les infrastructures, systèmes et services de transport | Recueil de concepts. Rapport d'étape (2015). Cerema.

(24) Quality images for engineering structures (IQOA)

Functional vulnerability refers to any failures that render part of the system unavailable, forcing users to suffer significant delays or postpone all or part of their journey, or operators to implement alternative solutions. Examples of functions include connectivity, accessibility, capacity, performance, etc.

Given the connectivity of the rail network, the more alternative routes there are to connect two points, the lower functional vulnerability will be. Conversely, functional vulnerability will be very high if no alternative route can be envisaged.

The vulnerability analyses must both be carried out and then combined to obtain what is commonly known as a risk analysis.

The final stage involves an analysis of the impact on travel. Not all networks have the same functionality or the same priorities, so the analysis must be built using a systemic approach.

- 2 - Characterisation of climate hazards

For the rail system, the main priority is to maintain transport functions. The failure or breakdown of a subsystem, caused by the impact of a climate hazard, affects the level of service: regularity, capacity, traffic, etc.

In a second study[25], CEREMA sets out a method for characterising climate hazards. Hazards refer to climate events extrinsic to the subsystems, and to their consequences for the region. They are defined by an intensity and a spatial and temporal probability of occurrence. The hazards mentioned in this report have an impact on the physical vulnerabilities of the rail network's subsystems, which depend on the characteristics of the components, their strength, their behaviour, etc.

This makes it necessary to identify current climate events and their evolution. The information in chapter 1 should provide a basis for determining which climate events are present in the geographical area under study, as well as their characteristics, frequency and intensity.

The various climate simulations make it possible to visualise changes in the timing, frequency and intensity of climate events.

The list of hazards to be studied can then be modified according to the objectives of the risk analysis (focusing on one hazard in particular or studying all of the identified hazards) and/or its the scope (different spatial and temporal scales). The hazards that have an impact are determined and selected by iteration in parallel with the breakdown of the railway system into sub-systems.

3b • Risk analysis

▶ **Having characterised the climate hazards, described the network to gain an exhaustive knowledge of its vulnerabilities and characterised the associated priorities, all these elements need to be brought together.** The appropriate tool is a risk matrix, which offers the possibility of classifying and visualising the risks by defining different categories (by subsystem, gradual functional vulnerability, physical vulnerability, etc.).

The following exercise therefore involves assessing the impact of each of the hazards identified on each of the critical or functional vulnerabilities of the subsystems or individual components, and incorporating the priorities. This assessment can initially be carried out on a macroscopic scale by considering the subsystems and then, if the exercise is worthwhile, on the scale of the individual components of all or some of the subsystems. For example, it may be a good idea first to assess the impact of heavy rain on the track and then to break down the effect of this hazard on each of the track components (ballast, rail, supporting soil, etc.).

Together, the combination of hazards, the physical and functional vulnerabilities of the infrastructure and the priorities are called a risk analysis. Following consultation, it is important to define a scale for scoring the probability of occurrence of each hazard in space and time, but also to score each physical or functional vulnerability. By multiplying the hazard score by the vulnerability score, we obtain a risk score that can be used to rank the various risks identified.

To illustrate this, let's assume that we have identified four vulnerabilities and four climate hazards. Following consultation, we come up with the following analysis:

- Vulnerability no. 4 is the most sensitive according to our priorities: we give it a score of 4;
- Vulnerability no. 1 is the least sensitive according to our criteria: we give it a score of 1;
- Climate hazard no. 1 has the greatest impact according to our priorities: we give it a score of 4;
- Climate hazard No. 4 has the least impact according to our priorities: we give it a score of 1.

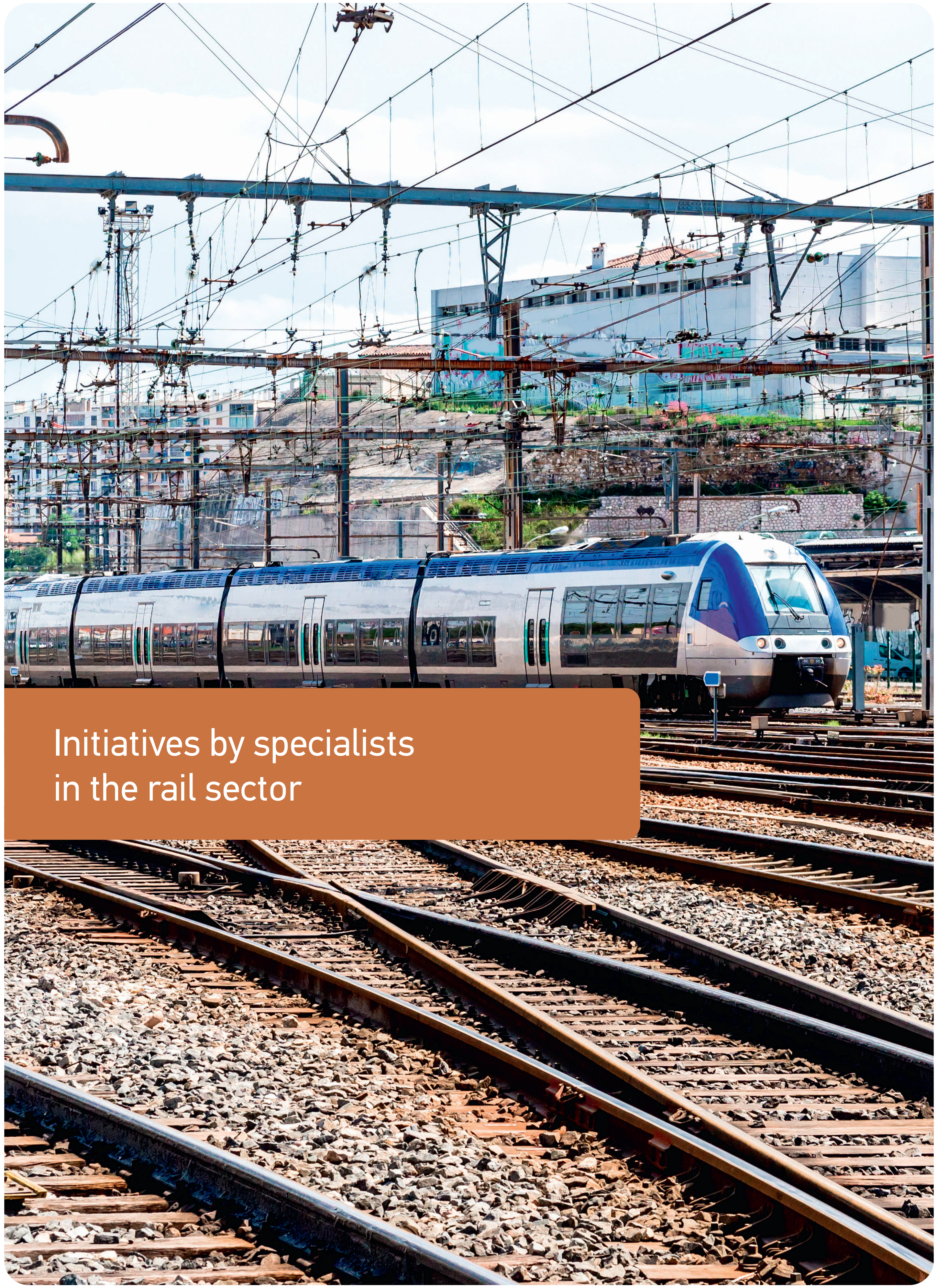
In schematic form, this gives us:

	Vulnerability 4 with score 4	Vulnerability 3 with score 3	Vulnerability 2 with score 2	Vulnerability 1 with score 1
Climate hazard 1 with score 4	16	12	8	4
Climate hazard 2 with score 3	12	9	6	3
Climate hazard 3 with score 2	8	6	4	2
Climate hazard 4 with score 1	4	3	2	1

Figure 8: Risk analysis matrix

The exercise involves defining the level of risk acceptability. This makes it possible to prioritise the serious risks that need to be managed first. Depending on the limits defined, these priority risks will give rise to short-term actions. This should also lead to implementation deadlines being defined for risks deemed less critical. To ensure the relevance of this approach, it is important to work collectively to define the scale of severity and acceptability of the risk.

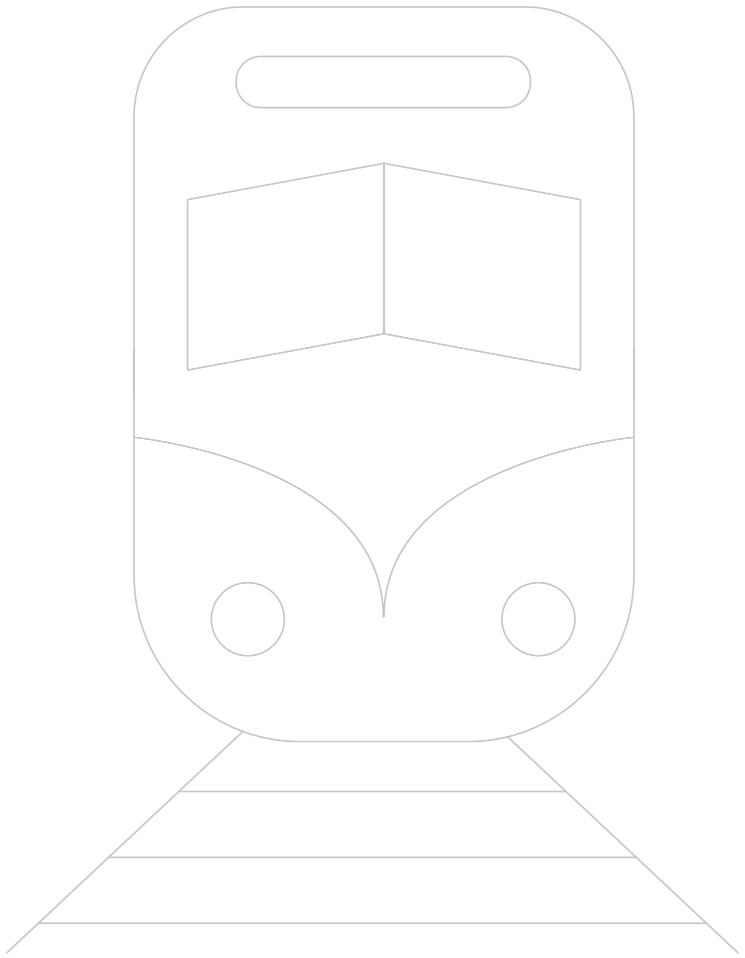
(25) Vulnérabilités et risques : les infrastructures de transport face au climat. In the "Connaissances" collection (2019). Cerema.



Initiatives by specialists in the rail sector

II.

The rail industry has already demonstrated its initiative in guarding against these risks. Several railway operators have already taken up the issue and initiated studies into the risks associated with their activities. In Europe, the national safety authorities are also looking into the subject, and a number of accounts are given in this chapter.



II.

1• Initiatives by Infrastructure Managers

1a • The South-East Atlantic high-speed line

▶ LISEA is the first private infrastructure manager to be commissioned to finance, construct, operate and maintain a high-speed line: the South-Europe Atlantic (SEA) high-speed line. The line entered service in 2017, covering 300 km between Tours and Bordeaux. The infrastructure is thus very recent.

As part of their efforts to adapt to climate change, and in response to various requests, LISEA has initiated an assessment of the resilience of the SEA line. Issues such as line availability (traffic interruptions, slowdowns, prolonged stoppages), maintenance (infrastructure maintenance requirements, maintenance methods and organisation) and renewal (deterioration, destruction, premature ageing, changes in components) were also factors in the launch of this study.

Based on scientific studies modelling climate change over the coming century, LISEA's approach is to assess the potential impacts on the high-speed line, its operation and its maintenance. The aim is to prioritise the issues and identify courses of action, taking the new line management parameters into account. At present, maintenance takes no account of climate change, so the aim is to understand the expected changes so that they can be incorporated into management as effectively as possible.

The study began in 2019 and nearly a year was needed to establish a study strategy and method. In terms of organisation, a project manager was appointed to steer the project and coordinate between the service providers involved (methodological input) and the LISEA/MESEA operational experts (contributing knowledge of the line and railway expertise). Around twenty LISEA/MESEA employees were called upon (interviews, transmission of documents, reviewing of deliverables and adjustments, etc.).

LISEA relied on CEREMA and its L3 analysis method dating from 2015[26]. Two objectives were set:

- understanding and analysing climate change within the geographical scope of the line;
- analysing the potential impact on line availability, maintenance and renewal.

The first step of the study was to define its framework. To do this, they chose two scenarios proposed by the IPCC, a realistic scenario and a pessimistic scenario[27].

(26) Described in the National Climate Change Adaptation Plan (PNACC), this method was first tested on road and port infrastructure before being applied to rail infrastructure with the help of SNCF Réseau.

(27) Realistic scenario: RCP 4.5, which envisages the stabilisation of GHG emissions at an average level before the end of the 21st century. Pessimistic scenario: RCP 8.5, where GHG emissions continue unabated throughout the 21st century

▶ The second step was to define the scope of the study in terms of space and time. The geographical scope was delimited by the railway line, catchments and nearby facilities. The time horizon was defined as the near future (before 2050) and the medium term (before 2075).

The study, based on data analysis, was carried out in seven phases:

- identification of the climate hazards to which the geographical area is exposed;
- identification of the system components studied;
- analysis of the physical and functional sensitivities of system components;
- analysis of climate data;
- scoring of sensitivity to the climatic hazards identified based on a scale;
- mapping of the results;
- analysis of vulnerabilities by cross-referencing sensitivity with exposure to risk.

In this second stage, the main task was to break down the assets and then measure vulnerability for each asset class according to the different types of climate hazard.

LISEA also drew on the expertise of other players such as VINCI Autoroute, the Nîmes-Montpellier bypass project (CNM), SNCF Réseau, etc. The benchmark was useful for identifying risks, ensuring consistency of practices and the risk management methodology.

The immediate risks identified include forest fires and earth movement caused by clay shrinkage and swelling. These two risks were identified as having a significant impact on network operations. In addition, the risks identified for the longer term are:

- the risk to overhead lines associated with rising temperatures;
- the risk associated with extremely low temperatures, which have an impact on switches and crossings, for example.

In the short term, the actions to be taken are to reinforce vegetation control around known fire sites. Work is also planned on a system for assessing sensitivity to clay shrinkage and swelling.

In the medium to long term, an adaptation plan will be drawn up, specifying and prioritising medium and long-term actions (impact/cost/effectiveness).

The company's organisation also includes a project manager to oversee these tasks.

1b • The Nîmes and Montpellier bypass line

▶ OC'VIA is the concession holder and infrastructure manager for the Nîmes-Montpellier bypass (CNM) high-speed line. CNM is a new 60 km line, opened in 2017, which is unusual in being a high-speed line open to both TGVs and freight traffic. OC'VIA has been entrusted with the financing, design, construction and maintenance of the line.

Like LISEA, OC'VIA also initiated an assessment of the line's resilience in 2021. This study was prompted by the intensification of climate events and their frequency over the last fifty years (heat, storms). It was also motivated by economic considerations.

The aim of the study was to estimate the costs of climate change. The methodology was much the same as for LISEA, except that OC'VIA drew on the expertise of a private body. It also used two more recent IPCC scenarios[28]. The scope of the study was more targeted, and the following systems were analysed:

- earthworks and civil engineering;
- hydraulic structures;
- engineering structures;
- the railway track;
- railway signalling;
- overhead lines;
- HV/LV energy and telecommunications;
- buildings;
- the surrounding area.

The study was carried out in three stages. The first involved studying exposure to climate risks and changes over time. The second analysed the level of preparedness and degree of adaptation to the risks associated with climate change. The final stage identified and formulated recommendations for strategic adaptations.

OC'VIA drew up a list of eight climate hazards considered to be generic:

- flooding;
- extreme rainfall/Cévenol episodes;
- high temperatures (over 34°C);
- fire;
- strong winds/winter storms;
- thunderstorms;
- low temperatures (below -5°C);
- snow.

They then drew up a risk matrix by cross-referencing the severity of the impact with the probability of the climate hazard occurring. The severity scale is divided into four, from the least to the most extreme.

(28) SSP2-4.5: scenario in line with current climate policies and the targets for the nationally determined contributions for 2030. This scenario should lead to mid-century warming of 1.6 to 2.5°C. SSP5-8.5: scenario leading to global warming of 1.9 to 3°C by the middle of the century, the most pessimistic scenario, but only 0.4°C higher than the SSP2-4.5 scenario by the middle of the century.

This work identified two major risks to the operation of the line. Firstly, the increase in extreme rainfall (frequency and intensity) was identified as a major risk, particularly for earthworks. Secondly, rising temperatures and the risk of fire can damage or destroy signalling installations, track and overhead lines, making it necessary to replace installations.

In light of these findings, the study demonstrated the resilience of the line and the effectiveness of maintenance. Secondly, OC'VIA established priority adaptation measures. For example, with regard to the risk of fire, the braking zones of goods trains have been identified as areas at risk of fire outbreaks. In order to limit the probability of a fire starting in the CNM perimeter, the associated recommendation is to treat the vegetation around these areas more intensively (in terms of frequency and surface area). The benefit identified is to reduce the risk of traffic disruption and damage caused to the infrastructure.

To take this work further in other areas, OC'VIA is also experimenting with connected remote climate monitoring (rail temperature, air temperature, rainfall) and the inclusion of this data in feedback when incidents occur.

1c • The historic manager in France

▶ As manager of the national rail network, SNCF Réseau sells access to the network, manages traffic (passenger and freight) and carries out infrastructure maintenance and development.

For SNCF Réseau, the strategy for adapting to climate change is based on current and future vulnerabilities. It is working to anticipate chronic and extreme events. Development and deployment will be gradual and based on a long-term vision.

Within this organisation, a Natural and Technological Risks division (RNT) has been set up, working with other SNCF Réseau divisions to draft and update the RNT policy, support the deployment of the RNT policy, monitor its implementation, define guidelines and action plans for the risks it manages, monitor and use incident reports, monitor regulatory and technical developments and events and represent SNCF Réseau on various issues at national level (working with ministries and other network operators). The RNT division is not responsible for defining SNCF Réseau's climate change adaptation strategy, but contributes to it through the missions described above.

The RNT division has thus identified the natural and technological risks to which SNCF Réseau is exposed. It then grouped these risks by shared methods for addressing them, similar impacts on infrastructure and traffic, and similar procedures and internal regulations.

The climate hazards considered to be the most serious are:

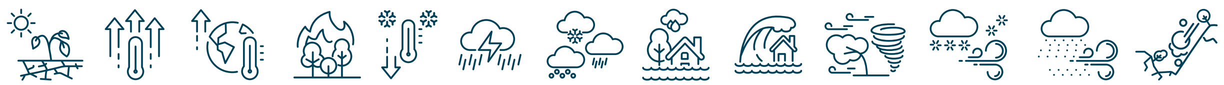
- high winds, cyclones and tornadoes;
- extreme cold (frost, etc.) and snowy weather;
- extreme heat;
- rock risk (falling boulders, avalanches, etc.);
- hydraulic risk (flooding, mudslides, erosion);
- animal intrusion;
- movement risk (landslides);
- sinkholes (cavities, mines, etc.);
- earthquakes;
- risks associated with vegetation (dangerous trees, obscured signals);
- lightning.

They then carried out a risk analysis based on incident reports, taking into account the frequency and proven seriousness of the risks. The positioning of risks in a matrix is reviewed each year on the basis of incidents in previous years that have had an impact on safety. This matrix provides a short/medium-term vision. This strategy only takes into account the proven seriousness of the risk, partly because SNCF Réseau has a large database on past incidents.

Bearing in mind that climate hazards are not the only cause of incidents (ageing structures, design and maintenance faults), the most serious risk identified is hydraulic risk, followed by rock risk, which is less serious, and then vegetation risk and lightning risk.

SNCF Réseau's RNT safety policy is a short/medium-term strategy based on a microscopic data scale, located at a specific site under current climate conditions. It is also based on the identification and scoring of risks according to real incidents. This prioritisation guides prevention, protection, warning and crisis management actions, as well as any revisions to design standards and processes based on past incidents.

The RNT safety policy, explained above, feeds into a longer-term climate change adaptation strategy. This adaptation strategy is based on a more macroscopic data scale: across a region with a spacing of several kilometres. Risks are identified on the basis of climate scenarios and the vulnerabilities of the rail system. It can be used to adapt maintenance, production, regeneration and network development issues. For example, it can be used to prioritise regions in relation to each other, particularly in terms of the most problematic hazards. This adaptation strategy also raises awareness, helping to ensure the safety policy is implemented.



2• Initiatives by Railway Undertakings

2a • Freight transport: FRET SNCF

▶ Fret SNCF is a French railway undertaking. A subsidiary of the SNCF, it is part of Rail Logistics Europe, the rail freight and logistics arm of the SNCF group.

As part of the SNCF group's adaptation strategy, Fret SNCF contributes to policies aiming to make the rail business more resilient. The SNCF group has long had a strategy for adapting to weather conditions. With the expertise of SNCF Réseau, the SNCF group has set up seasonal action campaigns, for example. They have put specific actions in place for the "hot season", for "slipping/skidding" and for the "cold season".

Exceptional weather conditions have meant that Fret SNCF and SNCF Réseau have had to modify their procedures and define activities that had not yet been identified. In 2021, a serious accident in the Rhône-Alpes region led SNCF Réseau to introduce a framework for snow clearance operations on switches and crossings. Two Fret SNCF operators were supposed to take delivery of a service on an industrial spur[29], but the points up the line were covered in snow and could not operate. The operator therefore decided to clear the snow from the points and entered the danger zone on the adjacent main track. Unfortunately, the operator was hit by a regional express train. This serious and significant event led to a change in procedure. From now on, RU operators are prohibited from clearing snow from switches and crossings. SNCF Réseau is responsible for this task, which is now set out in an SNCF regulatory text.

Another incident, this time due to the hot weather, occurred when a fire broke out because of a jammed wheel. The damage to the railway infrastructure and the surrounding area was considerable. These significant events prompt Fret SNCF to draw up incident reports so that the risks can be taken into account and to put protective and corrective measures in place. Fret SNCF uses feedback as a form of continuous risk analysis.

The company says it is sensitive to climate hazards such as hot weather. These hazards have an impact on the rolling stock (distributors, the phenomenon of "stuck iron", problems in the pneumatic lines). High temperatures also have an impact on electronic and computer circuits, which require efficient air conditioning. As a preventive measure, Fret SNCF carries out preventive maintenance on the ATS system[30] for the hot season, and they also have specific measures linked to on-board IT. High temperatures can also have an impact on current capture. Regular inspections on power car roofs are therefore planned to detect any malfunctions.

Rolling stock is also sensitive to cold snaps (linkage freezing) and thawing, which subjects various circuits to humidity. As a preventive measure, Fret SNCF preheats its power cars, empties water tanks and carries out preventive maintenance on ATS systems. It also provides for preventive inspections of power car roofs, as in the case of very hot weather. There are also plans to adapt the pantographs on power cars to scrape ice off the overhead lines. Finally, increased vigilance is now being applied to reports of equipment faults caused by snow, frost or ice.

(29) Site industriel privé

(30) Automatic Train Stop: ATS is a system on board a train that automatically stops the train if certain situations occur (unconscious train operator, earthquake, disconnected rail, train passing a stop signal, etc.) to avoid accidents

Strong winds have also been identified as a problem. This phenomenon can cause trains to derail. Finally, the impact of flooding is a future area of work, given the climate upheavals that the company has been experiencing in recent years.

Other measures have also been put in place to mitigate other identified risks. These include measures relating to fixed installations, organisational measures in the context of OHS (Occupational Health and Safety), measures for rolling stock (powered or unpowered) and measures concerning safety procedures on the ground or in the cab within the framework of railway operating safety.

2b • Passenger transport: RENFE

▶ RENFE is Spain's national passenger railway undertaking. In particular, it operates on the border between France and Spain, running high-speed trains to Marseille and Lyon.

RENFE's concerns about the risks associated with climate change are growing and have been the subject of internal discussions. The Spanish company is concerned about the extreme weather conditions affecting both Spain and the south of France:

- torrential rain or flooding;
- extreme winds;
- extreme heat waves;
- sudden changes of temperature within a single day;
- extreme fires affecting the railway.

In addition to the impacts on rail infrastructure already mentioned, RENFE has identified other impacts, particularly on emergency management and self-protection. This includes changes to the timing of the seasonal periods for hot and cold season safety plans. It also includes reducing emergency response times in extreme conditions (transfers, evacuation, comfort conditions, etc.).

As far as rolling stock is concerned, adaptations such as improved performance of new equipment (air conditioning and heating systems, for example) need to be considered. Similarly, when new equipment is being built, consideration needs to be given to adapting the operating temperature ranges.

According to RENFE, it is also important to look at methods of information management and coordination between the authorities/players involved in emergency situations. They have identified five areas for improvement:

- coordination between players and authorities to limit losses of connection and information;
- information management to detect extreme climatic variations;
- weather forecasting tools focused on local phenomena and tailored to the route of the track;
- the use of Big Data, artificial intelligence (etc.) in the same way as the airline industry;
- mapping hot and cold spots.

In conclusion, RENFE is convinced that the various stakeholders' measures and actions need to be centralised for the system to perform well. This includes developing new information management software, for example. RENFE also considers it necessary to analyse the impact that climate change could have on risk management in the workplace.

3• EPSF initiatives

▶ As France's national safety authority (NSA), EPSF plays a supporting role in topical issues affecting the rail sector (safety, regulations, technological innovations, etc.). An independent public body, EPSF oversees the entire sector, taking a macroscopic view of the French rail system. In particular, this enables it to share and raise awareness about tomorrow's issues, especially in terms of safety.

The rail sector is a field in which many experts come together on a variety of issues. They collaborate to ensure that trains run under the best possible conditions of safety and productivity. At national level, EPSF organises a number of discussion forums, scheduled over the course of a year, with the aim of sharing knowledge and learning from experience. These events are special opportunities for members of the sector to take the floor and present their work and best practice; debates are held, and answers and clarifications are provided. These discussions are also a chance to tackle more global issues, such as the resilience of the rail system in the face of climate change. Cooperation between the various players is more necessary than ever if we are to make faster progress together towards adaptive solutions to climate change.

As part of its safety monitoring mission, EPSF collects information about all the safety events that occur on the NRN. This feedback is already being used to monitor safety levels, compile statistics and add to the sum of our experience so that we can adapt to climate change as effectively as possible.

In addition, in 2023, EPSF decided to ask rail operators about their presumed level of maturity with regard to climate change issues. EPSF wants to measure the extent to which these changes and the current thinking on the subject have been taken into account. This work will have the virtue of being shared with the sector to initiate as much consideration as possible of the risks associated with climate change.

At international level, the NSA Network supervised by the ERA[31], brings together all the European NSAs. EPSF participates as the French NSA by submitting initiatives at international level. Against this backdrop, EPSF, in collaboration with FOT[32], surveyed its members to gauge the position of European countries on the challenges of climate change. One of the aims of this work is to collect information on the key events identified by the NSAs and their initiatives on the issue of climate change, the associated risks and the actions taken.

(31) European Union Agency for Railways
(32) Federal Office of Transport: the Swiss NSA

4• Experience and initiatives from other European countries

▶ EPSF has collected statements of experience from several European NSAs. These experiences highlight key events that have taken place in neighbouring European countries, the studies that have been carried out and the actions that have been or will be taken.

4a • The NSA Network survey

The NSA Network is a discussion group consisting of all the European NSAs and the ERA. This group meets several times a year to talk about developments (regulatory, technological, etc.) in the European rail sector.

Against this backdrop, EPSF, in conjunction with FOT (the Swiss NSA), decided to conduct a survey of the impact of climate change on the European rail system. The purpose of the short questionnaire was to provide a brief overview of the context in the country concerned, the recurring climate events it faces, their consequences and the actions taken.

The responses provide a broad panorama of the different climate contexts in Europe. Here is some background to enable an analysis of the answers.

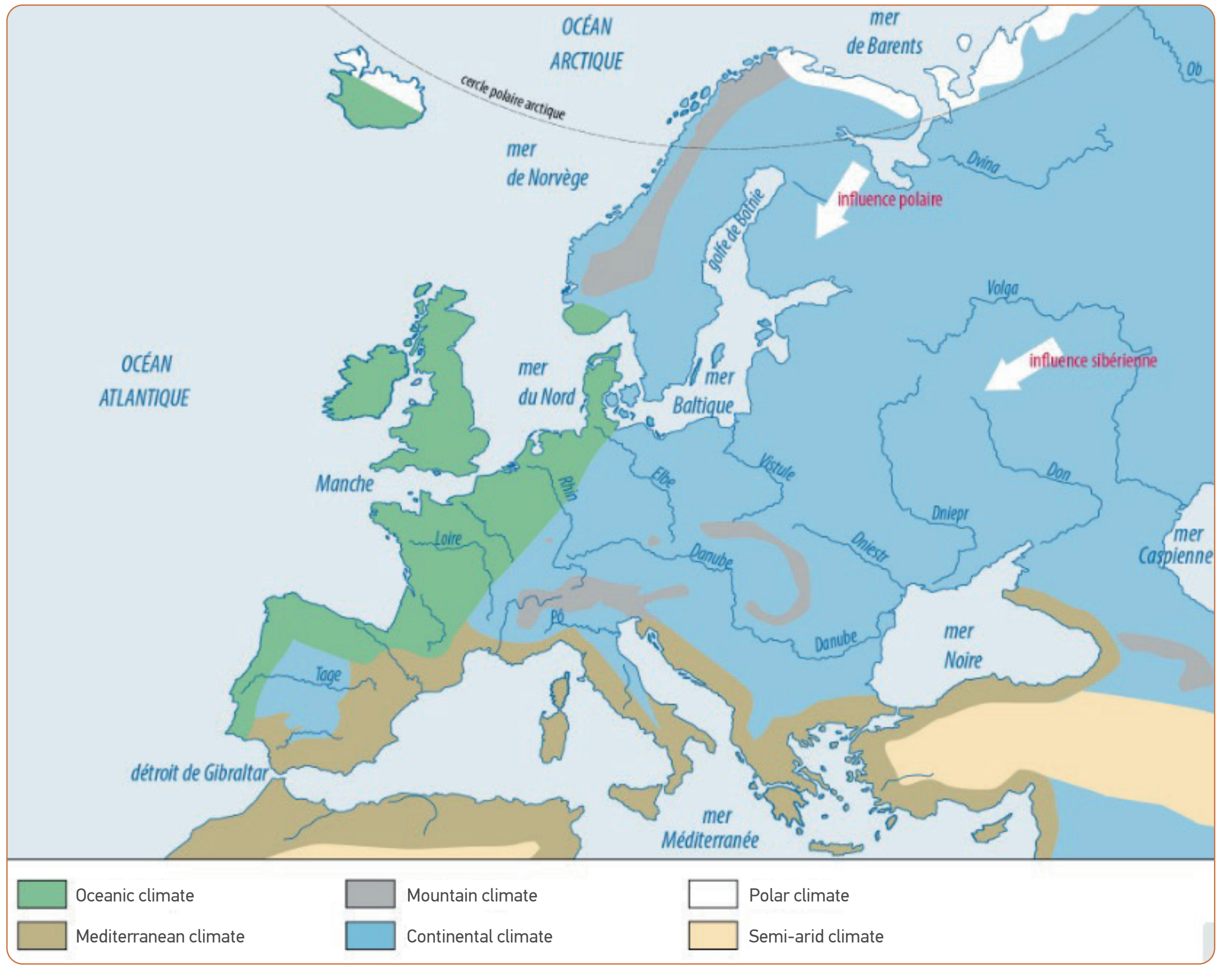


Figure 9: map of European macroscopic climates (source: www.universalis.fr)

There are six main types of climate in Europe: oceanic, continental, mountain, Mediterranean, semi-arid and polar. These are macroclimates, which characterise large geographical areas. They reflect annual trends. We are interested in three climates in particular.

The oceanic climate is characterised by a small temperature range, with a relatively small difference between the average summer temperature and the average winter temperature (maximum difference 10°C). This is reflected in mild winters and warm summers. This climate very often brings bad weather accompanied by heavy rainfall and humidity. It is found mainly on the Atlantic coast.

Continental climates are found in areas far from the coast at moderate latitudes. Although it is temperate, a continental climate is considered extreme because of the considerable variations in temperature over the months. Temperatures can drop to -20°C in winter and rise to 30°C in summer. Spring and autumn are very short, and the season often passes directly from winter to summer and vice versa. Rainfall is low due to the distance from the coast. Precipitation is concentrated in the form of violent thunderstorms in summer and snow in winter. These areas are also susceptible to forest fires.

The mountain climate is the climate that characterises mountain regions, regardless of the climate zone of the surrounding area. It is characterised by cold winters and cool, wet summers. In each climate zone, the temperature and rainfall patterns in the mountains are very similar to those in the neighbouring plains, but the temperature is lower and rainfall increases up to a certain altitude.

The seven survey responses were therefore analysed in terms of the three macroclimates described above.

A number of key figures emerge from this survey, which are set out in this report. For example, 86% of respondents acknowledged that major events caused by exceptional weather had occurred over the last five years. In Switzerland, for instance, where the climate is mostly continental, two derailments were caused by strong gusts of wind, resulting in physical injury to passengers and financial consequences for the company. In another country, this time with a predominantly oceanic climate, 80 to 100 mm of rain fell in the space of a few hours. An underground passage at a station was flooded and the escalators and lifts stopped working. Other roads and cycle/pedestrian tunnels under the railway line were also flooded. Finally, in a country with a continental climate trend, an embankment fire damaged the railway infrastructure and the track had to be closed. The fire spread to neighbouring houses and injured several people.

The signs of climate change are already visible in Europe. Based on the results obtained, we were able to draw up a table of the most damaging climate events in Europe:

1 • Wind gusts
2 • Heavy rainfall
3 • High temperatures (or sudden temperature changes)
4 • Landslides and rock falls
5 • Heavy snowfall
6 • Drought
7 • Embankment/vegetation fires

This list of major climate events should be seen in conjunction with the following list of the most sensitive components of the railway system, according to the responses obtained:

1 • Damage to infrastructure
2 • Collisions between rolling stock and obstacles
3 • Damage to overhead lines
4 • Disrupted or interrupted traffic
5 • Derailments
6 • Damage to rolling stock
7 • Forest fires
8 • Safety

The main risks identified for the future by the NSAs surveyed include higher temperatures, which will lead to more track deformation, forest fires and the risk of electronic failures. For example, alternating temperatures will lead to problems in the rails, but also in earthworks (backfill) due to soil shrinkage and swelling. Difficulties are likely in setting a reference temperature when building or replacing tracks. Preventive maintenance for hot weather will be prolonged, which could cause delays in operational maintenance activities. Passengers will have to be evacuated due to disrupted traffic and faulty vehicles. The working conditions of employees working unprotected in a warmer climate will also need to be monitored.

Several European countries have taken action to adapt to these serious climate phenomena and mitigate their impact on the railway system. Risk analyses are being carried out in various European countries. Weather forecasting tools have been developed, and discussion groups have been set up between the various stakeholders and decision-makers (meteorological service, hydrological service, climate specialists, civil protection, politicians, etc.).

Other European countries have chosen to regulate certain aspects of their fight against the harmful effects of climate change, such as a country with an oceanic climate that has chosen to map the areas most sensitive to extreme weather events and adapt the technical guidelines for infrastructure and rolling stock (drainage systems and air-conditioned carriages, for example). In a country with a continental climate, a law imposes a minimum distance between trees and the edge of the track. The same law also applies to protect the track from snowdrifts in winter.

In another country with a continental climate, a decision was taken to reinforce the overhead contact lines to guard against wind storms, and above all to build snow retention barriers and screens by planting rows of trees along the track. Here we can see the difference between two countries with the same dominant climate that regulate trackside vegetation with opposing strategies, one seeing it as a potential obstacle and the other as a potential protection. This shows how everyone must ensure that the actions taken in response to the vulnerabilities and risks identified are consistent.

An adaptation plan has been drawn up in a country with an oceanic climate that includes specific measures for the rail sector[33]. The most relevant measures for the rail sector are:

- mapping the sensitivity of rail infrastructure to various extreme weather events to help with long-term planning;
- adapting technical guidelines for the design and construction of new rail drainage structures by rail infrastructure managers;
- managing specific weather conditions;
- analysing the impact of climate change on services that are essential to society.

To conclude this survey, several dozen different studies have been carried out in different European countries. These are available in appendix 3.

(33) Towards a climate change resilient society by 2050 – Federal adaptation measures 2023-2026. (2020). In Adapt2climate.be.

4b • The Network Rail study

▶ Network Rail owns, operates and develops the UK's rail infrastructure and is responsible for managing around 20 of the country's largest stations. The British network comprises 17,000 km of lines, 7,200 km of which are electrified.

With the aim of ensuring the safety and operability of the UK network, Network Rail has carried out a study[34] to understand the impact of weather conditions on network performance.

Starting from a simple observation about the financial and time costs of exceptional climate events, Network Rail has drawn up a list of the climate hazards that have the greatest impact on the British network. After carrying out a risk analysis, they now know the most severe risks to their network. This list of major risks is being used to develop a national strategy for adapting to climate change. The following is a summary of the study report.

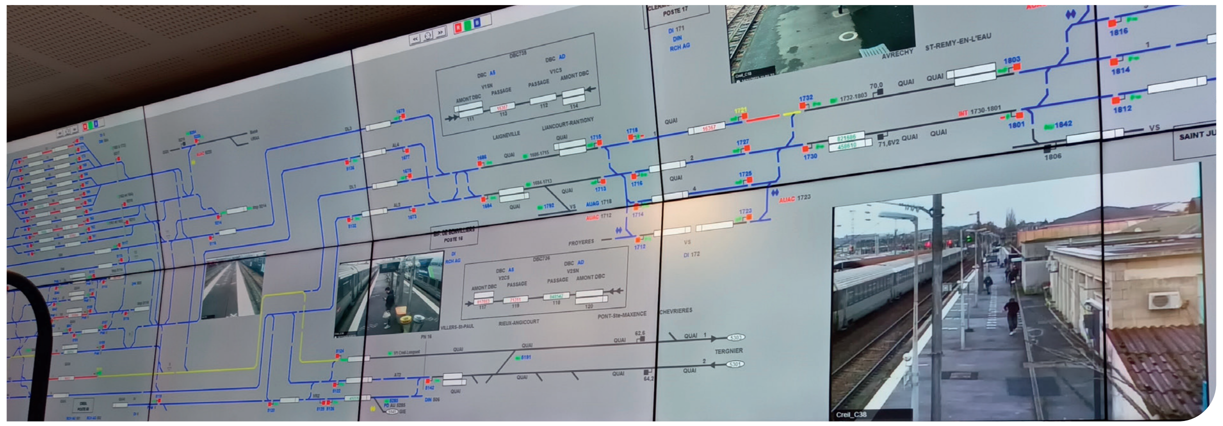
Firstly, they gathered and analysed a large amount of data, including the costs of compensation for delays and the total number of minutes of delay since 2006-2007. They attributed this data to specific types of weather event and recorded the cost and minutes lost for each incident. Although the impacts of extreme adverse weather vary considerably from one year to the next, this 15-year dataset makes it possible to identify certain general trends.

The climate variables identified by Network Rail and assessed as having a potential impact on the network are:

- snow, ice, hail, a long, wet winter/spring, heavy rain/showers, light rain/drizzle;
- sea level rise, coastal erosion, coastal flooding, storm surges;
- extremely cold temperatures, extremely hot days, heatwaves, higher average temperatures, a wide range of daytime temperatures, a long hot/dry summer, glare from the sun;
- lightning, strong winds and storms.

These climate hazards are recognised as having an impact on the safety of the rail system. In particular, Network Rail has identified a number of key risks caused by exceptional weather events due to climate change, such as grip, cold and flooding.

The strategy adopted in the UK is adaptation. Key risk management actions have been identified, such as the preparation of drainage renewal and renovation programmes to reduce the risk of flooding.



(34) Third Adaptation Report. Network Rail (December 2021).
https://www.networkrail.co.uk/wp-content/uploads/2022/01/Network-Rail-Third-Adaptation-Report-December-2021.pdf

Risk summary

III.

IMPACT STUDY

1• The major risks identified and their consequences

▶ **The results presented in this chapter are not exhaustive and emerge from the thinking process within EPSF.**

This is a national approach, and consequently it cannot take account of regional specificities and exceptions. This analysis should thus be taken as a whole and, if necessary, supplemented with a more detailed assessment of each area and each sector under consideration.

The results were obtained by identifying the climate hazards with the highest probability of occurrence in France. For example, climate hazards such as earthquakes and volcanic eruptions were ruled out.

To identify the impact of these climate hazards on the railway network, the system was broken down into two subsystems: infrastructure and rolling stock. These subsystems were themselves broken down into more detail in order to obtain specific subsystems with regard to the impact of climate hazards. As an illustration, the infrastructure was broken down into subsystems such as the track, signalling, overhead lines, etc.

The subsystems identified are considered to be in good general working order, with maintenance carried out correctly and within the prescribed time scales. The results therefore do not include any degraded subsystems, and this aspect will have to be added by the rail operators. This means it will be necessary to draw up a preliminary review of the various subsystems and their varying degrees of vulnerability to each of the hazards.

The aim is to identify the impact of each hazard on each component of the railway system. These impacts are colour-coded according to their severity. The severity scale reflects the impact on network operations, from the shortest to the longest term.

The results are presented below in the form of icons.

Taking the analysis further, climate hazards can be added according to the meteorological characteristics of the area studied. This work could also be supplemented with the probabilities of climate hazards occurring in the various areas studied. A GIS* representation can also be used as a visual aid.

* GIS: geographic information system

Key to climate hazards

Climate hazards

Temperature

Drought
Increasing periods of drought

Extreme temperature
Increase in extreme temperature values

Heatwave
Heatwave/prolonged high temperatures

Fire
Forest fires in the vicinity of tracks

Cold/frost
Cold snap/frost

Thunderstorm/lightning
Lightning

Solid mass movement

Solid mass movement
Avalanches, landslides, landslips, mudslides, rockfalls, subsidence

Water

Rain/snow/hail
Increasing periods of drought

Flooding
Increasing periods of drought

Marine submersion
Rise in sea level

Wind

Strong wind
High winds, cyclones, tornadoes

Snowstorm
High winds, snow and ice

Sandstorm
High winds and sand

Type of impact

Impact with **LONG-TERM CONSEQUENCES**

Impact with **MEDIUM-TERM CONSEQUENCES** on network operations: adaptive measures needed to keep trains running (e.g. TSR), and if nothing is done, traffic will inevitably come to a halt

Impact with **IMMEDIATE MAJOR CONSEQUENCES** for network operations (e.g. stopping traffic)

III. The impact of temperature-related climate hazards on rail infrastructure

Download the poster

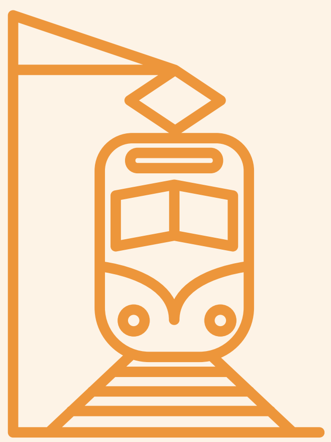
Overhead lines

Overhead line deflection outside tolerance

Destruction

Network freeze
Increased fragility
Rupture due to excessive voltage

Destruction by overvoltage



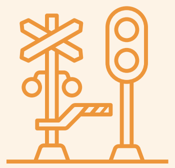
Track

Expansion
Deformation
Excessive strain
Reballasting and tamping (shrinkage of backfill)
Loss of mechanical capacity in the track (shrinkage and swelling of clay)
Rail buckling
Damage to track circuits
TSR

Destruction

Shrinkage
Rail fracture (tight radius curve: track tension on the inside of the curve)

Signalling



Increase in electricity consumption
Malfunction

Destruction

Malfunction

Destruction

Surroundings = earthworks + vegetation

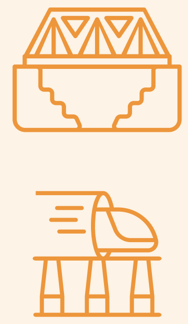
Weakening of stability
Loss of mechanical capacity (shrinkage and swelling of clay, absorption of water by vegetation)
Destruction

Vegetation fire

Weakening of soil stability
Destruction

Falling of trees struck by lightning

Engineering structures



Increased fragility
Cracking
Expansion
Breakage of metal parts

Destruction

Increased fragility
Cracking
Breakage

Signalling centre

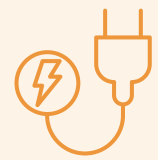
Increased insulation
Malfunction
Circuits overheating
Concrete expansion

Destruction

Electrical circuit malfunction

Electrical circuit malfunction
Network breakdown

Power supply • Cables



Increase in electricity consumption
Structural damage (rapid expansion and contraction of conductors and insulators)

Destruction

Increase in electricity consumption
Network freeze
Breakage

Destruction

III. The impact of climate hazards related to water, wind and solid masses on railway infrastructure

Download the poster

Overhead lines

- Malfunction due to humidity
- Structural damage
- Structural damage
  Cable tearing
- Formation of solid ice
  Freezing of the whole system
- Destruction

Track

- Soil saturation
  Loss of mechanical properties
  Loss of ballast resistance
- Stagnant water
  Damage
  Track circuit failure
  No access to tracks
- Projection of obstacles to traffic
  Collision
- Accumulation of ice on conductor rails and points
  Blocked or ruptured tracks
- Creation of obstacles to traffic
  Instability
  Sinkholes
  Destruction

Signalling

- Loss of insulation
  Sudden re-powering of circuits
  Reduced visibility
- Loss of direct operating capacity
- Structural damage
  Fog: reduced visibility
- Equipment malfunction due to snow
  Poor visibility
- Equipment malfunction due to sand
- Destruction

Surroundings = earthworks + vegetation

- Lack of visibility due to vegetation growth
  Long-term instability
  Saturated soil (erosion, soil swelling, run-off, etc.)
- Destruction
  Creation of obstacles to traffic
- Instability
  Creation of obstacles to traffic
- Long-term degradation (freeze-thaw, snow melt)
- Weakening of stability
  Destruction

Engineering structures

- Flooding
  Destruction of the structure
  Erosion
  Damage to electrical equipment (tunnel)
  + ground instability
- Fragility of the structure (bridge)
  Signal dislodging (tunnel)
- Overloading of the structure
  Breaching (bridge)
  Damaged equipment (ice in the tunnel)
- Destruction
  Obstruction of openings (tunnel)

Signalling centre

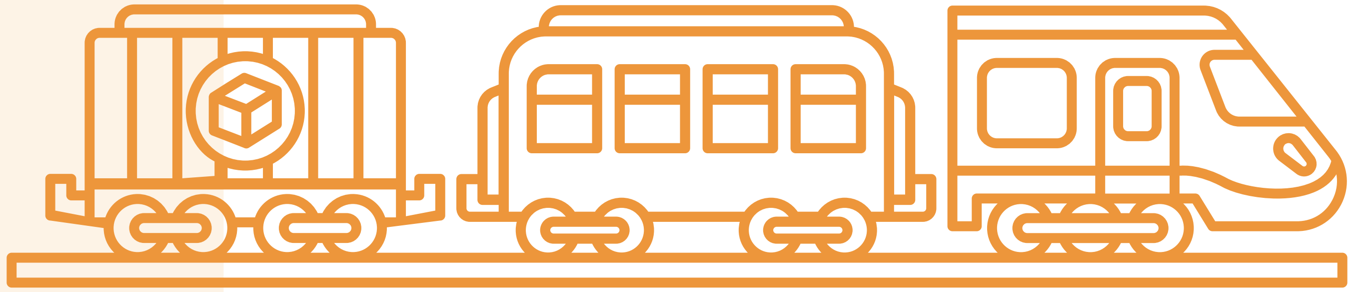
- Loss of insulation
  Sudden re-powering of circuits
- Loss of direct operating capacity
- Structural damage
- Equipment malfunction due to snow
- Equipment malfunction due to sand
- Destruction

Power supply • Cables

- Loss of insulation
  Sudden re-powering of circuits
- Loss of direct operating capacity
- Rupture due to tearing out of an overhead line
- Equipment malfunction due to snow
- Equipment malfunction due to sand
- Malfunction
  Breakage
  Erosion: exposure of buried cables and earthing resistance

III. The impact of temperature-related hazards on rolling stock

Train (locomotive + carriages/wagons)



- TSR if operating ranges exceeded
  Passenger comfort
- Fire in rolling stock
- TSR if operating ranges exceeded
- Malfunction caused by lightning

Air conditioning system

- Over-use of air conditioning
  Circuits overheating
  Pollen and dust particles in systems
- Fire that could spread through the system
  Explosion
- Overuse of heating
  Circuits overheating
- Malfunction caused by lightning

Dangerous goods

- Destruction of containers
  DG leak
  (emergency DG plan)
- Destruction of containers
  DG leak
  (emergency DG plan)

Driving

- Driver dazzle

Download the poster

Couplings (pneumatic, data)

- Expansion
  Condensation
  Coupling failure
- Destruction
- Coupling freeze
  Coupling failure

Braking system

- Sparks that can cause fires
- Overheating
- Destruction
- Frozen linkage (brakes)

Traction system

- Malfunction due to heat
  Overheating (fire)
  Engine failure (diesel)
- Fire that could spread through the system
  Destruction
- Malfunction due to extreme cold
  Humidity during thaw
- Malfunction caused by lightning

Electrical system

- Malfunction due to heat
  Current collection problem
- Fire that could spread through the system
  Destruction
- Malfunction due to extreme cold
  Humidity during thaw
  Pantograph current collection problem (icing)
- Malfunction caused by lightning

Electronic system

- Malfunction due to heat
  Equipment stoppage
  (temperature sensor setting)
- Fire that could spread through the system
  Destruction
- Malfunction due to extreme cold
  Humidity during thaw
- Malfunction caused by lightning

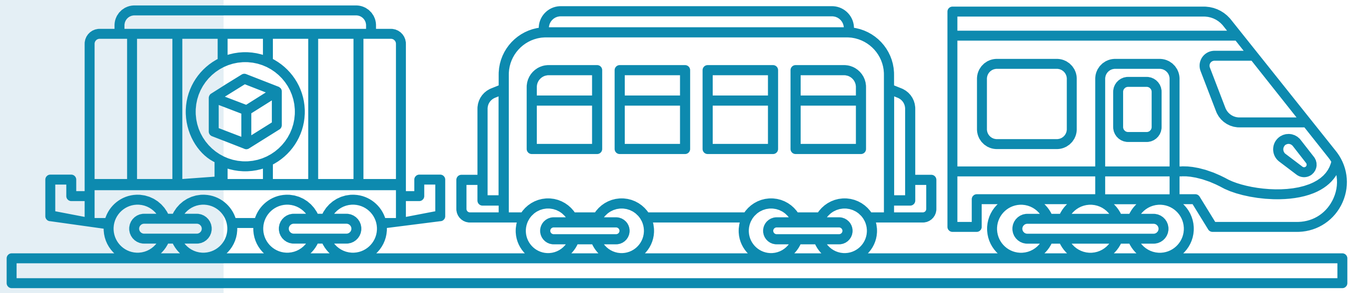
Hydraulic system

- Malfunction due to overheating of circuits
- Fire that could spread through the system
  Destruction
- Frozen pipes

III. The impact of climate hazards related to water, wind and solid masses on rolling stock

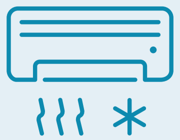
Download the poster

Train (locomotive + carriages/wagons)



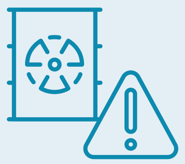
- Malfunction due to humidity; Loss of grip; Water accumulation in pantographs
- Leaks; Derailment
- Collision with obstacles; Damage to equipment; Skidding; Loss of train detection (leaves); Derailment
- Inability to function; Inability to travel
- Equipment malfunctions
- Collision with obstacles; Derailment

Air conditioning system



- Malfunction due to humidity
- Equipment malfunctions

Dangerous goods



- Destruction of containers; DG leak (emergency DG plan)
- Destruction of containers; DG leak (emergency DG plan)

Driving

- Poor visibility conditions

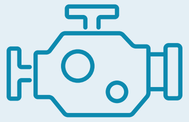
Couplings (pneumatic, data)

- Malfunction due to humidity
- Coupling failure
- Equipment malfunctions

Braking system

- Skidding; Lack of grip; Derailment
- Equipment malfunctions

Traction system

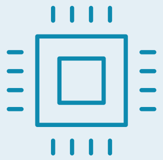


- Malfunction due to damp or frost; Material damage
- Equipment malfunctions; Breakage
- Slippage; Loss of grip
- Equipment malfunctions

Electrical system

- Malfunction due to damp or frost; Material damage
- Equipment malfunctions; Power supply failure
- Equipment malfunctions

Electronic system



- Malfunction due to humidity
- Malfunction; Breakage
- Equipment malfunctions

Hydraulic system

- Equipment malfunctions

2• Recommendations

▶ Points to remember when carrying out a risk analysis

Before starting the study:
- identify and bring together the necessary skills: risk analyses rely on cross-disciplinary skills (experts in various railway activities, risk specialists, specialists in climate tools, mapping specialists, cost specialists);
- supervise the study by appointing someone to be responsible for mobilising the necessary skills and setting up the working group;
- don't hesitate to ask for internal or external technical support.

During the study:
- establish the scope of the study with the resources available (geography, time, assets, finance);
- identify all the useful data that are available;
- identify the climate hazards;
- identify the physical and functional vulnerabilities of the network;
- identify the priorities for your activity;
- carry out the risk analysis by cross-referencing the results and defining a risk acceptability scale.

After the study:
- put the results into a usable form (e.g. a mapping);
- draw up a prioritised, managed action plan to address the risks identified.

For the final stage, once the risks have been identified, it is important to establish the protective measures to be put in place to reduce the level of risk. These protective measures can take various forms. They can be defined at each scale of the analysis of the system, at the level of the climate hazards identified or at the level of the priorities. These measures can be functional or organisational, aimed at reducing the effects of an impact or, on the contrary, increasing them, depending on the needs and objectives. The measures can also be combined. It is important to assess the costs and benefits of implementing one or more protective measures.

In addition, the design rules and models on which the manufacturing, management and maintenance processes for the various components of the rail system are based have not been challenged for fifty years. It may be necessary to revise these models to take the changing climate into account. For example, when tracks are built or replaced, a new reference temperature will have to be defined.

Finally, we must not overlook the benefits of cooperation between all the stakeholders in the rail system. By sharing results, analyses, feedback and best practices, the entire sector will be able to anticipate, adapt and progress in response to the problems of climate change.

CONCLUSION

▶ The primary aim of this report is to encourage players in the rail sector to consider the inherent impacts of climate change on their rail activities. Thinking about this issue in advance is one way of ensuring that we develop the most efficient mitigation and adaptation strategy possible. Climate change is already having an impact on rail operations. As exceptional weather conditions are unpredictable, it is advisable to start preparing as soon as possible.

Mitigation and adaptation are two concepts that contribute to the development of a national strategy to increase resilience, and particularly the resilience of economic activities. The rail sector is seen as an activity with a future. It produces little pollution and is part of a sustainable development approach. However, the consequences of climate events are leading to network disruptions that are less and less acceptable given the drive towards a modal shift from road to rail. Reliability, network availability and passenger comfort are all vital conditions for increasing rail freight and passenger transport. To achieve this, it is necessary to create the conditions for effective work on climate adaptation, prevent the negative consequences of climate impact by creating robust installations and manage the effects of climate influence. The management of rail activities is thus becoming truly strategic.

The study presented in this report is just the first step by the French NSA. The risks and consequences identified are not exhaustive, and it is up to each individual player to adopt the risk analysis approach for their own sector, with all the necessary knowledge. This work is also intended as an initial collection of data that is available and accessible to all.

In this investigation, EPSF notes that work is already under way. Thinking, discussions, analyses and studies have already been carried out. According to the rail operators surveyed, many companies are already taking action. It is therefore important to continue in this direction and to mobilise the entire sector in order to make a joint contribution to the long-term future of the French and European rail network. Cooperation and the pooling of information are strategic aspects of adaptation. Data and data sharing are at the heart of this new challenge. Connected surveillance tools now allow remote monitoring at all times, for example. This constitutes an initial database for developing effective warning systems which, combined with artificial intelligence, for example, will enable all this data to be exploited to the full. By efficiently cross-referencing all the data collected and merging the information, a complete picture of the railway system emerges, enabling faults to be anticipated so that teams can intervene more quickly.

EPSF remains a key player in discussions on this subject and is available to answer any additional questions, provide details or consider initiatives. Additional experience and feedback are welcome and will feed into the general discussions. Sharing and exchange are key to the success of rail transport in response to climate change and in relation to other modes of transport.

APPENDIX 1

Definitions of concepts

▶ The definitions of the following concepts are taken from the national database of statistical data and studies on climate change, energy, the environment, housing and transport[35].

Carbon footprint

France's carbon footprint represents the quantity of greenhouse gases (GHGs) caused by a country's final domestic demand (consumption by households, public administrations and non-profit organisations, and investments), whether the goods or services consumed are produced domestically or imported.

Clay shrinkage and swelling

Slow natural ground movements causing progressive deformation of soil or subsoil rich in so-called swelling clays. These clays shrink during periods of drought and swell when rehydrated after very heavy rainfall. This phenomenon of alternating shrinkage and swelling of the soil can cause damage to buildings, particularly detached houses with lightweight structures that are particularly vulnerable because their foundations are generally shallow.

Climate change

Variation in climate due to natural or human factors.

Climate change adaptation

Adjustment of a system to changes in climate (including climate variability and extremes) in order to mitigate potential damage, take advantage of opportunities or deal with consequences. The French government defines three different types of adaptation:

- Autonomous or spontaneous adaptation: adaptation in response to a climate hazard that is being experienced or its effects, without any explicit or conscious premeditation focused on combating climate change.
- Incremental adaptation: adaptation measures whose main objective is to maintain the nature and integrity of a system or process on a given scale.
- Transformational adaptation: adaptation that changes the fundamental elements of a system in response to the climate and its effects[36].

Climate change mitigation

Action to help stabilise or reduce greenhouse gas concentrations in the atmosphere in order to reduce the risks posed by climate change.

Climate normals

Averages of meteorological variables calculated over a relatively long uniform period covering at least thirty consecutive years.

Climate risks

Among the impacts of climate change, three types can be identified that cause natural risks: an increase in extreme weather events (heatwaves, coastal flooding, marine submersion, drought, etc.), rising sea levels, which may cause flooding in certain coastal areas, and the extension of areas exposed to a heightened risk of forest fires.

(35) Tous les concepts | données et études statistiques. (n.d.). https://www.statistiques.developpement-durable.gouv.fr/tous-les-concepts
(36) Adaptation de la France au changement climatique (2022, 13 April). Ministry of the Energy Transition. Accessed on 17 April 2023 at https://www.ecologie.gouv.fr/adapta-tion-france-au-changement-climatique

Climate vulnerability

Propensity of a population or ecosystem to suffer damage in the event of climate variations, which depends on their capacity to adapt.

Coastal erosion

Cliffs collapsing, bays silting up and beaches being reshaped during winter storms due to phenomena of marine origin (waves, tides and marine currents) and/or continental origin (rain, frost and wind).

Exposure to natural hazards

All the populations, environments and activities that may be affected by natural hazards. This is characterised by a type and a level of exposure that define the scale of the adaptation policy and the approach to be taken by the local authority.

Greenhouse effect

Phenomenon of heating of the Earth's surface and the lower layers of the atmosphere due to the fact that certain gases in the atmosphere absorb and reflect back some of the infrared radiation emitted by the Earth, which itself compensates for the solar radiation that the Earth absorbs. The anthropogenic greenhouse effect refers to the additional greenhouse effect induced by human activities through their emissions of greenhouse gases.

Greenhouse gas

A gas of natural (water vapour) or artificial origin (linked to human activities) that absorbs and re-emits some of the sun's rays (infrared radiation), the phenomena behind the greenhouse effect.

Landslides

Landslides occur when soil or rock is destabilised by natural phenomena (climatic, geomorphological, geological) or by human activity. Although rather slow, landslides can be devastating when they form mudslides or debris flows.

Natural hazard

Manifestation of a natural phenomenon (flood, landslide, earthquake, avalanche, etc.) of given occurrence and intensity.

Resilience

The capacity of an ecosystem to resist and survive alterations or disturbances affecting its structure or functioning, and ultimately to reach a new balance.

Taxon/taxonomic group

Group of living organisms constituting a systematic unit at a given hierarchical level (variety, species, genus, family, class, phylum, etc.).

APPENDIX 2

Bibliography

[1]: L'adaptation au changement climatique dans la taxonomie européenne | Carbone 4.
https://www.carbone4.com/analyse-adaptation-climat-taxonomie-europeenne?mc_cid=87e49bd788&mc_eid=305c502099

[2]: Adaptation de la France au changement climatique (2022, 13 April). Ministry of the Energy Transition.
Accessed on 17 April 2023 at https://www.ecologie.gouv.fr/adaptation-france-au-changement-climatique

[3]: Ce qu'il faut retenir du 6e rapport d'évaluation du GIEC.
https://www.ecologie.gouv.fr/sites/default/files/20250_4pages-GIEC-2.pdf

[4]: Changement climatique Les réseaux de transport aussi sont vulnérables ! In the "Le P'tit Essentiel" collection (November, 2018). Cerema.

[5]: Climat : un nouveau rapport alarmant du GIEC sur un réchauffement global de la planète. (2023, 21 March). Vie publique au coeur du débat public.
https://www.vie-publique.fr/en-bref/288687-rechauffement-climatique-un-nouveau-rapport-alarmant-du-giec

[6]: Comprendre le PNACC2. (2018).
https://www.ecologie.gouv.fr/sites/default/files/2018.12.20_Comprendre_le_PNACC2_0.pdf

[7]: Le climat futur en France | Météo-France.
https://meteofrance.com/changement-climatique/quel-climat-futur/le-climat-futur-en-france

[8] : Les Nouvelles Projections Climatiques de Référence DRIAS 2020 pour la métropole. (2020).
In http://www.drias-climat.fr/document/rapport-DRIAS-2020-red3-2.pdf

[9] : Les tendances à trois mois | Météo-France les dernières prévisions saisonnières.
https://meteofrance.fr/actualite/publications/les-tendances-climatiques-trois-mois

[10] : Lee, J.-Y., J. Marotzke, G. Bala, L. Cao, S. Corti, J.P. Dunne, F. Engelbrecht, E. Fischer, J.C. Fyfe, C. Jones, A. Maycock, J. Mutemi, O. Ndiaye, S. Panickal, and T. Zhou, **2021: Future Global Climate: Scenario-Based Projections and Near-Term Information.** In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 553–672, doi:10.1017/9781009157896.006.

[11] : Notre-environnement. (2023b, avril 17). Les risques naturels majeurs en France.
https://www.notre-environnement.gouv.fr/themes/risques/les-mouvements-de-terrain-et-les-erosions-cotieres-ressources/article/les-risques-naturels-majeurs-en-france

[12] : Nouvelles simulations du climat : quel réchauffement en 2100 ? | Météo-France.
https://meteofrance.com/changement-climatique/quel-climat-futur/nouvelles-simulations-du-climat-quel-rechauffement-en-2100

[13] : Plan National d'Adaptation au Changement Climatique, volet infrastructures et systèmes de transport | Analyse des risques liés aux événements climatiques extrêmes sur les infrastructures, systèmes et services de transport | Recueil de concepts. Rapport d'étape (2015). Cerema.

[14]: Rida, E (2023). Généralités sur le risque inondation en France. Ministry of Ecology, Energy and the Territories.
https://www.ecologie.gouv.fr/generalites-sur-risque-inondation-en-france.

[15] : Tous les concepts | données et études statistiques.
https://www.statistiques.developpement-durable.gouv.fr/tous-les-concepts

[16]: Third Adaptation Report. Network Rail (December 2021).
https://www.networkrail.co.uk/wp-content/uploads/2022/01/Network-Rail-Third-Adaptation-Report-December-2021.pdf

[17]: Vulnérabilités et risques : les infrastructures de transport face au climat. In the "Connaissances" collection (2019). Cerema.

APPENDIX 3
NSA research sources

[18]: Bedeutung des Klimawandels für die Infrastrukturen in der Schweiz. (2019). In Swiss Economics.

[19]: Szymczak, S, Backendorf, F, Bott, F, Fricke, K., Junghänel, T, and Walawender, E (2022). Impacts of heavy and persistent precipitation on railroad infrastructure in July 2021: a case study from the Ahr Valley, Rhineland-Palatinate, Germany. Atmosphere, 13(7), 1118
https://www.networkrail.co.uk/wp-content/uploads/2022/01/Network-Rail-Third-Adaptation-Report-December-2021.pdf

[20]: BMDV Expertennetzwerk - Publikationen - Einflüsse naturgefahrenbedingter Streckensperrungen auf überregionale Verkehrsströme - verkehrsträgerübergreifende Stresstestszenarien für die Region "Mittelrhein" - Schlussbericht SP-109.
https://www.bmdv-expertennetzwerk.bund.de/DE/Publikationen/TFSPTBerichte/SPT109.html?nn=1371986

[21]: Eisenbahn-Bundesamt (EBA). GeoPortal.EBA - verfügbare Kartendienste von GeoPortal.EBA.
https://geoportal.eisenbahn-bundesamt.de/?lang=de&topic=ulr_r4&bgLayer=sgx_geodatenzentrum_de_web_grau_EU_EPSG_25832_TOPPLUS&catalogNodes=15,11,12,10,13&E=579056.88&N=5687905.82&zoom=5

[22]: Resilience: Fabella, VM, Szymczak, S, 2021. Resilience of Railway Transport to Four Types of Natural Hazards: An Analysis of Daily Train Volumes Infrastructures 2021, 6 (12), 174;
https://doi.org/10.3390/infrastructures6120174

Fabella, VM, Szymczak, S, (accepted) Estimating railway resilience curves: recovery duration and train traffic response to floods and tree fall. To appear in Transportation Research Procedia

[23]: Heavy rain/sudden flooding: Szymczak, S, Backendorf, F, Bott, F, Fricke, K, Junghänel, T, Walawender, Impacts of Heavy and Persistent Precipitation on Railroad Infrastructure in July 2021: A Case Study from the Ahr Valley, Rhineland-Palatinate, Germany Atmosphere 2022, 13(7), 1118.
https://doi.org/10.3390/atmos13071118

[24]: River flooding: Klimawirkungsanalyse des Bundesverkehrssystems im Kontext Hochwasser - Schlussbericht SP 103
https://www.bmdv-expertennetzwerk.bund.de/DE/Publikationen/TFSPTBerichte/SPT103.html?nn=1371986

[25]: Storms/gales: Szymczak, S, Bott, F, Babeck, P et al. Estimating the hazard of tree fall along railway lines: a new GIS tool Nat Hazards 112, 2237-2258 (2022).
https://doi.org/10.1007/s11069-022-05263-5

Ableitung des Baumbestandes entlang des deutschen Schienennetzes.
https://www.dzsf.bund.de/SharedDocs/Textbausteine/DZSF/Forschungsberichte/Forschungsbericht_2021-10.html;jsessionid=A61E57856126D1FBB9D998343B69ED71.live21323?nn=2208196

Klimawirkungsanalyse des Bundesverkehrssystems im Kontext von Stürmen – Schlussbericht SP 104
https://www.bmdv-expertennetzwerk.bund.de/DE/Publikationen/TFSPTBerichte/SPT104.html?nn=1371986

[26]: Mass movements: Klimawirkungsanalyse des Bundesverkehrssystems im Kontext gravitativer Massenbewegungen - Schlussbericht SP 105
https://www.bmdv-expertennetzwerk.bund.de/DE/Publikationen/TFSPTBerichte/SPT105.html?nn=1371986

Erstellung einer ingenieurgeologischen Gefahrenhinweiskarte zu Hang- und Böschungsrutschungen entlang des deutschen Schienennetzes.
https://www.dzsf.bund.de/SharedDocs/Textbausteine/DZSF/Forschungsberichte/EBA-Forschungsbericht_2018-13.html?nn=2208196

[27]: Vers une société résiliente au changement climatique à l'horizon 2050 Mesures fédérales d'adaptation 2023-2026. (2020). In Adapt2climate.be.
https://www.networkrail.co.uk/wp-content/uploads/2022/01/Network-Rail-Third-Adaptation-Report-December-2021.pdf

[28]: ARISCC GROUP. ARISCC.
http://www.ariscc.org/

[29]: Third Adaptation Report. Network Rail (December 2021).
https://www.networkrail.co.uk/wp-content/uploads/2022/01/Network-Rail-Third-Adaptation-Report-December-2021.pdf

[30]: The future of rail. Prorail.
https://www.prorail.nl/

ACKNOWLEDGEMENTS

EPSF would like to thank everyone who responded favourably to its request for information on climate change. These fruitful collaborations, the sharing of findings and feedback and the quality and transparency of the exchanges are what made it possible for us to produce this document. The discussions were a rich source of learning and fed into our initial thinking.

Many thanks to Patrick Pressard and Nicolas Hélas-Othenin for their time and the quality of our discussions.

We would like to thank Gilles Rakoczy and Kevin Uba for sharing their high-quality work and their knowledge of their railway activities.

We would also like to thank Eric Richard for making himself available to answer our questions and for the quality of the information he provided.

We also thank Ignacio Hernández Vallhonrat, whose enriching contribution provided us with a fresh perspective on the issue.

Our warm thanks go to Stéphane Drilhole and Armand Caranobe for taking the time to detail all the work in progress, the analyses carried out and the actions implemented.

Many thanks to Linda Ay for her invaluable cooperation.

Finally, many thanks to our foreign correspondents Philipp Unger, Tamas Deri, Mariska Lievaart, Robert Hellström, América Riveros and Anna Dymowska.

Fiona Potet,

Olivier Omnes, supervisor.

July 2024 - Photo credits: EPSF - Shutterstock. Creation and production: TATANKA

établissement public de
sécurité ferroviaire

60 rue de la Vallée
CS 11758
80017 Amiens Cedex 1

Tél.33 (0)3 22 33 95 95

epsf@securite-ferroviaire.fr

www.securite-ferroviaire.fr