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**Manuscript title:** Organizational uptake of scientific information about climate change by infrastructure managers: the case of adaptation of the French railway company

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**Abstract:** Future development and renewal of transport infrastructures have to take into account how the effects of climate change will affect these complex sociotechnical systems. This article aims at understanding how to raise this issue to ensure an efficient and systemic uptake of climate change by infrastructure managers. It reports the results of an in-depth case study conducted on the French railway company. This study identifies several adaptation dynamics: one is top-down and stems from climate change impacts; others are more bottom-up and focused on vulnerabilities. However, both types of approaches have, so far, yielded limited results. Building on the existing literature, this paper reveals critical bottlenecks to overcome in order to get the organization ready to adapt. It suggests key components of an enabling framework for a more proactive preparation to climate change and mainstreaming climate adaptation into major organizational decisions.

**Keywords:** adaptation, infrastructure, railways, organization, climate change, decision-making

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## INTRODUCTION

In a context of climate change, the development and renewal of infrastructures is a critical challenge (European Commission 2013; Chappin and van der Lei 2014; Larrivé, O'Carroll, and Savard 2015; Stecker et al. 2011; Masood et al. 2016; OECD 2015; Forzieri et al. 2015; ToPDAd 2014). In the coming years, thousand billions of euros will have to be invested in transport, energy, water and telecommunication networks to preserve the connectivity, the efficiency and the resilience of the economies (The new climate economy 2014; Dobbs et al. 2013; Vallejo and Mullan 2016)<sup>1</sup>. Those infrastructures will have lifetime expectancies of several decades and will therefore be exposed to the impacts of climate change.

Railways play a structuring role in the European economy as they “facilitate the production and distribution of goods and economic services, and form the basis for the provision of basic social services.” (European Commission 2013). In Europe, most of the railway managers are big companies founded in the 19<sup>th</sup> or 20<sup>th</sup> century that today have to face important asset management challenges (e.g. aging infrastructure, underinvestment in the last decades, important evolution of technologies and mobility patterns). Several research programs have analyzed climate change implications in this context (UIC 2011; EEA 2014; Baker et al. 2010; Nemry and Demirel 2012; Koetse and Rietveld 2009; Armstrong, Preston, and Hood 2016), often focusing on infrastructures' vulnerability. A few case-studies have been conducted at national and sub-national levels, for instance in Sweden (Lindgren, Johnsson, and Carlsson-Kanyama 2009), Germany, Austria (Doll et al. 2014; Rotter et al. 2016) and the UK (RSSB 2015). They generally observed limited action in terms of large-scale investments but a reasonable level of awareness on climate change and a common focus on research and knowledge sharing. Very often, they focus on strengthening resilience to current hazards as a ‘no-regret’ option to start preparing for an uncertain future. This existing work also pointed at the increasing need to develop forward-looking thinking and to proactively integrate climate change concerns early in planning and decision processes. This literature shows how adaptation is not just a technical matter but also an institutional and organizational issue questioning values and priorities. As such, adaptive capacity relies on elements like governance, procedures or leadership (Berkhout 2012; Stecker et al. 2011).

This paper follows up with these projects and reports the results of an in depth analytical case study on the management of climate adaptation of the French railway system.

In France, the main player in the railway sector is a state-controlled group created in 1938 and called SNCF (*Société Nationale des Chemins de Fer Français*). It encompasses both the management of the network (with *SNCF Réseau*) and part of the operation of this network (with *SNCF Mobilités*). It is under the supervision of the transport department of the French Ministry of the Environment.

The French railway network is the second largest in Europe with more than 30,000 km of tracks and 3,000 passenger terminals. Fifteen thousand trains use this network daily, in carry 5 million people and 32Gt-km of freight every year. Climate change could produce severe disruptions in this network and adaptation is

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<sup>1</sup> Mc Kinsey Global Institute estimates global infrastructures needs between \$2.5 (current expenses) and 3.3 trillion per year – 40% in developed countries.

therefore a crucial collective concern. Nevertheless, where and how this issue should be raised and handled in such a big and complex organization is an issue without a straightforward answer. As a matter of fact, SNCF has about 150 000 employees and more than 650 branches - where decisions are distributed and shaped by various factors.

This paper, intends to understand how a big organization such as a national railway network manager can mainstream and increase the internal uptake of the issue of climate change. It aims at explaining how an infrastructure manager (IM) can integrate scientific knowledge about climate change into its decision-making process in order to implement adaptation strategies.

First, materials and methods of the case study are introduced. Then the article describes two types of observed approaches to adaptation. These are qualified after the IPCC (IPCC 2014) as impact-first and vulnerability-first, depending on where they start and how they frame climate change and related uncertainties. The limitations of these approaches are discussed. The second part of this paper describes the critical bottlenecks to overcome in order to increase the organization's readiness to adapt. Building on theoretical and empirical results available in the literature, it identifies key elements to build an enabling framework for a more proactive preparation to climate change and to mainstream adaptation into the decision-making process.

#### **Analytical framework, materials and methods**

Rooted in the field of science and technology studies (STS), this research adopts a descriptive approach and sees adaptation not only as an engineering issue but also as a sociotechnical concern (Latour 2006; Edwards 2003). It focuses on the interface between knowledge on climate change, the technical infrastructure and the organization as part of its socio-economic environment. It questions how climate change is understood and how this affects such a complex system. Moreover, this approach takes into account how organisational, corporate and economic values affect how the system understands and deals with the impacts of climate change (Hulme 2009).

In the objective of analysing the way the organisation is integrating adaptation, the article does not intend to evaluate which approach could be more relevant or efficient. It identifies and describes various initiatives contributing to adaptation, going from incremental reactive adjustments to enhance resilience to current weather down to significant transformations anticipating future changes (Simonet 2009; Adger 2010; Kane and Vanderlinden 2015).

This research did not intend to be comprehensive but aimed at covering a diversity of management functions<sup>2</sup>. In order to do so, twenty-five in-depth semi-directed interviews supplemented by secondary sources analysis have been conducted. The interviews allowed to engage into discussion with:

- People working in different units of the company:
  - Transversal support units in charge of corporate sustainability, standardisations and procedures, socio-economic analysis;

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<sup>2</sup> Starting with people who previously demonstrated an interest in addressing climate change issues within the organization and were involved in previous work related to this topic. Interviews with weather data users inside business or technical unit most sensitive to weather and climate conditions complemented those discussions.

- Technical units in charge of design and engineering ;
  - Units in charge of operation and maintenance planning and management.
- People intervening in the elaboration of adaptation strategies:
- Representatives of the French Ministry for Environment;
  - Governmental technical agency (CEREMA);
  - French national meteorological service (Météo France ).

### **1. Case study: where and how is the adaptation question raised?**

The analysis shows there are many places within the organisation where adaptation dynamics can start. Indeed, we have observed several initiatives explicitly seeking to contribute to climate adaptation in different departments and along various processes.

#### ***i) First adaptation strategy observed: starting from projected impacts***

In the last decades, concerns about climate change were raised by the publication of scientific results (five IPCC assessment reports between 1990 and 2015) and political discussions at supranational and national levels. This led to the adoption of “adaptation plans” at various levels of administration: ex. *EU Adaptation strategy to climate change, National Adaptation strategy or Subnational climate and energy plans*. In France, this topic appeared on the agenda in the early 2000s (with creation of the *Observatoire national sur les effets du réchauffement climatique* – ONERC in 2001) and then spread in a top-down way down to IMs. The Ministry for Environment and its subsidiary bodies<sup>3</sup> piloted the French national climate adaptation plan (PNACC) released in 2011 (MEDDTL-DGEC 2011), in partnership with research centres, utilities and IMs companies<sup>4</sup>. The process began with a demand to climate scientists for providing baseline scenarios of climate change in France. The mission, appointed by the Minister for the environment<sup>5</sup> and by a climate scientist member of the IPCC, published several reports<sup>6</sup> (Jouzel et al. 2014) describing climate projections for France based on three of the GHG concentration scenarios from the IPCC (RCP2.6, 4.5 and 8.5). Those reports established the basis for 20 sectorial action-sheets constituting the PNACC.

One of these sheets is dedicated to infrastructures and transportation systems. It highlights four actions:

1. General screening of the vulnerability of technical references and standards to climate change;
2. Analysis of the impact of climate change on transport demand;
3. Development of a common methodology for vulnerability assessment;
4. Realization of a state-of-the-art assessment of current vulnerability of the French transportation system.

SNCF’s contribution to this action-sheet was the starting point for an internal discussion on adaptation. The attention was mostly focused on the first action: the screening of technical standards containing references to climate parameters that needed to be updated according to the expected climate changes (CEREMA, 2015).

This approach is representative of what IPCC’s reports refer to as an “impact-first” approach or “top-down, science-first or standard approach” (IPCC 2014 Chapter 2). Tasks are clearly distributed: science is an upstream

<sup>3</sup> DGITM (transport and infrastructures department), DGEC (energy and climate department)

<sup>4</sup> This described process is in many ways similar to what has been observed in other European countries (AEE 2014)

<sup>5</sup> The letter of appointment sent by the Ministry of the Environment to Jean Jouzel in July 2010, requested an « in depth synthesis on climate scenarios to consider in order to implement the National climate adaptation plan.

<sup>6</sup> On the basis on modelling work of two climate-science teams from CNRM-Meteo France (Aladin-climat model) and from IPSL (WRF model).

activity that provides information for the decision about the future as a finished product<sup>7</sup>. Climate projections are generated “for wide application, and thus are not tied to any specific choice”. Therefore, very little direct interaction is expected between climate scientists and the IMs who eventually use the information.

***Climate change as an external constraint.*** In accordance with this linear approach, climate change is knowable, controllable and constitutes a specific issue. Scientific information is provided in a top-down manner to fill a knowledge gap (Blanchard 2011) and can result for instance in the modification of an existing temperature threshold in a normalized procedure such as rail installation. Even though individuals may acknowledge the complexity of the climate system and how it interacts with the sociotechnical infrastructure system, the adaptation process itself reduces this complexity by making simplified assumptions (Kane et al. 2014), for instance causal links between impacts and vulnerability. Consequently, the proposed responses are direct and incremental. Missing pieces of information are identified and demanded to scientists with no dialogue on the feasibility, relevance or costs of the necessary research (CEREMA 2015)<sup>8</sup>. Climate uncertainties are treated independently from others components of the situation.

***Limitations encountered: a limited appropriation across the IM activities.*** At the end of the period covered by the 1<sup>st</sup> French PNACC (2011-2015), sensitive standards were identified but not yet updated (CGEDD 2015). This approach failed to produce an engagement strong enough to go beyond a formal assessment of the procedures.

According to interviewees who were involved in this process, it was not specific enough and not self-sufficient. Making it operational in the context of the railway system would have required a large amount of work with dedicated resources the PNACC did not provide. Moreover, no tailor-made climate change indicators were delivered beyond generic climate projections. Indeed, there is no link between indicators in the Jouzel Reports and much more specific parameters currently used in the industrial processes (for instance temperature thresholds in technical guidelines). This appears to be a critical sticking point, never called into question. Neither the availability of further customized information nor the possibility to decide without it (Dessai et al. 2009) were explored. Engaging in a direct in-depth discussion with climate scientists was not considered an option as interviewees consider that high-resolution climate projections should be publically produced and made available.

It is not the revision of norms and standards by itself that interviewees judge irrelevant but the process set up to do so at the national level which was not transversal enough. According to several interviewees, climate change will not just affect a few procedures or standards that could be easily listed, but will also have impacts across the whole railway system. Mere listing instances of climate parameters in technical documents is therefore perceived as a sign of poor understanding of the system’s complexity. It assumes that it is possible to draw a linear causal link between climate impacts and standardization documents when there are thousands of interactions between the climate system and the infrastructure life cycle that are not always formalized. Moreover, the process described above, was conducted separately from related policy dynamics, such as European discussions on industrial standards and regulation. SNCF is associated with a European cross-sectoral group working on

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<sup>7</sup> General insights have to be provided publically for free (while more tailored information might be sold as a “climate service”), the public sector playing a role of knowledge-broker through its public policies (giving an official mission to scientists and broadcasting the results through official channels, being an intermediary between information needs and information supply

<sup>8</sup> Cf. requests to scientists in the PNACC, deliverable 1, p91

adaptation of industrial standards to climate change. Representatives of the company took part in drafting of specific technical guidelines that propose a step-by-step approach to address climate change in any standards (CEN-CENELEC 2016). SNCF executives perceive this logic of mainstreaming climate change questions into the general process standardization potentially more relevant and efficient. Applying this type of approach might have a significant effect on practice (e.g. Rotter et al. 2015; Rudberg et al. 2012; Ryghaug and Solli 2012), but this is not the direction followed through the PNACC implementation.

In a nutshell, this ad-hoc, impact-first approach struggles to address the diversity of business operations and its relationships with the climate system. It remains an incomplete process, depoliticized and far from the strategic concerns of the company. In practice, it did not succeed in considering climate change as a potential key element in the decision-making environment. Prescriptive approach to adaptation has left very little room for discussion and was very poorly appropriated throughout the firm. At the end of the day, impacts of climate change are still perceived internally as too ambiguous and not tangible enough compared to other priorities such as urgent renewal needs and security.

**ii) *Vulnerability-first: context-centered alternatives***

***Enhancing adaptive capacity by focusing on weather sensitivity.*** Public policy is not the only source of adaptation concerns within the company. A few people in various positions in the organisation tried to raise this question locally. They did it when providing feedback on their everyday activity, or when writing the specifications of new materials or infrastructure components. They did not refer to the institutionalised adaptation process described in the previous section.

Those “adaptation intrapreneurs<sup>9</sup>” know very well how the system is exposed to the weather and what its main vulnerabilities are. Most of them share a common diagnosis about the French railway network being globally robust to potential climate changes. Some extreme events might produce disruptions difficult to deal with<sup>10</sup>, but there are also large security margins: stabilized renewed railways tracks can for instance withstand temperatures up to 60°C. Recent drainage systems and major engineering works are designed to cope with at least a 1:100-year flood event.

In addition, adaptation measures are implemented continuously in a reactive mode. After the 2003 heat wave, which caused major disruptions due to track deformations and severe deterioration of travel conditions, SNCF took important measures: release of a reinforced heat wave contingency plan, establishment of an annual heat-day for a check-up of critical equipment, adjustment of temperature class specifications for the new regional rolling-stock, modernization of decision support tools to optimize monitoring and maintenance, etc.

Willing to go beyond reaction, punctual initiatives intend to improve the understanding of the existing interactions between the infrastructure components and climatic conditions. This is perceived as a first necessary step to improve readiness and to anticipate what the consequences of climate change might be. Indeed, there

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<sup>9</sup> entrepreneur from the inside of a large organization

<sup>10</sup> Rail buckling during heatwaves, fires because of droughts, flash-floods in the south of France, landslide because of heavy rain (Stamos et al. 2015). Old infrastructure and equipment are particularly vulnerable to this type of events.

is, for now, very little aggregated quantified information about the impact of weather on the French Railway system<sup>11</sup>.

**Example 1: An improved understanding of the relationships between the railway infrastructure and weather.**

Taking the opportunity of the renewal of weather service contracts, representatives from different SNCF departments launched initiatives to improve the understanding of the relationship between the railway infrastructure and weather. Through cross-analysis of weather data (observations and forecasts) and infrastructure data, those initiatives pursue several objectives such as detecting current vulnerabilities, providing a better picture of the capacity of the system to absorb shocks, designing indicators directly relevant for various management operations, improving decision making tools and updating technical standards and guidelines.

One of them aims at matching the internal incident databases with weather observations. Its primary goal is to improve the understanding of individual disruptions and of the conditions associated with them. A second one is the adoption of a decision support software to trigger and conduct heat-inspections of tracks. A robust statistical relationship was thus established and validated to replace the former empirical approach. This operation aims at reducing the number of non-useful inspections conducted and useful inspections not conducted.

**Example 2: A historical approach to crisis management.** A research project conducted in the Engineering and projects department of SNCF-Réseau<sup>12</sup> is exploring the benefits of a geomatics (GIS) approach to improve knowledge about flood risks for the railway network (Saint-Marc 2013). It provides descriptions and representations of past flood episodes with detailed chronologies of the events and how they were managed. The purpose is to strengthen the institutional memory in order to mainstream the culture of risk within the company. At the moment, it is indeed very hard to understand and compare individual weather events because the relevant circumstances are not systematically recorded, especially when the damages are not exceptional (Pams-Capoccioni et al. 2013). This project may lead to further developments providing a better description of the evolution of the network vulnerability through decades and questioning how the system reacts to changes.

**Continuity between weather resilience and climate change adaptation.** These approaches are representative of what IPCC's reports refer to as a "vulnerability-first" approach (or "bottom-up", or "context-first" approach) (IPCC 2014 Chapter 2) starting with the decision-making context before considering climate change projections. These discourses are more infrastructure-centred than climate-centred. In these examples, climate change is the exacerbation of existing stresses occurring between infrastructure and the environment. While not necessarily perfectly defined or understood, climate change provides incentives to improve the knowledge about the infrastructure itself. Detailed scientific information or climate change projections are almost never quoted or used. The general objective is to ensure a continuity of service with current and future climate conditions. It is consistent with many sectorial reports exploring how utilities are adapting to climate change (Rotter et al. 2016;

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<sup>11</sup> Similarly to the UK (NetworkRails 2017), understanding the impact of weather events on the railway comes a long way. There was attempts to perform economic estimations of those impacts, for instance on the cost of maintenance (Gaudry et al. 2014), but this aspect has not been fully addressed yet.

<sup>12</sup> This is a national department offering engineering services to business units of the group but also conducting autonomous researches.



EEA 2014; Lindgren, Johnsson, and Carlsson-Kanyama 2009; Ryghaug and Solli 2012). There is no rupture between current ability to deal with weather events and future adaptation; actions to be taken are the result of trade-off between risks and opportunities.

**Context-centred initiatives responding to day-to-day concerns at the expense of anticipation and transversality.** These initiatives have a priori a stronger capacity to foster the uptake of climate challenges in infrastructure management. Still, they meet some important obstacles. First, interviewees reported the prevalence of reaction over anticipation. There is a strong ability in the organisation to deal with crisis, but no culture of prevention of events that have not been experienced yet (let alone unpredictable events). Promoters of those context-centred initiatives describe their action as a first step to enable future evolution towards more prevention. Indeed, an enhanced knowledge of the current infrastructure vulnerability may be used as a starting point to stress-test assets and the reliability of procedures<sup>13</sup> under different climate change scenarios. However, this development is not considered at this point.

A second major limitation of those approaches is their low transversality. Most of them remain context specific and poorly interconnected. There are very few interactions between various business units, phases of the infrastructure lifecycle or decision-levels where the issue is raised.

In a nutshell, these vulnerability-first approaches remain local processes of knowledge acquisition with no institutional uptake. Proposals for more strategic approaches did not raise enough interest from the top management. For instance, a prospective analysis of the climate-induced evolution of transport demand was proposed but not marked as a priority. There is no scepticism about whether there might be changes in climate, however, IMs have not considered these evolutions as potentially disruptive or as structuring drivers for the activity.

TABLE 1: SYNTHESIS OF IDENTIFIED LIMITATIONS OF CURRENT ADAPTATION APPROACHES

	General interaction between management and science	Sharing a vision of climate change across the organisation	Processes and procedures for decision-making under uncertainty
<b>Impact-first approach</b>	Projections of future climate remaining too far from daily concern	A top down approach with no direct contact with everyday activities. No specific resources dedicated or provided for a transversal analysis.	Classical predict-then-act instruments (such as statistics-based standards) relying on a linear, centralized and deterministic framework with no consideration of potential disruptive changes or uncertainties.
<b>Context-centred approaches</b>	Robustness of current weather sensitivity to potential future changes not questioned. Scientific information about climate change not mobilized.	Context-based initiatives do not succeed to demonstrate potential consequences across the whole infrastructure organization.	Reaction systematically preferred to prevention, potential breakdown not considered. Knowledge on the infrastructure not complete yet.

Source: author

## **2. Discussion of observations and comparison with existing literature on adaptation to climate change: overcoming bottlenecks to build collective ownership and enable proactive adaptation**

In the recent years, SNCF took some steps towards an institutional uptake of adaptation to climate change. Both company executives and public authorities recognize climate change as a concern and adaptation as a challenge.

<sup>13</sup> i.e. to evaluate their ability to deal with unusual and suboptimal situation.

However, as of now, adaptation processes have remained incomplete and do not enable the definition of a framework to generalize the uptake of this question. While the literature states that adaptation is able to disrupt classical ways of doing business (Richard 2016), it has been very difficult until now to challenge the current infrastructure management framework and go beyond weather resilience.

As described in the first part of this article, many context-based questions related to climate adaptation are raised across the company (table 2). However, there is no consensual vision on how to describe this phenomenon and how it affects the infrastructure and the organisation. As a result, no collective ownership of the issue is built either.

**TABLE 2: EXAMPLES OF CONCERNS EXPRESSED BY VARIOUS INTERVIEWEES DURING OUR RESEARCH**

<b>Various readings of climate change</b>	<b>Implications for infrastructure management, types of adaptation questions raised</b>
Climate change as a new public concern	How to respond to regulatory and policy requirements (e.g. European and national adaptation strategies)? How to accompany and anticipate changes in regulatory frameworks?
Climate change as a source of perturbations for technical systems and daily organization	Which adjustments or modifications can be proposed to existing procedures, practices and standards to keep them fitted for climate conditions?
Climate change as a source of costs & potentially enhanced stresses	Do we know how much weather events cost; can we attribute the evolution of costs to climate change? Are management choices (for instance maintenance or renewal of selected options) robust or flexible enough to handle uncertain future climate change? How to prioritize options by considering this new constraint? What type of information is needed?
Climate change as an uncertainty for infrastructure planning and design	Is climate change uncertainty comparable to socio-economic uncertainties? How to deal with this deep uncertainty during planning and design phases? Are currently used decision-making tools able to take it into account?
Climate change as a structuring driver for the future, among others	How to articulate various undergoing transition dynamics (e.g. energy transition, digital transformation, country planning, and evolutions of competitive and institutional landscapes, climate changes)? How to deal with potentially conflicting objectives and time steps?

Source: author

This table is an attempt to characterize the diversity of adaptation questions raised by the interviewees. It does not depict the number of times either of these questions came up during the interviews. For example, more interviewees mentioned as a new public concern than as a new structuring driver of the future of railway infrastructure. Even though all the interviewees generally perceived climate change an important concern, priorities clearly differ from one department to the other.

A lesson learned from STS (Rittel and Webber 1973; Hulme 2009) is that the description of a complex phenomenon like climate change as a critical issue for an organization does not pre-exist. It has to be collectively built out of the relationship between this phenomenon and the sociotechnical system. Our analysis reveals serious bottlenecks that prevent management from achieving this objective. Those are quite similar to obstacles faced in other countries that have started to address them. For instance in the UK, a dedicated program called TRACCA<sup>14</sup> funded through the Rail Safety and Standards Board, recently led to creating an adaptation strategy (NetworkRails 2017) to address the “lack of ownership and governance” of adaptation. These examples as well as recent literature suggest different levers of action to enable a more proactive preparation to climate change and to mainstream adaptation into major relevant decisions.

- i. **Lack of a consistent institutional framework: satisfying the necessary conditions for adaptation.** Some of the core elements of what would constitute a consistent facilitative framework for action appeared

<sup>14</sup> The Tomorrow's Railway and Climate Change Adaption (TRACCA) program led to the formulation of 5 objectives “for a railway that is safe and more resilient to the effects of weather, now and in the future”. These objectives are: 1. Infrastructure which is able to withstand the impact of future weather conditions; 2. Rapid recovery from the impacts of adverse and extreme events; 3. Improve performance and safety during adverse and extreme weather conditions; 4. Leverage financial savings through reduced compensation payments and repair costs; and 5. Enhance reputation and trust in the railway's ability to manage weather events.”(NetworkRails 2017)

to be lacking. The process for a national adaptation policy launched by the government was not able to facilitate them.

Alternative paths may be explored. Many situations may provide windows of opportunity to start building a common understanding of the climate related issues across the company. It might for instance be a response to a triggering event, an institutional initiative, a planned revision of the standards, or a catalysing R&D program (Ryghaug and Solli 2012; NetworkRails 2017; EEA 2014). In any case, it is important to structure the approach in order to ensure a strong leadership from top management, set up a clear and transparent governance, enhance engagement with external stakeholders and especially the public authorities and identify possible resources to design and implement adaptation actions (Ford and King 2015). This cannot be handled separately from other ongoing processes setting both the scientific agenda (e.g. development of climate services, new research frontiers, etc.) and the structural evolution of a sector such as transportation (e.g. asset management, energy transition of institutional evolutions).

- ii. **Poor engagement with climate science: creating opportunities for a strengthened dialogue.** With stable climatic conditions, the interactions between infrastructure management and the climate system remain most of the time invisible. Indeed, the infrastructure was designed to perform properly within a range of conditions large enough to absorb weather deviations. Weather is only an issue in some exceptional circumstances (extreme temperatures during heat waves, extreme precipitation leading to floods), rare enough to be managed ad-hoc as exceptional crises. Climate change disturbs this well-established relationship. With more extreme episodes and less historical data on their statistical distribution it becomes harder to keep the infrastructure fitted to different contexts (Edwards 2003). This creates new uncertainties that could be better managed with a proper use of climate change scenarios and a sustained dialogue between climate scientists and engineers that has not yet been set up. Thus, precise knowledge about climate change - with certainties and uncertainties, the complexity of the dynamics and an enhanced variability - are never considered. Yet, these characteristics are precisely what might challenge current practices.

To build a shared understanding of what climate change is, what it means for the railway system, and how it can be addressed, an iterative dialogue with scientists might be a beneficial first step. Beyond addressing specific demands for additional information, such a relationship would allow to overcome oversimplified representations of the phenomenon and to explore possible futures (Kirchhoff J, Carmen Lemos, and Dessai 2013; Cash et al. 2003; Vaughan and Dessai 2014). Different arrangements can be set up like research partnerships, common research projects, business partnerships, etc. Scientific knowledge can be integrated into management in many forms: participatory vulnerability assessments (following protocols such as the one developed by Engineers Canada (2011), prospective work based on few contrasted possible climate futures, systematic tests to assess the vulnerability of options to worst-case scenarios, etc.

- iii. **Processes and procedures not adapted to an uncertain dynamic phenomenon: experimenting alternative decision-making tools to mainstream adaptation.** The existing processes and procedures

are those of a big technical organization. Tasks are divided according to a classical, homogeneous and codified industrial model. Past experiences and standard situations play an important role in shaping up these procedures. For instance, every technical document with reference to climate parameters is based on empirical evidence of past climate records (e.g. drain systems designed according on past flood patterns, the installation of continuous welded rails is calibrated for average temperatures). These characteristics reflect a rarely challenged engineering culture. They are very different from what is usually described as a relevant approach to deal with climate change, favoring diversity, flexibility, anticipation, non-deterministic planning and continuous learning (IPCC 2014 Chapter 15).

Alternative decision-making tools and methodological frameworks might be powerful and performative instruments to foster the evolution of practices. In situations such as large project conception, maintenance budget planning or standard revisions, they can contribute to operationally mainstreaming adaptation into decision-making processes. The generalization of alternative decision-making tools is a matter of corporate strategy and moves forward alongside the revision of procedures and standards. However, a first interesting step might be to experiment this type of tools at different stages of projects analysis, from design phases (to display extended costs and benefits) down to monitoring and evaluation (to provide feedback). Many methodologies, including economic analysis, decision making under deep uncertainty techniques, multicriteria decision making, social network analysis, etc. have been explicitly developed to address climate change challenges (Watkiss and Hunt 2013; Dittrich, Wreford, and Moran 2016) but have not been mobilized yet in the French transport sector. A common property of this family of approaches is to disclose any underlying hypothesis and to make every methodological option explicit and open to discussion. These methods encourage more inclusive and participative decision making processes. They also challenge business as usual thinking. For instance, they question optimal economic efficiency as a unique decision criterion by emphasizing the value of flexibility (adjustability over time) or robustness (effectiveness in a broad spectrum of possible futures) as complementary valuable characteristics and by considering possible surprises. Mobilizing these tools to design an adaptive management strategy, to stress test a new management plan or to choose between options is therefore not always straightforward. They are more than additional decision-support tools– they embody and perform a “new paradigm” in decision-making, which can be hard to switch to. Indeed, any procedure of decision-making or indicator implicitly reflects underlying values and societal choices that can change with time (Callon and Muniesa 2009; Crozet 2004; Doganova 2014; Godard 2004). The experimentation with this type of instruments can therefore only be carried out as an explicit strategy in cooperation with all the relevant stakeholders including public authorities, SNCF engineers and climate scientists.

This last point shows that the needs and levers described in this article – common vision of adaptation challenges; enabling institutional framework; strategic support; relevant partnerships; adapted tools – are tightly interrelated.

## CONCLUSION

This paper, through the case study of SNCF, explores where and how large and complex organization managing a network infrastructure may raise adaptation issues. In the first part, it described two types of approaches: first, impact-centered processes focusing on the mobilization of climate science upstream, which struggle to percolate through the organization; second, localized vulnerability-centered initiatives, which strengthen current management procedures but do not bridge the gap with future climate changes. Most of them focus on resilience to current weather and do not go so far as to question future climate.

The analysis highlighted key bottlenecks at the interface between the production and the use of knowledge on climate change. Building a shared and politically backed vision of this phenomenon and formulating context-relevant questions appear to be essential steps to set the ground for an enabling framework for adaptation.

Finally, the article presented existing tools and methodologies suggesting an alternative approach to tackling adaptation challenges. These tools have not been tested in the French context yet. How such tools can be integrated in existing decision processes, in which situations it is relevant to mobilize them, what are the conditions of their acceptance and appropriation (for example in terms of credibility, salience and legitimacy (Cash et al. 2003)) remain open research questions. Tackling them would lead to a broader question about the nature of climate knowledge for a sector like transportation potentially revealing tensions within the sociotechnical system of the infrastructure interacting with its environment.

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