Rhine low water crisis: from individual adaptation possibilities to strategical pathways

Julie Gobert, Florence Rudolf

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Abstract

In 2018, the Rhine transport sector experienced an unprecedented low water crisis, during which large cargo vessels were no longer able to navigate on certain sections of the river. This led to a major disruption in inland waterway transport. This article aims at questioning how the crisis acted as a stimulus for port authorities and their customers to consider the risks for their assets and operations and as a window of opportunity for creating a new collective and for defining “solutions.” Inspired by the Impact Chain methodology, a step-by-step protocol integrating focus groups and interviews, was applied so that stakeholders affected by low waters can identify their individual and common vulnerability and define possible ways of acting (pathways). One of them, the transitional infrastructural pathway, targets to increase the water level and overcome low water levels (use of Lake Constance as a water reservoir or creation of new water storage areas; deepening of the channel at Kaub and Maxau). It appears as the most suitable because it is a technical, well-controlled process that provides a comfortable solution in the short term. It exemplifies the lock-ins set by infrastructure. However, the participative approach also highlights the fundamental challenge of developing new processes and new intermodal organisations in the long term.

Keywords

Inland river transport, low water, adaptation pathways, infrastructural pathway, climate change

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1. Introduction

The global trade in goods depends upon reliable transportation of freight along complex and long-distance supply chains (Curtis 2009). However, these supply chains are highly dependent on infrastructures: ports, rail, road, river, canals, etc. The exposure of these infrastructures to hazards has severe consequences on world economies and societies, not only because they lead to an interruption in traffic and flows, but also because they have cascading effects on other sectors of society (Argyroudis et al. 2020; Shughrue, Werner, et Seto 2020). In the context of climate change, these hazards will increase and then undermine the organisations of stakeholders, which manage the logistics and transportation of goods, as well as infrastructure reliability (Chester, Underwood, et Samaras 2020). Understanding this vulnerability and the possibilities for action require not only scientific and technical knowledge, but also contextual knowledge and in-depth reflexion from the involved stakeholders (Jonsson et Lundgren 2015).

Inland waterway infrastructure is one of these chokepoints; it is vulnerable to hazards and its disruption has local and transnational consequences (Bailey et Wellesley 2017). The Rhine is one of the major European rivers, flowing from Switzerland through Germany, France and the Netherlands into the North Sea. It is a major corridor of inland waterway navigation. The organisation of the commodities transport is based on the coordination of different firms and authorities (fig. 1), which have economic, social and political relations and will be named in this article "the Rhine transport sector". In 2018, this sector experienced an unprecedented low water crisis, during which large cargo vessels were no longer able to navigate on certain sections of the river. This led to a major disruption in inland waterway transport. The severity of this crisis was the result of several months of drought, reinforced by heat waves and low rainfall over the same period. Some of the traffic was absorbed by other intermodal providers and the wagon load rail system, but it was not sufficient. This crisis had cascading effects on the stock management of exporting and importing firms, customs regulation, and so on. This crisis was a confirmation of what was predicted by different researches: periods with low water levels are likely to occur more often and become more serious (Commission internationale pour la protection du Rhin 2018; Jonkeren et al. 2014; Klein et Meissner 2016). That is why some stakeholders, and particularly the Strasbourg port authority, decided to learn from this episode and to create a new arena of dialogue between stakeholders to define solutions. However, initiating a new thinking and working "community" results from a long process of different trials and confrontations of stakeholders' viewpoints (and sometimes their arrangement), which can be interpreted through pragmatic sociology (Lemieux 2018).

In this context, we can consider that crisis acted as a stimulus for port authorities and their customers to consider the risks for their assets and operations and as a window of opportunity for creating new collectives and for defining "solutions" (Kingdon 2003). As a matter of fact, major crises and disasters have the potential to change dominant ways of thinking and acting (Birkmann et al. 2010). They create new ways of considering the initial issue and the solutions to take, to push or to dismiss some ways of acting (Birkmann et al. 2010; Kingdon 2003; Rudolf 2007). But at the same time this impulse given by a crisis can reinforce some pre-existing ideas of adaptation solutions (Petitimbert, Bouleau, et Guimont 2022). It can enlighten an already-existing solution, enabling "business as usual", which dissolves individual responsibility into the expected consequences of a project managed by national or international authorities. Crises can be then considered as opportunities to re-politicize projects, which were postponed or even abandoned, because of their environmental impacts, the economic costs and so on.

The increasing complexity and uncertainty in decision making due to climate change and the associated wicked problems (Head 2022) make it necessary to better understand these possible levers of action (or inaction) and how the stakeholders react when faced with a crisis, how they try to define or impose strategies according to their capacity for action and their willingness to take their individual and/or collective responsibility to prevent risks (Meah 2019). In the presented research, we then investigated how stakeholders after this low water crisis decided to work together, accepting the methodology proposed by researchers (social and engineering scientists) and the Strasbourg port authority and, through this process, made emerge conflictual or consensual visions of the low water problem and solutions.

This article more precisely attempts to understand the adaptation driving forces at the individual and collective levels for the inland waterway navigation transport and addresses two sub-questions: Are the stakeholders able to overcome their individual interests to create collective adaptive pathways? Why do they favour one form of adaptation pathways over the others?

Consequently, this article will present the results of a case study dedicated to the sensibilities and vulnerabilities of SMEs in the Upper Rhine Region where researchers and river transport stakeholders have striven to build common knowledge, to find sustainable adaptation pathways. A mixed methodology combining semi-directive interviews and collective brainstorming with the help of a collaborative methodology (particularly deployed in engineering design processes based on the use of specific software (TRIZ)) was used to help to take into account nuances between collective exchanges and individual representations. This methodology participates in opening the “black box” of the supply chain, the internal processes, the unsaid things. The third part exposes the results obtained at the individual and collective levels to apprehend the possibilities of adaptation, to tackle the situation of low waters. In the fourth part, the preferred adaptive pathway is discussed while exploring two dimensions: the necessary combination of technical and engineering and organisational rationale and the infrastructural choice as a way of delegating individual responsibility.

2. Climate change adaptation and pragmatic sociology: basis of the theoretical framework

Addressing the increasing frequency and intensity of extreme weather events and natural hazards appears as a major challenge for humans and their activities. Climate change hazards have direct/indirect consequences for economic activities (losses and/or disruption of their routine functioning, decreasing productivity, infrastructure damages, capital assets weakening) (Averbeck, Rudolf, et Gobert 2021; Chester, Underwood, et Samaras 2020; Gobert et al. 2017; Thornton et Manasfi 2010). Climate change adaptation refers to the capability of a socio-technical system (and its stakeholders) to cope with risks, hazards, while integrating vulnerability (Puupponen et al. 2015; Smit et Wandel 2006). Enhancing knowledge on risks, impacts and defining adaptation measures is more and more considered as a necessity (Thornton et Manasfi 2010, IPCC 2022; Linnenluecke, Griffiths, et Winn 2012;

Settele, Scholes, et Betts 2014). However socio-technical systems on which are organised economic activities like the inland waterway transport are embedded into different kind of lock-ins, which can prevent/slow down the implementation of coping measures (Berrang-Ford, Pearce, et Ford 2015; Burnham, Rasmussen, et Ma 2018; Fazey et al. 2016; Klitkou et al. 2015; Simoens, Fuenfschilling, et Leipold 2022; Winz, Trowsdale, et Brierley 2014). Then, adaptation measures differ depending on the sector of human activity and the vulnerability of the stakeholders and their assets (Harries 2021).

Concerning the inland waterway navigation (Schweighofer 2014), involving stakeholders in identifying the problems, their individual and collective vulnerability and the solutions are key steps, as international river navigation gathers numerous actors from different countries and activities (PIANC 2020). Stamos, Mitsakis, et Grau (2015) worked on adaptation measure roadmaps for the protection and resilience enhancement of transport infrastructure. Desquesnes et al. (2016) present the tools dedicated to design adaptive management strategies for the inland navigation waterway transport.

The theoretical framework deployed for this research is at the crossroads of two approaches. The first one is based on the literature on climate change adaptation: it aims at apprehending and explaining the pathways taken by stakeholders (through values, rules, knowledge, path dependency, levers of action, etc.). Different articles display typologies of adaptation strategies. Three main adaptation processes are often distinguished, although they may be named differently according to the authors (Hadarits et al. 2017):

- Incremental adaptation: a ‘‘central aim of maintaining the essence and integrity of an incumbent system or process at a given scale’’ and founded in ‘‘the decision to continue responding to the same organizational objectives and within the same governance systems’’ (Park et al. 2012: 119). This adaptation attempts to fix the existing infrastructure: stakeholders progressively (sometimes unconsciously) adjust their behaviour, their habits, because they are hit by a hazard, because they take into account a “natural” evolution, but without integrating this change into a strategic decision of adaptation. This appears as a reactive adaptation process or spontaneous adaptation (Godard 2010).

- transitional adaptation is ‘‘…an intermediary form or adaptation. It can indicate an extension or resilient adaptation to include a greater focus on governance or an incomplete form of transformational adaptation that falls short of aiming for or triggering cultural or political regime change’’ (Pelling 2011: 56). The stakeholders recognize the effects of climate change on their daily operations (and clearly attach the reasons to climate change) and build a well-considered action to anticipate hazards and to minimize impacts. This way of thinking intends to keep “business as usual” (for example, new freight schedule planning for river transport as illustrated by Zheng et Kim (2017)) and do not challenge the structural causes of the dysfunctions. The adaptation process is then intentional.

- transformational adaptation (Kates, Travis, et Wilbanks 2012; O’Brien 2012). In line with Folke, we consider that it is not just a question of upscaling the adaptive answer, but of work on the causes of the system degradation (supply chain organisation at the global scale, resource vulnerability, etc.). Then, it does not imply a simple relocation of economic activities, but a new organisation of these activities to respect ecological rhythms. “The capacity to transform the stability landscape itself in order to become

> a different kind of system, to create a fundamentally new system when ecological, economic, or social structures make the existing system untenable" (Folke et al. 2010).

These researches often outline that "business as usual" strategies that do not challenge the current system are privileged; because they do not question the current way of thinking and doing (cognitive comfort), they appear more "reachable" and less time-, money- and resource-consuming (Fedele et al. 2019). Climate change issues are often observed and addressed from fragmented points of view and by domain; this process tends to promote "techno-fixes", although they raise multi-scale, integrated and systemic challenges, mixing technical, individual, organizational and institutional dimensions, that are required to be dealt with simultaneously (Abson et al. 2017). Even when methodologies of knowledge production become more participative, from formalization of the issue until the proposition of solutions, as it was the case, they do not fundamentally transform this preference. Fedele et al. (2019) particularly study transformative adaptation, considering it aims to reduce the root cause of vulnerabilities to climate change, but many barriers hinder implementation: human, financial, time high investments, power imbalances between stakeholders (dominant actors can block the evolution, because their position may be disputed).

These pathways are defined by actors, who have each a vision of the world, a way of perceiving climate change and its impacts. It resonates with pragmatic sociology, which explores "the reasons for acting and the moral exigencies that these persons give themselves, or want to give themselves, if not by way of 'ideals'" (Boltanski et Thévenot 2000: 20). Human action is seen as deeply embedded in situations. Some stakeholders can use the opportunity of an event to enrol other stakeholders to share their perspectives and to define new actions. The ability to adjust between different rationalities may be the main social skill needed in response to environmental challenges of our time and the methodology deployed can help some boundary organisations/actors to reach this goal. That is to say they are able to translate the expectations and interests of other actors, even if they do not share the same apprehension of a problem, and to build a bridge, a consensus. That is why this understanding of the stakeholders' agency is the second dimension of our framework.

3. A co-production process based on a mixed methodology

3.1. A case study imbedded in the project UNCHAIN

This article is the result of one of the case studies, carried out for the project UNCHAIN ("Unpacking climate impact chains -a new generation of climate change risk assessments") in correlation with the INTERREG project, Clim'Ability Design. This project takes as reference point the concept 'impact chain'(IC), first published by Schneiderbauer et al. (2013), and then 'catalyzed' by the German cooperation (GIZ), in the Vulnerability Sourcebook (VS). As outlined by Zebisch et al. (2021) the 'VS' was developed to address the need for an operational vulnerability and risk assessment. The VS - with its supplement and adaptations (Zebisch et al. 2022) - is a standardised methodological framework for climate change vulnerability assessments.

The Unchain project is consequently based on the postulate that CC adaptation requires a shared scientific knowledge (Bremer et Meisch 2017; Nogueira, Bjørkan, et Dale 2021).

Therefore, a constructive dialogue between different professionals (researchers, public authorities, private sectors, NGO's, etc.) has to be completed, in order to build a collective understanding of the issues due to climate change and actionable knowledge. The project assumes that adaptation strategies could fail if they are not embedded in the perceptions, representations and experiences of individuals, in their specific context of action and interaction. As well, they do take into account the local adaptive capacities (Burnham, Rasmussen, et Ma 2018).

In line with previous and complementary European projects developed in the Upper Rhine Region and dealing with climate change adaptation strategies (Interreg Projects Clim'Ability and then Clim'Ability Design), it was decided to focus our attention on the low water periods and their consequences on the river's international transport and to deploy the IC methodology while adapting it to the context.

It was decided to explore the consequences in Strasbourg of the 2018 crisis when the Rhine transport sector experienced a major disruption of inland waterway transport. Low and high waters are common periods integrated in the planning of the stakeholders. Water levels on the Rhine River fluctuate with seasonal rainfall[1], and both high and low water levels can create problems for barges. As such, barges need to adjust the amount of cargo they carry to balance bridge clearance and deep draft restrictions based on water levels. Low water levels mean barges must carry less cargo, increasing the freight rate per unit of cargo. Low waters are particularly impacting at certain water levels because many vessels can no longer move because they need a large draft for loading the goods they carry. Inland waterway transport can even be stopped to avoid accidents and groundings. This was the case in 2018.

That year, Strasbourg Autonomous Port recorded its lowest tonnage of goods for half a century. A drop in the commodities transported by river was observed (-35% for Upper Rhine French ports). Some sectors at the European level were particularly affected, like agriculture: crops could not be exported. The direct economic impact for firms had resulted in a difficulty in being provisioned and in increased barge freight rates. Low water surcharges are indeed applied at critical water levels. According to the goods transported and the transport modes[2], intermodal solutions had been rapidly considered (transferring goods from inland waterway to roads or rail). But the other transport modes also have their own inertia. First and foremost, transferring all containers on roads or rail was impossible because of the considered volumes and the types of goods. Alternatives to shipping products on the Rhine River are expensive for shippers. It also appeared complicated to change transport modes if the transport providers impacted by the crisis did not have previous contracts with rail or road transport companies. As Caris et al. (2014) outline it, Intermodal transport decisions need to be integrated in advance with supply chain decisions. Moreover, some resources may have been lacking. For instance, railways are considered as insufficient and too

[1] Since the early 90s, it has been studied how climate change has changed the Rhine towards being a rain-fed river (Parmet, Kwadijk, et Raak 1995). Winter discharge increases, which can have consequences for safety, and summer discharge decreases with consequences for shipping, industry, agriculture and ecology. The climatic and hydrological consequences of these unpredictable weather patterns include prolonged periods of heavy rainfall and dry conditions leading to drought, as well as the continuous melting of glaciers in the Alps that feed into the river. Increased rainfall and snowmelt in the Alps, with water levels rising, seasonally cause river shipping to be suspended at several sections between Karlsruhe and Koblenz. Low waters have consequences for inland navigation, where the river is shallow.

[2] By dry cargo ships (for grain, scrap, etc.) and tanker ships (for transportation of oil, chemical liquid products, etc.), in container or in bulk.

overloaded to assure the transferability. The lack of skilled drivers is also a European issue[3], which reveals itself as particularly symptomatic when a crisis breaks. That is why reacting in the face to this kind of crisis requires a collective agility and demands deeper and longer work between stakeholders: firms which have to transport goods or resources, carriers, port authorities.

In 2020, Strasbourg Port Authority proposed a process of collective brainstorming with researchers to better identify the different issues raised by low waters, the solutions which could be drafted, and the contradictions between them, so as to select the best solutions worth being explored.

3.2. A mixed methodology combining semi-directive interviews and guided collective workshops

The preparatory phase was based on the reading of the grey literature (literature produced by institutionalised stakeholders like the Central Commission for the Navigation of the Rhine, the port authorities, the national authorities managing inland waterway transport and flows, etc.), of academic literature (dedicated to the specific impact of droughts and lack of rainfall on river levels and then the capacity for transport providers and the associated supply chains) (Parmet et al., 1995; Thirel et al. 2015).

Moreover, after a long approach phase with Strasbourg Port Authority, a working relationship was built and enabled researchers to identify key stakeholders (transport providers, importers/exporters using inland waterway transport, etc.), and to immerse themselves into an existing network[4]. This immersion and consequently the understanding of the issues raised by low waters from operators' point of view were particularly noteworthy. It progressively opened access to the operators, not only to organise collective workshops, but also to facilitate the possibility to fix appointments for interviews.

A mixed method was then employed to understand the vulnerability of the firms and the territories to low waters: semi-directive interviews with stakeholders concerned by low waters, and the implementation of the Inventive Design Method (IDM) to stimulate a cooperative understanding of the collective vulnerability to the risk. This was a step-by-step approach, similar to the method proposed by the Vulnerability Sourcebook (VS) (fig. 4 in Appendix).

Then, from September 2020 to March 2021, four workshops brought together inland navigation stakeholders according to their activities. They were prepared by researchers from the engineering and social sciences in order to apply the IDM to the problem of severe low water levels (using Triz software). The IDM is a participatory engineering approach that enables breakthrough solutions to be proposed to resolve problems in the industrial system especially for designing new products (Cavallucci 2018; Coulibaly et al. 2022). The IDM highlights an overview of the logical links between these problems and the actions (already

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[3] A shortage of skilled drivers is affecting the freight and logistics sector at the European scale. This could affect the transport prices and is considered as a major challenge for national and international carriers.

[4] The Port Authority had already organised groups of stakeholders concerning other issues and some of these collective workshops had already resulted in actions (and the transformation of these groups into coalitions for action) to work on industrial ecology and find synergies between firms for example.

implemented or only envisaged) to try to solve them (fig. 3 in Appendix). The links between problems and solutions imposed by the software in the construction of the tree diagrams facilitate the understanding of the overall problematic situation[5]. Furthermore, one of its interests is to capture the positions built in interaction and obtaining the largest consensus (Zhou et al. 2022).

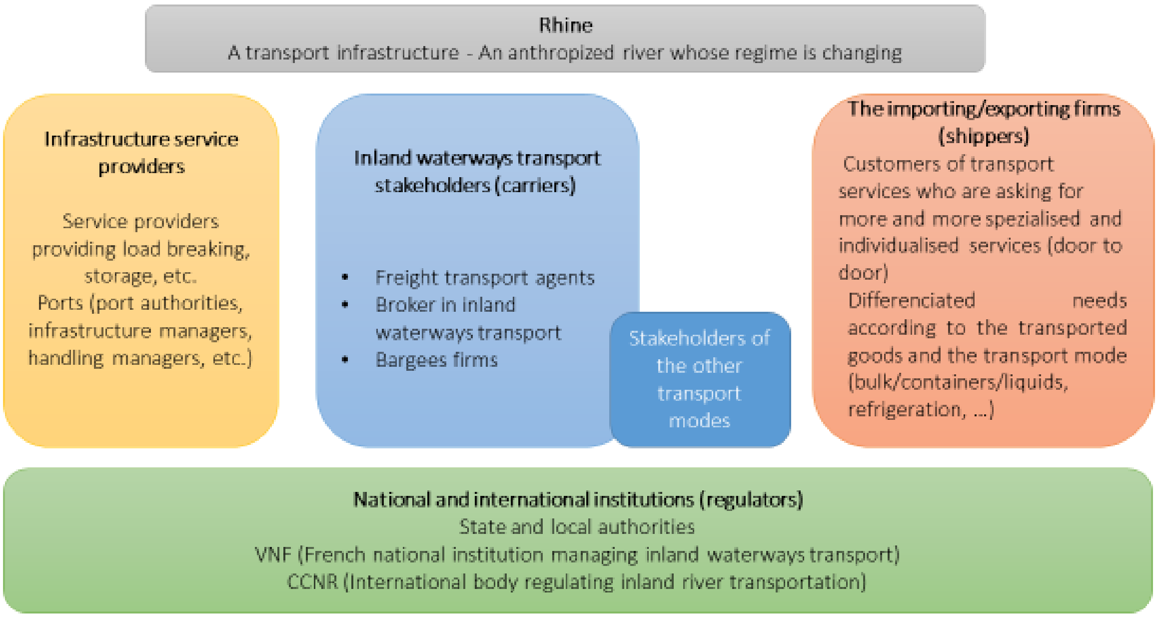
However, co-production of knowledge raises several challenges, since stakeholders have diverse expectations, worldviews and interests. Besides, during workshops, some processes of domination can take place and erase the diversity and subtlety of opinions. We noticed that the inland waterway transporters' interventions were more frequent, more developed and, in both groups, they were the ones who proposed to favour infrastructure development rather than another partial solution. The reasons for this imbalance may be explained by the ease of speaking.

To tackle this issue and to apprehend social representations concerning climate change, the challenges of adaptations at the intra-organisational level, since July 2020, semi-directive interviews had been conducted with river operators (infrastructure managers, shippers, transporters, etc.), specialists on the Rhine and operators of other transport modes (see table 1). The interviews lasted between 90 min and 3 h each; and were fully recorded, transcribed, coded and analysed (Lejeune 2015). This qualitative methodology is based on a very patient reading of the interviews to better understand the processes at work and the resources used and to identify the narratives elaborated by each stakeholder and possible associations or contradictions between them. The interviews were also a way to enlarge the panel of involved stakeholders, while researchers also questioned cruise transport representatives, environmental associations, or firms located on the other side of the border, in Switzerland.

The semi-structured interviews conducted with Rhine transport operators make intelligible different dimensions of a complex field of activity; each actor gives insight into concrete practices situated in specific contexts. Compared to quantitative survey methods, and even compared to collective interviews (focus groups), the methodological interest of the individual interview is to make accessible the way in which the different actors understand the situation(s) in which they find themselves, the problems and issues they encounter in their activities and the margins of manoeuvre they have available.

Figure 1 - The different stakeholders involved in the process and impacted by low waters

[5] The Triz Inventive Design Method is a participative engineering approach that allows participants to propose breakthrough solutions to solve problematic situations or industrial impasses. The process is divided into six main steps: Collecting information from a sample of firms and operators impacted by the issue; building a "problem graph" whose root corresponds to the key problem. In this case, because of drought and a lack of rainfalls, navigation on the Rhine is hindered during low water periods and then stopped for inland waterway transport, which has consequences on different levels, at the international, local, and intra-firm scales; identifying evaluation and action parameters, which respectively allow the problems to be placed on a scale of intensity (severity) and the possible solutions to remedy them; constructing a graph of contradictions resulting from the evaluation and action parameters and action parameters; solving the contradictions (Solution Concepts); evaluation of the solution concepts in order to identify the most relevant that could be implemented.



4. Results. Adaptation possibilities: from individual involvement to strategical pathways

This section presents the results obtained at the individual and collective levels to apprehend the possibilities of adaptation, that is to say of adjustment to tackle the situation of low waters. The different combinations of technical, infrastructural and organisational solutions draw pathways of possible adaptation.

4.1. Individual vulnerability and adaptation possibility

Dependence on the river makes sensitivity and vulnerability to the hazard stronger. The Rhine is considered as a human-made infrastructure. The dependence on this infrastructural “resource” has a significant influence on the way stakeholders consider the effects of climate change and their willingness to act, to develop solutions. As a matter of fact, shippers (firms which export and/or import commodities or raw materials) are less sensitive to water level, than to prices and sometimes transport time, according to the commodities transported[6]. Other work has highlighted this different sensitivity in relation to the place occupied on the supply chain and the proximity to the resource affected more directly by climate change (Rudolf, Gobert, et Averbeck 2019). Each link of the supply chain is then hit by a significant change of the water level, but to understand at which degree, the workshops and the interviews were explored to identify the variables of sensibility and the level of vulnerability (see the table 1.)

Individual actors have their own resources and ability to act through preventive, reactive or structural changes. They may develop an adaptation capacity as illustrated in the table, while transforming their internal organization, raising their infrastructural investment (as far as shippers are concerned, by increasing their storage capacity for example) or creating new

[6] For example, pharmaceutical products (high-value goods) cannot suffer from a break in the cold chain, because of their vulnerability to certain temperature.

bilateral relations with other professions. For instance, the transport providers may resort to other modes. However, this coping adaptability can be hampered by lack of resources (financial, cognitive, etc.) or the competition between firms (column 4) as the international freight transport market operates within a very competitive environment (Sys et al. 2020), exacerbated by the transnational character of the river. Side effects can also affect the credibility of some solutions. The crisis may disqualify the river transport mode, while demonstrating a reliability gap, and meanwhile rehabilitate other modes, considered as more reactive. That is why the promotion of multimodality and particularly the combination of rail and river modes, according to different stakeholders (port authorities, transport providers, etc.) have to be consolidated not just in the crisis period, but in the daily processes. Infrastructures have to be developed as well in this objective (new terminal, better linked to rail, improvement of rail capacities to maritime ports).

Table 1. Sensibility, vulnerability and adaptation capacity according to the types of stakeholders

Stakeholders by profession	Variables of sensibility	Level of vulnerability to low waters	Adaptation capacity and possible difficulties
Ship owners	- Water level (and singularly in Kaub and Maxau) - Fleet type: number of vessels, number of large vessels, vessel size, lifetime of the boats	Very strong because of water level dependency Tonnage limited by water level, even inability to move	Transforming the ship fleet ≠ investment capacity ≠ impossibility to "displace" the cost on the exporting or importing firms
Transport providers (carriers)	- Water level (and singularly in Kaub and Maxau) - Contract with different transport modes (flexibility)	Strong	Capacity to use other transport modes (horizontal coordination) ≠ unavailable railways ≠ not previous contracts/relationships with rail or road transport firms ≠ not sufficient number of skilled truckers ≠ not adapted to all products
Port authorities	- Water level - Storage capacities - Available infrastructure to facilitate the modal transfer (intermodal connectivity)	Medium	Capacity to develop new storage sites Capacity to promote multimodality while investing in new platforms and materials ≠ competition between ports (private and public transport)
Firms (exporters/ importers) Shippers	- Transport prices (comparing to the product price) - Volumes of goods - Types of goods transported - Conditioning mode (in bulk or in containers) - Optimisation of the supply chain (each little spanner in the work may be difficult to overcome)	Strong if their goods are rapidly degradable (edible, pharmaceutical goods) Medium if their goods are less sensitive to degradation	Capacity to adapt its contracts with carriers Storage possibility on the production location
Firms specialized in storage of bulk liquid products (proposing rental storage capacity)	- Storage capacity (number of storage sites) - interconnexion with different modes of transport	Medium	Capacity to increase the storage capacity in building more storage infrastructure on the port

Not only do the different professions not have all resources available, but moreover, stakeholders, even if they are working in the same environment, have a situated rationale and socio-professionally constructed knowledge. Each profession has a good knowledge of its own weaknesses in the supply chain, but a limited apprehension of the impacts caused by low waters to other stakeholders and of the behaviours they will adopt. These "spaces of ignorance"[7] limit their capacity and their will to act, if they are not involved into a collective dynamic (like the Impact Chain approach and our methodological attempt to develop).

What appeared significant for almost all stakeholders is the possibility to have access to information about water levels but also about the operating of other stakeholders in order to identify the margins of individual and collective manoeuvre. For example, a modal shift is highly dependent on the rail capacity and the numbers of transport firms, which intend to use it at a precise moment. But the individual actor does not have this information. This need for information can be broken down into different variables: Degree of reliability of forecasts, and anticipation of water level changes in Kaub and Maxau (the narrowest stretches of the Rhine river, which raises navigation problems in case of low waters). This information is necessary so that stakeholders can be able to make useful decisions and work together to adapt the supply chain and the transport system at a given time. The stakeholders expect very precise information to be able to plan new transport solutions and to make predictions on travel time. They therefore can select suitable travel routes and modes. It appears this information system could result from a collective ability to define expectations and needs.

4.2. Adaptation strategies to low water

From the data obtained through the TRIZ IDM methodology, it was possible to study collective strategies, because the workshops create stages where conflicting rationales that do not always fit with the norms and ethics of the different professions that can be found in confrontation.

The stakeholders of a shared supply chain could have very different sensibilities and vulnerabilities (according to their proximity to the natural elements hit by a hazard, for instance) (Averbeck, Rudolf, et Gobert 2021; Gobert et al. 2017) and then very strong or weak motivations to act. Some of them may push for action (and deploy an internal plan for action) whereas others may slow down. But when they discuss together, the analysis leads us to distinguish three main strategies. Each pathway is based on specific technical, organisational, institutional modalities and a certain degree of knowledge and know-how: That is why we firstly display the possible strategies and secondly the organisational and technical solutions which may be mobilized by the different strategies.

The reactive adaptation pathway corresponds to an immediate response to the crisis. This adaptive answer is limited to technical and organisational reactions (like short-time work, decreasing the volumes transported, etc.). Stakeholders may attempt during the crisis period to shift to another transport, but flexibility needs to be prepared for because of the lack of drivers, of railways, and because confidence between transport firms has to be structured through agreements.

This reactive adaptation is symptomatic of stakeholders and communities of stakeholders which are not very sensitive to climate change and specific hazards. They do not consider the issue as a regular one or suppose they can tackle it without more investment and involvement than necessary during a crisis. According to Burch et al. (2016) many SMEs tend to have a reactive position towards environmental initiatives that discourages environmental

[7] This ignorance can also be a strategic behaviour to minimise the individual cost of an action (High, Kelly, et Mair 2012).

improvements, spurring the need for external engagement. Moreover, in certain firms, strategies are elaborated in headquarters, far from their local establishments and the difficulties they encountered. Then, the local entities have to fix problems according to the crises (Gobert et Brullot 2017; Rudolf 2015) and their limited means.

So, the trans-organisational dimension stays at micro level, because the concerned firms can take measures in their own organisation, without expecting actions from others and without being solicited to act outside their own perimeter of competence. In crisis periods, this trans-organisational dimension can be requested (to find new transport modes) at a meso-level (between organisations). But this coordination during crises necessitates some preliminary preparation, as the 2018 crisis highlighted it.

The **transitional infrastructural adaptation** is the kind of solution which most convinces the stakeholders involved, as it involves planning strategies to increase the water level and overcome low water levels (use of Lake Constance as a water reservoir or creation of new water storage areas; deepening of the channel at Kaub and Maxau). This transformative change may only occur with intentional action in the realms of policy and practice. This requires lobbying from local authorities (ports, shippers, etc.) towards competent authorities, but does not lead to a reconfiguration of actor/system relations because it strives to maintain the current business path.

This solution extends the vision that "business as usual" is possible but with major changes. This adaptation pathway improves the existing situation, makes inland waterway transport and the associated logistics more efficient for all stakeholders (except the Rhine, as these solutions are considered as impactful).

The deepening of the channel (dredging) at Kaub and Maxau in order to increase the water level is frequently mentioned, but the difficulty of this decision to remove the two main bottlenecks is not under the responsibility of one or more French entities but of the German authorities, or even of an international agreement. In fact, deepening the Middle Rhine was already set on the agenda of the German Federal Transport Infrastructure Plan (Bundesverkehrswegeplan 2030) before the low water crisis of 2018. The decision process is very long, however, and depends on a myriad of environmental decisions.

Some less environmentally impacting solutions are mentioned: The creation of additional dams (e.g. rock dams) and locks. More specifically, the installation of movable (or flap) dams at Kaub and Maxau could limit the environmental damage caused by the channelling or deepening of the channel, but also the problem of stagnation and heating of the stored water.

The **radical (or transformative) adaptation** appears principally in the discourses of some regulators or representatives of the "river" as a natural component[8] when they are personally asked (during interviews). Changing transport and production systems at an international level would require a deep transformation of the "industrial" system (from production to consumption). This adaptation pathway strongly recognises the agency of non-humans, including the Rhine and the natural components, as well as the limits of technical solutions. This adaptation was not discussed during workshops because representatives of environmental organisations were not invited and the exchanges between stakeholders did

[8] Even if in line with Actor-Network theory we recognize the non-human agency (Latour 1997), non-humans may need in some political arenas translators and voices, which are often embodied by environmental NGOs.

not grasp this possibility of global and systemic evolution, which does not directly rely on the individual or local responsibility.

5. Discussion

The results displayed above raise reflexion about the way in which the stakeholders of the Rhine navigation sector consider their ability to act and to adapt their socio-technical system to low waters. Even if the promise of technical fixes and infrastructure are strong and often privileged in the exchanges, because they are considered as the most suitable, the stakeholders are collectively obliged to combine technical and organisational procedures of adaptation (4.1.). The transitional infrastructural pathway appears as the most suitable because it is a well-controlled technical process that provides a comfortable solution in the short term and enables to delegate responsibility (4.2.).

5.1. Combination of technical and engineering and organisational rationale

The "technical solutions" focus at first on technical and engineering expertise to resolve a problem at a micro-, meso- or macro-scale. In our case, this could be: transforming ships and adapting boats to low waters (retrofitting), or designing lighter boats and widening mid-size boats at the micro-scale. These kinds of solutions can also aim at facilitating the information system and data sharing between operators. They are highly dependent on the intentions of transport providers and their investment capacities. However, some cooperative agreements can be signed to share the costs for studies and research. At the macro-scale, this would be the transformation of existing infrastructure or the siting of new ones, in order to prevent risks. Over-reliance on technical expertise and engineering solutions is a well-known phenomenon in the frame of risk prevention (Heazle et al. 2013). Luhmann outlined that in the absence of norms collectively validated and accepted, the technical temptation prevails (Luhmann 1994). This perspective is named "techno-fix" bias by some authors (Thornton et Manasfi 2010). The collective decision has to rely on precise technical data to legitimise policy choices, collective action and decision making, and to deliver a feasible and promising future (Joly 2015). Moreover, infrastructures and infrastructural works give the impression the issue is taken into attention. They offer a feeling of security and the impression to act against climate change. They build a promising narrative. The construction and management of infrastructure continue to be a key technology of government (Joyce 2003).

However, this technical reliance has been criticized for a few decades (Durand et Richard Ferroudji 2016; Rudolf 2016). The promise of infrastructure (Anand, Gupta, et Appel 2018) and technical engineering to limit the impacts of hazards and climate change has displayed some dysfunctions. A technical-driven solution may increase vulnerability. For example, dykes can strengthen vulnerability if they justify the siting of new populations in the "protected" areas behind them. Some experts and scientists underline the necessity to combine a technical approach with "soft" solutions (risk awareness, adaptation of the activities according to the risk and new governance system, etc.) (Petersson 2021; Pigeon 2015; Wesselink et al. 2015). Soft solutions require the interaction of different skills and oblige stakeholders to a certain humility against uncertainty.

Even when they prefer infrastructural solutions that enable the delegation of responsibility to others, in our case study, stakeholders have to admit a more balanced management configuration, where technical and infrastructural measures have to be combined with organisational and governance resolutions (Hoang et al. 2018). The organisational solutions are essentially based on inter- and multimodality. The principle is: when the water level no longer allows inland waterway traffic, the transport provider switches to another mode of transport. These solutions are based on a collective reflection, but do not need a global consensus. Arrangements can be made bilaterally or multilaterally, at the scale of transport providers or more broadly at a regional scale. The objective is to increase the cooperation between the different transport providers and to enable the recourse to one transport system or another (water, train or roadways), according to climate events and the availability of the given transport system. There is a need to access railways and to make railway management coherent between the different countries. Besides, the port and firms proposing storage capacities would have to create new storage facilities to create buffer zones and times and enable transfers when the water levels return to normal.

5.2. Privileging infrastructural response to redistribute and share the responsibility

Involving stakeholders impacted by the same hazard (low waters) into a process of discussion, issues definition, and evaluation of solutions does not substantially change the solutions that each actor appraises, and does not guide stakeholders to adopt more transformative solutions. This creates new arenas of dialogue, exchange of information, knowledge, which can be transformed into lobbying capacities towards regulatory authorities.

The process defined between Strasbourg Port Authority and the researchers can be analysed as a step to structure a community of stakeholders sharing the same objectives: integrating climate change as a collective issue that can be tackled at different levels. Some solutions can be easily achieved (innovation for improving boats); others need to organise new rounds of negotiation, to enrol the national and international authorities, to make the dominant infrastructural narrative credible by way of new knowledge, by solidifying a coalition of Rhine ports.

The transitional infrastructural pathway appears as the most suitable because canalisation is a well-controlled technical process that provides a comfortable solution in the short term. It exemplifies the lock-ins set by infrastructure (Klitkou et al. 2015) and infrastructural policies (Pierson 2000), as the required investments are susbstantial and “irreversible” and community of incumbent stakeholders try to preserve the status quo (Winz, Trowsdale, et Brierley 2014). The incumbent way of managing an issue and a natural and artificial infrastructure such as the Rhine hampers thinking through the problem and the solution in another manner. This partly explains why radical strategies are not chosen. Rip et Kemp (1998: 338) characterise the regime as “the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems—all of them embedded in institutions and infrastructures.” The regime of management of the Rhine is thought through controlled lenses (navigation rules, professional practices guiding the river navigation, inter-organisational links, infrastructures like ports, sluices, etc.). The Rhine could be considered as an artefact whose reliance and regularity is questioned, but not the way of considering it.

Moreover, these infrastructural solutions are a means to redistribute the responsibility between stakeholders and to release individuals from financially contributing and organisations from seriously changing. They may be considered as a way of temporising and postponing investments. Delaying a soft solution and contributing to build the legitimacy of an infrastructural solution is a social strategy to play with the political time of the crisis, of the protest. Temporisation of a “complicated” solution enables the guarantee of a certain social opacity, because the decision is linked to a specific expertise, to very precise environmental processes, which take time and that are not really visible by an organisation over the long term (Blanck 2016). The infrastructural solution is both a temporary arrangement between viewpoints, the current situation (Boltanski et Thévenot 2000) and the stakeholder’s expectations, and a way to dismiss environmental issues raised by a human-driven intervention on the Rhine (Petitimbert, Bouleau, et Guimont 2022).

6. Conclusion

The low water crisis of 2018 has revealed for supply chain stakeholders of Rhine inland river transport the need to gather the different stakeholders and define common visions on the ways of adapting this recurrent hazard. Three possible pathways have been identified on the basis of the collective work. Technical and infrastructural solutions prevailed (e.g. dredging of the Rhine river). Likewise, the fundamental challenge of developing new processes of discussion and new intermodal organisations appears significant. The actors were therefore obliged to put water in their wine, to take into account the limits of their action in a global market and a transnational natural “infrastructure,” to extend their influence and, without doubt, to fall back on softer, but no less complex, solutions: those that combine new organisations and new infrastructures for the storage and circulation of flows.

This work shows to what extent a thorny subject and source of uncertainty such as climate change and the necessary adaptations requires new forms of interaction with operational actors, researchers and public actors. The apprehension of this problem on a transborder river, on which many goods circulate, shows even more that individual and collective action often implies the creation of spaces of common discourse that could allow for the combination of scientific, lay and professional expertise, and the emergence of coalitions of persuasion and action. Moreover, climate change issues demand the integration of new actors and dimensions into the decision process.

Finally, the combined methodology used does not create “new” solutions but new “collectives”, which strive to produce tools for improving their knowledge of the situation, convincing and enrolling new stakeholders in their approach (transitional infrastructural adaptation pathway).

Future research should enlarge the perimeter of the involved actors. Even if solutions can emerge and be negotiated by stakeholders, they have to be submitted to the civil society and confronted to the non-human entities (Roelich et Litman-Roventa 2020). As they are not incorporated in the discussion circles, both could resist.

7. Conflict of Interest

The Author declare that there is no conflict of interest.

8. Author Contributions

JG: Conceptualization, methodology, validation, formal analysis, investigation, writing – original draft, writing – review & editing, supervision

FR: Conceptualization, Methodology, investigation, project administration, funding acquisition

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Appendix

Figure 3. Problems graph worked by the group of in bulk carriers, storage providers and firms (TRIZ extraction)

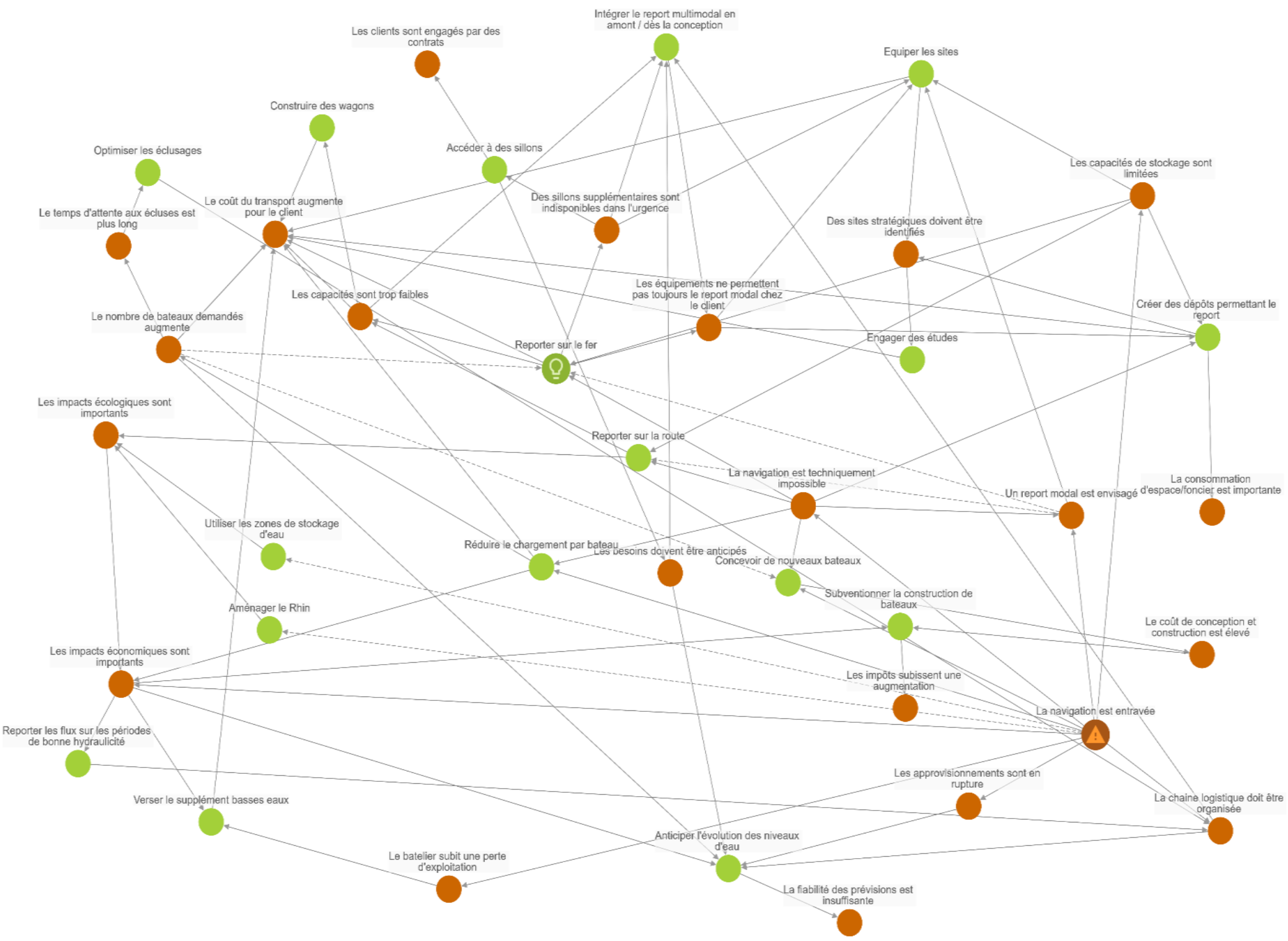

Figure 4. Methodology: Impact chain methodology in combination with TRIZ and semi-directive interviews