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

## 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

## Number of words

Number of figures: 2

## 29 1. Introduction

30

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

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

65 In this context, we can consider that crisis acted as a stimulus for port authorities and their  
66 customers to consider the risks for their assets and operations and as a window of  
67 opportunity for creating new collectives and for defining “solutions” (Kingdon 2003). As a  
68 matter of fact, major crises and disasters have the potential to change dominant ways of  
69 thinking and acting (Birkmann et al. 2010). They create new ways of considering the initial  
70 issue and the solutions to take, to push or to dismiss some ways of acting (Birkmann et al.  
71 2010; Kingdon 2003; Rudolf 2007). But at the same time this impulse given by a crisis can  
72 reinforce some pre-existing ideas of adaptation solutions (Petitimbart, Bouleau, et Guimont  
73 2022). It can enlighten an already-existing solution, enabling “business as usual”, which

74 dissolves individual responsibility into the expected consequences of a project managed by  
75 national or international authorities. Crises can be then considered as opportunities to re-  
76 politicize projects, which were postponed or even abandoned, because of their  
77 environmental impacts, the economic costs and so on.

78 The increasing complexity and uncertainty in decision making due to climate change and the  
79 associated wicked problems (Head 2022) make it necessary to better understand these  
80 possible levers of action (or inaction) and how the stakeholders react when faced with a  
81 crisis, how they try to define or impose strategies according to their capacity for action and  
82 their willingness to take their individual and/or collective responsibility to prevent risks (Meah  
83 2019). In the presented research, we then investigated how stakeholders after this low water  
84 crisis decided to work together, accepting the methodology proposed by researchers (social  
85 and engineering scientists) and the Strasbourg port authority and, through this process,  
86 made emerge conflictual or consensual visions of the low water problem and solutions.

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

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

105

## 106 **2. Climate change adaptation and pragmatic sociology: basis of the theoretical** 107 **framework**

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

118 Settele, Scholes, et Betts 2014). However socio-technical systems on which are organised  
119 economic activities like the inland waterway transport are embedded into different kind of  
120 lock-ins, which can prevent/slow down the implementation of coping measures (Berrang-  
121 Ford, Pearce, et Ford 2015; Burnham, Rasmussen, et Ma 2018; Fazey et al. 2016; Klitkou et al.  
122 2015; Simoens, Fuenfschilling, et Leipold 2022; Winz, Trowsdale, et Brierley 2014). Then,  
123 adaptation measures differ depending on the sector of human activity and the vulnerability  
124 of the stakeholders and their assets (Harries 2021).

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

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

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

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

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

163 a different kind of system, to create a fundamentally new system when ecological,  
164 economic, or social structures make the existing system untenable” (Folke et al.  
165 2010).

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

180 These pathways are defined by actors, who have each a vision of the world, a way of  
181 perceiving climate change and its impacts. It resonates with pragmatic sociology, which  
182 explores “the reasons for acting and the moral exigencies that these persons give  
183 themselves, or want to give themselves, if not by way of ‘ideals’” (Boltanski et Thévenot  
184 2000: 20). Human action is seen as deeply embedded in situations. Some stakeholders can  
185 use the opportunity of an event to enrol other stakeholders to share their perspectives and  
186 to define new actions. The ability to adjust between different rationalities may be the main  
187 social skill needed in response to environmental challenges of our time and the methodology  
188 deployed can help some boundary organisations/actors to reach this goal. That is to say they  
189 are able to translate the expectations and interests of other actors, even if they do not share  
190 the same apprehension of a problem, and to build a bridge, a consensus. That is why this  
191 understanding of the stakeholders’ agency is the second dimension of our framework.

192

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

#### 194 **3.1. A case study imbedded in the project UNCHAIN**

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

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

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

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

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

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

---

<sup>1</sup> 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.

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

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

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

252

### 253 **3.2. A mixed methodology combining semi-directive interviews and guided collective** 254 **workshops**

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

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

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

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

---

<sup>3</sup> 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.

<sup>4</sup> 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.



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

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

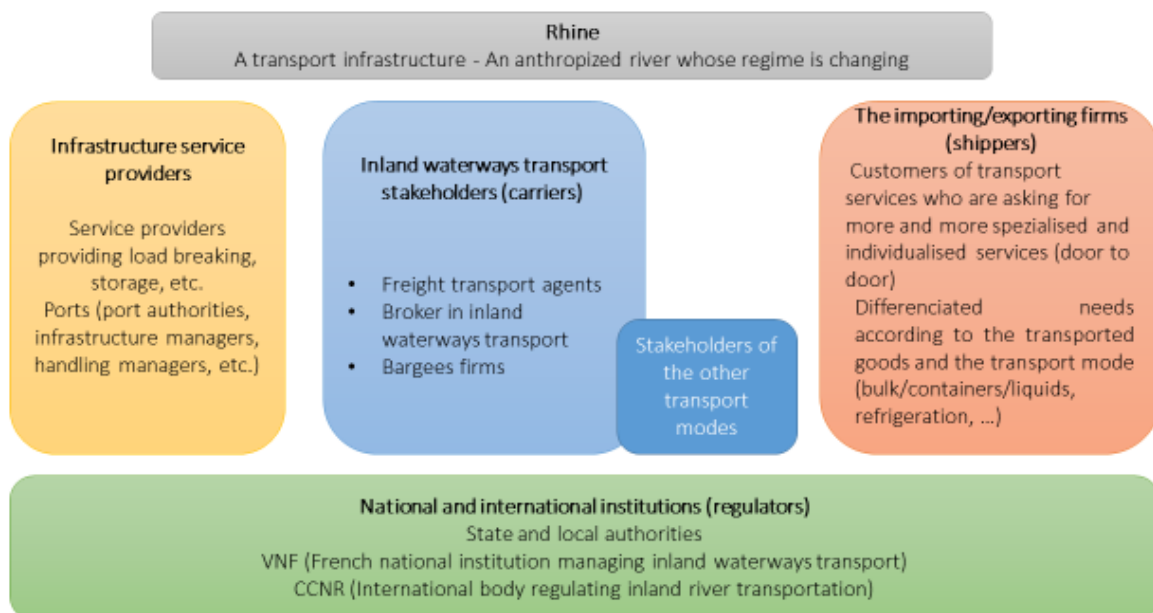
293 To tackle this issue and to apprehend social representations concerning climate change, the  
294 challenges of adaptations at the intra-organisational level, since July 2020, semi-directive  
295 interviews had been conducted with river operators (infrastructure managers, shippers,  
296 transporters,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

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

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

---

<sup>5</sup> 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.



312  
313

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

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

320 **4.1. Individual vulnerability and adaptation possibility**

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

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

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

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

349

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

Stakeholders by profession	Variables of sensibility	Level of vulnerability to low waters	Adaptation capacity and possible difficulties
Ship owners	<ul style="list-style-type: none"> <li>- Water level (and singularly in Kaub and Maxau)</li> <li>- Fleet type: number of vessels, number of large vessels, vessel size, lifetime of the boats</li> </ul>	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)	<ul style="list-style-type: none"> <li>- Water level (and singularly in Kaub and Maxau)</li> <li>- Contract with different transport modes (flexibility)</li> </ul>	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	<ul style="list-style-type: none"> <li>- Water level</li> <li>- Storage capacities</li> <li>- Available infrastructure to facilitate the modal transfer (intermodal connectivity)</li> </ul>	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	<ul style="list-style-type: none"> <li>- Transport prices (comparing to the product price)</li> <li>- Volumes of goods</li> <li>- Types of goods transported</li> <li>- Conditioning mode (in bulk or in containers)</li> <li>- Optimisation of the supply chain (each little spanner in the work may be difficult to overcome)</li> </ul>	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)	<ul style="list-style-type: none"> <li>- Storage capacity (number of storage sites)</li> <li>- interconnexion with different modes of transport</li> </ul>	Medium	Capacity to increase the storage capacity in building more storage infrastructure on the port

352

353 Not only do the different professions not have all resources available, but moreover,  
 354 stakeholders, even if they are working in the same environment, have a situated rationale  
 355 and socio-professionally constructed knowledge. Each profession has a good knowledge of its  
 356 own weaknesses in the supply chain, but a limited apprehension of the impacts caused by

357 low waters to other stakeholders and of the behaviours they will adopt. These “spaces of  
358 ignorance”<sup>7</sup> limit their capacity and their will to act, if they are not involved into a collective  
359 dynamic (like the Impact Chain approach and our methodological attempt to develop).

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

#### 373 **4.2. Adaptation strategies to low water**

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

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

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

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

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

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

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

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

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

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

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

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

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<sup>8</sup> 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.

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

442

## 443 **5. Discussion**

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

### 452 **5.1. Combination of technical and engineering and organisational rationale**

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

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

481 Even when they prefer infrastructural solutions that enable the delegation of responsibility to  
482 others, in our case study, stakeholders have to admit a more balanced management

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

496

## 497 **5.2. Privileging infrastructural response to redistribute and share the responsibility**

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

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

511 The transitional infrastructural pathway appears as the most suitable because canalisation is  
512 a well-controlled technical process that provides a comfortable solution in the short term. It  
513 exemplifies the lock-ins set by infrastructure (Klitkou et al. 2015) and infrastructural policies  
514 (Pierson 2000), as the required investments are substantial and “irreversible” and  
515 community of incumbent stakeholders try to preserve the status quo (Winz, Trowsdale, et  
516 Brierley 2014). The incumbent way of managing an issue and a natural and artificial  
517 infrastructure such as the Rhine hampers thinking through the problem and the solution in  
518 another manner. This partly explains why radical strategies are not chosen. Rip et Kemp  
519 (1998: 338) characterise the regime as “the rule-set or grammar embedded in a complex of  
520 engineering practices, production process technologies, product characteristics, skills and  
521 procedures, ways of handling relevant artefacts and persons, ways of defining problems—all  
522 of them embedded in institutions and infrastructures.” The regime of management of the  
523 Rhine is thought through controlled lenses (navigation rules, professional practices guiding  
524 the river navigation, inter-organisational links, infrastructures like ports, sluices, etc.). The  
525 Rhine could be considered as an artefact whose reliance and regularity is questioned, but not  
526 the way of considering it.



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

## 539 **6. Conclusion**

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

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

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

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

566

## 567 **7. Conflict of Interest**

568 The Author declare that there is no conflict of interest.

569 **8. Author Contributions**

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

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

574

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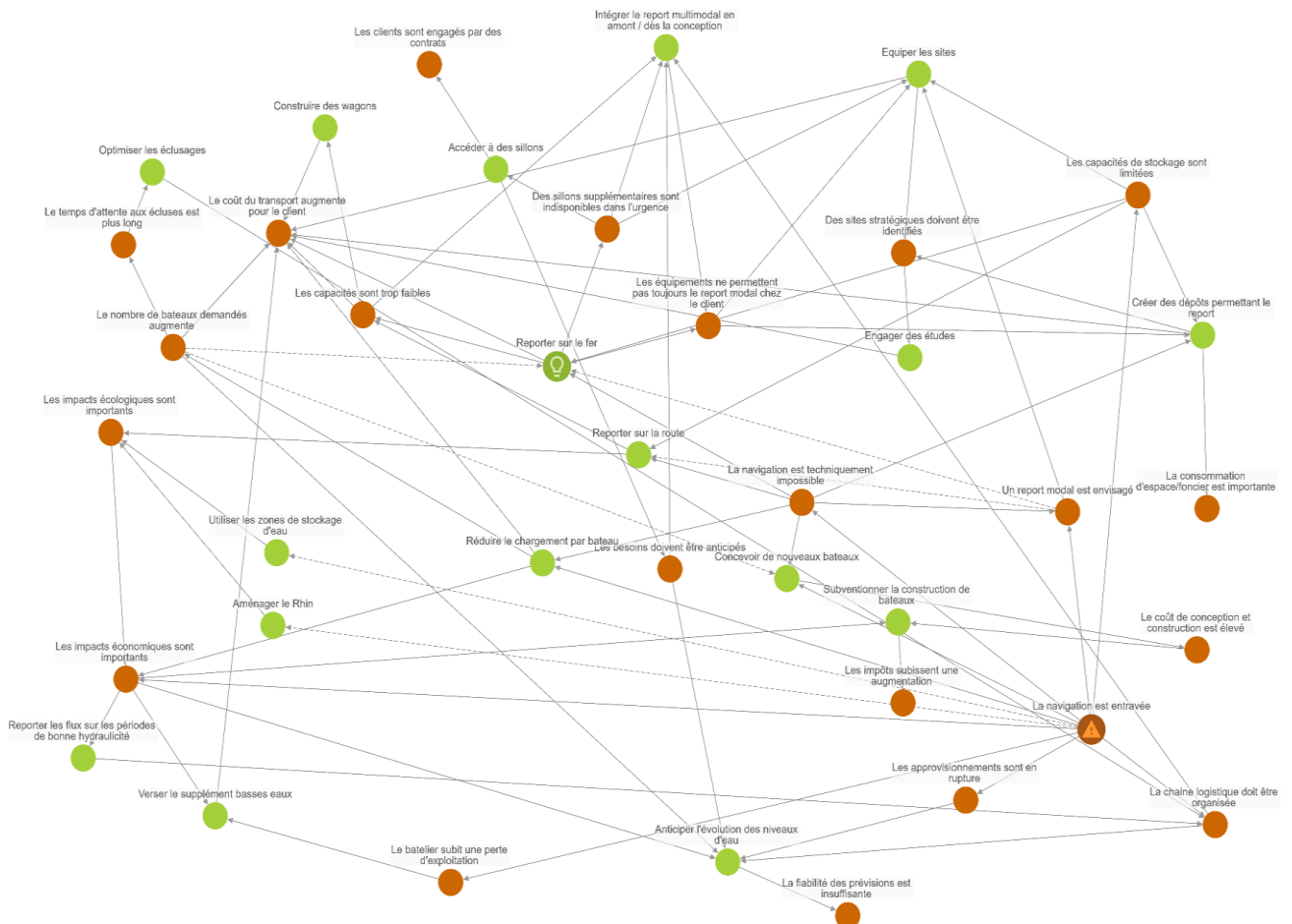
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827 **Appendix**

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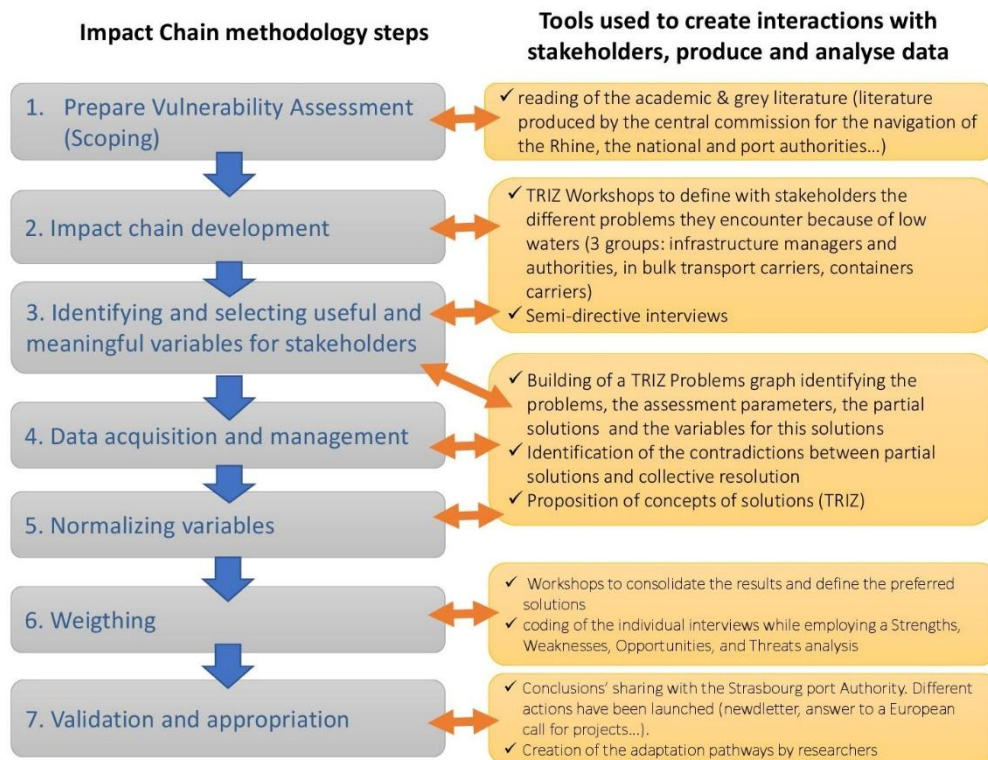


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Figure 4. Methodology: Impact chain methodology in combination with TRIZ and semi-directive interviews



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