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Institutional dependencies in climate adaptation of transport infrastructures: an Institutional Network Analysis approach

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ABSTRACT

Climate adaptation measures are shaped and implemented through processes of governance, where the interactions and decision-making among actors lead to the creation and reinforcement of institutions. Institutions in this respect are the rules that shape the interactions of actors in different phases of climate adaptation. Currently there is no comprehensive method to systematically identify and map dependencies between institutions. This study proposes the Institutional Network Analysis (INA) approach that is based on the Institutional Grammar as a systematic and comprehensive tool to (1) visualise institutional dependencies, (2) identify points of concern in the institutional landscape such as conflicts and voids, and (3) provide quantitative insights into the centrality of actors, embeddedness of institutional outcomes, and dependencies between institutions. The approach is applied to the case of climate adaptation of transport infrastructures surrounding the Port of Rotterdam, the Netherlands. The analysis reveals a conflict in the use of risk assessment criteria, as parties in the Port may follow their own matrices in the presence of a shared decision-making framework. Nonetheless, the network metric analysis reveals that the criteria, whether shared or individual, build on the same source of risk analysis, suggesting that this duality may not be detrimental for climate adaptation efforts. Additionally, an institutional void is identified for financial responsibilities in locations where infrastructures overlap. Finally, the network metrics show high dependency between institutions in the risk dialogue phase, and reveal the centrality of infrastructure owners ProRail and RWS in the institutional landscape instead of local or regional governmental bodies.

1. Introduction

It is widely agreed that anthropogenic activities, in particular the burning of fossil fuels, have led to a variety of climate change phenomena, such as the current trend of global warming, and more frequent extreme weather events (Forzieri et al., 2018; Rattanachot et al., 2015). These climate impacts pose serious risks for transport infrastructures, especially those connecting seaports to the hinterland (Chappin and Van der Lei, 2014). Transport infrastructures are important enablers of economic growth and development on multiple scales, given that 80% of the world's trade is carried across the seas (Becker et al., 2013). Climate hazards may lead to substantial economic costs associated with infrastructure replacement and repair, and numerous broader implications, due to the concentration of populations, assets and services associated with ports (Nemry and Demirel, 2012). Therefore, effectively responding to these risks is crucial to preserving the balance between long-term environmental protection, social well-being, and economic prosperity (IPCC, 2018).

Interdependencies between transport infrastructures influence climate adaptation pathways. Disruptions due to climatic impacts in one infrastructure may propagate to other infrastructures, potentially resulting in network-wide failure (Bollinger et al., 2014). The functioning of transport infrastructure therefore pre-supposes coordination of the climate adaptation measures by public and private parties who manage and use these different infrastructures.

Adaptation measures are shaped by actors through the creation, reinforcement, or reproduction of institutions (Hufty, 2011). Here, institutions are defined as humanly devised constraints that organise the behaviour of actors in a social context (North, 1991). From an institutional perspective, climate adaptation can be described in terms of different phases of decision-making, "in which actors expect, perceive, and experience climate impacts and adapt to them, thereby interacting with each other" according to these institutions (Hinkel and Bisaro, 2016, p. 9).

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Studies on the institutional dimension of climate adaptation have focused on whether existing institutions facilitate or hamper climate adaptation in different decision-making processes. Research shows that existing institutions do not always allow actors to adopt flexible approaches to climate adaptation that recognise the dynamic character of natural and human systems (Bierbaum et al., 2013; Lawrence et al., 2015). In these systems, frequent monitoring, reviewing, and changing of policies are paramount (McDonald and Styles, 2014). Even more, the lack of formal, written institutions or lack of enforcement cause uncertainty in stakeholders' roles in climate adaptation (Bierbaum et al., 2013; Ng et al., 2019; Ruiten et al., 2016) as the responsibilities of the actors involved are often not clearly allocated and ambiguous (Mees, Droessen and Runhaar, 2012).

With little experience in climate adaptation, it remains unclear who should take the lead in adaptation and how institutions are to be put into place (Kretsch and Becker, 2016). Individual actors as well as constellations of actors are thus forced to come up with solutions for climate adaptation with little support from existing institutions. Actors interpret the few formal existing institutions to their own institutional learning and rely more on informal institutions, making it harder for formal institutions to eventually be put into practice (Ng et al., 2019). Incomplete institutions also make it harder to link existing strategies to the required adaptation strategies (He and Ng, 2019; Zhang et al., 2017) and move to actual planning and implementation (Messner et al., 2016) even with more understanding of climatic predictions and impacts (Ford et al., 2011).

Therefore, to identify institutional barriers towards climate adaptation, it is not only necessary to look at the role of individual institutions, but also consider the relations that exist between institutions. Having multiple institutions in place can lead to overlap and duplication, or inadequate coordination of trade-offs between policy agendas, values and priorities between the stakeholders involved in climate adaptation (Delmas and Toffel, 2004; Mutombo and Ölçer, 2017; Pittock, 2010; Storbjörk and Hedrén, 2010; UN, 2014). Although the importance of relations between institutions is acknowledged, the impact of these relations are only briefly and seemingly unsystematically reported on in case studies (Glaas and Juhola, 2013; Mclean and Becker, 2019; Well and Carrapatoso, 2016). This makes it challenging to adequately and comprehensively understand the complete puzzle of institutional complexities and the resulting barriers for climate adaptation.

This research aims to be a first step towards a comprehensive institutional approach to climate adaptation, by providing insights in the connections and dependencies between institutions underlying climate adaptation, in order to prevent potentially unsystematic, and isolated climate adaptation efforts. To conduct this research we propose a novel network approach called Institutional Network Analysis (INA) to study the dependencies between institutions. This network approach builds on the Institutional Grammar (IG) tool, initially proposed by Crawford and Ostrom (1995) and brings together formal and informal institutions and visualises their dependencies in a specific context. In this case, INA visualises the complexity of the institutional landscape to accurately identify potential barriers in climate adaptation efforts. Besides the visualisation, the network metrics that accompany INA provide quantitative insights into the position of actors, institutional outcomes, and the level of dependency among institutions. By dependency, we mean a relation between institutions where the outcome of one institution is required for the execution of another institution. Our case study is the transport infrastructures connected to the Port of Rotterdam. The surrounding region is one of the "hotspots" in the Netherlands which is particularly vulnerable to the impacts of climate change (Westerhoff et al., 2010). This is due to the presence of the Port of Rotterdam, and the economic benefits it generates for the region and the Dutch economy. Its multimodal transport infrastructure to and from its hinterland is particularly vulnerable to extreme weather events (Ruiten et al., 2016). Given the position of the region and the Port, it is crucial for infrastructure owners, the Port, and users of the infrastructure to have a mutual understanding of the institutional interactions for climate adaptation as a starting point to improve and align adaptation practices. We assess the performance of climate adaptation at this port, by analysing the institutions involved in climate adaptation and their dependencies.

The structure of the paper is as follows: first, the theoretical grounding of INA is explained through institutional and social network theory. Next, the case study is presented. Finally, INA will be applied to demonstrate its added value to understanding institutional dependencies for climate adaptation.

2. Theoretical background

According to Ostrom (2011), institutions are rules, norms, and strategies that are created and changed through human interactions in frequently occurring or repetitive situations. In the context of climate adaptation, the implementation of institutions ultimately aims at addressing the impacts of episodic and extreme events such as extreme precipitation, drought, and floods on transport infrastructures (Earl and Potts, 2011). Existing studies distinguish between formal and informal institutions (Roggero et al., 2018). Formal institutions are explicitly set by legislators and manifest themselves through laws, regulations, and protocols. Informal institutions are more implicit, such as administrative practices, norms, professional codes, traditions, and customs (Juhola and Westerhoff, 2013; Obeng and Agyenim, 2013). In this section, we provide the theoretical basis for this research, and position ourselves in the existing research on climate adaptation and institutions as networks.

2.1. Institutions for climate adaptation

The focus in literature on the institutional dimension of climate adaptation is two-fold. One body focuses on whether existing institutions allow and encourage actors to develop and realise adaptation strategies to enhance the adaptive capacity of society (Termeer et al., 2011). Adaptive capacity is developed when institutions allow actors to prepare for climate stresses and changes and to adjust, respond, and adapt to them (Berman et al., 2012; Obeng and Agyenim, 2013). The other body of literature focuses on *institutional void,* which refers to a lack of formal planning and management tools due to a lack of formal institutions on climate adaptation (Biesbroek et al., 2009). In other words, there are no generally accepted institutions according to which policy measures are to be agreed upon (Hajer, 2003). Consequently, parties engaging in adaptation efforts have very diverse, and at times, conflicting risk perceptions of the problems and/or the solutions that are being considered (Preston et al., 2015).

In both bodies of literature, institutions are mostly studied in isolation from each other to assess whether they stimulate the adaptive capacity in their own policy making context (Stead, 2013). When "institutional interactions" are mentioned, the focus is on the interactions between organisations at different institutional levels rather than the interactions between institutions themselves (Glaas and Juhola, 2013). In fact, in climate adaptation literature, the interactions between two or more distinctive organisations that interact in the governance of the same activity is what is referred to as "institutional complexity" (Oberthür and Stokke, 2012, p. 3; De Bruin et al., 2009), which is different from the perspective of "institutions as rules".

However, the relations between institutions (as rules) are also acknowledged in the existing literature. Oberlack (2016) mentions that formal rules on a higher institutional level might constrain the changing of lower-level rules, and the extent to which local actors can undertake adaptation efforts. The effectiveness of institutions for adaptation measures, therefore, also depends on whether other institutions foster policy learning, necessary to improve adaptation measures in place (Juhola and Westerhoff, 2013). In such a context, and in this research, *institutional complexity* relates to these specific dependencies and the connectivity between institutions.

With respect to the relations between institutions, the notion of *institutional conflict* has also been mentioned in existing studies (Biesbroek et al., 2009). Institutional conflict occurs when different institutions exist at different levels of governance, leading to actors adopting conflicting institutional structures to engage in climate adaptation. This means that there are multiple institutions guiding actor behaviour, and that these institutions seek different outcomes.

2.2. The Institutional Analysis and Development framework

The INA approach uses the concept of "action situations" from the Institutional Analysis and Development (IAD) framework (Ostrom, 1999) to define the institutional landscape of a single network.

In an action situation, actors (individuals or groups) interact with each other, exchange goods or services, or work towards problem-solving (Ostrom et al., 2014, p. 271). The action situation is influenced by three sets of external variables: the attributes of the physical world (e.g. biophysical resources, capital, labour, technology), the attributes of the community (shared values, beliefs, and preferences), and the rules-in-use (Ostrom, 1999).

From the action situation, patterns of interactions result in outcomes that are then assessed by using certain evaluation criteria. In this research, we use the concept of action situation to divide the system being analysed (e.g. transport infrastructure in the Port of Rotterdam) into smaller, but institutionally related units of analysis for constructing network diagrams. To be able to visualise an action situation from an institutional angle, we use the Institutional Grammar.

2.2.1. The Institutional Grammar

An institutional statement is a "shared linguistic constraint or opportunity that prescribes, permits, or advices actions or outcomes for actors…they are spoken, written, or tacitly understood in forms intelligible to actors in an empirical setting" (Crawford and Ostrom, 1995, p. 583). The IG syntax subdivides institutional statements into five different components:

1. **A**ttribute(A): the actor whom an institutional statement applies to.
2. O**b**ject(B): the inanimate or animate part of a statement that receives the action (later added by Siddiki et al., 2011).
3. **D**eontic(D): the prescriptive operator that indicates whether the attribute is required, forbidden, or permitted to perform the focal action of the statement. The deontic indicates the strength of enforcement of a statement. Words such as "should (not)" or "must (not)" both express the obligatory nature of a statement, however, "must" is more likely to be associated with a rule than with a norm, while "should" could be an indicator of both types of institutions.
4. A**i**m(I): the action of the statement.
5. **C**ondition(C): the temporal, spatial, or procedural boundaries in which the action of the statement is or is not performed. Whenever specific conditions are not stated, it is assumed that the statement applies at "all times and in all places".
6. **O**r else(O): explicit sanctions in case of non-compliance of the attribute to the institutional statement.

There are three different types of statements. (1) A "rule" contains all IG components (ABDICO). (2) A "norm" does not have a sanction that is formally captured in legislations or documents, but one with an emotional nature (ABDIC). (3) A "shared strategy" does not have a formal sanction either nor a legal or normative pressure, making the deontic also absent (ABIC).

2.2.2. Studying institutional dependencies

Interactions between institutions has been addressed from various angles in the literature. Most notably, Young (2002) distinguishes between horizontal (e.g. interaction between trade and environmental regulations) and vertical levels of interaction (e.g. national and local level land use regulations). The vertical levels of interactions, have also been addressed by Williamson (1998) and Ostrom (2009). In more detail, Lubell (2013) proposes the Ecology of Games framework to address institutional complexity, aiming to study policy arenas from a complex adaptive systems perspective and by looking at multiple policies over time. The EG approach is an extension of the IAD, aiming to produce hypotheses about drivers of individual behaviour and institutional change. The EG makes use of bipartite networks to form connections between actors and institutions.

Another network approach to study institutions is the "networks of action situations" (NAS) approach which builds on the seven types of rules that define an action situation (McGinnis, 2011). Action situations (including actors and outcomes) are the nodes of these networks and are connected to each other based on causal links.

The INA approach follows the same theoretical basis (IAD) as the EG and NAS approaches. However, it aims to add more granularity to the way institutions are connected to each other, by making use of the IG. Via an analysis of interconnections between institutions at the level of institutional statements (rather than action situations), it is possible to locate exact points of institutional overlaps including conflicting situations, voids, and conformance issues. Furthermore, following the IG distinction between formal and informal rules (i.e. rules, norms, shared strategies), it is possible to extract the actual interplay between the rules-in-form and the rules-in-use in an institutional landscape. An additional advantage of such a granular analysis of institutional networks is that the analysis builds on the extensive body of literature on formal (or automated) codification of institutions using the IG syntax (Rice et al., 2020), thus contributing to the knowledge base of uniformity and even allowing for automatic construction of the network diagrams themselves.

Case specification: Port of Rotterdam. As a case of climate adaptation of transport infrastructures, the Port of Rotterdam, as one of the "hotspots" in the Netherlands, is considered. The Port has a multimodal transport infrastructure (roads, railways, waterways) connecting it to its hinterland, which is particularly vulnerable to extreme weather events (Ruiten et al., 2016).

In the Netherlands, the national government, provinces, municipalities, waterboards, civil-society organisations, and private businesses cooperate under the Delta Programme, a national policy programme set up to ensure that the Netherlands is water-robust and climate-resistant by 2050 (Delta Programme Commissioner, 2020a). The Delta Programme has three Delta plans (Delta Programme Commissioner, 2020b):

1. Water Safety: protecting civilians and the economy against floods.

2. Freshwater Supply: reducing water shortages and optimising freshwater usage for the economy and public utility functions.

3. Spatial Adaptation: realising water-robust and climate-resistant spatial planning. The Delta Plan on Spatial Adaptation (DPSA) focuses on waterlogging, heat stress, drought, and sea-level rise (Delta Programme Commissioner, 2020c).

The Port of Rotterdam is situated in the Rijnmond-Drechtsteden area, a region of economic importance in which all three Delta plans apply. The approach to climate adaptation taken in the area of the Port consists of three phases of climate adaptation in the DPSA, namely: *gathering knowledge, conducting risk dialogues, and drawing up an implementation agenda*. The infrastructure owners whose infrastructures are connected to the Port, all work according to these steps in the DPSA. In this research, we focus on the DPSA as it involves multiple actors from various infrastructures and concentrates on climate adaptation as a whole.

We focus on one area where infrastructures come together and cross each other called *Botlek and Vondelingenplaat*. This area is a hub of great economic importance on a national and international level, and contains hinterland connections via rail, road, water, and pipelines (Port of Rotterdam, 2016).

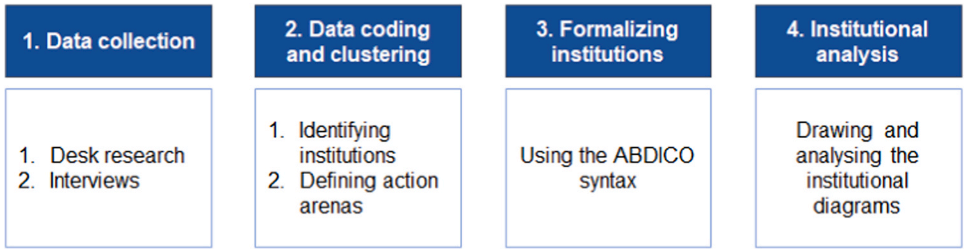

Fig. 1. The steps of the Institutional Network Analysis (INA).

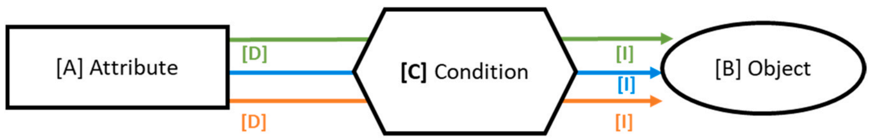

Fig. 2. The network representation of a single institutional statement, depending on the type, the link will be colour-coded.[11]

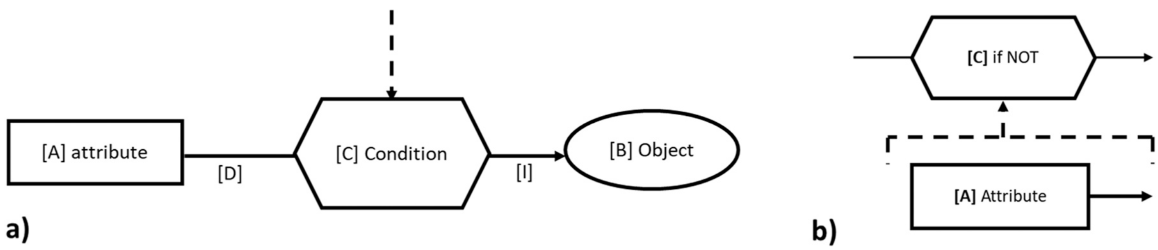

Fig. 3. Connecting institutional statements in the diagrams.

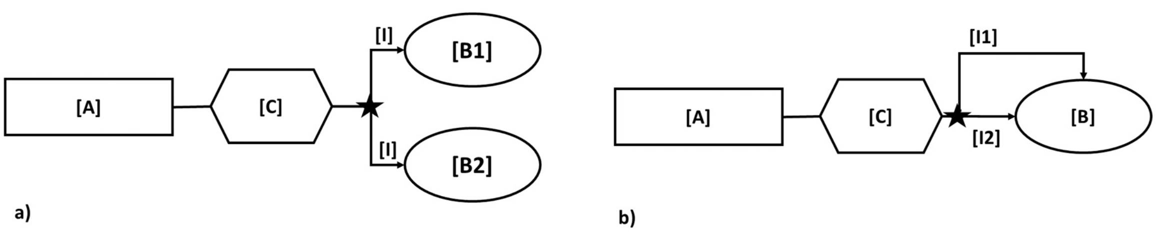

Fig. 4. Points of concern depicted in the diagrams with a star.

3. Method

In this section, we explain the steps taken to conduct INA on the Port of Rotterdam. The methodological steps are presented in Fig. 1.

The data collection phase provided insights about existing institutions. Desk research was conducted by reviewing publicly available sources (Appendix A, Table A1). Furthermore, semi-structured interviews were conducted based on questions outlined in Appendix A (Table A2) with 16 respondents in 9 organisations (Table A3).

Next, the interview data was coded and clustered (Appendix B), and the clusters were assigned to one of the three phases of the DPSA: knowledge gathering, conducting risk dialogues, and drawing up an implementation agenda. These three phases were also used to define action situations in our analysis.

For the formalisation of the institutions, IG was used. We followed the six step guidelines of Basurto et al. (2010, p. 526) for using IG to extract institutions from written documents. We also followed Watkins and Westphal (2016) to extract institutions from interviews, again using the IG.

Network diagrams were consequently constructed using the IG coded institutions. The diagrams show the connections between the institutions for a particular action situation. In these diagrams, each component of the IG is represented either by a node or a link. More specifically, the “Attribute”, “Conditions” and “Objects” are different types of nodes, while the “Deontic” and the “Aim” are links between these nodes. A single institutional statement in a diagram form is shown in Fig. 2. For connecting different institutions to each other, the “Object” (outcome) of one statement is connected to the “Condition” of another statement. In case of non-compliance, the statement that has not been complied with by an actor is linked to a sanctioning statement (See Fig. 3 b). The dotted lines in Fig. 3 show the two different types of connections between institutions. The steps to drawing an institutional network diagram are shown in Table C1.

The diagrams provide a visual depiction of how institutions are connected in an action situation. From these diagrams, it is also possible to identify points of concern (Fig. 4). These points, which are marked by a “star”, occur when two institutional statements are identical except for their “Objects” (Fig. 4 a) or except for their “Aims” (Fig. 4 b). The diagrams in the next section will give examples of such points of concern.

Besides the visual overview of institutional dependencies, network metrics are also defined to provide a more quantitative analysis. The network metrics (Table C2) measure the centrality of the attributes (actors) and objects in the institutional context, the embeddedness of each object in the network, and the density of the network as a whole,

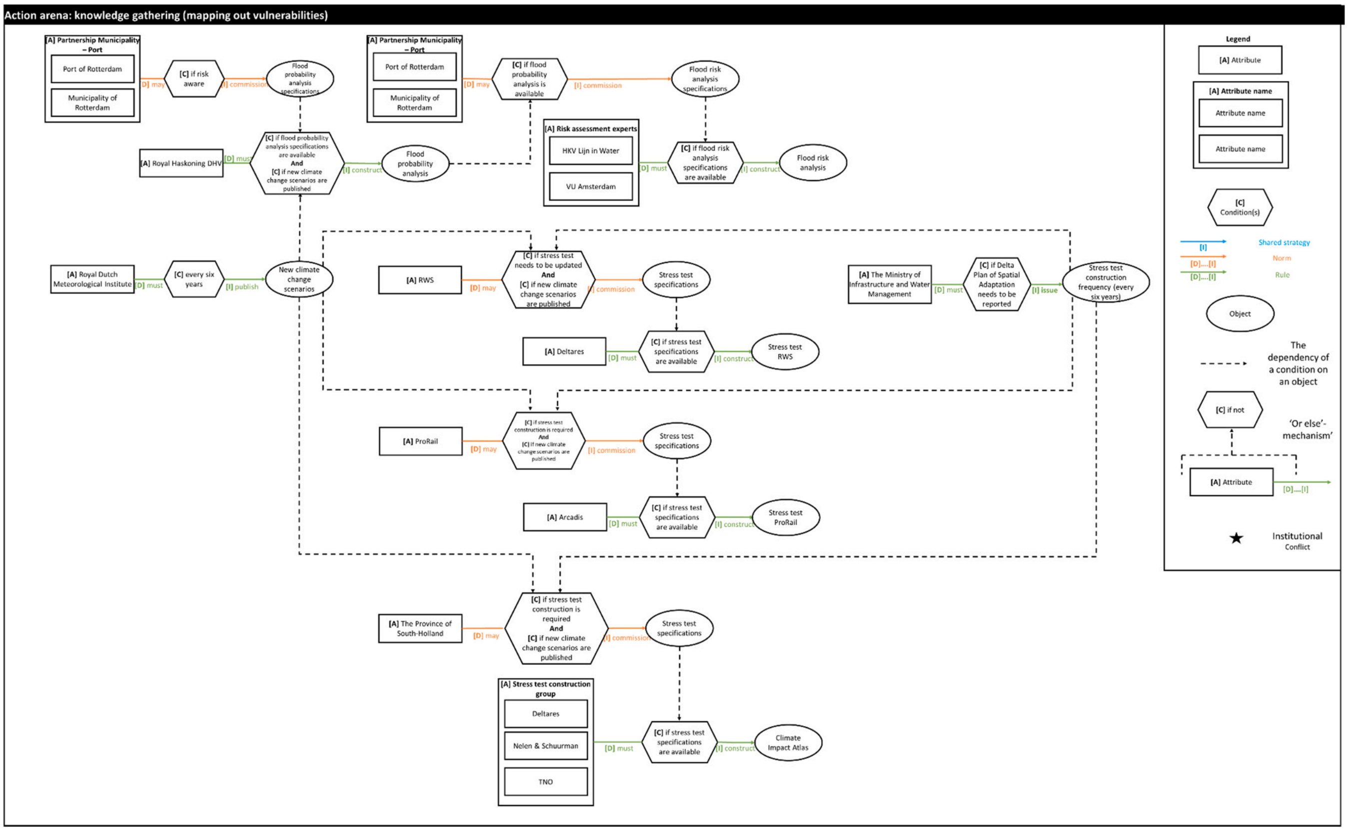

Fig. 5. Knowledge gathering: mapping vulnerabilities.

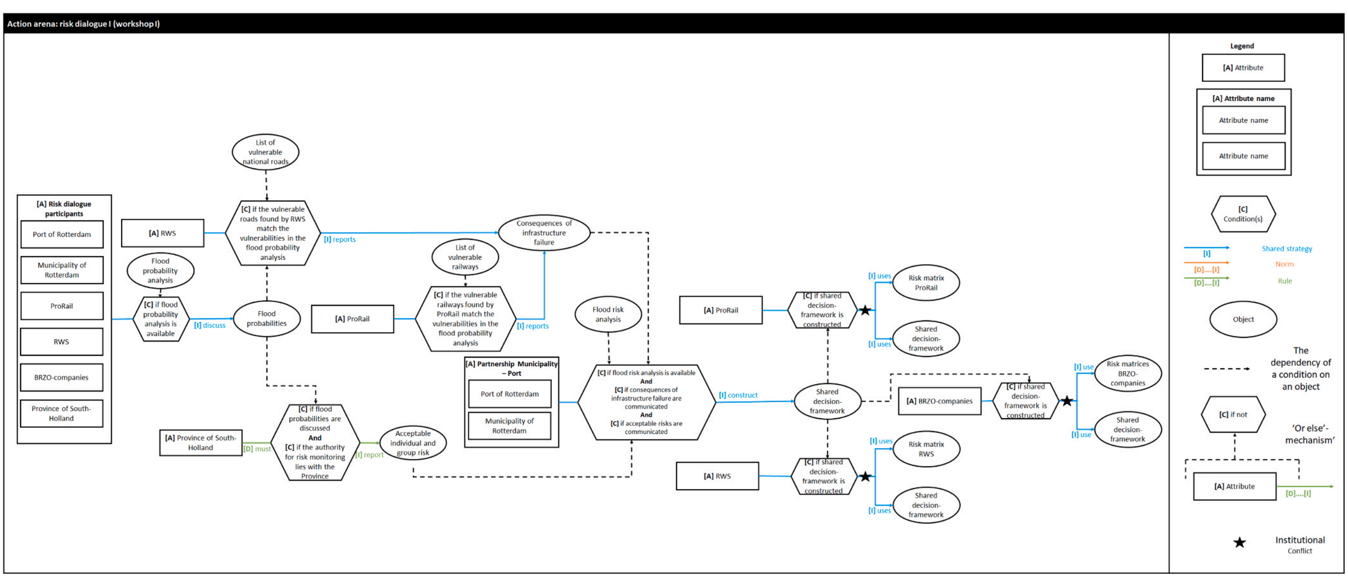

Fig. 6. Risk dialogue I.

which reflects the level of institutional dependency.

[1] It is important to note that while drawing institutions in a network diagram, the attributes and objects can be shared across different institutions, but for each institution, the condition needs to be drawn separately and cannot be shared among institutions.

4. Institutional Analysis of the Port of Rotterdam

This section applies the INA approach to the case of climate adaptation of transport infrastructures connected to the Port of Rotterdam. As mentioned before, the DPSA has distinguished three phases, namely: knowledge gathering, conducting risk dialogues, and drawing up an implementation agenda. These are considered as action situations and for each, an institutional network diagram is drawn.

Below, we illustrate how complex qualitative data can be visualised

Table 1
The proposed risk matrix (shared decision-making framework) by the Port of Rotterdam (based on Port of Rotterdam et al., 2016, p. 39).

Number of deadly casualties	Total economic damage	Scale of environmental damage	Acceptable chance of failure (per year)
1	0,1 million euros	Area of impact has a span of < 1 km	1/100
10	1 million euros	Area of impact has a span of < 20 km	1/1000
100	10 million euros	Area of impact has a span of < 50 km	1/10,000
1000	100 million euros	Area of impact has a span of >= 50 km	1/100,000

in a more traceable format in the form of a network diagram and analysed. For each phase, we provide an analysis of the institutional context using the diagrams.

4.1. Knowledge gathering

In the knowledge gathering phase for climate adaptation, different actors map the vulnerabilities that are the result of climate change to assess the potential risks they pose.

4.1.1. Institutional context captured in the diagram

The entire knowledge gathering action arena has been visualised in two diagrams for better readability. Note that both diagrams belong to the same action arena. The first diagram shows how research efforts are initiated (Fig. 5). The second diagram (Fig. C1) depicts at what levels of climate hazards, infrastructures are ranked as potentially "vulnerable" by the Province of South-Holland (regional roads and waterways), ProRail (rails), and RWS (national roads).

As part of the DPSA, stress tests are made nationally by infrastructure owners, regionally by provinces and waterboards, and locally by municipalities. Stress tests enable the mapping of vulnerabilities on regional and local levels for water logging, heat, drought, and sea-level rise. Every 6 years, the stress tests are updated based on new climate change scenarios of the Royal Dutch Meteorological Institute. To safeguard the comparability between the different stress tests, the platform of the DPSA has published several guidelines on the underlying assumptions, input data, calculations, and approaches to communicating the results of the stress test and standards for the procedure of carrying out the stress test (Delta Programme Commissioner, 2020c). For example, it is permissible to add other climate change impacts to the four existing categories, as long as this is substantiated.

For illustrative purposes, in the following text, we annotate the text (ABDICO) based on the IG to show how the institutions have been depicted in the diagram. In Fig. 5, the Municipality of Rotterdam and the Port of Rotterdam in partnership (A) commission (I) the specifications for a flood probability analysis (B). The Ministry of Infrastructure and Water Management (A) issues (I) the frequency with which stress tests should be made (B) by infrastructure owners whose infrastructures are connected to the Port of Rotterdam: ProRail (A), RWS (A), and the Province of South-Holland (A). These parties commission (I) the

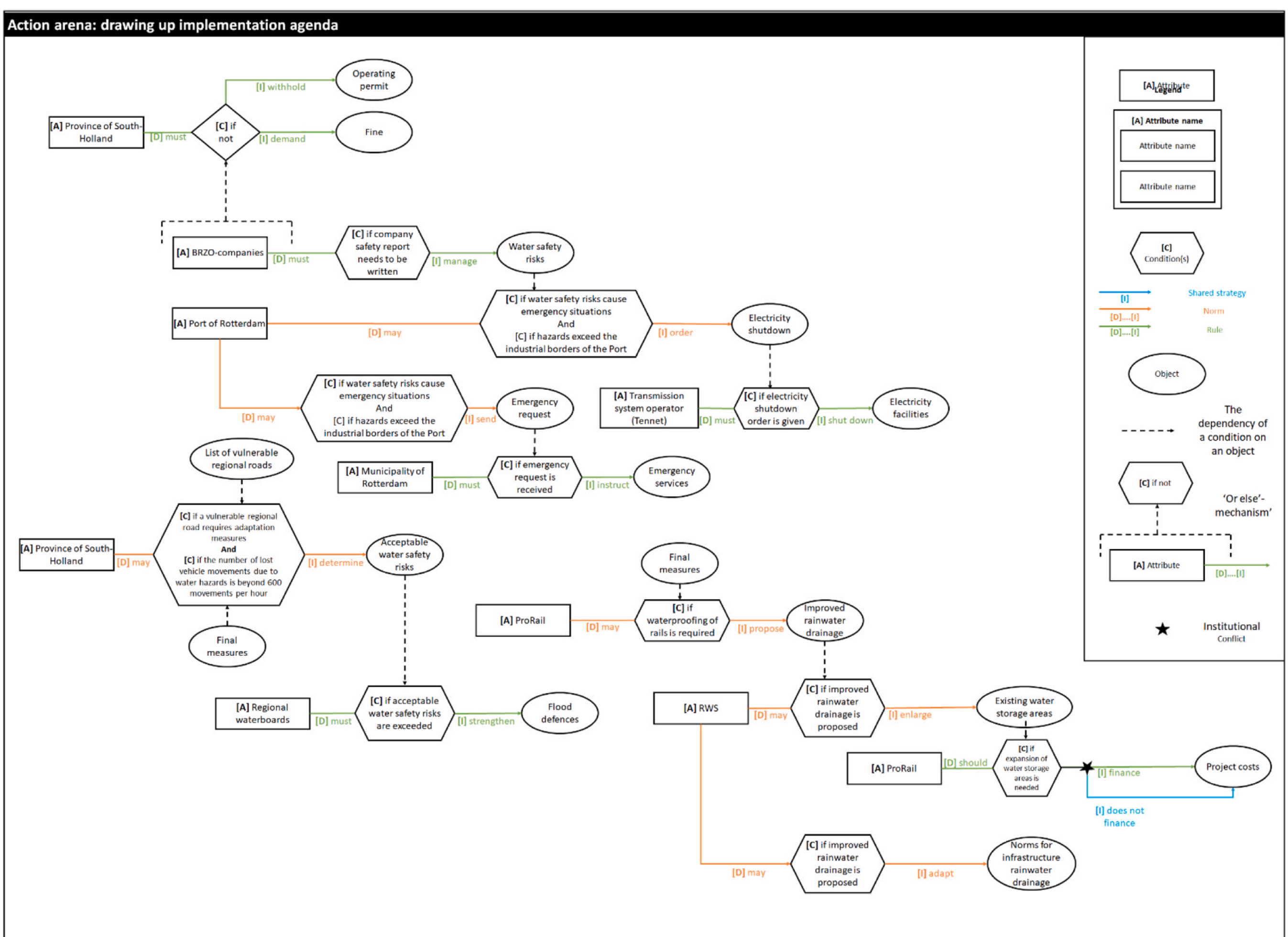

Fig. 7. Drawing up an implementation agenda.

specifications of the stress tests or flood probability analysis (B). When these specifications are available (C), external engineering firms, like Deltares, Arcadis, and Royal Haskoning DHV (A), must (D) construct (I) stress tests or a flood risk analysis (B). These engineering firms also base their analysis on new climate change scenarios (B), which the Royal Dutch Meteorological Institute (A) must (D) publish (I) every six years (C).

There are several differences in the working style of the actors involved. The infrastructure owners, following the policy of the DPSA, conduct stress tests that provide information on risks related to water logging, heat, drought, and sea-level rise. Not being formally part of DPSA, the Port does not commission a stress test, but a flood probability analysis, to see where floods may occur in the Port. Next, the information is used to make a flood risk analysis for the risk dialogue.

4.1.2. *Conclusions from the diagram*

The knowledge gathering diagram shows several institutional dependencies (dotted lines) in this phase of the climate adaptation programme, implying that many of the institutions are dependent on other institutions for their execution. More specifically, all infrastructure owners are dependent on the climate scenarios produced by the Royal Dutch Meteorological Institute and the policy requirements of the Ministry of Infrastructure and Water Management to issue specific types of stress tests, in order to carry out their actual tests. At the same time, the diagram also shows that research efforts are subsequently conducted by actors such as infrastructure owners in isolation from each other. No joint research efforts are undertaken. Although this does not mean that communication between different infrastructure owners and the Port is absent, the communication does not focus on nor contribute to an increased understanding of the mutual impact that infrastructures have on each other. The separate actors commission stress tests (ProRail and RWS) and a Climate Impact Atlas (Province of South-Holland), which do not have the same level of detail, or focus with regard to the identified climate hazards. This can be observed in the vulnerability assessment diagram of the knowledge gathering phase (Fig. C1). The vulnerabilities are identified by each party according to different criteria.

To calculate the network metrics, we consider both knowledge gathering diagrams (Fig. 5 and Fig. C1) together. When looking at both diagrams as one network, the institutional dependency rate (IDR) which is the ratio of outgoing links from all objects relative to all possible links of all objects, is in fact very low (0.08 in Table C5). This low number is the result of having a high number of institutions (27) in this action situation which in turn increases the number of possible connections between them.[2] The embeddedness metric which is the ratio between outgoing links of objects and total number of links for an object (Table C4) shows that stress tests of RWS (0.8), ProRail (0.86), the Climate Impact Atlas (0.83), climate change scenarios (0.8), and flood risk analysis (0.8) are the most embedded objects in the network that lead to dependencies between institutions and even between action situations. Lists of vulnerable infrastructures on the other hand are the least embedded as they are only partially needed for the execution of other institutions. Finally, in terms of centrality of actors in the network (Table C3), ProRail is the most central actor in the network (3.08), followed by the Province of South-Holland (2.64), and RWS (2.2). This shows the important role of infrastructure owners as compared to governmental bodies (~0.44 on average) for the knowledge gathering process, since the vulnerability of infrastructures is assessed based on the stress test specifications that they draft and commission.

[2] Although there are many shared objects between institutions, this does not necessarily make them dependent because the connection between objects (aka outcomes) and conditions is what creates dependency.

4.2. *Conducting risk dialogues*

In the second phase of the climate adaptation programme, different actors share their assessments and perceptions of critical vulnerabilities.

4.2.1. *Institutional context captured with the diagram*

The DPSA provides general guidelines for how to prepare, conduct, and complete a risk dialogue (Delta Programme Commissioner, 2020c). A risk dialogue is a working session during which a group of participants discuss the climate change risks which are found in the stress tests or other model analyses. Participants look at different vulnerabilities and climate change risks, discuss and decide which risks need to be prioritised or tackled on the short-term, and which risks levels require no immediate action or are acceptable. Most organisations have an internal risk dialogue first where they discuss, trade-off, and prioritise the identified risks within their own organisation, before discussing them in a setting with external actors.

For the area of the Port of Rotterdam, the risk dialogue is conducted via two workshops. Two different action situations are defined: risk dialogue I (Fig. 6), and risk dialogue II (Fig. C2). Risk dialogue I is the starting point for information exchange on flood probabilities and its potential consequences. All actors who conducted research are invited by the Port of Rotterdam to provide input on identified vulnerabilities. Based on the findings of the various actors, a shared decision-making framework is constructed, showing acceptable economic, social, and environmental consequences of floods in the area. Risk dialogue II focuses on choosing pathways for adaptation, and parties use different decision-making frameworks, such as risk matrices, to determine which measures should be implemented.

Risk dialogue I. First, as shown in Fig. 6, the participants of the risk dialogue discuss the flood probabilities. ProRail and RWS validate this information through vulnerable roads or railways they had identified in their own stress tests. If the vulnerable roads or railways match the vulnerabilities of the flood probability analysis, RWS and ProRail report the consequences of potential infrastructure failure due to flooding. Another consequence which the Province of South-Holland reports is the acceptable levels of individual and group risk, which apply to BRZO-companies. The individual risk is the probability per year for an individual during a calamity, such as a flood, in a company's sphere of influence. The group risk is the probability per year that a group (for example 10, 100 or 1000 people) die as direct result of a calamity in a company's sphere of influence (Port of Rotterdam et al., 2016). Based on the input of the infrastructure owners and the Province, a shared decision-making framework (Table 1) is constructed. This collective overview of economic, societal, and environmental consequences of floods, creates a common overview and understanding of the various objectives actors wish to achieve, and what impacts they wish to prevent with adaptation measures.

Risk dialogue II. During risk dialogue II (Fig. C2), potential measures are identified and selected based on their ability to reduce risks as formulated in the shared decision-making framework and/or the risk matrices of the individual actors. Depending on whether the acceptable risks in their matrices or the shared decision-making framework are exceeded, actors such as BRZO-companies, ProRail, and RWS point out specific areas where flood risks pose unacceptable infrastructure failure. For these areas, the Port of Rotterdam and the Municipality of Rotterdam commission a cost-benefit analysis, which Deltares must construct. The risk dialogue participants decide that if the cost-benefit analysis of the measures is positive, the implementation measures are considered adaptive and feasible from an institutional and technical perspective, and the risk dialogue participants select the measures as final measures.

4.2.2. Conclusions from the diagrams

Risk dialogues I and II show that the Port of Rotterdam and the Municipality of Rotterdam have an important coordinating role in conducting the risk analysis and aligning the risk perceptions of the other actors involved. They do so through the development and formulation of a shared decision-making framework and by considering the input of the parties involved. However, the diagram visualises three points of concern in the first risk dialogue (Fig. 6) pointing to three parties, namely ProRail, BRZO and RWS, who can use both their own risk matrices and the shared decision-making framework developed during the risk dialogue. These points of concern suggest a conflict between the risk acceptance level in the rules-in-form (i.e. shared decision-making framework) and the actual rules-in-use (i.e. individual risk matrices of infrastructure owners and the BRZO-companies). This can also be related to an institutional void: there are no institutions that predetermine the criteria based on which an actor must determine risk acceptance, and in what manner this must be done. The absence of a common systematic approach for prioritising and weighing different short-, mid-, and long-term can impact the translation of identified risks into an actual implementation agenda.

The second point is that not all categories of climatic impacts are discussed during risk dialogue I and II: a focus on drought and heat is missing, and their impacts are also not incorporated in the shared decision-making framework (Table 1). While risk dialogues may be arranged for different climatic hazards, and different areas, it is important to note that potential climatic impacts can be neglected.

The third point follows from a reflection on the network metrics for the risk dialogue diagrams. ProRail (1.5) and RWS (1.5) are again the most central actors in risk dialogue I as compared to all other actors (0.75 in Table C3) reflecting the importance of their inputs for carrying out the dialogue. For the second workshop however (risk dialogue II), all actors have equal roles (centrality of 1) in identifying failures and concluding final measures. Nonetheless, by looking at the embeddedness of objects in both workshops (risk dialogue I, II) (Table C4), we see that the objects that create dependency between institutions are in fact the risk analyses that were initially conducted in the knowledge gathering phase (flood risk analysis and stress tests) rather than the ones used in the risk dialogues (individual risk matrices and shared decision-making framework), highlighting the importance of the initial analysis not only during risk dialogues but the eventual construction of an implementation agenda. Complementing this information with the institutional conflict marked in the diagram, we can conclude that although risk assessment criteria (shared framework, individual) matrices are not clear to involved parties, given that the probability analysis is fundamental in carrying out various institutional activities in all phases, the final institutional outcome may still be effective in terms of climate action. This can also be supported by the high embeddedness of the ultimate object of the risk dialogue namely “final measures”. Finally, in terms of IDR (Table C5), the risk dialogue workshops have the highest value (0.60, 0.36) among all diagrams as almost all of the institutions within this action situation depend on the implementation of other institutions for their execution. This high connectivity between institutions shows the complex institutional environment in which parties have to carry out a “dialogue” using various sources of information and their existing and internal institutions which may at times be in conflict with the formal requirements of DPSA.

4.3. Drawing up an implementation agenda

After conducting the risk dialogues, implementation agendas are formulated for concrete plans of actions. The implementation agenda also includes the investments necessary to conduct the plans.

4.3.1. Institutional context captured in the diagram

The interviews showed that none of the actors are actually implementing measures yet. Therefore, only two types of measures are incorporated in Fig. 7 which have the potential to be implemented across the Port: improved emergency procedures, and the adaptation of infrastructures to flood risks.

In the knowledge gathering phase for climate adaptation, every party focuses on its own infrastructure. However, every infrastructure is situated in an area where multiple infrastructures with different ownerships overlap or lie adjacent to each other. Sometimes, the cause of the climatic hazards leads to the conclusion that interventions in the areas of other stakeholders are necessary. An example in the diagram (Fig. 7) shows waterproofing of rails is required, and ProRail proposes improved rainwater drainage to achieve this. However, in order to improve rainwater drainage, ProRail needs to cooperate with RWS since the water storage areas are owned by this actor. RWS may either enlarge water storage areas near the railways, or adapt the norms for rainwater drainage of roads.[3]

4.3.2. Conclusions from the diagram

The diagram highlights a point of concern: it is not clear who will be financing the expansion of the water storage areas: is it the party who is capable of realising rainwater storage close to the railways, or is it the risk bearer, in this case, ProRail? This point of concern, suggests an institutional void regarding the division of responsibilities for the financing of adaptation measures. The absence of regulations that clarify liabilities, compensation, and other financial responsibilities could leave actors with little guidance to expand water storage areas. The network metrics reflect low institutional dependency (0.16) in the drawing up of an implementation agenda. This does not necessarily mean that the institutions are independent of each other for execution, but points to the fact that this action situation has not yet been fully rolled out to create a complex institutional environment similar to the risk dialogues with dependencies and potential overlaps between institutions. This is also confirmed by the low embeddedness of different objects (0 – 0.5 in Table C4) in this action situation. Finally, similar to other action situations, ProRail and RWS as infrastructure owners and the Province of South-Holland are central in carrying out institutions as compared to other parties in this action situation.

5. Discussion

In this section we summarise the findings for climate adaptation in the Port of Rotterdam, that the INA approach has offered.

5.1. Visualising institutional interrelations and dependencies

To build the diagrams, data from both documents and interviews were used, which allowed us to identify both formal and informal institutions to map them in one picture, and to observe and analyse their potential relations. By focusing solely on institutional statements, we were able to shift our focus from actors and decision-making processes, to conditions and outcomes that define institutional processes. The relationships between institutions indicate a form of causality, explaining how the outcome of an institution triggers the execution of a different one.

Given the polycentric and explorative character of climate change adaptation policies such as those in this study, the INA approach can be highly beneficial as a tool to concurrently map *all* institutions and to observe how institutions defined in different levels relate to one another. This could allow policy makers to better align formal and informal institutions in order to support their actual execution.

[3] Roads have norms for how fast rainwater needs to flow away from the road. In Dutch they call this ‘hemelwaternormering’.

5.2. Identification of points of concern

Besides providing a visualisation of institutional relations, being able to identify points of concern is an important benefit of drawing network diagrams.

Institutional points of concern were identified in two diagrams. The first point of concern highlighted a conflict between the rules-in-use and rules-in-form for risk assessment. During the risk dialogue which is organised by the Port of Rotterdam, a shared decision-making framework is constructed based on various economic, societal, and environmental consequences that actors report on and use in their risk assessments. However, actors may also use their own risk matrices to determine the acceptability of risks. This can be problematic since the individual risk matrices do not take the risks of other infrastructures into account. The shared decision-making framework can secure the alignment of diverse perceptions and tolerances for climate risks.

The second point of concern was related to the financial responsibilities for climate adaptation.

While officially, companies and citizens are responsible for the risks of water hazards in outer-dike areas, the financial responsibilities of actors in climate adaptation are ambiguous and not defined when infrastructures cross each other. The risks that one infrastructure owner perceives, may only be mitigated through adaptation measures taken by the other infrastructure owner, but it is not clear how the measures ought to be financed. This point of concern is in fact the result of a higher-level institutional void. There are no institutions that formally clarify and distribute financial responsibilities for climate adaptation among actors in a setting where infrastructures cross each other.

While these points of concern may also be identified through qualitative analysis of interviews and policy documents, being able to systematically point at specific institutional statements that are in conflict with each other, is an advantage that these diagrams and the INA approach offer.

5.3. Insights from the network metrics

The network diagrams can also be quantitatively analysed through three metrics: centrality of attributes, embeddedness of objects, and the institutional dependency rate (IDR). These metrics provide complementary insights that are not immediately visible in the diagrams. They also facilitate quantitative comparison between objects, actors (attributes), and between diagrams. For example, while the knowledge gathering diagram seem to show many connections between different institutions, the IDR metric showed that this phase of climate adaptation has actually the least institutional dependency as compared to all the other diagrams. Likewise, the centrality metric showed that ProRail is a very important actor across all action situations as it carries out many institutional activities while by just looking at the diagrams or through a qualitative analysis, one may assume that various government bodies (national, regional and local) play a more central role. Finally, by looking at the embeddedness value of objects in the institutional context, we were able to conclude that the point of concern identified in the diagram that was related to ambiguity in assessment criteria (shared framework vs. individual risk matrix) may not be too problematic for the eventual goal of climate adaptation, as the analysis that these assessment criteria build on are in fact the same.

5.4. Linking institutional network diagrams

The network metrics already provide a basis for comparison across diagrams. Yet the diagrams can also be connected to each other for a more comprehensive view. This linking can be done in two different ways: (1) based on the sequence of action situations, and (2) based on objects. For the case of Rotterdam, the links were including objects in one diagram to the institutions they affect in the subsequent diagram (these are already visible in the diagrams in this paper). The linkages show that the outcomes of the knowledge gathering phase determine the risk perception of actors in the next phase. The risk perception gives substance to the shared decision-making framework constructed for the risk assessment, and how much budget will be required to take the necessary measures.

6. Conclusion

The goal of this research was to systematically track the connectivity and dependencies between institutions in climate adaptation of transport infrastructures around ports to enhance the adaptive capacity of society as a whole. This was done by a new approach called the "Institutional Network Analysis" (INA).

The analysis of our network diagrams provides two main insights for our case study: (1) institutional ambiguity in the use of assessment criteria, and (2) institutional void on the definition of financial responsibilities where infrastructures overlap.

For conflicts raised due to multiplicity of assessment criteria, although a shared decision-making framework has already been implemented, actors tend to follow their own criteria. At the same time, our quantitative analysis revealed that the primary analysis used to build the assessment criteria stem from the same source, suggesting that this multiplicity may not have a detrimental impact in the final carrying out of adaptation strategies. Nonetheless, our analysis highlights the need to bring more legitimacy to the shared decision-making framework by facilitating more dialogue among actors for more consensus building.

The conflicts that arise from the lack of clarity on financial responsibilities actually lead to a more general institutional void. This highlights the need for institutional frameworks that more clearly outline the responsibilities of involved parties. This clarification should also include information on the availability of financial sources on national, regional, and local levels depending on the size of the hazards.

The INA approach offers three distinct features that are especially insightful for climate change adaptation, given the polycentric and layered nature of this domain. First, visualising institutions from various sources, both formal, and informal and capturing their relations, provides a comprehensive picture of the institutional landscape which can help to analyse policies and align climate efforts. Second, the diagrams allow us to locate exact points of concern at the level of institutional statements such as institutional voids or conflicts, that may act as barriers towards the implementation of climate agendas. Third, the network metrics, given complementary quantitative evidence about the importance of actors and objects in the institutional landscape as well as its level of institutional dependency for carrying out climate strategies.

6.1. Limitations and recommendations for future research

One of the main limitations of this work was related to data collection. The majority of the national infrastructure owners are still in the phase of gathering knowledge about the impacts of climate change. Therefore, the interviewees had less experience with regard to other phases.

There are also several areas for further development of the INA approach. First, the diagrams solely focus on institutional statements, and do not include the underlying objectives and interests of actors that may influence the whole institutional landscape. Second, the diagrams provide a static snapshot of institutional relations. A promising future direction would be to include these networks into computational models with approaches such as agent-based modelling and system dynamics modelling to (1) study the institutional landscape overtime, (2) include a two-way interaction between actors and institutions, and (3) include other components of the IAD framework (e.g. physical environment) in the analysis. Finally, with the current case study, we were not able to study compliance with the diagrams, while this can be an important institutional consideration worth studying in other case studies.

CRediT authorship contribution statement

Batoul Mesdaghi: Writing – original draft, Conceptualization, Formal analysis, Investigation. **Amineh Ghorbani**: Writing – original draft, Conceptualization, Methodology, Validation, Formal analysis, Investigation, Supervision. **Mark de Bruijne**: Writing – review & editing, Supervision, Validation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Data gathering

In selecting respondents for the semi-structured interviews, the following criteria were used:

1. The respondent is part of an organisation which owns and manages transport infrastructures connected to the Port of Rotterdam. The Port of Rotterdam has an extensive network of intermodal transport connections, namely: rail transport, inland shipping, road transport, and pipelines.[4]
2. The respondent is part of an organisation that is a user of the Ports' infrastructure.[5] Disruptions in infrastructures connected to the Port pose economic risks to these users. Therefore, it is important to understand to what extent and in what way the private sector is involved in climate adaptation.
3. The respondent is part of an organisation who has a stake in climate adaptation in the Port of Rotterdam. The Municipality of Rotterdam is the biggest shareholder in the Port. It does not only attach value to the economic prosperity of the Port, but also to the societal disruptions which might result from problems that the users of the infrastructures experience.
4. The respondent is affiliated with climate adaptation policy making in the Netherlands. First, the Ministry of Infrastructure and Water Management is the responsible ministry for climate adaptation in the Netherlands. An interview with this Ministry helps in getting a better understanding of the larger and more long-term objectives behind the current structure of the DPSA. Furthermore, the Royal Dutch Meteorological Institute is responsible for making climate change scenarios in the Netherlands. The institute may therefore provide information on how this data is used and what the needs are of different actors in terms of climatic information.
5. The respondent is involved in climate adaptation efforts in or surrounding the Port of Rotterdam.

Table A1
A list of key documents reviewed during the desk research.

Documents	
Adaptation phase	Sources
Mapping out vulnerabilities	Standardised stress test information leaflet for the Delta Plan for Spatial Adaptation, other climate impact research of infrastructure owners.
Conducting risk dialogues	Risk dialogue guides, climate adaptation strategies (national, regional, local).
Drawing up an implementation agenda	Climate adaptation implementation programmes, climate adaptation guides (e.g. how to preserve climate-resistance in planning), rules and guidelines for infrastructure construction.

Table A2
The topics based on which the semi-structured interviews were conducted with some general example questions.

Questions	
Topics	Example questions
Knowledge gathering efforts	In what ways do you assess the sensitivity of an area for climate impacts? Are stress tests the leading means for knowledge improvement? Do you work together with other parties in knowledge gathering efforts (e.g. providing input, collaborative research…)? How often do you update existing research?
Risk assessment and perception	What climatic impacts do you focus on the most? How do you decide whether a climatic impact is significant?
Knowledge exchange	How are risks communicated between actors? Through risk dialogues? Which parties participate in these dialogues? What are the objectives of these dialogues? How do you decide which knowledge base to give prevalence to, given that different parties conduct research? How do you come to an agreement on the course of action to take?
Implementation and monitoring	Which rules and regulations do you have to comply to in spatial adaptation of infrastructures? When is a policy climate-resistant? How do you translate your knowledge efforts into climate adaptation measures? How do you decide which measures are necessary? Who is responsible when climatic hazards impact infrastructures?

Table A3
List of actors who were interviewed.

Actors	
Government agencies	Ministry of Infrastructure and Water Management, RWS, (**R**ijks**w**ater**s**taat, the executive agency of the Ministry of Infrastructure and Water Management), Province of South-Holland, Municipality of Rotterdam.
Experts	Dutch Royal Meteorological Institute (KNMI)
Private sector	LSNed, ProRail, Port of Rotterdam, Deltalinqs

Respondents with job positions which included the words "spatial adaptation", "environmental", or "climate adaptation" were the first to be contacted. Through email, the purpose of the research was explained, and timeslots were proposed for an interview. A total of 29 potential respondents were contacted, of which 16 agreed to participate in an interview.

While all the interviews were planned at the working offices of the respondents, the interviews were conducted online through Skype, Microsoft Teams, or phone calls because of the coronavirus outbreak. Prior to the interviews, prepared consent forms were emailed to the

[4] The rail infrastructure is owned by ProRail. Inland waterways and roads are either owned by Rijkswaterstaat or the Province of South-Holland. Pipeline owners are mostly chemical companies and refineries. Pipelines run between companies in the port, or run to other destinations in the Netherlands, Belgium, and Germany. One of the supervisory bodies for the pipelines routes in LSNed

[5] The logistic, ports, and industrial enterprises in the Port of Rotterdam are represented by the interest group Deltalinqs.

respondents, and emailed back. During all the interviews, notes were taken. The interviews were recorded, and transcripts were made for the data coding and clustering (Figs. B1 and B2), and the formalisation of the institutions (Table C1).

Appendix B. Data coding and clustering

For this research, the data was clustered through several steps.

After formulating some initial themes related to climate adaptation of transport infrastructures, all the interview transcripts were read to write down common themes that were found within the transcripts themselves. These common themes found in transcripts, along with the three phases of climate adaptation, were used for coding the data (Harding, 2015). The following larger clusters were identified:

1. Important risks for infrastructures. When explaining climate adaptation efforts, respondents had different climatic impacts that they considered to be critical for their organisation. This was done by giving examples of how the functionality and capacity of infrastructures is affected by these impacts, such as drought, extreme weather, or heavy rainfall.
2. Rules and guidelines. Respondents explained according to which frameworks their organisation were undertaking climate adaptation efforts.
3. Measures which can be implemented for climate adaptation. Given the geographic area or infrastructure that the organisation of the respondent owned and managed, different types of adaptation measures could be undertaken.
4. Decision-making processes on climate adaptation. Respondents described which decisions were undertaken for climate adaptation, and in what manner these decision-making processes took place (e.g. through iteration, one-off…).
5. Links and cooperation between stakeholders. Respondents mentioned different organisations cooperating with them in enhancing the knowledge on climate adaptation through research, or other actors they were dependent on for undertaking measures for infrastructures.
6. Views and perceptions on climate adaptation efforts. The stakeholders expressed how they perceive the cooperation and interaction with other stakeholders so far with respect to generating knowledge and forming an implementation agenda for climate adaptation.

For every respondent, a network was made with the network-creation function in Atlas.ti. This function allows the researcher to connect codes, along with their quotations in the interviews. The relationships are defined by the researcher, and follow from reading the interview transcripts. Two examples of the networks is shown in Figs. B1 and B2.

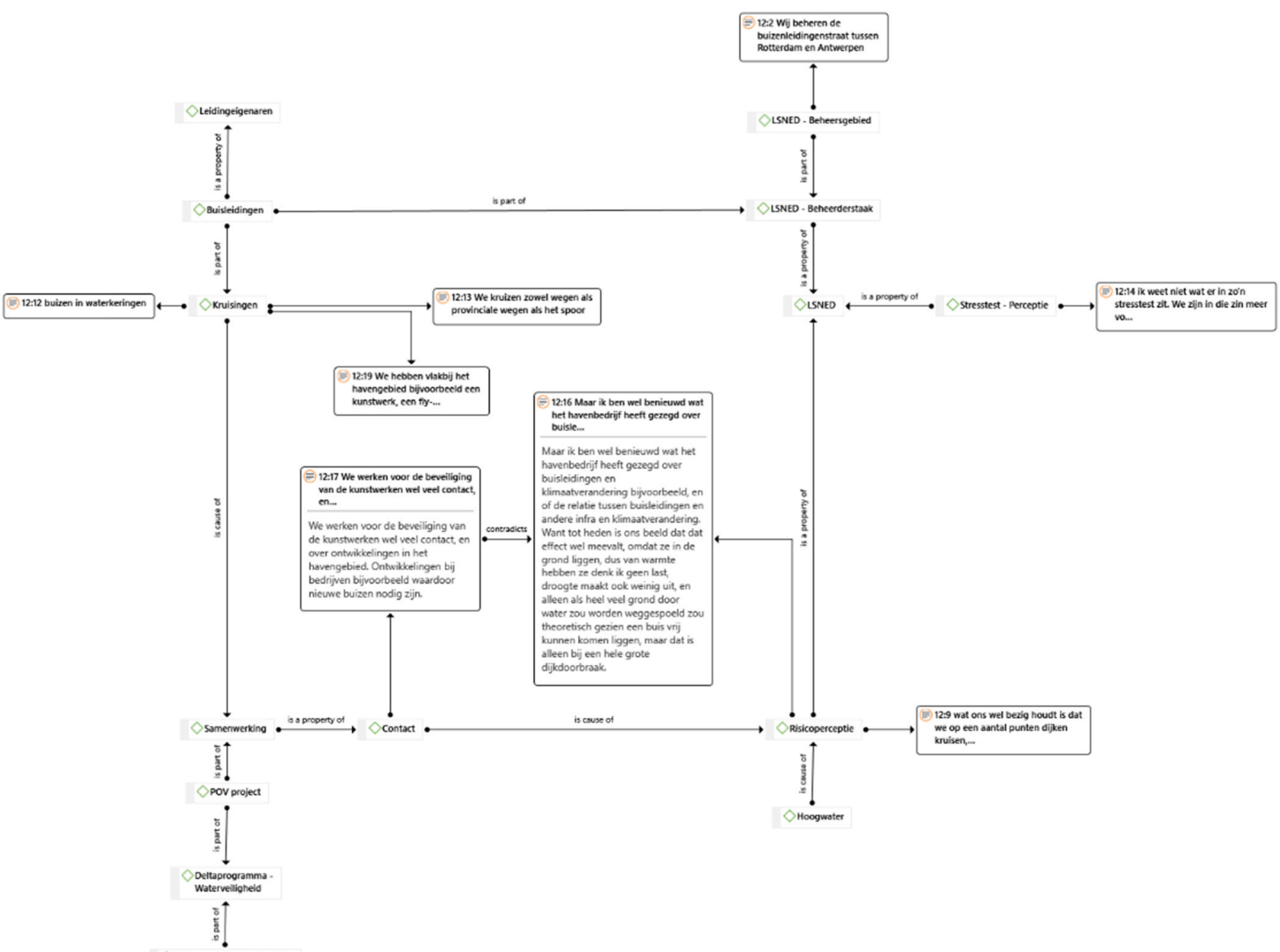


Fig. B1. An example of part of a networks made for the interview transcripts.

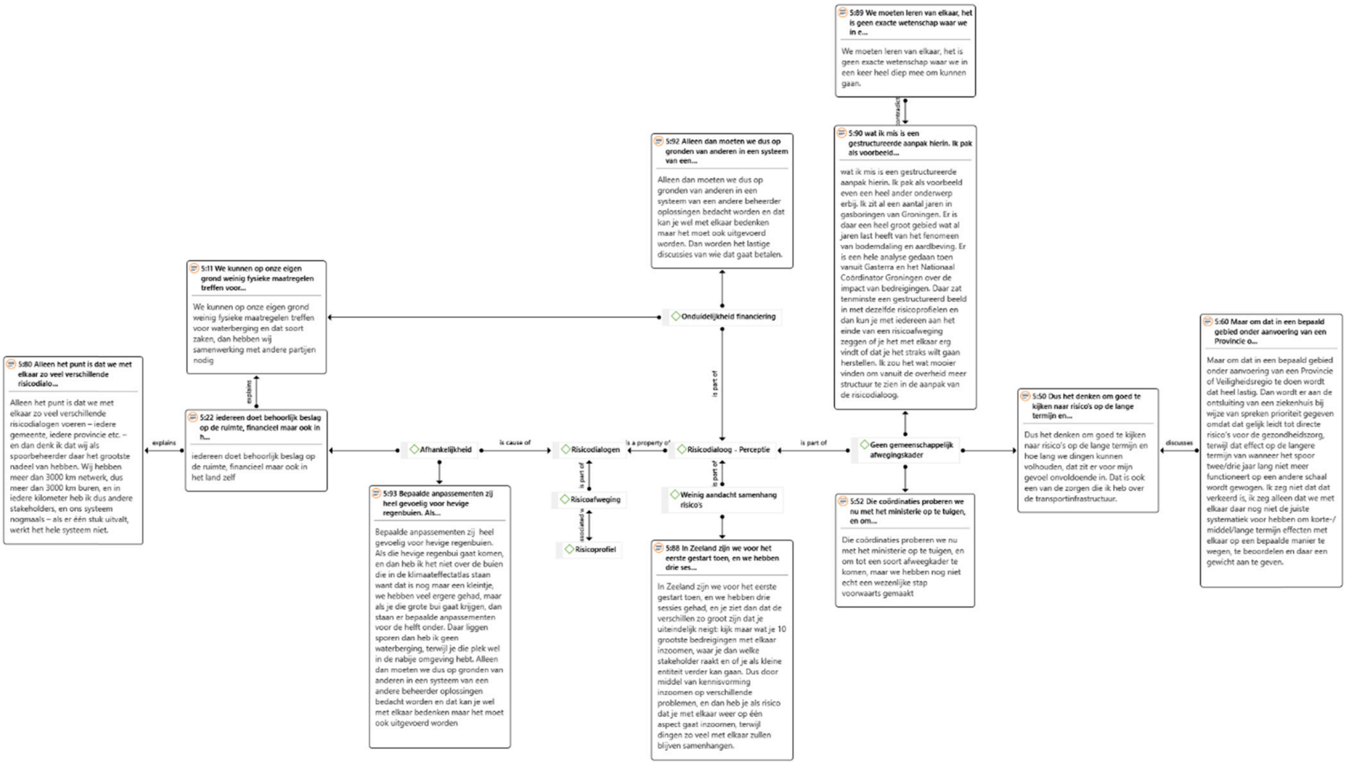


Fig. B2. An example of part of a networks made for the interview transcripts.

Appendix C. Institutional Network Analysis

C.1 Network diagram methods and metrics

Table C1 shows the steps for drawing a diagram according to the INA approach. Table C2 shows the network metrics that are defined in the INA approach. The results of the metrics for our case can be found in Tables C3, C4 and C5. Figures C1 and C2 show the diagrams for the vulnerability assessment of the knowledge gathering phase and risk dialogue II.

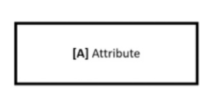
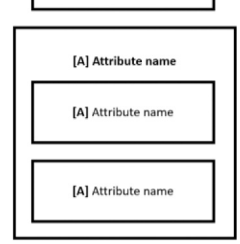
C.2 Complementary network diagrams

Stress tests generally include two types of visualisations: the first type of visualisation shows the climatic effects, so where the water hazards, drought, heat, and floods are at their highest levels. In this action arena, the Climate Impact Atlas of the Province of South-Holland was published online (Province of South-Holland), and the stress test for the national road network by RWS was sent to the researcher. The stress tests were used to assess how every climatic hazard was quantified, and how the vulnerabilities were shown in the maps.

For several stakeholders, the stress tests were not publicly available or were being updated. The Municipality of Rotterdam also made a stress test, but this was not published. In the case of railway owner ProRail, the stress test was also not available, but there was a guide which showed different vulnerability categories for climatic hazards (ProRail).

The reason why these three actors are shown in the diagram is because only they had made this information publicly available. Not all the actors involved had made their stress test publicly available or they

Table C1
Steps for drawing an institutional network diagram.

Step	Concept in ABDICO syntax	Visual representation in the diagram
1. Define action arena for the basis of the diagram.	–	Title of the diagram
2. Determine institutional statements that belong to the action arena.	–	–
3. Per institutional statement, a rectangle represents an attribute [A] which can be single or multiple. Note: if several institutions share the same attribute, one attribute box can be drawn and shared across institutions.	Attribute(node)	
4.	Attribute(node)	

(continued on next page)

Table C1 (*continued*)

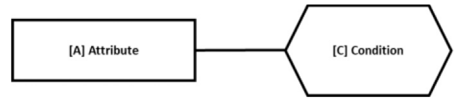
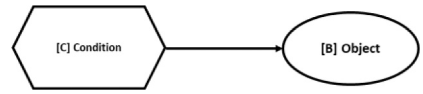
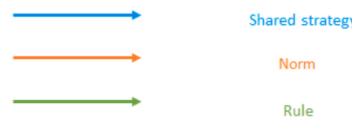
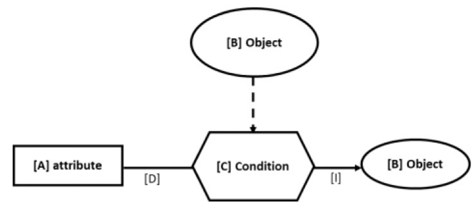
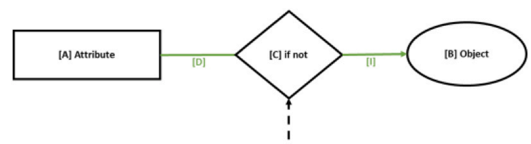
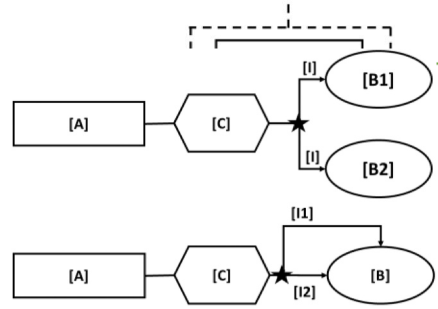
Step		Concept in ABDICO syntax	Visual representation in the diagram
	The link between the attribute and the condition of a statement captures the deontic type [D] of that statement. In case of shared strategy, this link does not have a name.Note: if several institutions share the same condition, this condition has to be drawn separately for each institution.	Deontic(link) Condition(node)	
5.	The link between the condition and the object of a statement captures the aim [I] of that statement. Note: if several institutions share the same object, one object can be drawn and shared across institutions.	Condition (node) Aim (link) Object (node)	
6.	The links are colour coded to distinguish between rules, norms and shared strategies (between attribute and condition(s), between condition(s) and object).	ABDICO ABDIC ABIC	
7.	If the object of one institutional statement influences the condition(s) of another institutional statement, draw a dotted arrow from the object of that institutional statement, to the condition(s) of the other institutional statement.	Object Condition	
8.	Sanctions are defined as special types of institutional statements with an "if not" condition. In the presence of a sanction, the (potentially) non-conforming attribute is connected to the condition of the sanctioning statement.	Or else	
9	Points of concern occur in two situations: 1. When the attribute, the aim and the condition of two statements are the same, but the objects are different 2. When the attribute, the condition and the object are the same but the aims are different. This is depicted with a black star.	–	

Table C2
Network metric calculations.

Metric	Calculation	Range
Centrality	Number of links per attribute connecting them to conditions, divided by the average number of links per attribute connecting them to conditions (Janssen et al., 2006)	Range: [0, ∞] A high degree for an attribute implies an important position in the carrying out of institutions and the spread of information (Hanneman and Riddle, 2005).
Embeddedness	Number of links directed out of the object, divided by the total number of links (in-degree + outdegree) per object. Note that these links are counted across all diagrams per object.	Range: [0,1] A high value for an object implies that high number of institutions are dependent on this object for their execution.
Institutional dependency rate (IDR)	Number of outdegree links from all objects divided by all possible outdegree links (i.e. every institutions (i.e. object) being connected to all other institutions (only possible through conditions)). All possible connections $= 0.5 *$ conditions $*$ (conditions – 1) To count all institutions in a diagram, the conditions can be counted as they are always present and there is always one condition per institution. Note, while counting outdegree links of objects, all diagrams should be considered.	Range: [0,1] A high value for a diagram implies that a high number of institutions in the diagram rely on the execution of other institutions for their own execution.

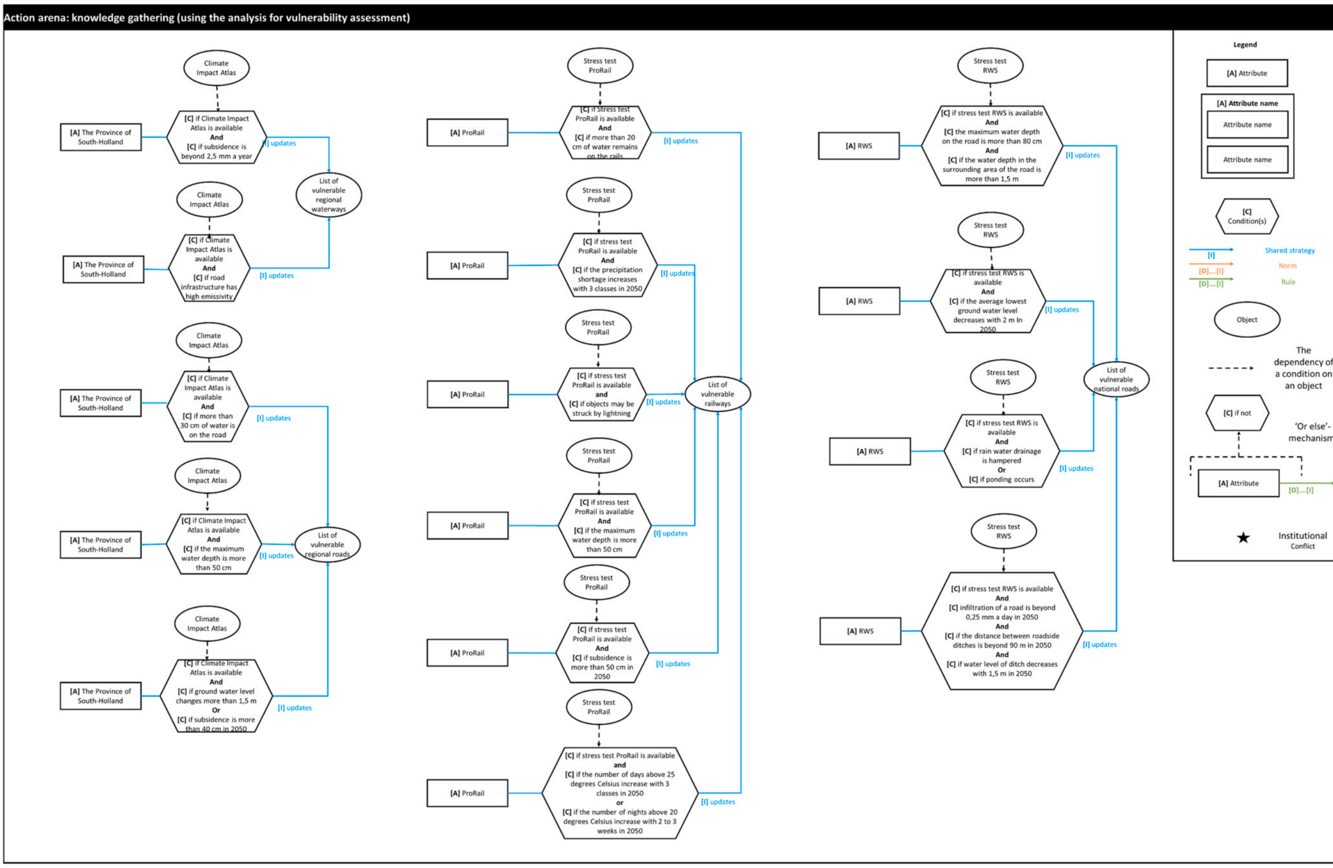


Fig. C1. Knowledge Gathering: vulnerability assessment.

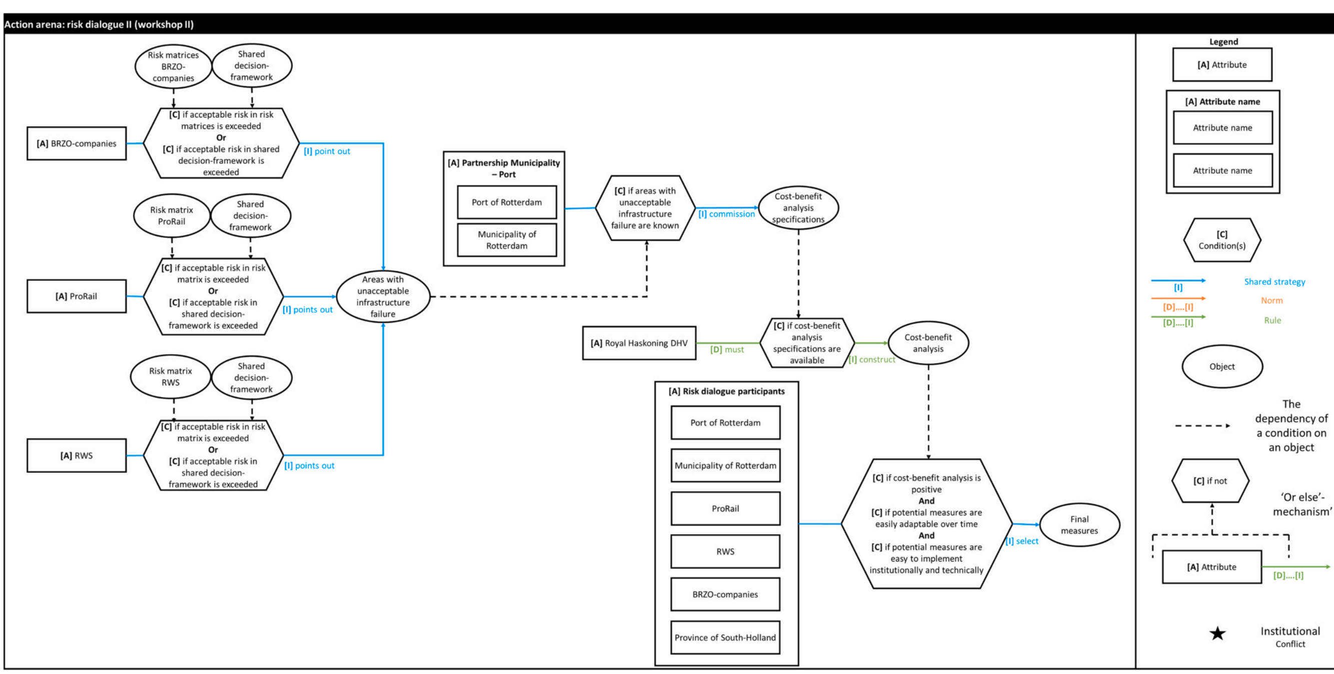


Fig. C2. Risk dialogue II.

were still constructing the stress test. In the case of ProRail for example, the stress test was not put online, but the information about categories showing the vulnerability of the rail infrastructure for climate change could be retrieved in a special guide related to sustainable project management, but this was not the case for other parties. RWS was constructing both stress tests for the national waterways and the roads, but only the latter was finished and shared for this research only.

C.3 Network Metric Results

See Tables C3–C5 for the network metric results.

Table C3
Centrality of actor for each action situation (i.e. diagram).

Knowledge gathering	
Attribute	Centrality
Partnership Municipality – Port	0.88
Royal Dutch Meteorological Institute	0.44
ProRail	3.08
The Ministry of Infrastructure and Water Management	0.44
RWS	2.2
Province of South-Holland	2.64
Royal Haskoning DHV	0.44
Stress test conduction group	0.44
Risk assessment experts	0.44
Average	*2.27*
Risk dialogue I	
Partnership Municipality – Port	0.75
ProRail	1.5
Risk dialogue participants	0.75
RWS	1.5
Province of South-Holland	0.75
BRZO-companies	0.75
Average	*1.33*
Risk dialogue II	
Partnership Municipality – Port	1
ProRail	1
Risk dialogue participants	1
RWS	1
Royal Haskoning DHV	1
BRZO-companies	1
Average	*1*
Drawing up implementation agenda	
ProRail	1.45
RWS	1.45
Province of South-Holland	1.45
BRZO-companies	0.73
Port of Rotterdam	0.73
Municipality of Rotterdam	0.73
Transmission systems operator (Tennet)	0.73
Regional waterboards	0.73
Average	*1.38*

Table C4
Embeddedness of objects.

Knowledge gathering	
Object	Embeddedness
Flood probability analysis specifications	0.50
Flood probability analysis	0.67
Flood risk analysis specifications	0.50
Flood risk analysis	0.50
New climate change scenarios	0.80
Stress test construction frequency	0.75
Stress test specifications (RWS)	0.50
Stress test specifications (ProRail)	0.50
Stress test specifications (Province of South-Holland)	0.50
Stress test RWS	0.80
Stress test ProRail	0.86
Climate Impact Atlas	0.83
List of vulnerable railways	0.14
List of vulnerable national roads	0.20
List of vulnerable regional roads	0.25
List of vulnerable regional waterways	0.00
Average Embeddedness	*0.52*
Risk Dialogue I	
Shared decision-making framework	0.50
Consequences of infrastructure failure	0.33
Flood probabilities	0.67
Acceptable group risks	0.50
Risk matrix ProRail	0.50
Risk matrix RWS	0.50
Risk matrices BRZO-companies	0.50

(*continued on next page*)

Table C4 (*continued*)

Flood probability analysis	0.67
List of vulnerable regional roads	0.25
List of vulnerable railways	0.14
Flood risk analysis	0.50
Average Embeddedness	*0.46*
Risk Dialogue II	
Areas with unacceptable infrastructure failure	0.25
Cost-benefit analysis specifications	0.5
Cost-benefit analysis	0.5
Final measures	0.67
Risk matrices BRZO-companies	0.5
Risk matrix RWS	0.5
Risk matrix ProRail	0.5
Shared decision-making framework	0.5
Average Embeddedness	*0.48*
Drawing an implementation agenda	
Operating permit	0
Fine	0
Water safety risks	0.5
Electricity shutdown	0.5
Electricity facilities	0
Emergency request	0.5
Emergency services	0
Acceptable water safety risks	0.5
Flood defences	0
Improved rainwater drainage	0.5
Existing water storage areas	0.5
Project costs	0
Norms for infrastructure water drainage	0
List of vulnerable regional roads	1
Final measures	0.67
Average Embeddedness	*0.31*

Table C5
Institutional dependency rate (IDR) for each action situation.

Action situation	IDR
Knowledge gathering	0.08
Risk dialogue I	0.36
Risk dialogue II	0.60
Drawing up an implementation agenda	0.16

References

Basurto, X., Kingsley, G., McQueen, K., Smith, M., Weible, C.M., 2010. A systematic approach to institutional analysis: applying Crawford and Ostrom's grammar. Political Res. Q. 63 (3), 523–537.

Becker, A., Acciaro, M., Asariotis, R., 2013. A note on climate change adaptation for seaports: a challenge for global ports, a challenge for global society. Clim. Chang. 120 (4), 683–695.

Berman, R., Quinn, C., Paavola, J., 2012. The role of institutions in the transformation of coping capacity to sustainable adaptive capacity. Environ. Dev. 2, 86–100.

Bierbaum, R., Smith, J.B., Lee, A., Blair, M., Carter, L., Chapin III, F.S., Verduzco, L., 2013. A comprehensive review of climate adaptation in the United States: more than before, but less than needed. Mitig. Adapt. Strateg. Glob. Chang. 18, 361–401.

Zhang, H., Ng, A.K.Y., Becker, A., 2017. A Critical Discussion on the Roles of Institutions on Ports' Adaptation to the Impacts Posed by Climate Change. In: Filho, W.L., Keenan, J.M. (Eds.), *Climate Change Management: Climate Change Adaptation in North America – Fostering Resilience and the Regional Capacity to Adapt*. Springer, Hamburg, pp. 105–117.

Biesbroek, G.R., Termeer, C.J.A.M., Kabat, P., Klosterman, J.E.M., 2009. Institutional governance barriers fort the development and implementation of climate adaptation strategies. In: International Human Dimensions Programme Conference 'Earth System Governance: People, Places, and the Planet', Amsterdam, 2nd-4th December.

Bollinger, L.A., Bogmans, C.W.J., Chappin, E.J.L., Dijkema, G.P.J., Huibregtse, J.N., Maas, N., Schenkel, T., Snelder, M., Van Thienen, P., De Wit, S., Wols, B., Tavasszy, L.A., 2014. Climate adaptation of interconnected infrastructures: a framework for supporting governance. Reg. Environ. Chang. 14, 919–931.

Chappin, E.J.L., Van der Lei, T., 2014. Adaptation of interconnected infrastructures to climate change: a socio-technical systems perspective. Util. Policy 31, 10–17.

Crawford, S.E.S., Ostrom, E., 1995. A grammar of institutions. Am. Political Sci. Rev. 89 (3), 582–600.

De Bruin, K., Dellink, R.B., Ruijs, A., Bolwidt, L., Buuren, A.V., Graveland, J., Ierland, E. C.V., 2009. Adapting to climate change in the Netherlands: an inventory of climate adaptation options and ranking of alternatives. Clim. Chang. 95, 23–45.

Delmas, M.A., Toffel, M.W., 2004. Institutional pressure and environmental management practices: an empirical analysis. Bus. Strategy Environ. 13, 209–222.

Delta Programme Commissioner, 2020a. Wat is het Deltaprogramma? ⟨https://www.deltacommissaris.nl/deltaprogramma/wat-is-het-deltaprogramma⟩.

Delta Programme Commissioner, 2020c. Deltabeslissing Ruimtelijke Adaptatie. ⟨https://www.deltacommissaris.nl/deltaprogramma/deltabeslissingen/deltabeslissing-ruimtelijke-adaptatie⟩.

Delta Programme Commissioner, 2020b. What is the Delta Programme? ⟨https://english.deltacommissaris.nl/delta-programme/question-and-answer/what-is-the-delta-programme⟩.

Earl, P.E., Potts, J., 2011. A nobel prize for governance and institutions: Oliver Williamson and Elinor Ostrom. Rev. Political Econ. 23 (1), 1–24.

Ford, J.D., Berrang-Ford, L., Paterson, J., 2011. A systematic review of observed climate change adaptation in developed nations. Clim. Chang. 106 (2), 327–336.

Forzieri, G., Bianchi, A., Silva, E., Herrera, F.B., Leblois, M.A.M., Lavalle, A., C, Aerts, J. C.J.H., Feyen, L., 2018. Escalating impacts of climate extremes on critical infrastructures in Europe. Glob. Environ. Chang. 48, 97–107.

Glaas, E., Juhola, S., 2013. New levels of climate adaptation policy: analysing the institutional interplay in the Baltic Sea region. Sustainability 5 (1), 256–275.

Hajer, M., 2003. Policy without polity? Policy analysis and the institutional void. Policy Sci. 36, 175–195.

Hanneman, R.A., Riddle, M., 2005. Centrality and power. In: Hanneman, R.A., Riddle, M. (Eds.), Introduction to Social Network Methods. University of California, Riverside, pp. 144–169.

Harding, J., 2015. A Discourse Analysis Approach to Interview Data: The Guidance Tutor Role in Higher Education. SAGE Publications Ltd., London, UK.

He, Y., Ng, A.K.Y., 2019. Climate change adaptation by ports: the attitude and perception of Chinese port organisations. In: Bergqvist, R., Monios, J. (Eds.), Green Ports: Inland and Seaside Sustainable Transportation Strategies. Elsevier, Oxford, pp. 155–171.

Hinkel, J., Bisaro, A., 2016. Methodological choices in solution-oriented adaptation research: a diagnostic framework. Reg. Environ. Chang. 16, 7–20.

Hufty, 2011. Investigating policy processes: the Governance Analytical Framework (GAF). In: Wiesmann, U., Hurni, H. (Eds.), Research for Sustainable Development: Foundations, Experiences and Perspectives. Geographica Bernensia, Bern, pp. 402–424.

IPCC, 2018. Summary for Policymakers. Global Warming of 1.5 °C: An IPCC Special Report on the Impacts of Global Warming of 1.5 °C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening

the Global Response to the Threat of Climate Change. October 30, 2020, ⟨https://www.ipcc.ch/sr15/chapter/spm/⟩.
Juhola, S., Westerhoff, L., 2013. Challenges of adaptation to climate change across multiple scales: a case study of network governance in two European countries. Environ. Sci. Policy 14 (3), 239–247.
Kretsch, E., Becker, A., 2016. Leadership and responsibility for long-term hurricane resilience: port of providence. In: Transportation Board Research Conference for Committee on Maritime Transportation System (CMTS), 21–23 June 2016, Washington, United States.
Lawrence, J., Sullivan, F., Lash, A., Ide, G., Cameron, C., McGlinchey, L., 2015. Adapting to changing climate risk by local government in New Zealand: institutional practice barriers and enablers. Int. J. Justice Sustain. Local Environ. 20 (3), 298–320.
Lubell, M., 2013. Governing institutional complexity: the ecology of games framework. Policy Stud. J. 41 (3), 537–559.
McDonald, J., Styles, M.C., 2014. Legal strategies for adaptive management under climate change. J. Environ. Law 26 (1), 25–53.
McGinnis, M.D., 2011. Networks of adjacent action situations in polycentric governance. Policy Stud. J. 39 (1), 51–78.
Mclean, E.L, Becker, A., 2019. Decision makers' barriers to climate and extreme weather adaptation: a study of North Atlantic high- and medium-use seaports. Sustainability Science 14 (5), 1–13.
Mees, H.L.P., Droessen, P.P.J., Runhaar, H.A.C., 2012. Exploring the scope of public and private responsibilities for climate adaptation. J. Environ. Policy Plan. 14 (3), 305–330.
Messner, S., Becker, A., Ng, 2016. Port adaptation for climate change: the role of stakeholders and the planning process. In: Ng, A.K.Y., Becker, A., Cahoon, S., Chen, S.L., Earl, P., Yang, Z. (Eds.), *Climate change and adaptation planning for ports*. Routlegde, Abingdon, pp. 9–23.
Mutombo, K., Ölçer, A., 2017. Towards port infrastructure adaptation: a global port climate risk analysis. WMU J. Marit. Aff. 16, 161–173.
Nemry, F., Demirel, H., 2012. Impacts of Climate Change on Transport: A Focus on Road and Rail Transport Infrastructures (Report No. JRC72217). European Commission, Joint Research Centre (JRC), Institute for Prospective Technological Studies (IPTS).
Ng, A.K.Y., Monios, J., Zhang, H., 2019. Climate adaptation management and institutional erosion: insights from a major Canadian port. J. Environ. Plan. Manag. 62 (4), 586–610.
North, D.C., 1991. Institutions. J. Econ. Perspect. 5 (1), 97–112.
Obeng, P.A., Agyenim, J.B., 2013. Climate change adaptation: institutional approaches for developing countries. In: Knieling, J., Filho, W.L. (Eds.), Climate Change Governance. Springer-Verlag, Berlin, pp. 185–204.
Oberlack, C., 2016. Diagnosing institutional barriers and opportunities for adaptation to climate change. Mitig. Adapt. Strateg. Glob. Chang. 22, 805–838.
Oberthür, S., Stokke, O.S., 2012. Institutional complexity and interplay management: compatibility and change in global governance. In: Lund Conference on Earth System Governance – Towards a Just and Legitimate Earth System Governance: Addressing Inequalities, Lund, 18th-20th April.
Ostrom, E., 1999. Institutional rational choice: an assessment of the institutional analysis and development framework. In: Sabatier, P.A. (Ed.), Theories of the Policy Process. Westview Press, Boulder, CO, pp. 35–71.
Ostrom, E., 2009. Understanding Institutional Diversity. Princeton University Press.
Ostrom, E., 2011. Background on the institutional analysis and development framework. Policy Stud. J. 39 (1), 7–27.
Ostrom, E., Cox, M., Schlager, E., 2014. An assessment of the institutional analysis and development framework and introduction of the social-ecological systems framework. In: Sabatier, P., Weible, C. (Eds.), Theories of the Policy Process. Westview Press, CO, pp. 35–71.
Pittock, J., 2010. A pale reflection of political reality: integration of global climate, wetland, and biodiversity agreements. Clim. Law 1, 343–373.
Port of Rotterdam, Municipality of Rotterdam, & RWS, 2016. Botlek Waterveiligheid Pilot Botlek Waterveiligheid: een veilige haven – nu en in de toekomst. ⟨https://www.portofrotterdam.com/nl/onze-haven/onze-themas/een-veilige-haven/waterveiligheid⟩.
Preston, B.L., Rickards, L., Fünfgeld, H., Keenan, R.J., 2015. Towards reflexive climate adaptation research. Curr. Opin. I Environ. Sustain. 14, 127–135.
Rattanachot, W., Wang, Y., Chong, D., Suwansawas, S., 2015. Adaptation strategies of transport infrastructures to global climate change. Transp. Policy 41, 159–166.
Rice, D., Siddiki, S., Frey, S., Kwon, J.H., Sawyer, A., 2020. Machine Coding of Policy Texts with the Institutional Grammar. Public Administration.
Roggero, M., Bisaro, A., Villamayor-Tomas, S., 2018. Institutions in the climate adaptation literature: a systematic literature review through the lens of the Institutional Analysis and Development framework. J. Inst. Econ. 14 (3), 423–448.
Ruiten, K.V., Bles, T., Kiel, J., 2016. EU-INTACT-case studies: impact of extreme weather on critical infrastructure. E3S Web Conf. 7, 1–7.
Siddiki, S., Weible, C.M., Basurto, X., Calanni, J., 2011. Dissecting policy designs; an application of the institutional grammar tool. Policy Stud. J. 39 (1), 79–103.
Stead, D., 2013. Climate change, sustainability, and urban policy: examining the validity and function of best practices. In: Knieling, J., Filho, W.L. (Eds.), Climate Change Governance. Springer-Verlag, Berlin, pp. 243–258.
Storbjörk, S., Hedrén, J., 2010. Institutional capacity-building for targeting sea-level rise in the climate adaptation of Swedish coastal zone management. Lessons from Coastby. Ocean Coast. Manag. 54, 265–273.
Termeer, C., Biesbroek, R., Van den Brink, M., 2011. Institutions for adaptation to climate change: comparing national adaptation strategies in Europe. Eur. Political Sci. 11, 41–53.
UN, 2014. Institutional Arrangements for National Adaptation Planning and Implementation. United Nations Climate Change Secretariat, Bonn.
Watkins, C., Westphal, L.M., 2016. People don't talk in institutional statements: a methodological case study of the institutional analysis and development framework. Policy Stud. J. 44 (1), 98–122.
Well, M., Carrapatoso, A., 2016. REDD+ finance: policy making in the context of fragmented institutions. Climate Policy 17 (6), 687–707.
Williamson, O.E., 1998. Transaction cost economics: how it works; where it is headed. De Economist 146 (1), 23–58.
Young, O.R., 2002. Institutional interplay: the environmental consequences of cross-scale interactions. In: The Drama of the Commons, pp. 263–291.
https://www.zuid-holland.nl/onderwerpen/landschap/water/klimaateffectatlas/. 2021.
2019 2019.https://klimaatadaptatienederland.nl/actueel/actueel/nieuws/2019/prorail/.