

Prescribed by law and therefore realized? Analyzing rules and their implied actor interactions as networks

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Abstract

Managing environmental problems requires cross-sectoral and cross-level collaboration among actors. Scholars of institutional arrangements investigate how rules shape such collaboration. Scholars of the Advocacy Coalition Framework (ACF) look for explanations for collaboration in actors' values and beliefs. Rarely have these two factors been considered together when studying collaborative behavior. This paper considers institutional arrangements and actor values to examine the structure and potential drivers of actor collaboration. The study combines the Institutional Analysis and Development framework and the ACF, applying social network analysis to explore an interaction network prescribed by rules and a surveyed collaboration network. It tests the influence of actor beliefs, reputation, and institutional arrangements on collaboration investigating water management in the German Ruhr catchment. The study finds that perceived power and actor beliefs explain actor collaboration better than institutional arrangements and that perceived interactions are more diverse and denser than hierarchically structured networks of prescribed interactions.

KEYWORDS

Advocacy Coalition Framework, Institutional Analysis and Development Framework, institutional grammar

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INTRODUCTION

A unifying theme of public policy and management studies is collective action, its different forms, such as coordination or collaboration, and the many different types of actors and how and why they interact. Explanations for collective action, broadly speaking, divide between behavior and institutional arrangements. Behavioral studies focus on beliefs, values, and perceptions in explaining collective action. Institutional studies focus on property rights, laws, and rules. Studies grounded in the Advocacy Coalition Framework (ACF) focus on beliefs to explain why actors collaborate (Sabatier & Jenkins-Smith, 1999; Weible & Sabatier, 2005). In contrast, studies grounded in the Institutional Analysis and Development (IAD) framework identify rules as key to explaining the resolution of social dilemmas (Baggio et al., 2016; Basurto, 2005; Ostrom, 2005). Although scholars from both approaches recognize the importance of beliefs, values, perceptions, and institutional arrangements for collective action, rarely are the two explicitly combined.

Examining institutional arrangements, beliefs, and behavior together is challenging, in part because there has not been a common metric and method to incorporate both in a comparable analysis. We present an approach for bringing together fine-grained measures of institutional arrangements and well-developed measures of beliefs and perceptions of behavior: We apply the institutional grammar tool (IGT) to a German federal water law to derive networks of *prescribed* (by rules) actor interactions (Olivier, 2018), and we identify the *perceived* interactions of actors through a survey of actors to whom the law applies, focusing on beliefs, as defined in the ACF and actors' perceptions of whom they interact with. We draw on the policy network literature and use social network analysis (SNA) to explore the extent to which networks of prescribed interactions (NPIs) compare to networks of perceived interactions. We also compare the influence of institutions and beliefs for coordination in policy networks. In this context, we ask the following questions:

1. To what extent do networks of prescribed actor interactions and of perceived actor coordination overlap?
2. Who are the central actors in these networks?
3. And what is the relative contribution of rules, beliefs, and allocations of power in the setup of the perceived collaboration network?

The case under investigation is the management of water quality in the Ruhr catchment, a tributary to the river Rhine in Germany. It is an ideal case to study as both “collaboration realities” are present: First, a water quality law lays out rules to be followed, which relate to how certain actors should behave and interact with each other. Second, public and private actors are involved in daily water quality management and can thus be surveyed regarding their perceptions of collaborations. Finally, a salient issue related to water quality is on all actors' agenda: the reduction of micro-pollutants stemming from industry, agriculture, and household in the Rhine catchment area.

To study water quality management in the Ruhr and answer our research questions, we apply a novel analytical approach that combines the analytical process of the IGT with SNA, thereby conceptualizing rules as dyads between actors, and that explicitly considers actor beliefs as defined by the ACF. The paper's added value is thus twofold: It initiates a conceptual discussion about the interrelationships of institutions and values in relation to resource management, and it offers a novel methodological approach with which to study the conceptual considerations empirically (for the latter, see also Appendix S1).

The paper is structured as follows: The Theory section outlines the conceptual framing of institutions, values, and actor behavior and thus the study's theoretical starting points and justification; we then briefly describe the case study and our methodological approach and data collection procedure, with an in-depth description in Appendix S1. The results are presented along with the research questions and discussed subsequently. We finish the paper with a reflection on further research contributing to the core of this study: (a) assessing policy instruments, that is, secondary aspects in the terms of the

ACF, and behavioral responses to these; (b) studying how specific rule types condition actor behavior; and (c) assessing the interactions of rules and beliefs.

THEORY

Many theories in political and policy sciences are interested in actors' behavior, the interactions among actors, and the outcomes that are collectively realized. Such outcomes include voting and election outcomes, bargaining and decision making in a specific policy field, and the regulations and laws actors create for a society or for a community in order to solve societal problems (Knill et al., 2012; Ostrom, 1990). Among the many forms of actor behavior, actor interactions, and outcomes is collaborative governance.

Collaborative governance can be thought of as networks of actors, public and private stakeholders together with public agencies, that interact in collective forums and engage in consensus-oriented decision making (Ansell & Gash, 2008). Participation of affected, concerned, and responsible actors promotes comprehensive decision-making processes and the acceptance of decisions, which may improve implementation and the quality of outcomes (Berkes & Folke, 2002; Christensen et al., 2012; Macnaghten & Jacobs, 1997; Newig, 2012). However, there is not yet a consensus among scholars about the effectiveness or performance of collaborative forums (Gerlak et al., 2013).

One way to study interrelated, multilevel, and cross-sectoral actor arrangements is by using policy network analysis (Berardo & Scholz, 2010; Lubell, 2013). Policy outputs and outcomes are the product of networks of public and private actors (Henry, 2011; Ingold, 2011; Koppenjan & Klijn, 2004; Weible & Sabatier, 2005). Issues explored include how patterns of interactions, or networks, impact information exchange, the role of boundary organizations in linking actors and promoting knowledge exchange, or how the quality of natural resource management is affected by different forms of stakeholder involvement (Adger, 2003; Crona & Bodin, 2006; Crona & Parker, 2012; Duit & Galaz, 2008; Prell et al., 2009).

We build on this literature in two ways. First, by explicitly incorporating institutional arrangements, understood as configurations of rules, into policy network analysis, drawing on the institutional tools of the IAD framework. And second, by measuring networks of perceived collaborative interactions, in order to explore how beliefs and perceptions, in addition to rules, relate to forms of collaboration. To our knowledge, studies on policy networks and collaborative governance have not yet studied both institutions and beliefs in the context of collaborative governance in the form of actor networks but have examined these aspects independently of each other (for a study on beliefs and network structure, see, for instance, Henry et al., 2010; for a focus on the relation of institutions and policy networks, see Lubell et al., 2014).

In sum, we wish to investigate these two network types (prescribed and perceived) among the same set of actors and consider their relative relevance for each other. We first describe how we use the institutional tools of the IAD framework to create NPIs, before turning to how we draw from the ACF to create networks of perceived interactions.

IAD framework, institutions, and behavior

We draw upon the IAD framework and its categories of institutions to identify and measure the institutional design of a water law. In interdependent settings, that is, action situations, actors must engage in cooperation and collaboration if they are to avoid social dilemmas and realize improved or desirable outcomes. To understand social dilemmas and cooperation, the IAD framework identifies three clusters of factors that structure action situations: the physical and material conditions, such as hard infrastructure (roads, dams, and hospitals), natural and artifactual common pool resources, and supporting and regulating ecosystem services; community characteristics, which include world views; and rules in use and in form. In a "typical" IAD framework-based study, the material conditions set the collective problems to be studied. Once the material conditions are fixed, the bulk of the analysis centers on institutional

arrangements and actors. Institutional arrangements structure action situations and influence the interactions among actors (Ostrom et al., 1994).

The IAD framework classifies institutions by levels of action, a rule typology, and the grammar of institutions. Levels of action refer to rule-following and rule-making activities. The operational level of action refers to day-to-day activities, such as diverting water or cleansing water. Collective choice and constitutional choice levels of action involve rule making, rule monitoring, and rule enforcement (Ostrom, 2009, p. 45). If the outputs of an action situation are rules, monitoring systems, compliance processes, or mechanisms for rule enforcement, the action situation is situated at the constitutional choice or collective choice levels of action. Outputs of these levels of action structure and shape operational level action situations, identifying the rules to be followed by actors engaged in day-to-day activities. In our institutional analysis, we focus on collective choice and operational level rules, with the former being more prevalent.

Relatedly, the rule typology identifies rules that directly affect and shape the parts of the action situation (Ostrom, 2005, 2009). Actors and how they enter and exit action situations are affected by position and boundary rules. Actions are guided by choice rules and information sharing among actors by information rules. If an action or choice requires more than one actor to carry it out, those are structured by aggregation rules. Scope rules identify “states of the world” to be realized, such as water permits that specify an amount of water that may be diverted, and payoff rules guide the allocation of costs and benefits among actors engaged in the action situation. In the analysis, we focus on the most common rule types found in the studied water law.

Finally, the rules themselves, or more broadly institutional statements, may be systematically analyzed using the grammar of institutions, which includes a syntax that allows for the parsing of statements into who carries out the directive contained in the statement (attribute); the action to be taken (aim), whether the action is allowed, required, or forbidden (deontic); the receiver of the action (object); and conditions for carrying out the action (what, where, when, and how). We parsed the institutional statements constituting the water law using the grammar, and we rely on the attribute and the object of the syntax to create actor networks. These actor networks are situated at the collective-choice level with their nodes being the statements' attributes and objects and the edges being the choice, information, or aggregation rule that link them.

Thus, the forms of institutional classification of the IAD framework constitute a rich set of tools allowing analysts to situate actors and action situations in levels of action, identify the configurations of rules shaping action situations, and explore the prescribed interactions among the actors. As Ostrom (1990) noted three decades ago, there is not a single rule or rule type that explains successful collective action and thus actor behavior.

What is not as fully developed and well understood in IAD framework scholarship are the following closely related issues: (1) how actors respond to institutional arrangements, and what accounts for the variation in responses to the same sets of institutions; (2) the degree to which institutional arrangements condition, guide, and make possible actors' interactions relative to (or in addition to) other cognitive, value, or social influence factors; and (3) how actor–institution interactions vary by physical/material settings.

Institutional arrangements do not determine actor behavior, they condition and guide it. Identifying how and why actors respond to the guidance provided by institutional arrangements is important in order to develop more workable policy instruments better matched to the action situation context. This paper directly addresses issues one and two.

The role of beliefs, values, and power in shaping behavior

We draw on the ACF and related literatures to explore cognitive and value influences on the choices and behaviors of actors in institutional settings. The model of the individual within the ACF is boundedly rational–goal oriented but with cognitive limitations (Jones, 2002; Simon, 1957). Boundedly rational

actors are motivated by beliefs, which lead to biases in decision making (Jenkins-Smith et al., 2014, p. 191). Policy core beliefs “reflect basic orientation and value priorities” (ibid.) in relation to problem severity, basic causes of problems, and preferred solutions (Jenkins-Smith et al., 2014, p. 191; Sabatier and Jenkins-Smith, 1999, p.120;). These beliefs condition how actors will interact in the context of prescribed interactions. Actors may prefer one type of policy instrument, rather than another, because they perceive it as being more efficacious in realizing their values. Or actors may decide to more often exchange information or resources with actors who share their beliefs about causes of a problem and how to best address it, than with actors with different problem perceptions (Elgin, 2015). However, like institutional arrangements, beliefs do not determine behavioral interactions. Rather, actors who possess a specific configuration of beliefs are more likely to take some actions and less likely to take other actions, depending on the context, still leaving a wide array of behaviors that may emerge. In sum, as actors interact in rule-structured settings, how they pursue their goals and values is conditioned by beliefs. The extent to which beliefs condition responses of actors to rules is one of the questions we explore.

In addition to beliefs (and institutions), ACF scholars expect people's behavior to be affected by other factors, such as the intensity of conflict (Jenkins-Smith et al., 2014). In settings of high conflict, opposing beliefs or ideologies dominate policy networks, and actors who share the same values tend to coordinate actions with each other (Gronow et al., 2020; Henry, 2011; Ingold & Fischer, 2014). In low-conflict settings, however, power allocations of actors have a crucial impact on actor interaction, and powerful actors can dominate the setup of coordinative arrangements (Calanni et al., 2015; Gronow et al., 2020). Power in politically charged networks can take very different forms, from formal competence and responsibilities, to (informal) reputation of being powerful, to power acquired through occupying the right position (Smith et al., 2014). Most recent studies conclude that the second, reputation, seems to be particularly decisive: Actors tend to coordinate actions with those whom they perceive as influential, regardless of whether the actors share beliefs (Calanni et al., 2015; Gronow et al., 2020).¹ Having the reputation of being influential in a decision-making process complements other forms of power (such as authority or competence; see Ingold & Leifeld, 2016). In early elite studies, reputation was conceptualized, and later operationalized as a tie, thus a relationship that is often also reciprocated: Actors have the tendency to mutually attribute influence to each other (French, 1969; Hunter, 1953). Such reputational power relations impact how actors coordinate and how mutually perceived influence can lead to coordinated actions (Calanni et al., 2015; Ingold & Fischer, 2014).

We thus claim that institutions and beliefs solely do not explain actor behavior. Rather, institutions induce constraints of and instructions for specific behavior; beliefs provide incentives for actor behavior. How actors react to both institutions and beliefs, in concert, is what our study analyzes.

CASE STUDY

We study actor interactions in the context of water quality management in a European river basin. This case provides the empirical context in which we explore the dynamics between institutions, beliefs, and actor interactions.

Many different regions in the world rely on surface water and bank filtration for the provision of drinking water. This type of water is particularly vulnerable to so-called *micro-pollutants*, which stem from various point or diffuse sources and occur in low concentrations but which are often persistent in water and have diverse adverse effects on the aquatic ecosystem and on human health (Bertelkamp et al., 2014; Schwarzenbach et al., 2006; WHO, 2011). This study focuses on micro-pollutants regulated by a water quality law and managed by different public and private actors.

Our case study is the Ruhr basin. The Ruhr is a tributary to the transboundary river Rhine that flows from Switzerland through France and Germany to the Netherlands and into the North Sea.

The Ruhr river covers an area of 4485 km², has a length of about 221 km, and gave its name to the industrial region “Ruhrgebiet” (LANUV, 2013; Ruhr-Guide, 2018). Its surface water is the drinking water source for 4.6 million people, providing 20% of drinking water in the German federal state of North

Rhine-Westphalia (NRW; MKULNV 02/2009, p. 16). To ensure drinking water security, 26 drinking water providers process surface water of the Ruhr into drinking water (AWWR, 2018). The Ruhr surface water, however, is affected by micro-pollutants that stem from agriculture, settlements, and production processes like electroplating and paper manufacture. A peak in surface water micro-pollution was reached in 2006, when researchers from the University of Bonn detected high concentrations of perfluorooctanesulfonic acid (PFOS) in Ruhr surface water (Herzog, 2020). As a consequence, state authorities initiated a program of measures intended to manage PFOS concentrations in the Ruhr's surface water (MKULNV, 2014a). Since then, a strict monitoring system has been put in place, surface water treatment plants have been upgraded, research on drinking water treatment and early warning systems and microbiological analyses were supported, and measures to reduce the entrance of micro-pollutants in the Ruhr's surface water put in place (Herzog, 2020). In short, a water management process regarding micro-pollutants was established in the Ruhr basin that involves actors from the public and the private spheres. The rules guiding these actions are laid out in the Federal Water Act (FWA) of NRW, the so-called Landeswassergesetz (LWG; MKULNV, 2014b).

DATA AND METHODS

On the basis of our theoretical reasoning, we propose an analytical approach to study actor behavior influenced by institutional arrangements while accounting for actor beliefs and power dynamics. We operationalize actor behavior through perceived interactions, which are the collaborative interactions among actors that these actors are aware of and thus named as interacting with other actors in the specific empirical context. By collaborative interactions, we mean the working together of two or more actors, thereby producing an outcome the collaborators benefit from (Huxham, 1993, p. 603; Oxford Living Dictionaries, 2021). They serve as a proxy for definite actor interactions. Prescribed interactions are the operationalization of rule-based actor interactions; they are what we call the interactions among actors that an institutional arrangement, such as a law or an ordinance, stipulates.

For our analysis, we rely on two types of data: Survey data measure the *perceived actor interactions*, reputational power, and actors' belief systems in the water quality management process in the Ruhr basin; the coded FWA of NRW offers the data for *actors' prescribed interactions*. The first data source stems from a survey and study of actor collaboration in the Ruhr catchment area (Herzog, 2020). The second data source has been collected and prepared for the purpose of this study, offering the NPI outlined by the federal law that covers the jurisdictional and geographical area of the perceived collaborative interactions that were surveyed beforehand. The two networks we study should be understood as artifacts based on which we apply our methodological approach to discuss our theoretical considerations.

The grammar of institutions and the FWA of NRW

The prescribed interactions are deduced from the LWG, the Federal Water Act, of NRW. The FWA of NRW guides the regulation of groundwater and surface water on the state's territory and realizes the requirements of the German hydrologic balance (*Wasserhaushaltsgesetz* [WHG]) at the federal level. The WHG provides the general framework for the handling and management of the resource water in Germany; the specific detailed elaboration and adaptation to the respective regional context is carried out by the federal states in the form of their state water laws (Berger, 2017, p. 6). The WHG intentionally leaves space for the federal authorities to substantiate instructions and regulations within the regional context (cf. Herzog, 2020). The FWA, originally adopted in 1995, is the legal document guiding the use, protection, provision, disposal, and management of the state's waters (MKULNV, 2014b).

We coded the institutional statements composing the FWA using the syntax that is part of the grammar of institutions (Crawford & Ostrom, 1995).² Crawford and Ostrom (1995) developed the grammar and syntax as a means of allowing for the systematic differentiation and identification of rules, norms,

and strategies, which then can be used to address a variety of theoretical questions. The institutional statements composing the FWA are rules as defined by Crawford and Ostrom (2005). Rules are institutional statements that are enforceable by a specified actor following defined procedures. In addition to coding each statement according to the grammar of institutions, we also classified each statement according to the rule typology.

In Appendix S1 (Section 1), we describe our methodological approach to transform the information of actor interactions within institutional arrangements into actor networks based on the IGT. On the basis of the coded statements, we derived the NPIs by constructing three network matrices, one for each of the three rule types that most closely reflect actor collaboration as conceived by policy network analyses: information rules, which indicate the obliged, prohibited, or permitted communication channel, the flow of information, its timing, and the recipients of information; aggregation rules, which relate to decisions or actions that require two or more individuals (Ostrom, 2005, p. 202); and choice rules, which specify actions that an actor must, may, or must not do (Siddiki et al., 2012). In a final step, we created a fourth NPI: the merged network of the three different types of NPIs.

Perceived actor interactions, beliefs, and reputational power—An actor survey

Moreover, we are interested in perceived interactions. Perceived interactions (collaboration) are the dependent variable in our regression model (see below). We assessed perceived collaborative interactions through a stakeholder survey among the collective actors involved in water quality and micro-pollutant management (see Section 2 in Appendix S1 for details on data gathering and preparation).

The survey partners were identified as all relevant public and private organizations involved in water quality management and regulation in the Ruhr catchment. They included local and regional authorities, local water suppliers, consumer and fishing associations, representatives of firms and the industry, scientific institutions, and environmental nongovernmental organizations (NGOs), altogether 39 organizations. We validated this list through expert interviews, asking the experts to evaluate the actor list regarding the actors' relevancy in the water quality management process and to indicate potential missing actors.

The perceived interaction was defined in the survey as regular collaboration in water quality management related to micro-pollutants in the Ruhr catchment, including the discussion of new findings on the issue and working on joint projects. Survey partners were asked to indicate with whom of the 38 other organizations they maintained regular collaboration relations. The survey was sent out between September 5, 2016 and February 6, 2017. Out of the 39 organizations, two thirds ($n = 26$; 66.6%) answered the key question on collaboration in the questionnaire. This is in line with the standard needed for sound SNA and lies above response rates of other SNA studies (Lubell et al., 2010; Lubell et al., 2014). The bias of nonrespondents towards the analysis' results is likely low as each sector is represented by organizations important for water quality management (see Section 2.3 in Appendix S1). Nevertheless, we cannot exclude the possibility of a small bias, which is inherent to almost every survey-based investigation.

The perceived interaction was assessed as a collaboration network. We created an adjacency matrix: an Actor A indicating having collaborated with Actor B led to a 1 in the common cell of those two actors. In the absence of collaboration, we put a 0 in the respective cell (see also Section 2.4 in Appendix S1).

In the survey, we further assessed other types of relations and actor attributes. We asked actors about their beliefs, so-called *secondary aspects* in the ACF (Sabatier and Jenkins-Smith, 1999). Actors indicated through which policy instrument water quality could be improved in their view. The list of instruments presented to the actors was based on preliminary research and prior studies on water quality management (Metz, 2017, p. 265): best available techniques related to water filtration, product charge (taxing pesticides, chemical substances, etc.), and subsidies for drinking water upgrade. On the basis of their answers, we calculated the Manhattan distance between actors, a standard procedure to detect belief

conflict in a policy network: the greater the distance between two actors, the higher their disagreement related to their policy preferences. We then ran a tabu search cluster analysis and entered secondary aspects as a heterophily effect in the regression analysis (see Drivers for collaboration—A QAP regression section).

We furthermore asked the collective actors about their *policy core beliefs* as defined by Sabatier and Weible (2007, p. 195), which refer to general principles actors want to see implemented regarding water quality. They include five policy core beliefs: economic efficiency, ecological compatibility, provision of security for the population, competition, and social justice. Also, we calculated the Manhattan distance between actors related to their policy core beliefs and ran a tabu search cluster analysis. The policy core beliefs are also conceived as a heterophily effect in the regression.

In addition, actors indicated the 38 other organizations whom they perceived as powerful and influential in water quality management in the Ruhr basin. On the basis of their answers, we created a reputational power matrix similar to the collaboration matrix in which 1 indicates the presence of power attribution from Actor A to Actor B and a 0 its absence. These variables (beliefs and power) were used as independent variables in the regression analysis. Descriptive statistics and details of the variables are displayed in Table IV in Appendix S1.

Comparing the two networks

To compare the dyads in the NPI and in the network of perceived interactions, we identified the organizations who answered our survey and who are mentioned by the FWA (see Table III in Appendix S1). The institutional statements in the water law tend to classify types or categories of actors (water associations or local authorities) rather than to mention individuals or organizations (as we typically find them in surveys and collaboration network analysis, such as University of Duisburg-Essen or Fishing Union NRW). We checked which of the categories of actors defined by the FWA relate to an organization of the network of perceived interactions, thereby identifying the match of actors of the NPI with organizations of the network of perceived interactions.

Not all collective actors of our survey appear in the NPI, because some of the organizations we identified in the water quality management process in the Ruhr catchment are not mentioned by the water law. These are national state actors on the one hand and scientific institutions abroad on the other. At the same time, the water law mentions many more actor types than those we identified as relevant for water quality management in the Ruhr catchment. For instance, our actor sample of perceived actor interactions in the Ruhr basin does not include municipalities, property owners, or the public. This is because the public in Germany is seldom considered to contribute to environmental management plans or the implementation process of instruments. In the case under study, neither municipalities nor property owners are in charge of managing the water course—the issue at stake.

We are aware of this fact and discuss its implications for our theoretical reasoning more thoroughly in the Discussion section. The water law addresses multiple water management topics and issues, in addition to water quality; thus, we expected it to include more actors than identified in the field. Second, in a round of expert interviews prior to our survey, we had the interviewees validate the list of actors to whom the survey would be sent. The experts thus indicated additional organizations to be relevant for the regional water quality management process even though the law does not identify them as being directly subject to it or regulated by it. Our expectation is that the law is not exclusive in defining all actors that may be involved in some fashion with water management. Third and at the center of our attention, taking the network of perceived interactions as a point of departure and comparing it to the NPIs, we gain a first insight on the applicability of our methodological approach, assessing whether prescribed interactions are observed in a perceived interaction network and if so to what extent. The two networks serve thus as artifacts on the basis of which we conduct our study. A matching of the two types of networks resulted in a sample of 23 actors present in the NPI and in the network of perceived interactions.

Our analysis of the two types of actor networks is threefold. First, we compare the different types of NPIs with the network of perceived interactions based on the descriptive network statistics density, average degree centrality, and connectedness. For this comparison, we use the full actor networks, that is, $n = 50$ in case of the NPIs and $n = 39$ in case of the network of perceived interactions (see Table 1).

Second, we reduce both network types to those actors present in both networks to allow for a direct comparison across the networks based on actor activity, numbers of ties, and network density (see Table 2) and to analyze actors' centrality measures in each network type (see Table 3). By analyzing centrality measures, we identify the networks' key actors and through the comparison assess whether they are the same in the two types of networks or whether different actors dominate the NPI and the network of perceived interactions, respectively. For those actors with a outdegree or indegree in the collaboration network that is higher than the average, the respective degree measure is highlighted bold. So are the degree measures of those actors who score high or comparatively high in the NPIs.

Third, through a quadratic assignment procedure (QAP) logit regression on the network of perceived interactions ($n = 23$), we assess whether there is a significant relation between the ties given in the NPIs, actor beliefs, and actor reputation and the interactions between actors in the perceived interaction network (see Table 4; for descriptive statistics on the variables, see Table IV in Appendix S1). Figure 1 depicts our analytical approach.

RESULTS

We discuss the statistics of the complete networks of perceived and prescribed interactions to then present a reduced version of each network type comprising the overlapping sample of 23 actors. We complete our network analysis with a comparison of and a reflection on the key actors in both types of collaboration networks. We finish the section with a reflection on potential drivers for collaboration in water quality management.

The full networks of prescribed and perceived interactions— Descriptive statistics

Table 1 presents the descriptive network statistics of the complete collaboration network derived from our survey and the three types of NPIs. The active nodes, so-called *senders*, are put in brackets. For the case of the collaboration network, these are the 26 actors who answered the survey; however, all 39 actors are part of the collaboration network and presented here. This allows us to consider the wider collaboration network—not just the network of 26 respondents—which consists of the ties the 26 respondents indicated to interact with the overall 39 actors.³ Such a broader actor network allows for better comparison with the NPIs.

The three types of NPIs as well as the aggregated NPI of all three rule types each comprise 50 actors. The most active actors⁴ in the NPIs are the “competent authority” and the “supreme water authority,” followed by the “property owners” and the “municipalities.” The supreme water authority refers to the Ministry for Climate Protection, Environment, Agriculture, Nature and Consumer Protection in NRW (MKULNV). The competent authority as stated by the law are the district governments in NRW, which are responsible for the development of the river basin management plans and the program of actions (Wassernetz NRW, 2008).⁵ Apart from these four most active actors, the other active actors are prescribed to send only between one or two ties to other actors in the network.

For instance, in the NPI of *aggregation rules*, the five active actors are the “supreme water authority” with 10 outgoing ties, the “competent authority” with 9 outgoing ties, and the “authorities other than those competent under water law,” the “municipalities,” and the “property owners” with each one outgoing tie to another actor.

TABLE 1 Descriptive statistics of the NPIs and the collaboration network

Network	Nodes (active nodes)	Ties	Density	Average degree centrality	Connectedness
NPI of all three rule types	50 (18)	57	0.023	1.140	0.187
NPI of information rules	50 (15)	27	0.011	0.540	0.063
NPI of aggregation rules	50 (5)	22	0.009	0.440	0.020
NPI of choice rules	50 (8)	21	0.009	0.420	0.018
Collaboration network	39 (26)	265	0.179	6.795	0.615

Abbreviation: NPI, network of prescribed interactions.

The eight active actors in the NPI of *choice rules* play out a little different: Here, the “supreme water authority,” thus the Ministry for the Environment (MKULNV), is prescribed to send only one tie to another actor, just like “the tax payer,” the “community of participants,” the “companies supplying drinking water to the public,” the “upper water authorities,” and “the authority.” The “municipalities” send two prescribed ties to other actors, whereas the “property owners” send three prescribed ties to other actors, and the “competent authority” is prescribed to share ties with 10 actors.

Most ties exist in the NPI of *information rules*: 15 actors hold 27 ties. Although the NPI of information rules has more active nodes and more ties than the other two types of NPIs, it remains a loose network with a low connectedness and a low density.

These characteristics show also in the low average degree in all three types of NPIs. Actors in the three NPIs contact 0.4–0.5 actors on average. When merging actor interactions based on the statements of the three rule types information, aggregation, and choice (NPI of *all three rule types*), we see that the FWA of NRW prescribes interaction among actors that translates into a network with a density of 2.3% and a connectedness of 0.187. Actors in this network have on average a connection to 1.1 actors.

In contrast, the network of perceived collaboration in the Ruhr catchment area is much denser, with each of the network's 39 organizations maintaining more than six relations on average. The collaboration network has a density of 17.9%, meaning that of all potential connections among actors within the network, 17.9% are given. The connectedness term, which would be 1 in the case of full connectedness, is at 0.615.

The two sorts of networks are distinct with the NPIs encompassing fewer interactions than the network of perceived interactions.

In the next section, we reduce both types of networks to those 23 actors present in both—the actor sample of water quality management and in the NPI (see Table I in Appendix S1). By this, we can compare the two networks to identify overlaps in their structure and similarities and differences regarding the positioning of actors in both networks. The reduced networks serve thus as proxies to answer our first research question, to what extent do networks of prescribed actor interactions and of perceived actor coordination overlap, and our second research question, which asks about *the central actors in the networks*.

Bringing prescribed and perceived interactions together—A comparison

The two networks with the overlapping sample of 23 actors are shown in Table 2. At Position 1, we outline the network statistics of the reduced collaboration network. At Position 3, we display the statistics of the four NPI networks reduced to 23 actors. At Position 2, we present the Boolean combination of the network of prescribed and perceived interactions. The Boolean combination displays all those NPI relations (of all three types of NPI networks) that are also present in the collaboration network.

TABLE 2 The reduced networks of perceived and prescribed interactions and their match

Position	Network	Number of nodes (active nodes)	Number of ties	Density
1	Collaboration network	23 (23)	143	0.283
2	Network containing all dyads that are in the NPI (all rule types) and the collaboration network (Boolean combination network)	23 (12)	14	0.024
3	NPIs (Federal Water Act, all rule types)	23 (23)	28	0.055
	NPI information rules	23 (23)	22	0.043
	NPI aggregation rules	23 (10)	11	0.022
	NPI choice rules	23 (4)	3	0.006

Abbreviation: NPI, network of prescribed interactions.

With a density of 28.3%, the collaboration network (Position 1) is much denser than the NPIs (Position 3) whose densities vary between 0.6% and 4.3%. In the collaboration network, in the NPI of all rule types and in the NPI of information rules, all 23 actors are involved in at least one interaction (second column, numbers in brackets).

When looking at the overlap between the perceived and the prescribed networks, 12 actors that share ties in the NPI also send ties in the collaboration network. In turn, 14 collaboration ties in the collaboration network are identical to actor interactions as prescribed by the law (Position 2). The overlap between the two types of network is limited. Most overlap exists between the NPI of information rules and the observed collaboration network; the least overlap can be observed between the NPI of choice rules and the collaboration network.

Figure 2 shows the graph of the reduced collaboration network of perceived interactions; Figure 3 displays the reduced NPI of all three types of rules. The visualization shows the ego-network shape of the NPI, which centers around the actor DA.Duess (the district government Düsseldorf), which is the NPI's competent authority, and the rather compact format of the collaboration network. Figure 4 outlines the matched network of 23 actors, which contains the ties that are present in the collaboration and in the NPI of all rule types.

Having a look at actors' degree centralities reveals information on the networks' key actors, thus answering our second research question: Who are the central actors in these networks?

As shown in Table 3 below, the NPI is dominated by the two authorities: DA.Duess, the district authority Düsseldorf, and MKULNV, the Ministry for the Environment in NRW. DA.Duess stands for the *competent authority* as addressed in the water law; the Ministry for the Environment is the *supreme water authority* the water law refers to.⁶ They are the most frequently mentioned attributes and objects⁷ in the water law and are key actors of the federal water governance.

The district government Düsseldorf sends more information ties than the Ministry for the Environment. In the sample of the 23 actors, DA.Duess shares *information-related ties* to water associations, independent experts, and the supreme water authority. It receives information ties from the so-called *persons concerned*, thus those affected by a change in water quality. In the case of water quality management in the Ruhr catchment, those "persons concerned" refer to polluters and the companies that provide drinking water. The Ministry for the Environment does not send ties based on information rules.

It is the aggregation rules that guide the ministry's interactions with the water associations and the competent authority, that is, the district government Düsseldorf. The aggregation rules thus mirror the hierarchy of authorities: Aggregation rules specify joint action. MKULNV (the supreme water authority) engages in joint decision making with DA.Duess (the competent authority). DA.Duess itself engages in shared actions or decisions with other actors in the network, namely, the water associations AWWR and ARW and the scientific experts.

TABLE 3 Degree centralities of actors in the collaboration network and the NPIs, $n = 23$

Actor abbreviation (actor category of NPI)	NPI all rules		NPI information rules		NPI aggr. rules		NPI choice rules		Collabor.	
	In	Out	In	Out	In	Out	In	Out	In	Out
Mean avg degree	1.217		0.957		0.478		0.130		6.217	
ARW (water associations)	2	0	1	0	2	0	0	0	3	10
AWWR (water association)	2	0	1	0	2	0	0	0	11	11
BUND.NRW (person concerned)	1	1	0	1	0	0	1	0	5	8
CoA.NRW (polluter)	0	1	0	1	0	0	0	0	9	4
CompCent.NRW (expert)	1	0	1	0	1	0	0	0	7	5
DA.Duess (competent authority)	14	12	13	9	1	8	0	3	9	8
DEW21 (companies supplying drinking water)	0	1	0	1	0	0	0	0	3	6
Fish.NRW (person concerned)	1	1	0	1	0	0	1	0	4	1
Fish.RUHR (person concerned)	1	1	0	1	0	0	1	0	0	0
Gelsen.plc (companies supplying drinking water)	0	1	0	1	0	0	0	0	11	8
InstHyg.Gelsen (expert)	1	0	1	0	1	0	0	0	5	2
IWW (expert)	1	0	1	0	1	0	0	0	11	9
MKULNV (supreme water authority)	1	3	1	0	0	3	0	0	20	14
Paper.NRW (polluter)	0	1	0	1	0	0	0	0	0	1
RLV (polluter)	0	1	0	1	0	0	0	0	2	5
RV (waste water association)	0	1	0	1	0	0	0	0	13	12
RWTHAach (expert)	1	0	1	0	1	0	0	0	5	7
RWW (companies supplying drinking water)	0	1	0	1	0	0	0	0	6	9
UNI.Boch (expert)	1	0	1	0	1	0	0	0	3	3
UNI.Duis (expert)	1	0	1	0	1	0	0	0	5	7
VKU.NRW (companies supplying drinking water)	0	1	0	1	0	0	0	0	1	3
WLV (polluter)	0	1	0	1	0	0	0	0	2	5
WWW (companies supplying drinking water)	0	1	0	1	0	0	0	0	8	5

Abbreviation: NPI, network of prescribed interactions.

Choice rules prescribe action. In the NPI of choice rules, only DA.Duess is a sender of choice rule-related ties that reach the two fishing associations (Fish.NRW and Fish.RUHR) and the environmental NGO BUND.NRW (“persons concerned” as defined by the water law).

DA.Duess and MKULNV are also among the most active actors (out-degree centrality) in the *collaboration network* and thus in the water quality management of the Ruhr catchment. They share their central position in the network of perceived interactions with service providers, water associations, and experts.

On paper, that is, based on the coded statements of the water law of NRW, the competent authority DA.Duess is the most central actor with responsibilities regarding the distribution and the reception of information and the assignment of action-taking. The supreme water authority MKULNV is connected

TABLE 4 QAP logit regression for perceived interactions (collaboration)

	Model 1	Model 2	Model 3a	Model 3b	Model 3c	Model 4
Intercept	-2.629**	-0.703	-2.354***	-2.395***	-2.843***	-2.565**
AllRules	1.435	1.370	0.803	0.804	1.639	
CoreBeliefs Hetero	-1.817**	-1.287		0.217		-1.883**
SeconAsp Hetero	-0.886	-1.335*			-0.812	-0.830*
RepPower	3.274***		2.740***	2.743***	3.111***	3.259***
Log Lik	-22.706	-32.885	-221.785	-221.536	-24.155	-23.044
Pseudo R ²	0.407	0.103	0.310	0.310	0.349	0.388
Sig	0.000	0.019	0.000	0.000	0.000	0.000
Obs	77.000	77.000	506.000	506.000	77.000	77.000
Perms	9999.000	9999.000	10,000.000	10,000.000	10,000.000	10,000.000

Abbreviation: QAP, quadratic assignment procedure.

p*-values significance at the level ≤0.1; *p*-values significance at the level ≤0.05; ****p*-values significance at the level ≤0.01.

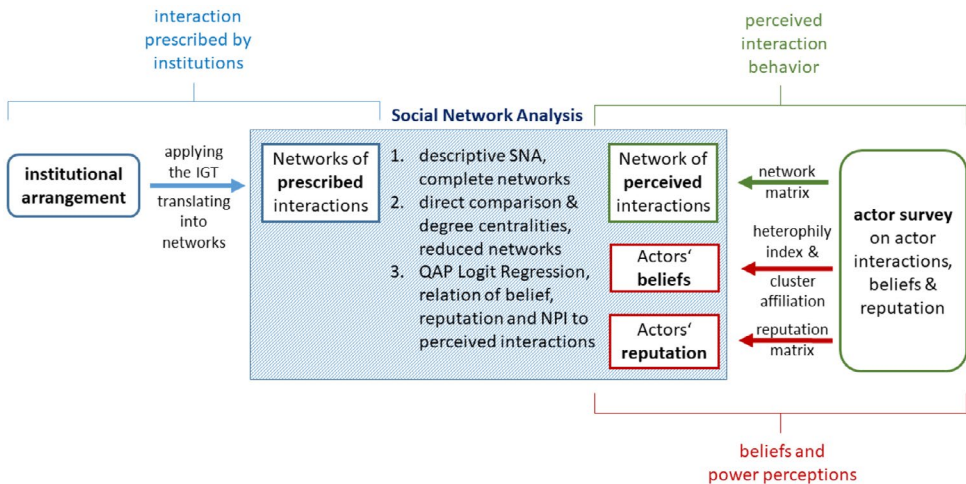


FIGURE 1 Schematic representation of the study's analytical approach, own depiction. IGT, institutional grammar tool; NPI, network of prescribed interactions; QAP, quadratic assignment procedure; SNA, social network analysis

to DA.Duess through aggregation rules and in turn receives specific information from DA.Duess. The NPI thus reflects the institutional and administrative hierarchy.

In the perceived context of water quality management in the Ruhr catchment, the two state actors MKULNV and DA.Duess are joined in their central network positions by water associations, drinking water providers, polluters, experts, and those directly affected by diminishing water quality—private and public organizations who bring in their stake in collaboration.⁸

Drivers for collaboration—A QAP regression

To answer our third research question, which asks about *the relative contribution of rules, beliefs, and allocations of power in the setup of the perceived collaboration network*, we calculated a QAP regression of our dependent

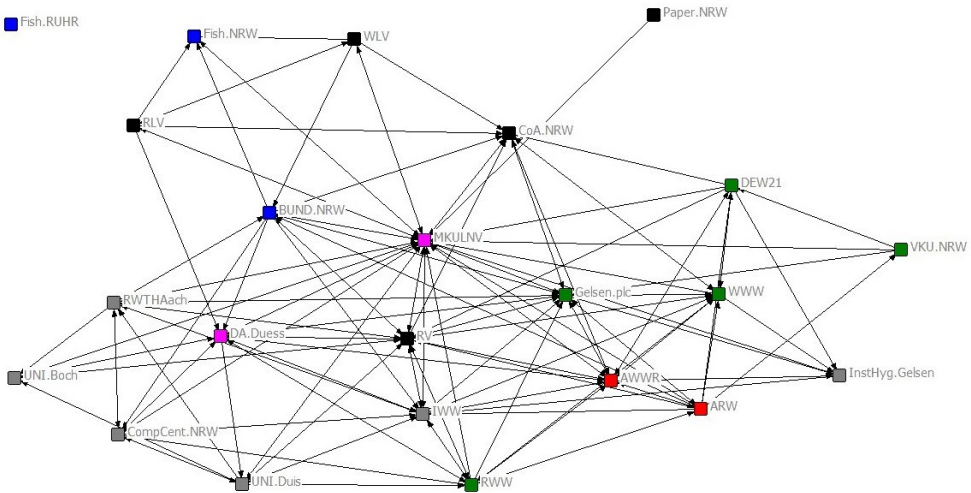


FIGURE 2 Collaboration network of perceived interactions, $n = 23$. The actor Fish.RUHR, which figures as an isolate in the network, is a fishing association that does not receive or send collaboration ties but which was rated as important as the other consumer organizations by the other actors. To see whether we have here a case of an actor that ought to have a tie as prescribed by law but does not do so in the network of perceived interactions, we kept this isolate in the network sample. Color code: purple: political actors/regulators; red: water associations; green: service providers; blue: nongovernmental organizations; black: industry; grey: science

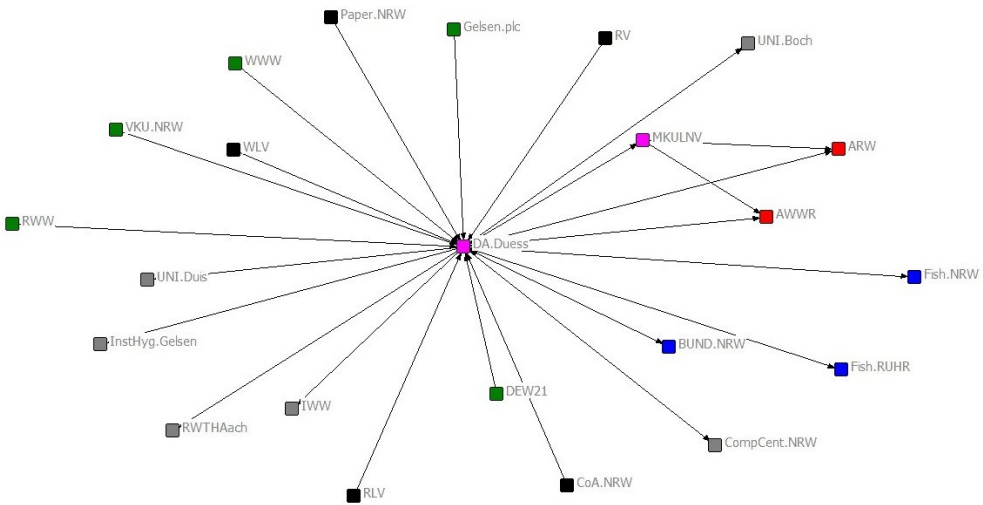


FIGURE 3 Network of prescribed interactions of all three rule types, $n = 23$. Color code: purple: political actors/regulators; red: water associations; green: service providers; blue: nongovernmental organizations; black: industry; grey: science

variable, perceived actor collaboration, that is, the collaboration network of 23 actors. This regression works similar to a logit model and additionally accounts for interdependencies of observations through permutations. More precisely, a QAP regression “calculates measures of nominal, ordinal, and interval association between the relations in two matrices, and uses quadratic assignment procedures to develop standard errors to test for the significance of association.” (Hanneman and Riddle, 2005, Chap. 18).

We include the NPI (AllRules) and the two heterophily terms in core beliefs (CoreBeliefs) and secondary aspects (SeconAsp) to account for actors' beliefs. Heterophily is the contrary of homophily and

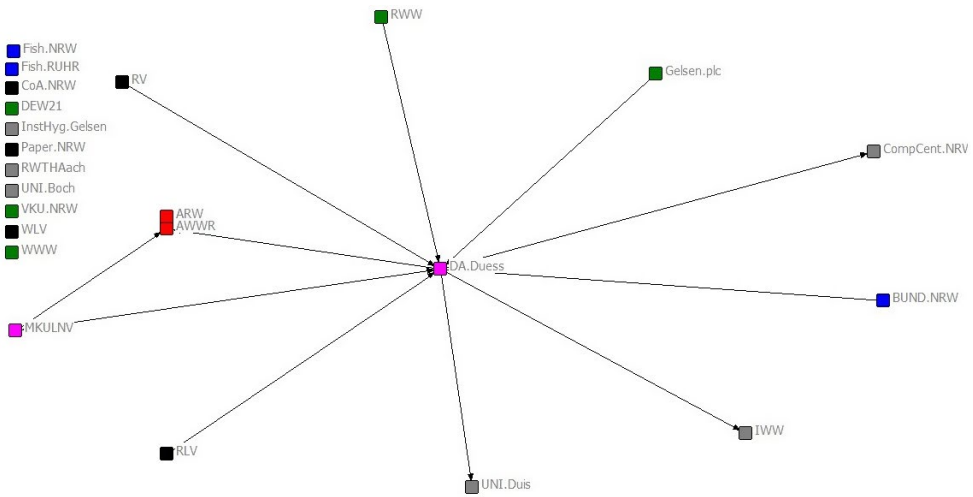


FIGURE 4 Matched network of 23 actors in which the ties present in both networks, collaboration and network of prescribed interactions, are displayed (active nodes $n = 12$). Color code: purple: political actors/regulators; red: water associations; green: service providers; blue: nongovernmental organizations; black: industry; grey: science

a proxy for belief distance or belief conflict. A negative belief coefficient indicates that two actors with similar beliefs tend to share a collaboration tie. We furthermore include reputational power (RepPower) as an independent variable. Results are outlined in Table 4.

Model 1 includes all variables of the analysis, whereas Models 2–4 each exclude one of the independent variables. Even though the coefficient of the prescribed interaction network (AllRules) is positive and considerably high (1.435) when including all variables (Model 1), the relation between prescribed interactions and collaboration is not significant and stays like this throughout all the models outlined in Table 4. Reputational power shows the strongest relation with collaboration having a highly significant coefficient: If Actor A perceives Actor B as powerful, the two also share a collaboration relation. Note that the overall model loses in its explanatory power as soon as we exclude reputational power as an explaining variable (Model 2). The coefficients of the other variables and their significance level largely stay the same.

The two belief heterophily terms are most often significant and negative, indicating a tendency for actor collaboration based on similar beliefs: As soon as two actors prefer the same policy instruments (SeconAsp, secondary aspects) or the same policy core beliefs like social justice or ecological effectiveness (CoreBeliefs) to regulate micro-pollutants in the Ruhr catchment, they have the tendency to collaborate with each other. Interestingly, as soon as we exclude one of the two belief terms (Models 3b and 3c), the other belief variable is insignificant. Or said differently, the policy core and secondary beliefs only show a significant relation with actor collaboration when they are tested for together.

When we exclude prescribed interactions (AllRules; Model 4), the coefficients and their effects stay very similar to the overall Model 1. This finding suggests that in our empirical case, rules are neither a strong predictor of perceived interactions, nor do they interact strongly with other explaining variables.

DISCUSSION

The actors engaged in addressing and resolving micro-pollutant problems in the Ruhr river basin in NRW do so based on functional and resource interdependencies. They engage in multiple and sometimes conflicting uses of the surface water, and they regulate, monitor, and enforce the uses of it. These

interdependencies are a function of the setting, a shared river basin, the many interacting uses of its water, the laws and rules that guide the uses and the resource management, and the beliefs, values, and worldviews of the actors.

In this complex setting of many interactions and factors driving them, our central question was if one can recognize overlaps between prescribed interactions as outlined in the water law and the network of perceived actor interactions. We can state that for our case study, an overlap of prescribed interactions and the collaboration network exists. Even though the collaboration network is much denser than the NPI (see Table 1), about one fourth of the prescribed interactions are also present in the collaboration network of water use and management in the Ruhr basin. We state the following expectation for future research regarding the interplay of interactions prescribed by rules and interactions as perceived by actors.

Expectation I for future research: In a shared problem setting, if two actors share a tie in the prescribed interaction network, they also do so in the perceived interaction network.

We furthermore observed that authorities play a central role in the NPI and keep a central position in the collaboration network. Water management in the Ruhr basin is thus dominated by state actors, on paper as well as on the ground: The regional (DA.Duess) and the supreme (MKULNV) water authorities who are central actors in the NPIs are also central and active in the collaboration network (see Table 3). They share this central position in the network of perceived interactions with other types of organizations who are less or not present in the NPI, such as water suppliers or experts. So we could extend our analytical framework (see Figure 1) on the right side by additional variables capturing actor types more generally and formal power and authority more concretely. This observation leads us to our second expectation for future research.

Expectation II for future research: In a shared problem setting, official authorities and state actors are still central nodes in the network of perceived interactions but less central than in the NPI.

Moreover, this state-of-the-art comparison of an NPI with a network of perceived interactions revealed that the federal law prescribing interactions—at least for our case—covers a vast range of actors, reaching from “beneficiaries” and “all interested parties” to “experts,” “towns,” and “authorities.” At the same time, we found that an empirically studied actor network of perceived interactions in a resource management setting might not comprise all these actors. We assume that the federal law does not define all actors who may be involved in a given resource management topic. Instead, regional resource management settings seem to possess a group of actors as prescribed by law who interact with actors beyond the scope of that law, such as experts from abroad or actors at the national level.

When focusing on the factors associated with the formation of perceived interactions—answering our third research question—the interactions prescribed by rules are not a significant driver for collaboration (see Table 4). Finally, and in line with previous research on collaboration networks as outlined in the Theory section, reputational power and sharing beliefs impact tie creation of perceived interaction networks. Reputational power is by far the strongest explaining factor of collaboration in our case study. In previous research, and when comparing beliefs to power, power is always the stronger predictor for collaboration in problem settings with a collaborative—in contrast to conflictive—culture or negotiation style (Gronow et al., 2020). It is likely that water management in the Ruhr basin is a collaborative management situation: All involved actors are similarly affected by reduced drinking water quality and keen in mitigating micro-pollutants.

On the basis of our findings on the influence of actor reputation on perceived actor interactions, we claim our third expectation for future research.

Expectation III for future research: In a shared problem setting, perceived influence and reputational power act as one factor impacting perceived interactions among different other drivers.

Given that beliefs seem to also impact collaboration in this problem setting, we state the fourth expectation.

Expectation IV for future research: In some shared problem settings, belief homophily will have a stronger effect on perceived interactions than will prescribed interactions.

Which actors share prescribed interactions and collaboration relations and seem to believe similarly? For instance, the cluster of the two authorities (DA.Duess and MKULNV) and the two water associations (ARW and AWWR) favors water charges, ecological compatibility and safe water provision. These are all policy instruments and intervention styles that lay in the hands of the state rather than the private economy.

In sum, our study showed that although the NPIs provided broad outlines for interactions, perceived collaboration patterns were conditioned by shared beliefs and reputational effects. However, further effects could and should be integrated in the analytical framework (see Figure 1) in order to triangulate perceived and prescribed interactions with other facets of collective action.

CONCLUSION

Collaboration—as perceived by actors—in water quality management in the Ruhr catchment is more intense and diverse than what the institutional arrangements require. The institutional arrangements identify a wide array of actors, all with a stake in water quality, whether because they are authorized to provide safe drinking water, or properly and safely treat waste water, or they are empowered to regulate these actors. And the institutional arrangements prescribe a variety of actions, from sharing information, to imposing levies, to directing how drinking water is to be treated. But only some of the institutional statements, or rules, prescribe specific interactions, or ties, among actors. Within the institutional context of the Ruhr catchment, actors may have limited discretion in the standards to which they treat drinking water, or the information that they share with regulators, but they have considerable discretion in choosing who to collaborate with as they manage, protect, and use the waters of the Ruhr. And that discretion is conditioned by beliefs and reputational power.

In this paper, we turned rules into relations and used SNA to compare rule-based interactions to perceived collaboration relations among the same set of actors. Although we are convinced that this approach is fruitful and holds different potential lines of research to be further explored, we also encountered some challenges and shortcomings. First, in rules, “problem-” or “policy-relevant” actors are often named differently (e.g., actor types) than within the concrete “management” setting. The same organization can take different roles in policymaking, or the law might miss an actor type that is present in the concrete management setting. So matching actors of the perceived network to actor types in the NPI is not an easy task. Second, and to compare some statistics between two networks, the nodes (actors) must be (quasi) identical. This means that both networks are needed to be reduced, which is why one creates a certain artifact rather than studying the empirical baseline of the two networks. Besides those shortcomings, SNA emphasizes an important, structural aspect of decision making and is a suitable method for comparison.

Moving forward, a number of lines of research may be pursued. The institutional design of specific policy instruments, the perceived interactions and behavioral responses in relation to those instruments, and the outcomes, both individual and collective, could be explored. For instance, policy instruments that vary by the level of discretion they grant actors could be empirically tested to further explore the interaction of rules and beliefs on behavior.

In addition, exploring the different means by which rules link actors together may be a fruitful line of research. Besides the direct links between attributes and objects that we used in this analysis following the grammar of institutions, actors are linked by rules granting them specific authorities, or specifying that they take specific actions, even though they are not directed to interact with one another. Identifying the different dimensions along which rules link actors and how these dimensions condition

collaboration would lead to more nuanced understandings of the role of rules in guiding behavior. And this in turn can then increase our understanding of policy failure or the policy implementation gap (Hudson et al., 2019): When actors' behavior deviates from what is expected from them.

Another fruitful line of research would be to examine equity and social justice dimensions of rules. For instance, position and boundary rules identify who is allowed to participate and how they gain access to an action situation. Are the position and boundary rules expansive, allowing widespread participation and low barriers to access? And how do payoff rules identify and allocate benefits and burdens? What resources or values are recognized as benefits to be allocated, how are allocations made, and to what end? The same should be questioned regarding potential burdens. These issues have yet to be addressed using the institutional grammar.

The IAD framework also recognizes levels of action, from the operational level to the constitutional choice level. That is, from day-to-day rule-following activities to the rule-making processes created by rules. Identifying how actors' beliefs condition who they choose to interact with in their rule-guided daily activities is an essential question this study aimed to address. Another interesting aspect to study is how beliefs shape the substantive rules actors choose to create. This could be examined by coding and comparing the beliefs of actors engaged in rule making with the beliefs that are embedded in the rules adopted. Such a research approach would outline how beliefs condition the substance of rules, which in turn are needed to coordinate actors in solving shared problems (Ostrom, 2005).

Furthermore, the beliefs and their role in shaping policymaking activity may be explored in new ways. It may not be the case that beliefs need to be reconceptualized within the ACF, as Jenkins-Smith et al., (2014) suggested. So far, the relationship between rules and beliefs is still underexplored just like the study of how and when beliefs translate into rules and how rules influence actor beliefs. The ACF assumes that actors advocate their beliefs in policy processes to see their beliefs represented in policies. As mentioned above, the link between beliefs in agency—as advocated by actors—and frozen beliefs in policy—typically written down in laws or decrees—is not yet studied in detail. One could even go one step further: Depending on the policy, the interplay of beliefs in agency and beliefs inherent in policy co-designs rules which, as we argue in this research, guide actor interaction but probably also shape actors' beliefs and worldviews. To disentangle rules, beliefs, and power further and to understand how they influence each other and collective action, further comparative and especially longitudinal research is needed.

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ENDNOTES

1. Policy network scholars have furthermore examined different types of factors, such as mutual trust (Berardo & Scholz, 2010) and joint participation in events, platforms, meetings, or forums (Lubell, 2013; Herzog & Ingold, 2019).
2. Crawford and Ostrom (1995, p. 583) provided the following definition of an institutional statement: "Institutional statement refers to a shared linguistic constraint or opportunity that prescribes, permits, or advises actions or outcomes for actors (both individual and corporate)."
3. For the list of all 39 actors and their degree centralities, see Table II in Appendix S1.
4. For an overview of actors' activity in the NPI that comprises all three rule types, see Table III in Appendix S1.
5. In the case of the Ruhr catchment, the competent authority is the district government Arnsberg (Wassernetz NRW, 2008). Because this actor did not answer the survey, we rely on the district government Düsseldorf (DA.Duess) as a proxy for the

district government Arnsberg and the case study's competent authority. DA.Duess is the Ruhr catchment's neighboring district government and also engaged in the water quality management process in the Ruhr catchment.

6. See Table III in Appendix S1.
7. Identified with the grammar of institutions, see The grammar of institutions and the FWA of NRW section in the manuscript and Section 1 in Appendix S1.
8. For the definition of collaboration as stated in the survey, see Section 2.2 in Appendix S1.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the Supporting Information section.

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