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SPECIAL FEATURE: REVIEW ARTICLE

Networks of Action Situations in Social-Ecological Systems Research

Networks of action situations: a systematic review of empirical research

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Abstract

"Action situations"—events, venues, or physically interdependent instances of decision-making—have become a central unit of analysis in the social–environmental sciences, particularly among scholars interested in bridging the social with the biophysical or ecological side of interdependent decisions. A growing body of empirical studies in social–ecological systems research has recently used case and comparative studies to analyse multiple interdependent action situations, structured into networks. In this article, we take stock of this body of empirical research, synthesize the diverse approaches that scholars have taken to assess "networks of action situations", and identify fruitful paths forward. We conduct a systematic review of the empirical literature in the field, reviewing and summarizing the key characteristics of the empirical studies, including network features, topologies, methods, and data sources used in each case. We summarize and discuss the conceptualizations, methods, diagnostic procedures, and conclusions used in this body of work in a narrative framework synthesis. The review indicates that an increasingly coherent approach is taking shape, but a systematic, protocol-driven, or formalized approach is only partly emerging. We derive future research needs that could help accumulate knowledge from empirical research.

Keywords Action situation · Situation-centred networks · Ecology of games · Polycentricity · Institutional analysis · Environmental governance

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Introduction

We are in the midst of an ecological crisis with unprecedented impacts that are rapidly cumulating and accelerating (Steffen et al. 2015). The manifestations of this crisis are often interrelated, as indicated by the growing number of studies in the field of nexus research across sectors and domains (Villamayor-Tomas et al. 2015; Al-Saidi and Elagib 2017; Kholod et al. 2021), geographical telecoupling (Friis et al. 2016; Oberlack et al. 2018), and the interrelated nature of the Sustainable Development Goals (Breuer et al. 2019; Kuenkel 2019; Reyers and Selig 2020). The most recent example acknowledging cross-sectoral interdependence is the joint endeavour of the international panels on climate change (IPCC) and biodiversity (IPBES), which seeks to address some pivotal aspects of biodiversity and climate change jointly (Pörtner et al. 2021).

Integrated assessments currently draw on multiple approaches for modelling complex systems. These diverse approaches include agent-based modelling, system dynamics, and related frameworks for complex adaptive systems (Scholl 2001; An 2012; Schinko et al. 2017; Schlüter et al. 2017), as well as connectivity science and social–ecological network models (Janssen et al. 2006; Turnbull et al. 2018; Bodin et al. 2019). Scholars increasingly acknowledge that governance processes are a fundamental part of such assessments (Peng et al. 2021). But despite significant progress in developing methods for studying polycentric governance (Oberlack et al. 2018; Kimmich and Villamayor-Tomás 2019) and in modelling the behaviour of policy actors within governance systems (Mewhirter et al. 2018), methods to operationalize and model the underlying governance structures and processes remain nascent.

In this article, we review these recent efforts, with particular emphasis on what we term situation-centred approaches that focus on multiple interdependent instances of interdependent decision making, called Action Situations (ASs) (Sendzimir et al. 2010; McGinnis 2011). The Networks of Action Situations (NAS) approach, originating from common-pool resource governance scholarship, is useful for unpacking multiple, interrelated biophysical, economic, and political decision-making situations, and assessing how these ASs jointly produce outcomes. This approach has the potential to reveal biophysical, technological, and ecological interdependencies and their coevolution with social processes (Kimmich 2013; Grundmann and Ehlers 2016), inspires procedures for model development, for example in agent-based modelling, among others (Schlüter et al. 2019), and helps to trace the dynamic effects of polycentric governance on biophysical processes and vice versa (Oberlack et al. 2018; Kimmich and Villamayor-Tomás 2019). The NAS approach also yields a new perspective on social–ecological networks (Barnes et al. 2017; Bodin et al. 2019; Sayles et al. 2019). We compare NAS with a closely related quantitative social–ecological network approach (Angst et al. 2018; Mewhirter et al. 2018) in the "Discussion".

Only a decade old, NAS research is still in its early stages, however, and scholars are just beginning to develop the protocols, scripts, formalization strategies, and related methods that are needed to systematically study networks of interdependent ASs. This is different for the study of single ASs. Scholarship relying on the AS perspective has grown rapidly in the last three decades, and this offers an opportunity to build on this experience for knowledge accumulation. The basic methodological toolkit needed to effectively and efficiently describe and model ASs is relatively well-established and includes enormous shelves of game-theoretic models (Bowles 2004; Gintis 2009; Bruns 2015; Podimata and Yannopoulos 2015; Madani 2010); the growing body of knowledge on situation archetypes (Bruns and Kimmich 2021); related knowledge in social psychology (Kelley et al. 2003; Rauthmann et al. 2015); and the systematic study of multilevel policy processes via formalized ASs (Schlager and Weible 2013; Di Gregorio et al. 2019), among others.

The use of these tools can also be supported by a number of situation-centred frameworks, each with different emphases on rules, transactions, and processes (Ostrom et al. 1994; Scharpf 1997; Hagedorn 2008; Pahl-Wostl et al. 2010; Lejano and Stokols 2013), and methods of interdisciplinary collaboration and model selection (Beckmann and Padmanabhan 2009; Poteete et al. 2010; Schlüter et al. 2017). These frameworks have already provided an orientation for many studies that we systematically review in this article. They also provide a pathway for consolidating NAS approaches.

Due to the growing number and diversity of research on NAS, it is now time to review the conceptualizations, methods, and results. This is the purpose of the present review. We aim to provide an orientation for future research. We review existing studies to identify how these studies conceive of ASs and the relationships between them, what frameworks and methods have been used, and what lessons were learned. We review key characteristics of each study, including the conceptualization of ASs, efforts to formalize the NAS, the methods used for network descriptions and data sources, and any network features and topologies. We also review the theoretical conclusions drawn from the empirical research. Synthesizing across these studies, we identify common grounds and promising avenues for future NAS research.

We find that while there is already substantial coherence among a sub-set of the identified studies, other studies have contributed important aspects, perspectives, and methods that can extend the NAS approach considerably. The NAS

approach has so far been applied in very flexible and creative ways. This case sensitivity contributes to the development of the approach and helps to avoid panacea traps (Ostrom and Cox 2010) but also prevents comparability. This review should help to find a balance between those two goals. A more consistent reporting of network approaches used in the field helps to learn from and build on or depart from others' procedures. We need a checklist, procedure, or protocol for NAS research, analogous to agent-based modelling (Müller et al. 2013) or experimental research (Rommel 2015), for example, so that all aspects of the social–ecological NAS analysis are explicitly considered and reported.

The next section introduces foundational concepts, including the Action Situation (AS) and related frameworks, and derives a series of operational questions we pose to the literature. The subsequent section introduces the review methods and the data extraction steps followed by which the results addressing the operational questions are presented. The final section discusses the results considering the research needs and potential directions ahead.

Consolidating situation-centred network research

Within any empirical NAS research, the AS is the core unit of analysis. ASs are fundamental building blocks of any governance system. ASs occur within a biophysical and socioeconomic context. ASs also occur at multiple levels: the operational level, where individuals make day-to-day decisions; the collective choice level, where groups of actors make shared policy decisions; and at the constitutional level, where groups of actors determine the overarching rules that shape how decisions will be made (Ostrom et al. 1994). Within any AS, individual actors transact and become interdependent (Hagedorn 2008), interact with others, share information, and undertake actions based on their own (perceived) self-interest, a common concern (Vatn 2005; Bromley 2006), habituated behaviour (Hodgson 2004), or practices (Welch and Yates 2018).

The interactions are shaped by rules that determine the scope of the AS, who can participate, what role(s) each actor plays, how information is shared, what actions can be taken, the costs and benefits of those actions, and how individual preferences are aggregated to produce final decisions and outcomes. This idea of ASs draws strongly from game theory, which formalises social interactions as (strategic or evolutionary) decisions with interdependent payoff structures (Ostrom et al. 1994). The potential applications are at least as diverse as the game-theoretic models that have been developed in the last decades for probably any relevant formalizable AS one can imagine, including situation archetypes (e.g., Bruns and Kimmich 2021), but AS frameworks also help to capture less formal and less structured situations that are not easily amenable to game-theoretic modelling.

To systematically describe ASs, the Institutional Analysis and Development (IAD) framework was initially developed by Elinor Ostrom and colleagues while studying systems for sustainable governance of common-pool resources (CPRs). Unlike many public policy problems that are regulated by a particular government agency, sustainably governed CPRs are often managed at the local level by groups of resource users (Ostrom et al. 1994). The terms and concepts that policy analysts traditionally use to describe regulation by state agencies thus often do not adequately describe the diversity of these self-governance arrangements. CPR users collectively decide how much of the resource each user can appropriate, establish systems for monitoring users' compliance with these limits, and develop appropriate conflict resolution mechanisms (ibid.). Each of these decision instances can represent one AS. While developed for the study of small-scale CPRs, the IAD provides a basic language and set of concepts and tools that can be used in virtually any policy and biophysical operational setting. It has been used across a wide array of domains and by scholars from across the social sciences, as the identified studies in our review demonstrate. The IAD has become particularly appealing for studying complex governance in today's "networked, multisector, no-one-wholly-in-charge' public sector" (Bryson 2004; Baldwin et al. 2019), and are increasingly used to study polycentric governance (McGinnis 2011).

One of the underlying goals of the IAD framework has been to enable analysts to diagnose problems in unsustainable social-ecological systems. Scholars in the IAD tradition often reject the idea of panaceas like centralization or decentralization, and instead focus on understanding what institutional arrangements communities have developed to solve particular problems, and assess how those institutional arrangements are contributing to sustainable resource use (Ostrom and Cox 2010). In all but the simplest of governance arrangements, such diagnosis requires the analysts to identify multiple ASs that collectively shape resource use or other policy outcomes of interest.

The idea that multiple ASs could be considered nodes within a broader governance network was first developed as a model in the Management and Transition Framework (MTF) and used to study regime transitions within river basins (Pahl-Wostl et al. 2010; Sendzimir et al. 2010). The MTF focuses on sequences of ASs, where the institutional, knowledge, or operational outcome of one AS affects subsequent ASs in a process-oriented manner. McGinnis (2011) developed a more explicitly network-based approach to NAS by extending the IAD framework to show relationships between multiple ASs that jointly produce governance outcomes, and also highlighted the relation to a more qualitative sociological literature on the Ecology of Games, dating

back to Long (1958). McGinnis recognized that multiple ASs could affect each other both within and across governance levels. For example, within a fishery, there may be an AS in which fishers establish take limits, another in which they make catch decisions, another in which each fisher's compliance is monitored, and still another in which conflicts are resolved. ASs that affect other ASs or that jointly affect outcomes are considered adjacent to one another and are part of a larger network of ASs.

In McGinnis's initial conception, ASs are distinguished by governance tasks, such as appropriation, monitoring, conflict resolution, and finance. They are linked when the outcome of one AS affects an input to another AS. Subsequent works by Kimmich (2013), Kimmich and Villamayor-Tomás (2019), and Baldwin and Tang (2021) have developed this initial conceptual approach by formalizing the conditions under which ASs are considered adjacent, disaggregating ASs into working components, and articulating the nature of links between ASs. For example, ASs may be linked through institutions, information flows, common participants, or biophysical conditions, for example when one AS results in laws, rules, or plans that shape what happens in another AS (Kimmich 2013; Kimmich and Villamayor-Tomás 2019).

Because of these links, ASs are often interdependent and connected. In some cases, this interdependence occurs within a single sector as in the fishery example, where interdependence among various fishery-related ASs jointly produces sectoral outcomes. In other cases, this interdependence can span sectoral boundaries, for example, when ASs in the energy sector are linked to ASs in the water sector through shared resources (Kimmich and Villamayor-Tomás 2019). In many instances, AS interdependence can also span governance levels—as is often the case in federalist governance systems, where policy decisions are often made within ASs at higher governance levels and then implemented in ASs at lower governance levels (Baldwin and Tang 2021).

The institutionalist and situation-centred approaches are not the only entry point for the study of complex governance networks, however. The development and use of social network analysis (SNA) methods for studying social-ecological governance arrangements has burgeoned in recent years (Bodin and Prell 2011; Barnes et al. 2017; Bodin et al. 2019). Early SNA studies typically focused on individual actors as nodes within a network, often surveying policy actors to identify ties between actors and using those ties to depict a network of social relationships among policy actors. More recently, the field has embraced bipartite networks, which include two different types of nodes—actors and policy venues—and construct networks by analysing ties between actors and policy venues (Lubell et al. 2014; Angst et al. 2018). Such studies recognize that social networks are produced by an underlying set of linked institutional arrangements (e.g., underlying ASs), but because these studies are actor-focused rather than AS focused, they observe and model relationships between ASs only through links with individual actors. Because these studies do not directly model the full set of ASs or the relationships between them, they are excluded from our review, although we further address the relationship between actor-centred bipartite and situation-centred NAS approaches in the "Discussion".

Thus, the purpose of this article is to review and synthesize existing studies using the NAS approach, with the goal of identifying common concepts and exploring diverse methods for the study of NASs. We have conducted a systematic review to identify all relevant studies and coded them to better understand the way that each conceptualizes ASs; boundaries of networks of ASs; and the nature of links between ASs. We also coded the research designs, methods, and data sources that different studies have used. Based on this analysis, we distilled insights and developed a narrative synthesis to inform future uses of the NAS approach.

Accordingly, we have structured our review to focus on three key themes: (1) An overview of the empirical context, including the domains covered and governance levels studied; (2) An overview of the conceptual approaches taken in the literature, including the frameworks used and approaches to conceiving of nodes and links; and (3) A summary of the methodological approaches used, including research designs, data sources, and methods used to define or identify nodes and links. Based on our review, we assess the potential of NAS and related Ecology of Game approaches for modelling governance systems and, ultimately, analysing polycentric governance in complex social–ecological systems.

Review method and data

We conducted a systematic review, as the number of empirical studies has increased significantly in recent years and the boundaries of the literature are relatively well defined (see, e.g., Sovacool et al. 2018), and one objective has been to include all relevant empirical studies. An important characteristic of systematic reviews is their replicability. We use the ROSES protocol for systematic reviews (Haddaway et al. 2018) as a guide to report all steps taken in identifying and selecting the relevant literature. Building on our own empirical work and related literature reviews, we started by creating a list of key words to identify all relevant literature streams. We then conducted a keyword search in both Web of Science (WoS) and Scopus, using the identified key words within the following search string: "ALL ("action situation") AND ALL (network) AND ALL (institution) AND ALL (link* OR adjacent OR connect*)". We included the terms "link", "adjacent", or "connect", because we wanted to identify

studies that focus on relationships between ASs, but studies currently use a range of terms to denote these relationships. Given the relatively short tradition of NAS research, we did not constrain our search to a specific time-period. WoS and Scopus have good coverage of peer reviewed scientific journals, but have less coverage of grey literature (e.g., as compared to Google Scholar). We did not consider this to be a problem, given the rather academic orientation of our analysis and the existing literature in the field. In Scopus, this search resulted in 155 relevant papers (date accessed WoS and Scopus: July 23rd 2020). Drawing from earlier literature reviews, as covered in our own empirical research publications, we assessed comprehensiveness of the results.

Next, we narrowed this initial pool to include only studies that (a) have empirically examined ASs as a unit of analysis, and (b) address relationships between ASs. To do this, we read each study's abstract and applied three selection and inclusion criteria. First, we checked whether AS or an analogous concept was used as a unit of analysis, implying the study of interdependent decision-making. To be included in the study, a conceptual framework that demonstrated a study of ASs had to be present, including the IAD framework, MTF, IoS or game theory, among others. Second, the article had to empirically examine at least two interrelated ASs. Studies could be empirical or conceptual with an empirical illustration, but we excluded all purely theoretical or conceptual contributions from the analysis. Third, the article had to consider links or relationships between ASs explicitly. When the abstract was not sufficiently detailed to answer all three questions, we also reviewed the main body of the paper.

In relation to our review objectives ("Consolidating situation-centred network research"), we developed a codebook (Table 1). The elaboration of the book followed several steps. First, we collectively developed a series of general questions and categories inquiring about the general approach to the NAS, the methods used, main results and main conclusions. Then we collectively reviewed five studies for further re-iteration of the initial categories. This resulted in a set of codes as shown in Table 1.

The subsequent results section provides a description covering all categories, including references to the supplementary information, where a detailed coverage in the article would have been too long. The discussion follows a narrative framework synthesis (Haddaway et al. 2018). Building on the coded results for each included empirical paper, we proposed key insights for each of the categories listed in the codebook and collectively selected the most relevant ones. Accordingly, the "Discussion" section only covers the major findings and themes based on our own evaluation of the literature.

Results: common concepts, empirical context, recurring methods

The number of publications that conceive of or assess network relationships between ASs has grown rapidly over the last decade (see Fig. 1a). In addition to our specific keywords and search string, we also conducted a search of all publications that used the term 'action situation' in Scopus (again, without year restrictions). This resulted in 584 papers and a clear upward trend that shows a fivefold increase of publications over the last two decades (see Fig. 1b).

Out of the 155 articles that matched our search string, we selected only those that had an explicit focus on NAS according to the three selection criteria set out in the methodology (see Fig. 2). This produced a subset of 23 articles.

As shown in Fig. 2, criterion 2 was the most limiting. 23 of the 35 studies that fulfilled this criterion also fulfilled the other two criteria. Criterion 1, on the contrary, was the least limiting. Only about 37% of the studies that fulfilled this criterion also fulfilled the other two. Some studies used network concepts and explicitly studied some network links (criterion 3) but did not study ASs as a unit of analysis (criterion 1). While 29 studies fulfilled criterion 1 and 2, 6 of these studies did not include an explicit analysis of links between ASs. As a result, we systematically coded only 23 studies, although the "Discussion" section also reflects on the contributions of the other subsets that only fulfilled two criteria, including non-empirical contributions.

The following provides a brief descriptive summary of the empirical domains, the conceptual frameworks used, and some basic patterns of the studied NAS, including network properties. Insights of the 23 coded papers which are not covered in the results and discussion sections, are summarized in the Electronic Supplementary Material S2.

Empirical contexts studied

Most of the studies have focused on natural resources and related technologies, including water, river basins, and irrigation; oil, gas, and renewable energies and related energy infrastructures, including pipelines; food systems and agriculture; landscapes and biodiversity; fish and marine resources; and tourism and urbanization questions. As expected, many studies spanned multiple sectors and empirical domains, but almost half of the studies focused on one sector only, particularly among studies on water or energy governance and related infrastructure. Only two papers focused on contexts outside the social-environmental sciences, one on civic engagement in public service delivery (Weise et al. 2017), and the other on childcare (Bushouse 2011).

Table 1 Codebook for the NAS case study review including categories and guiding questions

Category	Code[a]	Guiding questions
Empirical context	Sector(s), domains, issues	Which sector(s), domains, or issues are studied?
Conceptual approaches	Conceptual frame	Which conceptual frameworks are used or related/integrated?
	Research question	What are the paper's research questions (including empirical and non-empirical questions)?
	AS nodes and links	Which types of nodes (vertices) and links (edges) are addressed? How are they conceptualized?
Methodological approaches	Research design	Which overall research design is used in the study?
	Data gathering	Which data sources are used in the study?
	AS nodes and links	What methods and data sources are used to empirically identify AS nodes and links?
	AS boundaries, NAS boundaries	What methods and data sources are used to empirically identify boundaries of individual ASs or boundaries of the network?
	NAS description and analysis	Which methodological approaches are used to describe and analyse the network?
Results	NAS size: Number of different ASs/AS types	Which ASs are considered? Are ASs classified/categorized? How many?
	Level of ASs	Which levels of ASs are considered?
	Actor size of the network: Number of actors/types	Which actors are considered? Are actors classified/categorized? How many?
	Link size of the network: Number of links between ASs	How many links (edges) between ASs are considered?
	Node size of the network: Number of nodes / ASs	How many nodes (vertices) are considered?
	Names of the ASs	Is there a logic behind the names? Inductive / deductive and setting / context
	Outcome(s)	Is there one focal outcome or are multiple outcomes relevant for the evaluative criteria?
	Evaluative criteria	Which evaluative criteria are considered?
Conclusion	Further research questions	What further research questions, if any, were identified?
	Limitations	What limitations, if any, are identified relative to this study's analysis, or related to the study of NASs more broadly?
	Important contribution	What important contributions does this article make to the study of NASs?

[a]Note that codes can appear in multiple categories. AS links, for example, are both coded conceptually, as well as methodologically

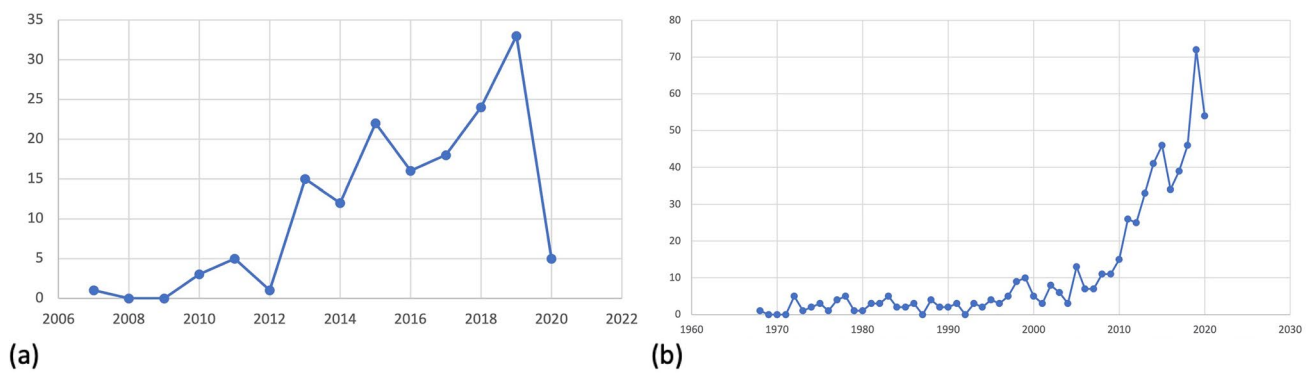

Fig. 1 **a** Number of new publications per year identified by the search string. **b** Number of publications per year identified by the string "action situation": yields 584 results in Scopus (accessed 23rd of July 2020)

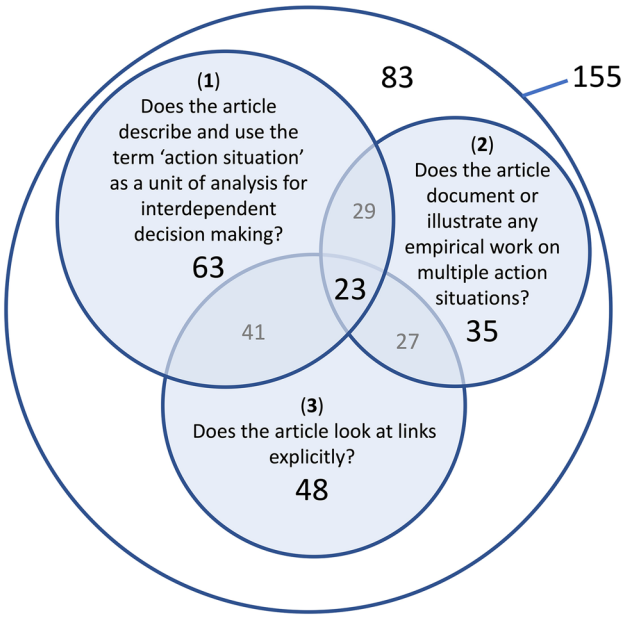

Fig. 2 Empirical NAS publications identified following three selection criteria, resulting in a sub-set of 23 studies out of 155 results of our search string

Most studies covered only one governance level, predominantly the subnational level, but there are also some multi-level studies, including multi-level infrastructures (Kimmich 2013; Cox 2014), cross-boundary rivers and pipelines (Sendzimir et al. 2010; Gritsenko 2018), telecoupling relations (Boillat et al. 2018; Oberlack et al. 2018), and value chains (Villamayor-Tomas et al. 2015).

Conceptual approaches used

Most studies used the rules-oriented IAD (Ostrom et al. 1994), the process-oriented MTF (Pahl-Wostl et al. 2010), or the transactions-oriented Institutions-of-Sustainability (IoS) framework (Hagedorn 2008) to structure the study of ASs. Only four cases employed game-theoretic models to describe and analyse ASs.

As might be expected for a series of papers focused on the NAS approach, most papers conceive of ASs or games as the primary nodes in their network analysis (Kimmich 2013; Oberlack et al. 2018; Gritsenko 2018; Kimmich and Villamayor-Tomás 2019; Therville et al. 2019; Möck et al. 2019; Edelmann et al. 2020). Several papers did not use the term 'action situation' explicitly, although mentioning the term in the body of the text, but identified nodes with conceptually overlapping terms, such as policy forums, events, or meetings (Weise et al. 2017; Mewhirter et al. 2018).

Whereas ASs are the primary nodes, some also disaggregate ASs into subcomponents in ways that suggest that these subcomponents could conceivably be 'sub-nodes'. For example, Therville et al. (2019) identify resource users, infrastructure providers, and infrastructures as aspects of ASs that can be linked to each other. Knieper et al. (2010) identify ASs, institutions, and knowledge as objects that can be linked to each other. Heikkila and Weible (2018) identify actors and rules as potential nested nodes within ASs. Kimmich (2013) and Kimmich and Villamayor-Tomás (2019) disaggregate ASs into "working components" that include institutions, biophysical resources/conditions, information, and actors, although these are not explicitly identified as nodes.

Similarly, most of the papers reviewed do not use technical network or graph-theoretic terms, and instead approach the idea of 'links' from working components of ASs or an inductive empirical approach to interdependencies. In these papers, links are often conceived in terms of 'strategic interactions' (Therville et al. 2019), interdependencies, or the presence of externalities between ASs (Mewhirter et al. 2018). Several papers identify links that occur when the output of a collective choice AS produces rules that structure an operational AS (Bushouse 2011; Carter et al. 2015). While these papers help to develop the idea of links between ASs conceptually, it is clear that the literature is not yet at a point where links are defined or classified in a way that facilitates systematic operationalization and computational approaches to network analysis (Cox 2014).

In fact, the literature has yet to settle on a common approach for classifying or conceiving of links between ASs. Six papers have classified links based on which types of nodes are connected. The most common approach follows the IAD framework closely by disaggregating individual ASs into working components such as institutions, actors, biophysical conditions, and information, and then classifying links by the type of working components that are connected (Kimmich 2013; Gritsenko 2018; Kimmich and Villamayor-Tomás 2019; Edelmann et al. 2020). Oberlack et al. (2018) take a similar approach to identify links between other properties of social–ecological systems, including information, rights, access, capital, duties, legitimacy, biofuel demand and supply. These papers tend to view links as occurring between same-type components of connected ASs. One paper draws on the robustness framework (Anderies et al. 2007) to consider the possibility that there may be links between different-type components within a single AS, for example links between resource users and resource systems (Therville et al. 2019).

A very small number of papers have attempted to go beyond simply identifying links to discuss *how* those ASs are linked and to define, classify or describe the characteristics of links in additional ways. Kimmich (2013), Kimmich and Villamayor-Tomás (2019), and Mewhirter et al. (2018) identify directionality and strength as important properties of links. Möck et al. (2019) define links as flows of

resources, rules, and information, implying directionality of links. Carter et al. (2015) and Bushouse (2011) implicitly discuss the directionality of influence when outcomes of one AS become the rules that govern another AS. Heikkila and Weible (2018) derive links by examining the components of institutional statements using the Institutional Grammar Tool; here, they use the rule deontics such as "must" "may" or "may not" to characterize links.

Methods used

NAS research has employed a variety of very different methods. The identified studies have adopted the NAS approach either to develop a new method or model (44%) or for empirical purposes (Fig. 3a). In their research design, the authors adopted NAS for single, comparative, or multi-site case studies as well as regional assessments. Main data sources were interviews, document analysis and secondary data (Fig. 3b).

Identifying NASs implies delineating the boundaries of ASs and their links. We find that previous studies adopted one of six different ways to delineate the boundaries of ASs (Fig. 3c, cf. Oberlack et al. 2018). They can be grouped into two types of approaches. First, seven studies (31%) adopted an inductive approach to identify social interactions that exert causal influence on the outcome or phenomenon of interest. Often, these studies used process tracing methods (Beach and Pedersen 2016) to explain how and why certain social interactions (in ASs) contributed to an outcome. The other set of studies mobilized a predefined concept to identify ASs. For example, four studies (17%) identified ASs around the use or governance of different resource systems such as water, energy, food, coastal areas, or land systems. Three (13%) mobilized governance functions,

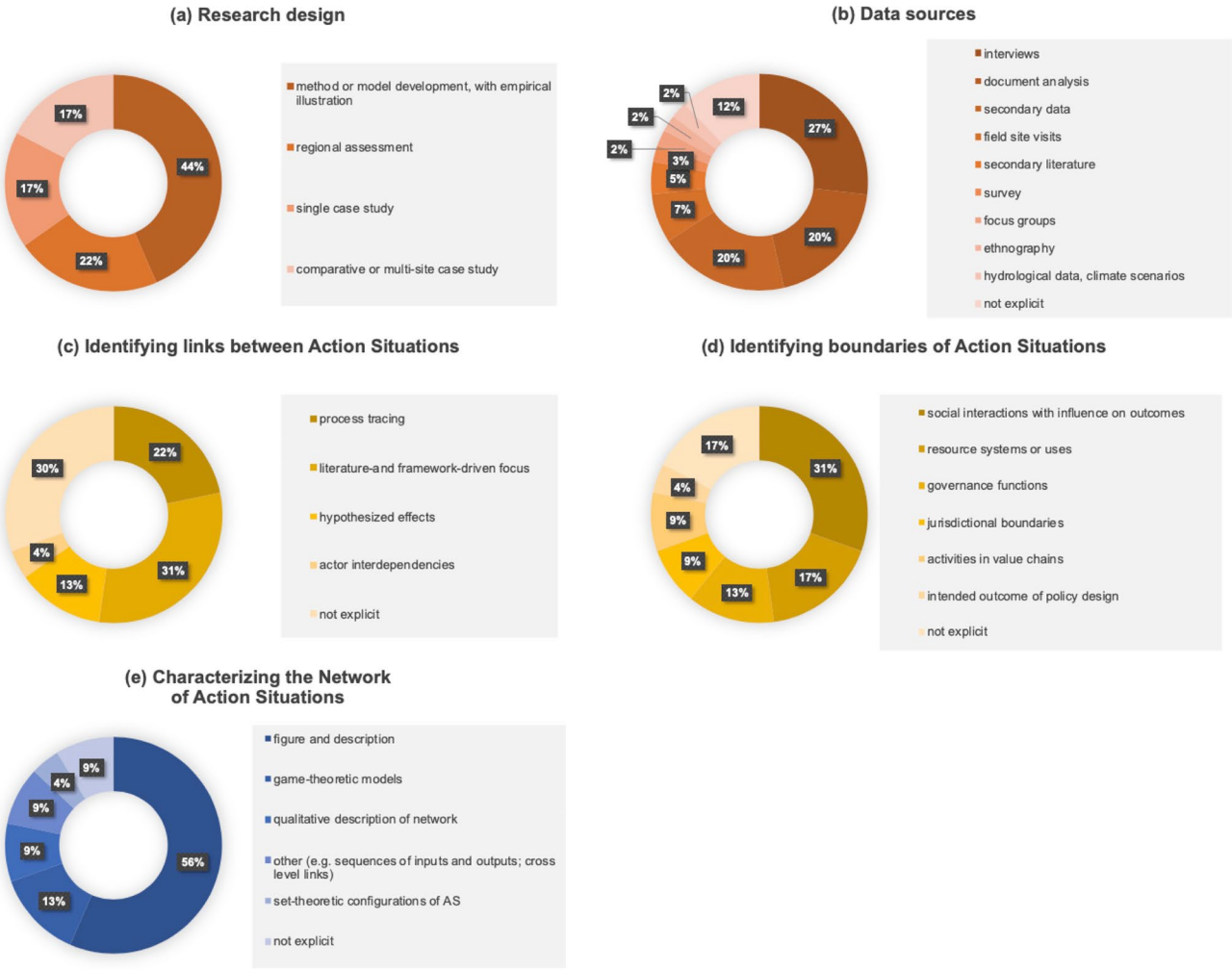

Fig. 3 **a** Research designs and **b** data sources in NAS research; **c** links among ASs; **d** identifying the boundaries of ASs; **e** characterizing the NAS. Note: for data sources, a single study can report multiple sources ($n = 23$ studies). The underlying coding results and related article references are available in Electronic Supplementary Material table S1

such as rulemaking, monitoring, or sanctioning, to identify ASs. Two characterize ASs along established jurisdictional boundaries such as municipal, district, and country levels, and two other studies frame ASs around the multiple steps in value chains. One study (4%) identified ASs based on statements within policy text about the policy's intended outcomes (Carter et al. 2015). The other four (17%) did not have an explicit approach for delineating boundaries of the NAS.

There are different ways to identify links between ASs. The studies that mobilize an inductive approach to identify the boundaries of ASs typically also utilize process tracing to identify the links between ASs (Fig. 3d). Most other studies depicted hypothesized effects or characterized links according to a literature- or framework-driven conceptual terminology. One study understands links as between actors, rather than ASs, and distinguishes between interactions that occur entirely within one location (AS) versus those that occur across multiple locations (Cox 2014). Notably, a large share (31%) of the studies are not explicit about their approach to identifying links between ASs.

Studies describe the resulting NAS in different ways. The clear majority (61%) describes the NAS through a figure or stylised graph that relates the ASs, including ties between ASs, and summarizes the actors, interactions, and outcomes of each AS. Few studies mobilized more formalized ways to characterize the network, such as through game-theoretic models or set-theoretic configurations of AS equilibrium outcome states (Fig. 3e).

Network size and governance levels covered

The number of identified ASs ranges from two to as many as 50 (Boillat et al. 2018), with five to seven ASs being the most frequent network size (see Table S2 in the Online Supplementary Material). The study of relationships between two ASs is common in CPR research. For example, several scholars have studied dyadic relationships between infrastructure provision and appropriation ASs in river water use for irrigation (Janssen et al. 2011). Another example captures grazing and alps maintenance as situations of appropriation and provision (Baur and Binder 2013). In a water–energy–food nexus example, solving a coordination problem of energy-efficient technology adoption helps solving a dilemma of electricity infrastructure overuse for irrigation (Kimmich and Sagebiel 2016). In such cases, the two situations are connected in multiple ways: physical proximity, shared actors, and information conveyed from one situation to the other. The outcomes of irrigation infrastructure provision, for example, affect the dynamics in the water appropriation situation. These dynamic relationships can look significantly different, however, if the analyst adds a third AS to generate a triadic network structure—for example, adding a collective choice AS where rules of provision or appropriation are endogenously adopted (Zikos et al. 2010). More generally, such collective choice situations can help analysts to understand the effects of endogenous institutional change (Rommel 2015; Yu and Kasymov 2020). The study of such AS dyads and triads helps to systematically identify and study their dynamics within a larger NAS, as well as to unpack the way that additional ASs may affect relationships within AS dyads of interest.

A key motivation for this systematic review was the observation that although researchers have studied operational, collective, and constitutional choice situations, researchers frequently neglect adjacent situations at the same governance level (McGinnis 2011). Our review shows that the empirical NAS literature has clearly addressed this shortcoming, as all studies cover at least two ASs at the same governance level. This focus appears to have come at the cost of neglecting the constitutional choice level, however. Among the reviewed body of NAS research, only three have extended their network analysis to all three choice levels (Knieper et al. 2010; Bushouse 2011; Möck et al. 2019). Most studies (40%) capture operational and collective levels (Table S2).

Collective choice ASs often exist in hierarchical relationships with operational level ASs, but analysts interested in hierarchies and power relations between ASs can also consider relationships within a single governance level, because the outcome of one AS may affect the working components of another AS. With the multiple direct and indirect links between ASs, the NAS approach has the potential to capture the hierarchies and diverse 'heterarchies' (Cumming 2016) in situation-centred networks, including polycentric, but also pyramidal properties of different networks. None of the reviewed studies have addressed these more general network patterns so far. This leads us to the major open questions and research needs identified in our review.

Discussion

Common ground for situation-centred networks

The diverse existing approaches to studying ASs and NAS described above provide rich material for cumulative knowledge generation. All studies build on existing AS frameworks (IAD, IoS, MTF), which provide a common language and set of concepts (types of rules, types of transactions, levels of action, etc.) that are applicable across a wide range of settings and compatible with a diverse range of qualitative and quantitative analytical methods. Frameworks provide a basis for communicating and agreeing on the common building blocks, facilitate the use of multiple analytical methods (Beckmann and Padmanabhan 2009), enable collaboration

across disciplines (Poteete et al. 2010), and structure meta-studies to further consolidate knowledge (Villamayor-Tomas et al. 2020).

Nodes, links, and the boundaries of situations and networks

Nonetheless, there are challenges and barriers to knowledge consolidation that need to be addressed for this literature to move forward. First, there is considerable diversity in the terms used for studying NASs. *Connected ASs* (Pahl-Wostl et al. 2013), *networked ASs* (Moser et al. 2019), *adjacent ASs* (McGinnis 2011), or *linked ASs* (Sendzimir et al. 2010; Kimmich 2013) all constitute a network, albeit with different emphases on the biophysical and social side of connectivity, and currently unspecified graph-theoretical properties. While this diversity of terms is not itself a barrier to knowledge accumulation, these different terms are often associated with unstated assumptions about what are the key components of the networks and what is the nature of the links between those components.

All articles reviewed study connectivity within complex networks, addressing both structure (network architecture of ASs) and process (interactions between ASs), providing analysts with a range of ways to conceptualize links between ASs, actors, institutions, and biophysical systems. The NAS approach accounts for social ties, institutional links, and strategic linking via actors, among others. This body of research would benefit from clear conceptual development about the range of nodes and links that can be studied within a NAS.

Indeed, studies diverge in whether and how ASs are defined as nodes in the network. The reviewed studies vary considerably, for example, in the degree to which they disaggregate or aggregate ASs. Some of them conceive of ASs broadly, defining AS boundaries by sector or jurisdiction, while others disaggregate sectors into ASs defined by specific governance functions (Kimmich and Villamayor-Tomás 2019), stages in a value chain (Villamayor-Tomas et al. 2015; Grundmann and Ehlers 2016), or social interactions that cause particular outcomes (Kimmich 2013; Oberlack et al. 2018). This diversity in approaches to AS nodes has implications for the way links are operationalized since, for example, sectors are likely to be linked in very different ways than governance functions or stages in a value chain. The way that ASs and links are conceived also shapes the analysts' choices about data and methods. When ASs are conceived as (formal) jurisdiction processes, for example, data will likely be collected at the chosen jurisdictional level, and the analyst may not seek out data sources at other governance levels. When ASs are conceived as governance functions, in contrast, there may be a more diverse array of data sources and potential methods of analysis needed.

While it might be appealing to settle on a single 'best practice' for defining AS boundaries, this may be premature given the relatively early stages of development of NAS as a concept with related methods, as well as the enormous range of potential ASs that are relevant for study. That said, such development and cross-feeding will probably work best if scholars are both creative in their approach and transparent about the choices they make—and the justifications for those choices.

The above also applies to the choice of network boundaries. Like SNA, NAS research must be explicit about the boundaries of the network (Kimmich 2013; Oberlack et al. 2018; Kimmich and Villamayor-Tomás 2019). In general, the network can be developed by either identifying those ASs that are considered relevant from a theoretical perspective (Schlüter et al. 2019), or by selecting those that are considered relevant with regards to problem, research objective or stakeholders' outcome(s) of interest (Kimmich 2013; Kellner and Brunner 2021).

NAS as a complex Ecology of Games

It is helpful to compare NAS research with other Ecology of Games approaches and prominent sets of methods for systematic analysis of complex governance arrangements, which have not been identified by our systematic literature search. These approaches are analogous and complementary in many ways, although they tend to rest on different theoretical assumptions. They also differ in terms of methodological development: whereas NAS research is nascent and remains characterized by a diversity of approaches to conceptualize nodes and links, there is a growing body of Ecology of Games studies that use a fairly standardized approach to conceptualizing nodes and ties, as well as a precise graph-theoretic formalization as bipartite networks (Angst et al. 2018; Mewhirter et al. 2018). Below, we make explicit some of the similarities and differences between these two approaches to the Ecology of Games, with a goal of helping analysts better understand the underlying conceptual foundations and assumptions that underlie each approach. Another strand of literature that draws on the Ecology of Games analogy (Long 1958), which is more qualitative in nature (Dutton and Mäkinen 1987; Dutton et al. 2012), or uses descriptive three-mode networks (Cornwell et al. 2003), will not be discussed here.

In bipartite network studies, two types of nodes exist: actors and policy venues. Venues include policy forums and meetings. Networks are generally conceived as a bipartite graph, where actors have direct ties with policy venues, and indirect ties with other actors that participate in those venues. This allows Ecology of Games analysts to define an actor-centred policy network that tracks the way that actors engage with different policy venues. This formalization

provides rigorous methods and reproducible insights, particularly about how actors navigate complex governance systems through their participation in multiple forums.

NAS research differs from the bipartite network approach in several ways. First, while both approaches have the potential to treat ASs as nodes, the bipartite network focuses its attention on policy venues—forums in which policy actors gather to make collective decisions, coordinate, or share information. While policy venues are critically important ASs in many social–ecological systems, they are one subset of a broader range of ASs that make up any complex governance arrangement. In many operational, biophysical, or ecological ASs, actors do not necessarily meet in the same place at the same time but are part of an AS nonetheless because their actions are interdependent. Rarely covered in bipartite network approaches but important are also constitutional choice ASs, such as the courts. The NAS approach, in contrast, considers a wider range of ASs that might potentially contribute to important policy or governance outcomes—including legislative, regulatory, judicial, or private sector ASs that might not typically be seen as policy venues or even bring actors together simultaneously, but that might nonetheless play an important role in structuring the broader governance system.

Along with this more diverse conception of ASs, the NAS approach requires scholars to assess the characteristics of ASs more explicitly. NAS scholars often differentiate among ASs based on governance levels, governance tasks, or stages in the supply chain—crucial differences between ASs that are less critical when policy venues are the primary AS of interest.

Finally, and perhaps most critically, bipartite network studies are actor-focused, and rest on an underlying assumption that ASs are linked to one another primarily through actors that participate in more than one policy forum. The NAS approach, in contrast, conceives of ASs that are interdependent in a wider range of ways: ties other than via actors exist between ASs. In some cases, the nature of these ties may imply a hierarchical set of relationships, for example, when the outcomes of one AS determine the structure of another AS. Since bipartite network studies conceive of policy venues as linked through participation by shared actors, they have less frequently examined or highlighted institutional, information, biophysical, or other types of links between policy venues, or considered the range of interdependent relationships that might occur as a result.

To summarize, both the bipartite network and the NAS approaches to the Ecology of Games capture important aspects of complex governance structures and processes, but the two approaches are based on different assumptions, and they are thus useful for answering different sets of questions. The bipartite network approach provides a robust set of well-defined methods for examining policy networks comprised of actors participating in multiple policy venues and can provide significant insight into the relationships and behaviours of policy actors within those networks. It has most often been applied within networks of watershed associations whose interdependence is largely based on joint actors' participation. The NAS approach, in contrast, can be used to examine the way that networks of interdependent ASs structure complex governance arrangements, even if those ASs are connected through rule systems, shared infrastructure, or shared biophysical conditions, rather than through joint participation by a similar set of actors. The NAS approach thus offers potential for examining complex governance in hierarchical, multi-level, or cross-sectoral contexts, where actors' participation in forums may not be the main source of interdependence among ASs. Perhaps because the NAS approach embraces a wider range of potential ASs and relationships between them, it is not currently defined by a single methodological approach, but rather a range of different ways and models that analysts might use to conceive of ASs and links between them.

Towards methodological good practices in NAS research

NAS analysis can follow different methodological protocols, depending on research needs and methods. In the more inductive, case-driven approach to NAS research, the process-tracing methodology provides researchers with established good-practice standards (Beach and Pedersen 2016). These standards include triangulation of data sources, testing of alternative hypotheses, and independent verification. Process tracing seeks to explain causal effects by tracing outcomes to explanatory conditions and mechanisms. Here, the specific analytical approach of NAS and its theoretical foundation in the IAD offers the analyst a heuristic, sense-making lens to trace outcomes to the situations of interdependent decision-making and the institutional, biophysical, and socio-economic–cultural–political conditions that shape these situations. In the words of process tracing, ASs entail the causal mechanisms explaining outcomes. The inductive approach offers conceptual flexibility to tailor explanations to the particular context of a study. However, this idiosyncrasy may limit replicability of results in NAS research and bias results to the subjective insights of the analyst. Thus, cumulative learning is needed about causally similar NAS cases.

The deductive, concept-driven approach to NAS may facilitate such cumulative learning because the researcher mobilizes an additional concept or theory to specify boundaries and expected links of ASs, such as concepts of value chains, governance functions, or the water-energy-food nexus. Via AS frameworks, the NAS approach can also add an institutional and game-theoretic rooting of these concepts.

As mentioned above, the creativity of scholars in developing NAS analyses should be accompanied by efforts to guarantee replicability. While we recognize that multiple approaches are useful for the field, reporting of any NAS study should certainly cover how the analyst identified, analysed, and verified (a) boundaries of ASs; (b) the links between the ASs; and (c) the boundaries and features of the entire network of ASs. The results of our systematic coding have shown that several studies did not explicitly address all these aspects (see Table S2). The guiding questions of our codebook provide a checklist of questions that need to be answered when conducting a NAS study to ensure that all aspects are considered. Our checklist (see Table 1) is preliminary and can be tailored to different research methods for studying NASs.

A frequent reference to describe ASs is the IAD framework. For example, the IAD's 7-rule typology helps to characterize ASs through seven components: actors, positions, choices, information, control, outcomes, benefits and costs (Ostrom et al. 1994). That said, this level of detail can quickly become unmanageable for multiple ASs in a network, and might also not be necessary to explain a phenomenon. We propose that key elements of an AS, which should be specified at minimum in any NAS application, are actors, their interactions, and outcomes; but studies may differ regarding the level of detail in which they specify the positions, choices, information, control, and benefits/costs, or game-theoretic models in multiple ASs.

Future research needs

The reviewed papers also point to several aspects for further research. While some studies focus almost exclusively on research questions and conclusions concerning their empirical cases, the majority also provide conclusions concerning theory, models, and methods. Big themes that we believe are worth pursuing in the mid to long term are the development of new ways to synthesise and visualize (e.g., beyond boxes and arrow diagrams) NAS data to facilitate analysis (Cox 2014; Wilkes-Allemann et al. 2015; Gritsenko 2018; Märker et al. 2018); the role of imaginaries, worldviews and power relations within and between ASs (Ruiz-Ballesteros and Brondizio 2013; Jones et al. 2017; Boillat et al. 2018; Mudliar and Koontz 2018); the conceptualization of ecological situations, in addition to the social-ecological and purely social ASs (Schlüter et al. 2019); and the study of the evolution and dynamics of a NAS over time through layers of older and more recent ASs (Möck et al. 2019).

From a more operational point of view, progress can also be made with the characterization of ASs, links between ASs, and network boundaries. Early game-theoretical characterizations (Kimmich 2013) of AS types have more recently been followed by studies distinguishing between different cooperation and coordination structures of ASs (Kimmich and Villamayor-Tomás 2019) and a periodic table of elementary situations (Bruns and Kimmich 2021). Concerning links, most studies have tended to give priority to information, operational, and institutional links, but actor links also appear crucial, as the bipartite network approach to the Ecology of Games demonstrates. Regarding the boundary specification challenge (see previous subsection), promising ways forward include best practices for stakeholder analysis (Reed et al. 2009) and SNA (Prell 2012).

The authors reviewed here point to the potential of combining the NAS approach with other frameworks and theoretical approaches to solve the above operational issues. Villamayor-Tomas et al. (2015), Grundmann and Ehlers (2016), and Carlson and Bitsch (2018), for example, show the potential of using value chain frameworks as a means to guide the identification of ASs (e.g., stages along the chain and across chains); Oberlack et al. (2018) and Boillat et al. (2018) call for combining place-based analyses of ASs with flow analyses in the study of telecoupled systems; Boillat et al. (2018) and Jones et al. (2017) integrate a political ecology perspective; Kimmich (2016) uses an institutional political economic perspective and analytic narrative approach to public choice situations of party competition and regulation; and Magnani et al. (2018) study how heterogeneous actors, including non-human ones, enact energy as a common-pool resource via polycentric intermediation networks, using Actor-Network Theory.

Finally, authors have also pointed out the possibility to use NAS analyses for scenario building. As illustrated in Kimmich and Villamayor-Tomás (2019), NAS can be used to explore the feasibility and implications of different policy solutions as they create cascading effects across different configurations of AS outcomes.

As mentioned earlier, many studies were excluded from our systematic analysis because they did not fulfil all inclusion criteria (see Fig. 2), or, in a few instances, were published after our initial coding process was complete. Several such studies make contributions that are worth mentioning here for their methodological contributions or potential to contribute to middle-range theory building. Heikkila et al. (2021), for example, use a semi-automated text analysis of 22 state-level policies governing oil and gas development in California to identify actors, issues, and rules and their connections around different focal areas (which they equate to "targeted ASs"). Baldwin and Tang (2021) provide an illustration of how hierarchical regulatory ASs can combine with markets to jointly produce outcomes of interest. Villamayor-Tomas et al. (2019) in turn theorize around the effectiveness of policy instruments and their bundles in promoting collective action depending on the type of AS at hand. Levänen and Hukkinen (2013) highlight the role of cognitive practices in ASs and the role of deliberation

in linking formal and informal institutions. Olivier (2019) builds on the network approach to interactions to understand whether cooperation versus coordination situations are addressed via more or less redundant bundles of rules in two cases of high-quality drinking water provision in New York City and Boston. Barreteau et al. (2020) develop a framework for modelling dynamic ASs based on feedback control loops, thereby enabling the identification of vulnerabilities in dynamic environments, and Kellner and Brunner (2021) combine hydrological modelling with a NAS approach.

Conclusion

There is widespread recognition that governance scholars gain considerable insights from empirically studying connected action situations (ASs). Situation-centred frameworks have been developed and used to guide three decades' worth of empirical analyses, focusing on specific, but frequently isolated ASs. Only in the last decade have these frameworks been extended to networks of ASs, but the situation-centred approaches to networks are currently rather diverse and have opened multiple paths and perspectives to the study of a variety of very heterogeneous networks. After a decade of empirical research into NAS cases, this review provides an orientation for the multiple paths and perspectives that have been taken, to consolidate the insights and experiences gained with the diverse approaches, and to highlight the most promising avenues for future research.

We take stock of the methods, results, network typologies, and most important suggestions and conclusions from empirical studies for NAS research. Although there is coherence along the lines of existing frameworks to describe and study single ASs, there is currently no general approach to extend the analysis to networks. This is the case because the types of ASs and links between ASs are heterogeneous. While acknowledging the diverse situation- and case-specific relevance of physical, institutional, or social links, respectively, future NAS research could profit from a typology of ASs, including network archetypes.

Our results suggest that the diversity of ASs and the multiple types of physical and social links call for a flexible and case-sensitive approach, which is reflected in the theoretical perspectives and methods taken in each case study. Although this sensitivity is crucial to prevent panacea traps and to foster creativity, a more explicit and consistent reporting of network approaches used in the field helps to learn from and build on or depart from others' procedures. A common procedure, checklist, or protocol would be fruitful to enable cumulated knowledge generation across studies of single and comparative case studies. Our codebook provides a preliminary checklist that could help to address the major challenges of NAS research identified and discussed in this review. A comprehensive list or typology of possible situations and a systematic procedure to identify relevant situations in an empirical case will also be crucial. The types of situations identified and summarized in this empirical literature review provide a first orientation. As discussed here, future research can also make use of the broader literature and perspectives on social and social–ecological networks to advance NAS research.

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