

Perspective

Networks of influence: Linking capitals and agency to understand actors' roles in sustainability interventions

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In the face of multiple social-ecological crises, the need for sustainability transformations has been widely acknowledged. Understanding how diverse actors influence processes and outcomes—and thus their agency—has been identified as an important lever for sustainability transformations. However, capturing the various dimensions of agency remains challenging. Despite several existing conceptual framings, a clear approach to fully understanding agency within governance networks is still missing. Here, we propose an actor-process network approach to characterize and assess actors' agency in influencing specific sustainability interventions. Our approach uses network analysis as a methodological bridging element to link the concepts of capitals and agency. We propose five forms of agency: allocating human resources, enacting political relevance, influencing financial flows, providing physical goods and assets, and steering social-ecological discourse. Our approach can contribute to discussions on how to distribute roles and responsibilities between diverse actors involved in sustainability interventions.

INTRODUCTION

Escalating social-ecological crises, such as inadequate responses to biodiversity loss, global warming, and persistent failures to advance equitable sustainable development, underscore the urgent need for sustainability transformations, which, in this context, refer to deep systemic shifts in how societies organize and interact with natural systems to achieve long-term sustainability. In light of this, calls for science to be more proactively engaged at the science-policy-society interface have been increasing, e.g., in the recent approval of the IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) Transformative Change Assessment,¹ the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC),² and the 2030 Agenda for Sustainable Development.³ Fostering sustainability transformations requires intense cooperation and commitment among (organizational and individual) actors to implement cross-sectoral and multilevel governance interventions by aligning interests, objectives, and resources.^{4,5} In the last decades, efforts have been made throughout the global science-policy community, e.g., through the IPBES and IPCC, to engage and empower a diversity of actors in governance processes that facilitate these types of interventions. Yet, practical cooperation and joint action efforts in governance that embrace plural actors' perspectives and contestation remain anecdotal and challenging to achieve.^{6,7} This implies that more methodological guidance is needed to support the organization and cooperation of societal actors for

establishing action networks that help operationalize governance interventions in favor of sustainability transformations.

For science to successfully engage at this interface, understanding who is acting how and when or who should be acting and how is thus fundamental.^{8–10} While we acknowledge the necessity of broad structural transformative changes, in this paper, we focus on the concept of sustainability interventions—defined as targeted actions or policies aimed at addressing specific sustainability challenges—and the governance processes through which they are implemented. Such interventions may, in turn, catalyze broader sustainability transformations, i.e., through amplification processes that extend their reach by upscaling, transferring, or adapting interventions to new contexts.¹¹ Understanding these interventions requires attention to both the actors involved in the targeted actions and policies and their roles within governance systems. Several scholars have emphasized the importance of acknowledging and addressing actors' agency—defined as the capacities of individuals or organizations to change the course of events or the outcomes of processes^{12,13}—to understand how actors intervene in governance systems and can contribute to achieving more sustainable futures.^{14–17} For example, scholars have stressed the importance of understanding how actors influence governance processes not only through formal authority but also through procedural tools,¹⁸ collaborative forums,¹⁹ and advocacy coalitions.²⁰

However, capturing the various dimensions of agency remains a key analytical challenge within environmental governance,²¹ and despite various frameworks, a clear approach for



operationalizing agency within environmental governance and at the science-policy-society interface is lacking. For example, long-standing and ongoing debates around the role of capitals in shaping sustainability outcomes exist, i.e., within the sustainable livelihoods literature. Scholars such as Scoones²² have emphasized the need to move beyond static stock-based models and understand capitals as embedded in political, historical, and institutional contexts, which is closely tied to questions of structural power and long-term change. Simultaneously, discussions of agency remain underdeveloped in many empirical applications, often lacking engagement with foundational theories, such as Giddens' structuration theory,²³ which explores the dynamic interplay between structure and agency. This gap limits our ability to understand how actors mobilize resources and exert influence within governance systems that facilitate or inhibit sustainability interventions.

Here, we propose an actor-process network approach to characterize and analyze the agency of actors in driving or preventing sustainability interventions. In response to the aforementioned gap, we explicitly link the concepts of capitals and agency using network analysis as a methodological bridging element. We propose five distinct forms of agency based on capitals: allocating human resources, enacting political relevance, influencing financial flows, providing physical goods and assets, and steering social-ecological discourse. Drawing on three case studies from diverse governance settings, we demonstrate how our approach can reveal the underlying dynamics of actor-process relations and identify pathways for successful sustainability interventions. By integrating these conceptual strands and operationalizing them through network analysis, we offer a methodological contribution that not only advances the study of environmental governance but also speaks to broader debates on sustainability transformations,²⁴ where understanding who acts, with what resources, and to what effect is central to enabling systemic change.¹

CONCEPTUAL FRAMING

Defining and linking capitals and agency

The concept of capitals and the capitals approach have their roots in the 1990s' sustainable development and sustainable livelihoods literature, notably influenced by scholars such as Scoones²⁵ and Bebbington.²⁶ The concept emphasizes the various types of assets or forms of capitals that individuals, organizations, and communities rely on to sustain and improve their livelihoods. Over the years, different frameworks and approaches have been developed to characterize and assess these capitals in various contexts, including sustainability, community resilience, and climate change adaptation. For instance, in the context of sustainability, the Asian Development Bank promoted the sustainable livelihoods capital approach in the early 2000s,²⁷ which focuses on five key types of capital: human, social, natural, physical, and financial. It aims to understand how these capitals interact and contribute to sustainable livelihoods, particularly in low- and middle-income countries. To evaluate and improve community resilience, Emery and Flora²⁸ proposed the community capitals framework by introducing two additional capital types, namely, cultural and political. In doing so, their approach recognizes more elaborate dimensions of capital and

flows that contribute to community resilience. More recently, the capitals approach framework was introduced to measure governance performance in the context of climate change adaptation.^{29,30} It integrates natural, human, social, political, and financial capitals to evaluate how governance structures and processes can effectively support climate resilience and adaptation efforts in integrated social-ecological systems.

Drawing on these frameworks, capitals can be understood as "the assets, capabilities, properties or other components of a system, which collectively represent its ability to function well."²⁹ They are often categorized as natural, human, social, cultural, political, manufactured/physical, and financial capitals (see Figure 1). A capital approach provides a holistic way to understand and manage the resources that contribute to the transformation toward sustainable and resilient social-ecological systems.^{31–34}

Agency, on the other hand, can be defined as the capacity of individuals and organizations to change the course of events or the outcomes of processes.^{12,13} It includes the ability to make decisions, implement policies, and affect change within social-ecological systems. The concept emphasizes the role of actors in actively influencing governance processes, i.e., driving decision-making and exercising authority rather than being passive recipients of decisions made by others. Thus, agency is seen as a key factor in how individuals and societies respond to environmental change across different systemic levels.^{35,36} The key elements influencing or enabling an actor's agency to act are often complex and can vary across contexts. For example, Duygan et al.³⁷ identify three essential components that constitute an actor's agency in realizing strategic actions capable of transforming institutions. These components are (1) resources that an actor can utilize, (2) discourses that convey one's beliefs, interests, and visions while also serving as tools for persuasion and collective understanding, and (3) social networks that reflect an individual's position and relationships with others. Similarly, Järnberg et al.¹⁶ highlight that informal networks, coalition forming, resource mobilization skills, a shared vision, trust, experimentation, and social learning contribute to actors' agency in driving sustainability transformations. Additionally, Celliers et al.¹⁴ define three dimensions and eleven indicators that constitute an organization's agency in coastal governance and propose different organizational archetypes based on the composition of agency indicators. These three dimensions are resources, scale, and power: (1) resources include human capacity, financial capacity, and infrastructure and goods; (2) scale encompasses operational scale, organizational mandate, and constituency; and (3) power involves enforcement, moral suasion, political relevance, legislative power, and executive power.¹⁴

The examples show how different elements of agency are closely intertwined with different types of capital. However, whereas capitals refer to a "stock" of resources or assets,³⁸ in this paper, we want to emphasize that an integration of the two concepts is useful to understand the "flow" of interactions among social actors and within the governance arena. In line with Giddens' structuration theory,²³ which highlights the recursive relationship between structure and agency, we argue that actors do not simply "own" capital, but they actively choose to or choose not to use or apply it for a specific action or process.

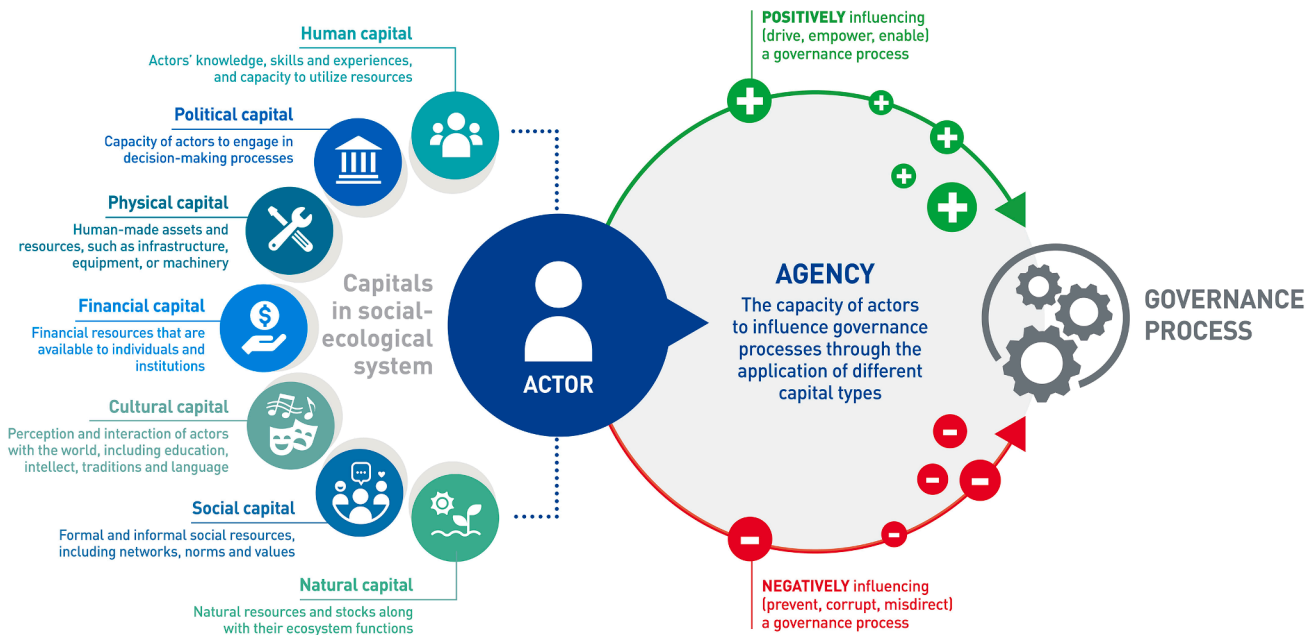


Figure 1. Graphical visualization of how capitals and agency are linked

On the left are the seven types of capital in social-ecological systems and their common definitions.^{28,32–34} These capitals can be used or applied by an actor in the form of agency to positively (drive, empower, or enable) or negatively (prevent, corrupt, or misdirect) influence governance processes.

For example, a governmental actor may have the financial means to implement a certain project (financial capital) but, for political reasons, chooses not to make use of it. Similarly, an organization may own the data infrastructure for hosting a warning system (physical capital) but does not allow for open access. The application of capitals is therefore closely linked to the exertion of influence of an actor on such processes and on other social actors, i.e., agency.

Thus, we define agency as the capacity of actors to influence governance processes through the application of different capital types within social-ecological systems (see Figure 1). Using their agency, actors can both positively influence (e.g., drive, empower, or enable) or negatively influence (e.g., prevent, corrupt, or misdirect) governance processes. By integrating these concepts, we provide a more nuanced understanding and categorization of what form of agency is applied or needed when in sustainability interventions. Although various scholars have emphasized a close relationship between the two concepts,^{35,39} a comprehensive approach on how to acknowledge and integrate this interplay is lacking.

Current challenges in analyzing influence in networks

Interactions within governance systems are often analyzed using network analysis, i.e., to analyze social networks or the interplay of social and ecological processes within social-ecological systems (see reviews by Kluger et al.,⁴⁰ Sayles et al.,⁴¹ and Schwenke and Holzkämper⁴²). Network analysis is based on graph theory and statistics to provide a rigorous, systematic approach to studying relationships and their structural patterns in these systems.⁴³ In the context of social networks, actors (referred to as nodes) and their connections (known as ties) are analyzed. Centrality metrics such as degree centrality, between-

ness centrality, or eigenvector centrality are used to identify the most influential nodes within a network.⁴⁴ These metrics provide insights into the roles of actors and their impact on overall network dynamics, such as bridging actors who can facilitate collaboration across different sectors, levels, or actor groups.⁴³ Some of the key aspects explored in the social network analysis literature are relations based on collaboration and information flows,^{45–47} learning,^{48,49} and conflicts.^{50–52} Such quantitative social network analyses are increasingly used and complemented with innovative methods that apply qualitative approaches for deeper insights into actors' relationships.^{53–55}

However, based on the literature, we identify two major gaps concerning capitals and agency: firstly, social networks only partially capture influence and power dynamics. In this context, it is important to distinguish between power, defined here as the formal authority to make decisions or take action, and influence, the ability to shape or sway decisions and actions without formal authority. Interestingly, the word agency in German (“Handlungsfähigkeit” or “Handlungsmacht”) includes the concept of influence and power, as the first term directly translates as “ability/capacity to act,” while the second translates as “action force,” “action authority,” or “action power.” However, assessing the interplay of influence and power dynamics is challenging with traditional, rather static social network approaches, especially given the often volatile nature of governance processes. In their review of network analysis applications in environmental governance, Schwenke and Holzkämper⁴¹ highlight the need for a deeper understanding of power dynamics within social networks and how actors influence environmental governance. While many scholars advocate for the need to understand power dynamics in environmental governance systems,^{56–60} the integration of power and influence in network analysis has only

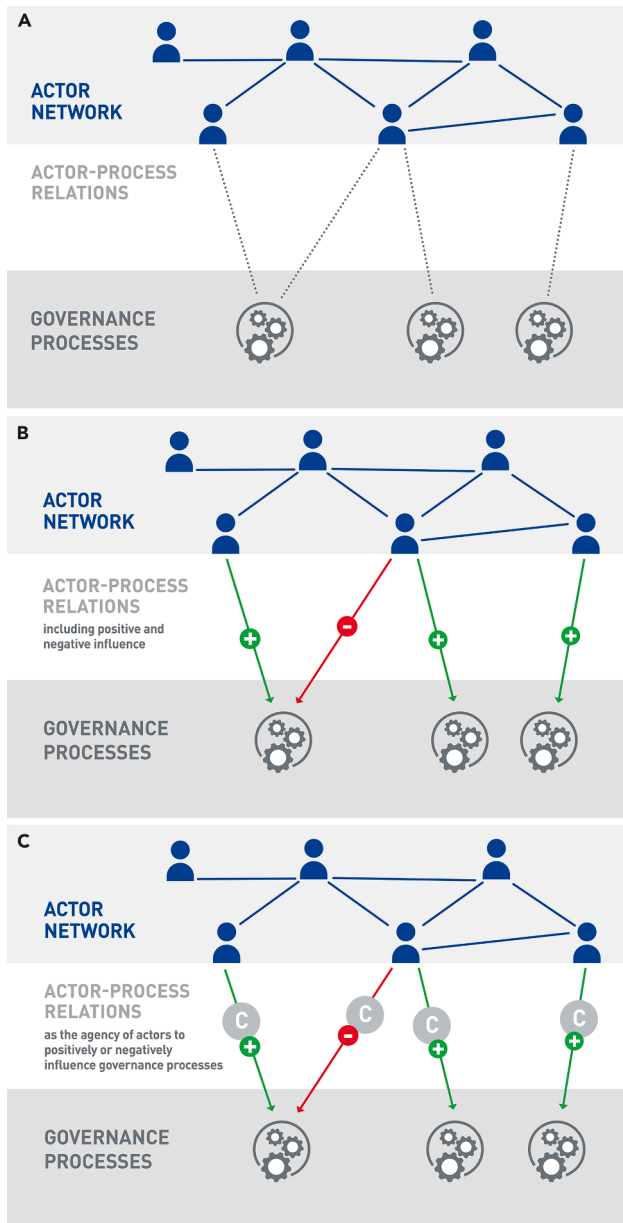


Figure 2. Visual representation of actor-process networks, including actors, their network, and governance processes and actor-process relations

While (A) presents a general actor-process network approach, (B) advances this by integrating the positive and negative influences of actors on governance processes, and (C) integrates the notion of agency through the application of capitals to governance processes.

been done recently.⁶¹ Moreover, Olofsson et al.⁶² highlight that social network analyses have predominantly focused on the influence of the most powerful actors on governance outcomes. However, a broader perspective is needed to fully understand how influence and power are exercised, as it is important to explore how a diversity of actor groups shape governance outcomes and foster collaboration⁶² and therefore have agency.

Secondly, existing research on social-ecological systems lacks an analysis of the dynamics of actor-process relations.

While scholars have increasingly characterized and analyzed social-ecological ties,^{40,41,63–65} the influence of actors themselves on governance actions and processes (actor-process relations) has been studied less rigorously. However, some studies examine the links between actors and processes or actors and policy issues without directly referring to the term. For instance, Giordano et al.⁶⁶ combine fuzzy cognitive mapping and agent-based modeling to understand the complexity of network interactions in flood emergency management. They highlight the need to move from rather static information management toward improving interactions across actors in applied management. In another case, Morrison et al.⁶⁷ investigated the relationship between actors, decision-making venues, and policy issues, specifically examining venue-to-actor, venue-to-issue, and venue-to-actor-to-issue relations. In doing so, they aim to understand how multiple actors coordinate across different decision-making venues and policy issues. While both approaches are useful for understanding information flows and coordination within governance systems, they only concentrate on social capital, neglecting other forms of capital flows within these systems and the dynamic nature of these within governance.






To advance these notions, research must first develop network approaches that grasp and characterize the influence of actors on governance processes. To propose such an improved approach, we introduce actor-process networks (see Figure 2A), in which we refer to social networks as “actor networks” and the influence of actors on governance processes as “actor-process relations” in the second part of this paper. Our approach offers three major advantages over other approaches. First, by focusing on actor-process relations, we provide a better understanding of actors’ influence in governance. This addresses the limitations of current analyses that tend to apply static views on social networks (e.g., on social-ecological ties) and hence may not fully capture or may completely miss the complexity of how actors intervene in governance processes. Second, by examining the influence of actors (positive and negative) within actor-process networks (Figure 2B), we shed light on the relevant processes (and the related capitals needed) that contribute to the formal power dynamics within sustainability interventions—a crucial element currently missing in assessments. Third, by linking agency and capitals and integrating them in such a network approach (see Figure 2C), we provide a more nuanced understanding and categorization of what form of agency is needed when in sustainability interventions. Our approach therefore emphasizes more process- and solution-oriented analyses.

ACTOR-PROCESS NETWORK APPROACH TO ASSESS ACTORS’ AGENCY

Five forms of agency

To advance our understanding of actors’ agency in a governance context, we distinguish between five forms of agency grounded in the different capital types (see Table 1). Namely, these are (1) allocating human resources, (2) enacting political relevance, (3) influencing financial flows, (4) providing physical goods and assets, and (5) steering social-ecological discourses. To demonstrate the importance of explicitly identifying the interplay between agency and capitals, here, we focus on organizational

Table 1. Forms of agency, the capitals they are grounded in, and guiding questions to assess both actor networks and actor-process relations in the governance arena

Form of agency	Capital type	Guiding questions
 Allocating human resources	Human	<p>What is the availability of human resources for the issue and the willingness to allocate them?</p> <p>Is there equitable access to relevant and useful knowledge and information?</p> <p>Are relevant skills available to address the issue?</p> <p>Are all forms of knowledge and experience relevant to the issue considered?</p>
 Enacting political influence	Political	<p>Who are the powerful actors concerning the issue and how and in which form is that power enacted?</p> <p>Which formal and informal institutions influence decision-making processes?</p> <p>Which actors have imminent power?</p> <p>What is the scale of influence of actors?</p> <p>Which checks and balances exist to limit an actor's power?</p> <p>Is there an equitable engagement in decision-making for all actors?</p> <p>Are there actors whose political voices are muted or suppressed?</p> <p>Who are low-power or powerless actors affected by the issue (intentionally or unintentionally)?</p>
 Influencing financial flows	Financial	<p>Which forms of financial capital are needed to address the issue (e.g., subsidies, aid payments, or generating new revenue streams)?</p> <p>Who provides these forms of financial capital?</p> <p>Which actors have access to relevant forms of financial capital?</p> <p>Which actors have capacities for funding acquisition?</p> <p>Which actors decide on the distribution of financial means?</p> <p>Are there relationships of financial dependence between actors?</p>
 Providing physical goods & assets	Physical	<p>What infrastructure, goods, or physical assets are relevant to solving the issue?</p> <p>What infrastructure, goods, or assets are provided to other actors or are shared?</p> <p>Which actors have access to and are able to use these forms of physical capital?</p> <p>Which actors grant or restrict access to physical goods and assets?</p> <p>Which actors decide on the use, construction, and/or manufacturing of relevant physical goods or assets?</p>
 Steering social-ecological discourse	Natural, social, cultural	<p>What are the underlying norms and values on which an actor makes their decisions?</p> <p>Which positions have actors regarding the issue, and are there any convergences/divergences?</p> <p>How are perspectives regarding the issue shaped by different actors, e.g., ethical or normative considerations?</p> <p>In which settings/modes of interactions do actors influence the issue at hand?</p> <p>Are there trustworthy relationships between actors or are there any experiences that undermine the trust between different actors?</p> <p>Do actors have a culture of shared responsibility or collaboration to solve the issue?</p> <p>What is the actor's willingness to address the issue (e.g., positive, negative, or neutral)?</p> <p>Are there any language/educational barriers to facilitate communication among actors?</p> <p>Are there any other cultural factors that could influence the solution to the issue at hand?</p>

actors instead of individual actors. This recognizes that their impact is often more significant, their role in decision-making tends to be more formalized, and their influence on specific governance processes follows more established procedures. In contrast, individual actors tend to act based on their personal beliefs and motivations, which potentially can change along the

process. Their actions and influence may thus be more flexible and difficult to assess. However, the presented approach may be adapted and used to assess individual agency in specific cases, e.g., if a person of public interest (e.g., a recognized scientist, activist, or media person) significantly influences governance processes.

In the following section, we briefly introduce each form of agency and elucidate its connections to various forms of influence and power. Additionally, we provide a concise overview of the five forms of agency, their related capitals, and respective guiding questions to assess them in [Table 1](#). The questions should be seen as examples that may be adapted and can be enriched by other questions depending on the context. Whereas the first four forms of agency are directly linked to individual types of capital (human, political, financial, and physical), the fifth form of agency is rooted in three types of capital: natural, social, and cultural. This is for two reasons. First, cultural and social capitals are often intertwined and frequently considered under the umbrella of social capital (e.g., in the capitals approach framework³⁰). Second, natural capital cannot be produced or enacted by an individual actor, as it pertains to the existence and condition of ecosystems.⁶⁸ Natural capital acts as a central framing condition in which respective social and cultural capitals emerge and are shaped and sustained. We therefore combine natural, social, and cultural capitals under the notion of “steering social-ecological discourse.”

Allocating human resources

This form of agency is linked to human capital. It considers the distribution of relevant and useful information and knowledge, implementation of training programs, inclusion of all forms of knowledge and expertise, and allocation of staff to a specific governance process. An analysis of the allocation of human resources supports a better understanding of where project management, stakeholder engagement, and knowledge transfer efforts are needed to increase efficiency, collaboration, and problem-solving.

Enacting political relevance

This form of agency is linked to political capital. The enactment of political relevance revolves around the dynamics of power, influence, and participation in decision-making. Analyzing this form of agency contributes to identifying those actors who hold power to make immediate changes or enact decisions over specific governance processes within sustainability interventions through legal or institutional positions. Moreover, it generates an understanding of the mechanisms in place to prevent single actors from becoming too powerful, such as through laws, committees, or institutional frameworks. It also helps to identify groups or individuals whose voices and participation are limited or ignored in decision-making processes, such as powerless or marginalized actors, who are not able to enact political pressure.

Influencing financial flows

This form of agency is linked to financial capital. Analyzing this form of agency helps to understand how financial capital influences the ability to address specific governance processes by highlighting the roles, relationships, and dependencies among various actors involved in funding and resource allocation. More specifically, it helps to identify (1) various types of funding, such as subsidies, aid payments, and revenue generation, and their funding sources; (2) the eligibility of actors to access these financial resources, as well as barriers that might prevent certain actors from accessing funding; (3) the capability of actors to secure funding; (4) the relationships of financial dependence between different actors; and (5) the actors who hold the power to allocate and distribute financial resources.

Providing physical goods and assets

This form of agency is linked to physical capital. The provision of physical goods and assets focuses on the relevant infrastructure, goods, or physical assets for solving a sustainability issue; the access to such resources; the provision and sharing of goods and assets; and the access to the necessary physical capital. An analysis of this form of agency can also support identifying the obstacles that might prevent certain actors from accessing required infrastructure or goods and understanding how physical capital can be shared to enhance collective efforts.

Steering social-ecological discourse

Social-ecological discourse refers to the way we talk about and understand the interactions between social systems (like communities, economies, and governance) and ecosystems. The nature and state of the ecosystem act here as framing conditions for these discourses. It thus focuses on the cultural, ethical, and relational dynamics among actors involved in a governance process. The social-ecological discourse shapes how actors perceive and address social-ecological issues, influencing policies, practices, and public attitudes. Analyzing this form of agency helps in understanding the modes through which actors exert their influence, including negotiation, advocacy, or collaboration. Furthermore, it can identify collaborative initiatives and partnerships and an actor’s willingness and attitude toward addressing an issue, whether that is positive or negative.

While other forms of agency may be more directly tied to power dynamics, steering social-ecological discourse represents a bottom-up approach to influencing policy design and decision-making. Over recent years, this type of discourse has gained importance, particularly in shaping legislation around environmental topics, such as the rights of nature (e.g., the concept of Pacha Mama in Ecuador⁶⁹). Thus, decisions in these contexts are significantly impacted by social perceptions, norms, values (i.e., intrinsic values⁷⁰), and cultural factors that reinforce them. Together, social and cultural capitals empower actors to construct shared meanings, develop agency, and build coalitions around environmental decisions.

Operationalizing the actor-process network approach

For assessing the five forms of agency identified in [Table 1](#), we propose conducting an actor-process network analysis to examine the roles and relationships of actors in different governance processes (see [Figure 3](#)). Rather than merely capturing the actor-to-actor relationship, this analysis aims to understand and enhance the quality of network interactions to foster collaborative action for sustainability interventions that may lead to sustainability transformations. In this section, we present an adaptable two-step methodology to apply the approach to different contexts.

First, we propose conducting interviews with all actors relevant to the specific sustainability intervention based on the guiding questions proposed in [Table 1](#). These interviews will provide qualitative information to map the network of forms of agency (and their related capital types) between different actors (actor network) as well as between actors and governance processes (actor-process relations) (see [Figure 3](#)). When conducting individual interviews, different perspectives regarding the same actor may arise, which need to be analyzed carefully.

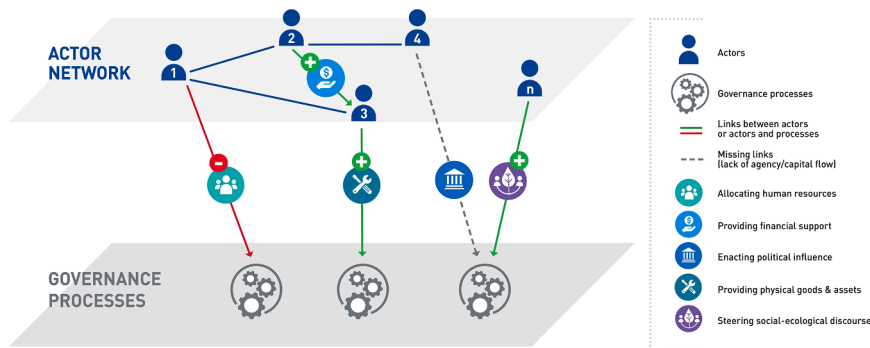


Figure 3. Visual representation of actors and their networks, the governance processes they influence, and actor-process relations that determine how actors drive or prevent specific governance processes that contribute to a sustainability intervention

The icons represent different forms of agency that are applied based on different types of capitals (see legend).

Alternatively, posing these questions in a workshop setting (i.e., focus group format) can facilitate discussion among actors, allowing them to explore various viewpoints and work toward a consensus-based and action-oriented result.^{71,72} While initial questions may explore the existence of links between actors and processes, subsequent inquiries might examine whether these influences are positive or negative or whether an actor lacks agency or capital.

Second, an analysis of the network, including connections and bridging actors, facilitates the identification of actors that drive or prevent the operationalization of specific governance processes (see positive and negative links, Figure 3), as well as those actors playing a central role in supporting others (flows between actors). Performing such an analysis allows us to identify different forms of agency. For example, network analysis can show where capital is lacking and highlight where an actor or governance process requires resources that are currently unavailable to them (see Figure 3: actor “n”: a lack of social-ecological discourse visualized by dashed lines). Additionally, the analysis can show whether actors directly or indirectly influence a governance process, e.g., in Figure 3, actor 1 directly allocates human resources to the governance process, whereas actor 2 provides financial capital to actor 3 (indirect agency), who then provides physical goods or assets to the governance process. While both qualitative and quantitative knowledge can be generated through this approach, the analysis should be specifically tailored to the needs of the study.

By following this methodology, the actor-process network approach allows us to analyze and understand (1) the governance processes that an actor influences and through which capital type/form of agency they influence them, (2) which actors drive or prevent the operationalization of specific governance processes within a sustainability intervention, (3) whether actors exhibit direct or indirect agency over a governance process, and (4) a lack of agency of an actor or in the provision of capital to a specific governance process. This multidimensional perspective not only clarifies the relational dynamics between actors and processes but also identifies leverage points for enhancing governance performance and, ultimately, the success of sustainability interventions.

The following examples illustrate how the actor-process network approach may be applied in different governance settings. Given the complexity of interactions between actors and governance processes, each example focuses on a single governance process within a broader sustainability intervention.

Coastal climate change adaptation in South Africa

Algoa Bay is located in the Eastern Cape of South Africa and is home to the Nelson Mandela Bay Municipality. The area features two key industrial ports, significant urban development, and diverse ecosystems.⁷³ Algoa Bay is experiencing climate-induced changes such as hotter days, longer droughts, intense floods, greater wind speeds, shifting wind directions, rising sea levels, and more extreme storm surges.^{74,75} Ongoing droughts already result in regular water shortages, while rising sea levels threaten tourism beaches, infrastructure, and development. Coastal management in South Africa is still often sector based with a nested governance structure with different administrative levels of government and area-based management tools and approaches.^{76,77} A lack of coordination between different management approaches presents a challenge to climate change adaptation and, ultimately, the sustainability of Algoa Bay. While some organizations already respond to the impacts of climate change, collective governance action across the land-ocean continuum in Algoa Bay is still conceptually abstract. In a study on the governance performance for climate change adaptation in Algoa Bay, Rölfer et al.³² identified several governance processes that need to be improved to enhance the resilience of the Bay and the associated actors to climate change. One of these processes is participation in the implementation of climate action plans (Figure 4). Study findings indicate that the provincial government has direct agency over the priority given to climate change in the integrated development plan (enacting political relevance), as well as the funding allocated to climate change projects (influencing financial flows). However, several actors noted that limited funding for climate action currently hinders participation in some cases, due to insufficient financial support from the provincial government. Nature conservation agencies, on the other hand, have indirect agency by engaging sea-based enterprises and parastatal (non-state) organizations in education programs to advocate for environmental protection and ocean activism in the Bay (steering social-ecological discourse). These then allocate human resources to climate action projects. Additionally, the study³² highlights a lack of awareness and understanding of climate change impacts, an essential driver for demanding action from the provincial government (missing social-ecological discourse). Applying the actor-process network approach to this case study helps to identify several resource gaps that need to be improved to enable participation in the implementation of climate action plans in Algoa Bay.

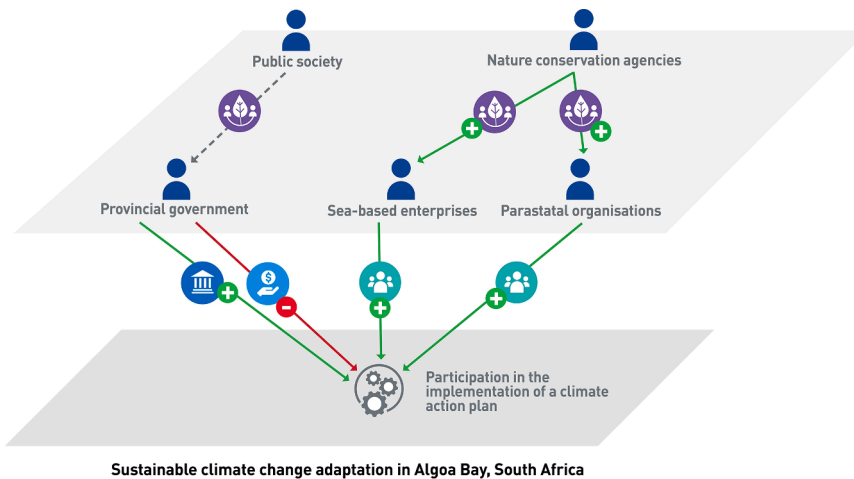


Figure 4. Example 1: Algoa Bay, South Africa

Exemplary visualization of the actor-process network involved in the participatory implementation of a climate action plan for sustainable climate change adaptation in Algoa Bay, South Africa.

Sustainable forest management in Germany

Forests are multifunctional and supply multiple “nature’s contributions to people” (NCPs).^{78–80} Actors differ in their demands for these NCPs, which holds the potential for conflicts to arise.^{81,82} In Germany, forests are managed under the so-called “German model” to meet these diverse societal and ecological demands.⁸³ Wood production remains an important source of income that finances the provision of other NCPs⁸⁴ and is influenced by formal governance arrangements across multiple levels.^{85,86} These include regulations on the national (i.e., German federal) and sub-national (i.e., federal state) levels, for example, in the form of forest laws, and set the legal framework for how wood can be harvested (enacting political influence).⁸⁵ To ensure sustainable harvesting, a forest inventory (German: Forsteinrichtung) for publicly and privately owned forests is required and is conducted every 10 years by the local forest administration or contracted experts to determine the potential amount to be harvested without risking other forest functions (enacting political influence) (Figure 5). District foresters decide based on the forest inventory which trees and what quantity can be felled per year, which machinery is used, and who is sub-contracted for the harvest (allocating human resources/

providing physical goods and assets).⁸⁵ Actors within the timber industry, e.g., sawmills or manufacturers, buy wood from private forest owners or state forests and negotiate price and quantity (influencing financial flows).⁸⁵ Employing an actor-process network approach could be beneficial to better trace how and why decisions concerning the quantity, location, and approaches to wood production are made. Specifically, such an approach could shed light on the informal actor-actor relationships that influence processes, i.e., those that are not formally regulated but rather built on mutual trust, common understanding, or experience. Additionally, such an approach could help to better understand how actor-process relationships shape and are shaped by target conflicts. For example, conflicts involving actors across multiple governance levels may arise around the decommissioning of forests for conservation purposes, which leads to minimizing the area in which harvesting can take place.

Governance of water resources in Spain

This sustainability intervention focuses on the Spanish drylands in the southeast of Spain, the driest region in Europe.⁸⁷ The scarcity and unpredictability of rainfall, along with the lack of perennial rivers, make water a key limiting factor. The region relies on aquifers as its primary water source. Since the 1960s, the area has undergone significant socio-economic changes, mainly driven by intensive agriculture, which has earned the region the nickname the “Orchard of Europe.”⁸⁸ However, this agricultural system has led to serious environmental issues, including aquifer overexploitation (80% of irrigation water) and contamination

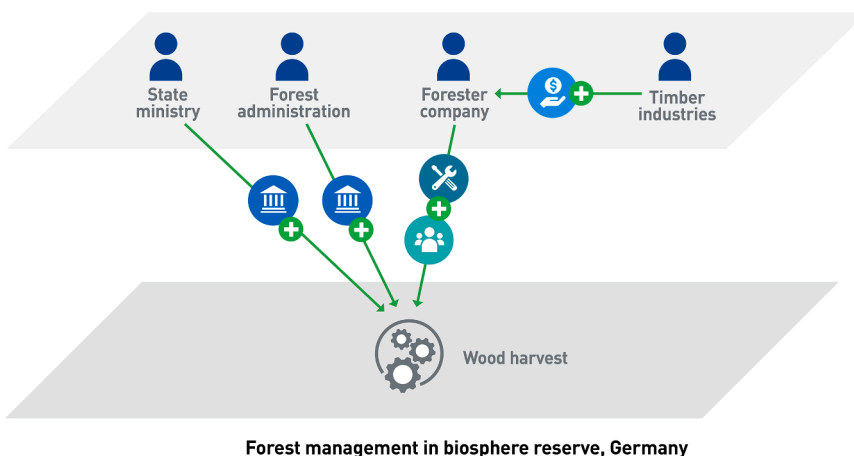


Figure 5. Example 2: Biosphere reserve in Germany

Exemplary visualization of the actor-process network involved in wood harvesting as part of forest management within a biosphere reserve in Germany.

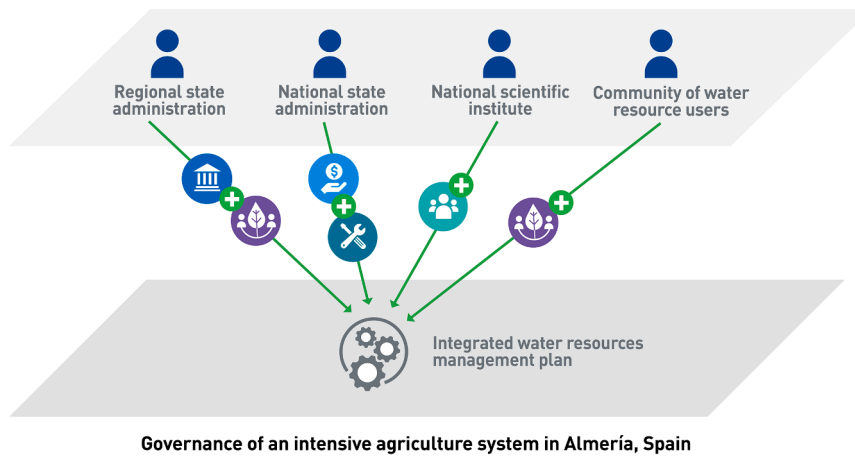


Figure 6. Example 3: Almería, Spain

Exemplary visualization of the actor-process network involved in establishing an integrated water resources management plan as a sustainability intervention within the governance of an intensive agriculture system in Almería, Spain.

from marine intrusion and fertilizer use.⁸⁹ The region's governance is complex, with state administrations possessing intersecting governing competencies at different scales (e.g., water resources, protected areas, and waste management) and a wide diversity of actors with varying interests. Some institutions and actors recognize the importance of protecting groundwater and are committed to addressing water challenges through an integrated water resources management plan (IWRMP) that was institutionalized in 2008 through a four-way agreement involving two state administrations (national and regional), a national scientific institute, and a water users' community, combining different forms of agency (Figure 6). The regional administration drives the IWRMP by establishing regulations and running awareness campaigns, exerting agency through enacting political influence and steering the social-ecological discourse. Similarly, the national administration supports the IWRMP by providing funding and infrastructure, such as desalination plants and reclaimed water facilities, taking direct agency through financial support and providing physical goods and assets. The national scientific institute contributes to the IWRMP by developing a research program focused on aquifer protection and regeneration, applying its expertise by allocating human resources to this effort. Meanwhile, the water users' community urges users to limit exploitation in aquifers and use complementary water resources, such as desalinated and reclaimed water. Thus, they exert a direct agency that guides the social-ecological discourse in implementing the IWRMP. This approach offers a visualization of a coordinated roadmap to move forward in IWRM while providing support to explore new potential associations with other (organizational and individual) actors with a diversity of forms of agency and capital types.

Advantages of applying the actor-process network approach

Applying the actor-process network approach in different governance settings can advance the understanding of agency and the influence of actors in several important ways. First, it enables a nuanced analysis of how different forms of agency, including the five forms, as well as direct and indirect agency, manifest across governance processes, revealing the specific roles actors play in shaping sustainability outcomes. For example, in the Algora Bay case study, the approach highlights the provincial

government's direct agency in setting political priorities and allocating financial resources while also capturing the indirect agency of conservation organizations in mobilizing social-ecological discourse and human capital for climate change adaptation.

Second, the approach reveals the interplay between formal institutional structures and informal actor relationships. While formal rules and mandates (e.g., forest laws, climate plans, and water regulations) define the boundaries of action, informal networks based on trust, shared understanding, or professional experience often mediate how decisions are made and implemented. This is particularly evident in the forest management case, where informal relationships influence decisions on wood harvesting and help navigate target conflicts between production and conservation goals. This dual focus allows for a more realistic and relational understanding of governance dynamics.

Third, the approach helps uncover critical barriers to sustainability interventions, such as limited funding, insufficient public awareness, or fragmented responsibilities, as seen in the Algora Bay case study. By mapping missing links or negative influences between actors and governance processes, the approach can help to identify capacity-building needs and potential intervention points to overcome these barriers. At the same time, the approach can support the exploration of new actor associations and practices to accelerate sustainability interventions. In the Spanish drylands, for example, the actor-process network approach provides a foundation for strengthening coordinated efforts and initiating new practices to improve sustainable water resource management. In doing so, it not only highlights where capacity building is needed but also offers strategic entry points for accelerating collective action.

While the case studies mainly illustrate positive examples of actors acting in support of sustainability interventions, the approach may also shed light on actors who obstruct governance efforts. By visualizing both positive and negative forms of influence (Figure 3), the actor-process network approach enables a more comprehensive understanding of how agency is exercised, i.e., to drive, delay, or prevent change. This includes identifying actors who may resist interventions due to conflicting interests, power dynamics, or strategic positioning. Such insights are crucial for anticipating opposition and navigating contested governance landscapes. This is in line with previous research showing that visualizing and reflecting on actors' willingness can help identify potential collaborators or opponents in implementing governance interventions.^{90,91}

Limitations and future research questions

While the approach presents a novel contribution to research at the science-policy-society interface, it is not without limitations to its implementation and the outcomes of such an analysis. For example, the resource intensity and complexity of the approach present significant challenges. Implementing such an approach requires time, effort, and resources, which can be a barrier, especially in resource-constrained environments.⁹² However, different depths of analyses are possible, making the approach suitable to provide both an overview of the actor landscape and their respective roles and resources in the form of a stakeholder mapping as well as an in-depth analysis of agency and potential strategies for resource allocation within sustainability interventions. From a conceptual perspective, the approach requires some form of epistemological agility, which may challenge its implementation, as actors must navigate and integrate various frameworks established in different research fields. This requirement can be challenging for researchers who may not have the necessary interdisciplinary experience. However, if the approach is broken down into simple questions to the actors, such as those provided in Table 1, actors (and researchers) may not need to fully capture the breadth of frameworks.

Regarding the outcomes of the analysis, the approach is inherently shaped by the participants' subjective understanding of the actors within governance systems, including their perceived agencies and capitals. This implies that outcomes might not become conclusive until such actors confirm their agency and capitals. Additionally, the approach cannot guarantee successful collaboration among actors or the effective combination of different types of capital since multiple political, institutional, social, and economic factors may inhibit it.^{93,94} Despite difficulties in predicting whether the approach will support meaningful sustainability interventions, we argue that its outcomes can serve as a valuable starting point for establishing a dialogue with actors and creating opportunities for them to self-organize and engage in collective action within real-world settings.

Finally, while the case studies showcase how the approach may be operationalized for real-world sustainability challenges, various open questions and possibilities for further research remain that may be addressed through context-specific case studies in the future. These revolve around the role of social dynamics and perceptions and the transformative potential of different forms of agency:

- (1) What forms of agency and types of capital are needed for what type of problem in social-ecological systems?
- (2) How do different forms of power interplay with different forms of agency? How are different forms of power exerted with different capital types?
- (3) What cultural, social, and/or religious perceptions influence agency and the way capitals are mobilized?
- (4) How do different forms of agency vary in their relevance? In what ways might governing one specific form of agency serve as a leverage point to initiate or accelerate broader sustainability outcomes?
- (5) Which forms of agency hold the greatest transformative potential in specific governance contexts? How does this potential vary depending on the actors involved and the types of capital they mobilize?

- (6) In what ways do shifting system dynamics (especially disruptive events) reconfigure governance structures and institutional arrangements, thereby reshaping how agency is exercised in the operationalization of sustainability interventions?
- (7) How does the timing of a specific form of agency influence its effectiveness, and what strategies can be used to identify potential windows of opportunity for advancing sustainability transformations?

CONCLUSION AND OUTLOOK

Achieving sustainability transformations requires meaningful collaboration among diverse actors to align interests and resources in governance. Yet, despite global efforts, operationalizing inclusive cooperation remains rare and challenging. The actor-process network approach addresses this gap by visualizing actors' agency and revealing their influence and power within governance processes that contribute to sustainability interventions. On this basis, the new approach can help to open up dialogue among actors across governance levels and sectors who are interested in driving sustainability interventions. It facilitates discussions on how to distribute roles and responsibilities by aligning complementary types of capital, such as political authority, financial resources, physical goods and assets, human capacity, and discursive influence. This, in turn, can support the formation of supportive networks grounded in mutual support and a shared understanding of collective agency. On the other hand, the approach also helps identify potential opponents and the form of influence or power they may exert to resist or obstruct sustainability interventions. By making these dynamics visible, the approach equips researchers, practitioners, and policymakers with the insights needed to anticipate resistance, negotiate trade-offs, and design more robust, inclusive, and context-specific strategies to progress toward sustainability. In particular, an analysis of power dynamics enabled through steering social-ecological discourse may offer valuable insights into how bottom-up interventions can function as deep leverage points,⁹⁵ triggering further action and fostering agency for transformative change. Future empirical research across diverse social-ecological and governance contexts will be needed to assess the suitability, applicability, and generalizability of the actor-process network approach and its implications for sustainability interventions and potential transformations.

ACKNOWLEDGMENTS

We thank Janenne Smit from Cohoot for illustration of the figures and GERICS for providing financial support for their development. L.R. and G.K. acknowledge funding by grant no. 03F0953A of the Federal Ministry of Research, Technology and Space (BMFTR) as part of the DAM mission "mareXtreme," project PrimePrevention. M.D.L.-R. acknowledges funding support through the Ramon y Cajal fellowship (RYC2023-045489-I) financed by MICIU/AEI/10.13039/501100011033 and by ESF+.

AUTHOR CONTRIBUTIONS

Conceptualization, L.R.; writing – original draft, L.R., R.I., M.D.L.-R., and G.K.; writing – review & editing, B.M.-L. and L.C.; visualization, L.R.; funding acquisition, G.K.

DECLARATION OF INTERESTS

The authors declare no competing interests.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the authors used Microsoft Copilot, an AI-assisted writing tool, to refine and improve the clarity and coherence of language and paragraphs. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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