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Analysing the Water-Energy-Food Nexus From a Polycentric Governance Perspective: Conceptual and Methodological Framework

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The Water-Energy-Food Nexus has emerged over the past decade as a useful concept to reduce trade-offs and increase synergies in promoting goals of water, energy and food securities. While WEF scholarship substantiates the biophysical interlinkages and calls for increased and effective coordination across sectors and levels, knowledge on conditions for effective coordination is still lacking. Analysing WEF nexus governance from a polycentricity perspective may contribute to better understanding coordination. In this paper, we propose a conceptual framework for analysing WEF nexus governance based on the Institutional Analysis and Development (IAD) framework and the concept of Networks of Adjacent Action Situations (NAAS). The interdependence among transactions for pursuing WEF securities by actors in different action situations generates the need for coordination for changing or sustaining institutions, policy goals and policy instruments that guide actions leading to sustainable outcomes. Coordination is attained through arrangements based on cooperation, coercion or competition. Coordination in complex social-ecological systems is unlikely to be achieved by a single governance mode but rather by synergistic combinations of governance modes. Particular coordination arrangements that emerge in a context depend on the distribution of authority, information and resources within and across interlinked decision-making centres. Further, integrating the political ecology based conceptualisations of power into the analytical framework extends the governance analysis to include the influence of power relations on coordination. Methodological innovation in delineating action situations and identifying the unit of analysis as well as integrating different sources and types of data is required to operationalise the conceptual framework.

Keywords: water-energy-food nexus, polycentric governance, coordination, governance modes, interdependencies, institutional analysis and development (IAD) framework, networks of adjacent action situations (NAAS)

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1 INTRODUCTION—WATER-ENERGY-FOOD NEXUS

The water-energy-food (WEF) nexus is promoted as a governance solution to complex resource management challenges. The WEF nexus concept serves multiple purposes—as an analytical tool, a conceptual framework, or a discourse (Keskinen et al., 2016). As an analytical tool, WEF nexus analyses typically include either quantitative or qualitative approaches or both in understanding the

interactions and interdependencies among water, energy and food systems (Albrecht et al., 2018). However, as a normative governance concept to achieve policy coherence, the WEF nexus has had limited success—if any—so far. As a discourse, though, it has made a significant contribution in terms of framing or reframing the problem of resource governance, especially of water. The WEF nexus framed as a governance challenge (Pahl-Wostl, 2019) presents a unique framing of the challenge of resource governance where different societal goals implicit in the policies to secure water, energy and food security compete with each other for resources.

The concept of WEF nexus originated from a normative goal of identifying and implementing strategies for achieving water, food and energy securities that are crucial for human well-being, poverty reduction and sustainable development (FAO, 2014). The literature provides separate nuanced definitions for each of the three securities (Pahl-Wostl, 2019), but broadly spoken WEF security mainly refers to access to sufficient water, food and energy for human well-being. While the initial focus was on water as a key natural resource input essential for WEF securities (WEF [World Economic Forum], 2011; Pahl-Wostl, 2019; Simpson and Jewitt, 2019), the scholarly focus has since shifted to the interdependencies among various natural resources and the need for the sustainable governance of soil and biodiversity besides water as inputs for the respective securities as outputs (Müller et al., 2015; Pahl-Wostl, 2019). In contrast to the broad conceptualisation of WEF nexus, Albrecht et al. (2018) contend that methods and tools to quantify and assess WEF interlinkages have not been sufficiently developed and have mostly been "borrowed or adapted from the conventional disciplinary approaches." With their limited ability to capture the interconnections and interdependencies among the sub-systems, these tools and methods mostly provide a narrow and fractured perspective of the nexus, which is not in line with the goals of the nexus (ibid.).

Moreover, heavy reliance on quantitative approaches alone was found to be not sufficient (Albrecht et al., 2018): without the inclusion of contextual factors, the design of socially and politically feasible resource use (management) policies is problematic (Endo et al., 2015; Foran, 2015). In their study of nexus projects which link science and policy, Yung et al. (2019) found that combining modelling efforts with the approaches of qualitative futures thinking were helpful in including more contextual variables, especially relating to uncertainty. Although these methods can be challenging for both researchers as well as stakeholders, the authors acknowledged that this process led to a "more holistic framing of [the] problem and an acceptance of different types of uncertainties, beyond simple data gaps that are usually included in modelling" (ibid., 13–14).

Although the nexus approach explicitly states the need to understand the interlinkages among key nexus sectors for advancing WEF securities and resource sustainability through coherent policies, the existing body of research is generally inconclusive as to the exact magnitude of impacts that pursuing one security has on the others. It is also widely acknowledged that the development of methodologies for even the nearly accurate understanding of the physical interlinkages among the various different sector-specific activities across different contexts is still at a nascent stage. The neo-Malthusian premise and statistics about growing populations, growing energy and food demand, and growing water scarcity have resulted in a reductionist scientific approach to framing the problem as one of resource efficiency and resource optimisation in respective sectors (de Grenade et al., 2016; Wiegleb and Bruns, 2018; Yung et al., 2019). The underlying assumption of the approaches in most of the technical studies is that improved knowledge of the physical interlinkages and technical and managerial solutions would be sufficient to achieve the respective goals related to WEF securities. However, research on technology adoption in resource-based sectors has provided ample evidence that such adoption is mediated and constrained by institutions and governance mechanisms [for natural resource management (NRM) technologies in smallholder agriculture, see Shiferaw et al., 2009]. Further, the dynamics of power influence the spaces for participation and decision making for innovation and adoption in natural resource management (Cullen et al., 2014).

The dominant scientific discourse on WEF nexus takes a technical-managerial view of the problem and its solutions, which ignores the power relations and social inequalities as causes and consequences of actions (de Grenade et al., 2016; Wiegleb and Bruns, 2018). There is an increased recognition of the need to include the issues of governance and the political economy of the concerned policy fields (Allouche et al., 2014). Pahl-Wostl (2019) argues that WEF nexus is so far rooted in the scientific and technical rationalities for integration, accounting little for the "power constellations, political economy issues, and transaction costs and how they vary at and across different spatial scales."

In this article, we aim to close this gap by proposing a polycentricity approach to analysing WEF nexus interdependencies and their governance. Hence, the underlying question we pursue is: how can we analyse the governance of interdependencies in polycentric WEF nexus systems? After conceptualising a polycentric WEF nexus governance system, we present a generic adaptation of Ostrom (1990) Institutional Analysis and Development (IAD) framework and the concept of "networks of action situations" (McGinnis, 2011) and a suggestion how to include power for studying governance of WEF nexus. In the following: we first provide a brief review of the existing literature on WEF nexus governance and their shortcomings (**Section 2**); elaborate our conceptual framework of WEF nexus governance based on the polycentricity approach (**Section 3**); a brief discussion on suitable methods to operationalise the concept is then presented (**Section 4**), followed by conclusions (**Section 5**).

2 STUDIES OF WATER-ENERGY-FOOD NEXUS GOVERNANCE—A BRIEF REVIEW

Systematic analyses of the governance of the WEF nexus have been limited. In much of the nexus debate, an explicit focus on

governance is missing (Al-Saidi and Elagib, 2017). In their review of governance approaches to the WEF nexus, Weitz et al. (2017) distinguished three perspectives, namely, technical (based on risk and security arguments); administrative (based on economic rationality); and political (based on the concerns of equity and power). The common proposition of all the perspectives, however, is that—in a given context—cross-sectoral coordination is required for managing the interlinkages and attaining WEF securities. Weitz et al. (2017) also argued that the technical and administrative perspectives do not explain why coordination does not occur, nor what the main barriers to coordination are.

If the interdependencies in the WEF nexus are to be addressed, both horizontal (across sectors) and vertical (across scales and levels) coordination are essential (Weitz et al., 2017; Pahl-Wostl, 2019). The primary objective of the WEF nexus governance analysis should be to unravel the conditions under which there is successful coordination among multiple interlinked decision-making centres. However, prior to the focus on coordination, it is important to identify and distinguish the relevant decision-making centres or action situations that are interlinked within the issues of water, energy and food. Various studies have employed different approaches to distinguish the interlinked decision situations related to the provision of food, energy and water security. Pahl-Wostl (2019) applied a combination of ecosystem services and actor network concepts and developed a typology of interactions among actors which depended on the type of ecosystem service of interest to the actors involved. The nature of interactions (the degree of directness or indirectness of interactions among involved actors) determined the type of governance mechanisms that might be effective in enhancing coordination. Further, Pahl-Wostl (2019) emphasised the importance of tele-connections among spatially remote actors without any established social relations through which they might influence each other and their interactions with nature, but who were connected through global trade. To this extent, a multi-level perspective was essential in order to address the governance gap in facilitating coordination among decision-making centres across levels and scales. Dombrowsky and Hensengerth (2018) found that regional organisations dealing with energy and river basins were instrumental in facilitating nexus governance in transboundary river projects through negotiating benefit-sharing arrangements and ensuring compliance with social and environmental safeguards.

Villamayor-Tomas et al. (2015) employ a novel combination of the value chain approach and the institutional analysis and development (IAD) framework (Ostrom, 2005) as well as the notion of the network of adjacent action situations (NAAS) (McGinnis, 2011) as an extension of the IAD to explore the biophysical and institutional interlinkages across different stages of production and consumption of food, energy and water resources. They select irrigation systems in four countries—Kenya, India, Spain and Germany—as cases of the WEF nexus that represent a close continuum of action situations along the value chain: water appropriation; electricity appropriation; and crop production. They found that the coordination problems identified in various different action situations of water and energy appropriations as well as the related crop-production choices were physically and institutionally interlinked. For example, in the Indian case, the technical and institutional solutions available for the coordination dilemmas relating to the quality of the electricity provided were found to be undermined by a series of institutional factors (subsidies on electricity, ineffective regulation of groundwater withdrawal and promotion of water-intensive crops) which were deeply rooted in the political economy of the country and the federal state (Kimmich, 2013). Further, the informal collusion of farmers and electricity service providers prevented investments to improve infrastructure for electricity generation and its maintenance. Such cross-sector path-dependencies were also found to hinder institutional reform of water and energy sectors in the Spanish case (Villamayor-Tomas et al., 2015).

A lack of recognition of the social embeddedness of interactions among actors was one of the key limitations of earlier approaches to governing water resources such as the Integrated Water Resources Management (IWRM). For this reason, Stein et al. (2018) followed a relational approach and analysed how existing social relationships shaped governance processes for WEF nexus interlinkages in the Upper Blue Nile basin in Ethiopia. They identified the network structure for nexus governance in Ethiopia as hierarchic, reinforcing the boundaries around spheres of political authority. Furthermore, they found that rather than sectoral boundaries, hierarchical relationships between actors at different governing levels, geographical locations and jurisdictions structured the interactions among WEF nexus actors (Stein et al., 2018).

WEF nexus literature likewise falls short on the knowledge of political and cognitive factors that determine policy change within the sectors (Weitz et al., 2017). The neglect of the inherently political nature of the WEF nexus problem by the dominant technical-administrative perspective of the nexus literature could possibly explain the dearth of knowledge on why incoherent policies and strategies persist. Failing to include the vertical interactions will provide only a limited understanding of the unintended consequences of the horizontally fragmented policies. The process of formulating and implementing sectoral policies relies explicitly on vertical coordination, and an analysis focusing on the vertical interplay of institutions can identify many of the factors that shape policy objectives the way they are, together with their effectiveness. Unravelling the institutional political factors behind incoherent sectoral policies and resulting trade-offs among WEF nexus goals require innovative research approaches.

Drawing on the research on integrative environmental governance, Weitz et al. (2017) suggested that coordination across WEF sectors and levels might be fostered through communicative, organisational, and procedural instruments. They further suggest that several attributes (principles) of governance—namely inclusiveness, transparency, accountability, empowerment of the weaker players, and access to information—also have a positive impact on coordination. The transformation of governance systems depends on the cognitive frames of the actors involved and "institutional learning

processes" are crucial for such transformations (ibid., 171). Beyond cross-sectoral coordination, Daher et al. (2020) focus on convergence of perspectives between researchers and stakeholders on the interlinkages in the nexus in the San Antonio region of Texas. Although, they find only modest levels of communication among different groups, both researcher and stakeholder groups seem to agree on the importance of increased communication and information-sharing in addressing nexus challenges (Daher et al., 2020).

While most scholarship on the WEF nexus has focused on the biophysical interlinkages (material flows) between the differing sub-systems (Yung et al., 2019), social, political and institutional dimensions of the nexus have received comparatively little attention. Nevertheless, in recent years, more and more researchers are applying analytical approaches stemming mainly from environmental governance. Several recent case studies (e.g., Never and Stepping, 2018; Rodríguez-de-Francisco et al., 2019) focusing on WEF nexus issues in various geographical contexts have highlighted the embedded nature of the focal WEF nexus decision-making situation (of the particular research) in the horizontal (sectors) and vertical (levels) network of action situations with strong biophysical and institutional interlinkages. These case studies show that there would be value in an analytical approach that is more strongly theorised. There is a need to further enhance the existing conceptual and theoretical framework of WEF governance analysis by systematically analysing more cases in differing environmental, social, economic and political contexts as well as in the context of crucial global goals and conventions such as the 2030 Agenda. Furthermore, the role of important factors in achieving coordination—such as different forms of power influencing the interaction among decision-making centres—need to be better accounted for.

3 POLYCENTRIC VIEW OF WATER-ENERGY-FOOD GOVERNANCE

Polycentric governance started as a descriptive concept of Vincent Ostrom and his colleagues with an ontological function of describing the ways in which metropolitan areas organised themselves to provide public goods and services (Ostrom et al., 1961). What began as a descriptive label for an observed pattern of societal organisation turned into a theory of polycentricity or polycentric governance. There are normative and positive dimensions to it. In his treatment of the evolution of research on polycentricity, Thiel (2016) describes the concept, theory (normative and positive) and analytical framework as different constituents of the polycentricity approach. The concept has ontological, operationalising and sensitising functions. As defined/described by Ostrom et al. (1961), polycentric refers to

> . . . many centres of decision-making, which are formally independent of each other. Whether they actually function independently, or instead constitute an interdependent system of relations, is an empirical question in particular cases. To the extent that they take each other into account in competitive relationships, enter into various contractual and cooperative undertakings or have recourse to central mechanisms to resolve conflicts, the various political jurisdictions in a metropolitan area may function in a coherent manner with consistent and predictable patterns of interacting behaviour. To the extent that this is so, they may be said to function as a system (Ostrom et al., 1961, 831).

Normative polycentric governance theory makes "hypothetical, value-laden statements about ways in which societies organise themselves in order to comply with certain performance criteria that are considered desirable" (Thiel, 2016). If a study subscribes to the normative perspective, this would mean that a polycentric system of organisation would lead to WEF securities without compromising on the sustainability of natural resources. The analysis would then focus on the conditions that lead only to the emergence of a polycentric WEF governance system, which is assumed to be inherently effective in managing the interdependencies. This would then be analogous with the recommendations of the huge body of research conducted on the governance of local common pool resources which is implicitly based on the normative polycentric theory (Ostrom, 2005; Thiel et al., 2019). Positive polycentricity theory, on the other hand, "posits specific causes that help to explain governance structures, actors' behaviour and performance of governance" (Thiel, 2016). Therefore, using positive polycentricity theory would mean that we test the claims that the normative theory makes in terms of its performance besides testing its causal conditions.

Heikkila et al. (2018) call for a positive analytical perspective on polycentric governance systems for environmental governance. They mention that "only pure centralised or decentralised systems, which are ideal types and elusive in practice, would fall outside the polycentric space" (Heikkila et al., 2018). Measurement of features and variation across polycentric systems are affected by the binary view of polycentricity: whether a system is polycentric or not. Against this conception, polycentric systems exist in multiple designs and functional forms. They further identify an empirical bias in the scholarship of polycentric systems towards a focus on traditional common pool resources (CPRs) which therefore excludes the interactions across sectors from its analysis (Heikkila et al., 2018).

In this section, following the analytical perspective, we outline a conceptual framework for understanding the governance of WEF nexus and adapt the IAD framework and the concept of NAAS to provide a heuristic for analysing coordination in WEF nexus systems. Srigiri et al. (2021) illustrate the application of this conceptual framework to understand the factors affecting the effectiveness of coordination across sectors and levels to manage the nexus interlinkages in the lower Awash River Basin of Ethiopia. Similarly, Dombrowsky et al. (2022) use the framework to analyse natural resource governance in Jordan's Azraq basin in light of the 2030.

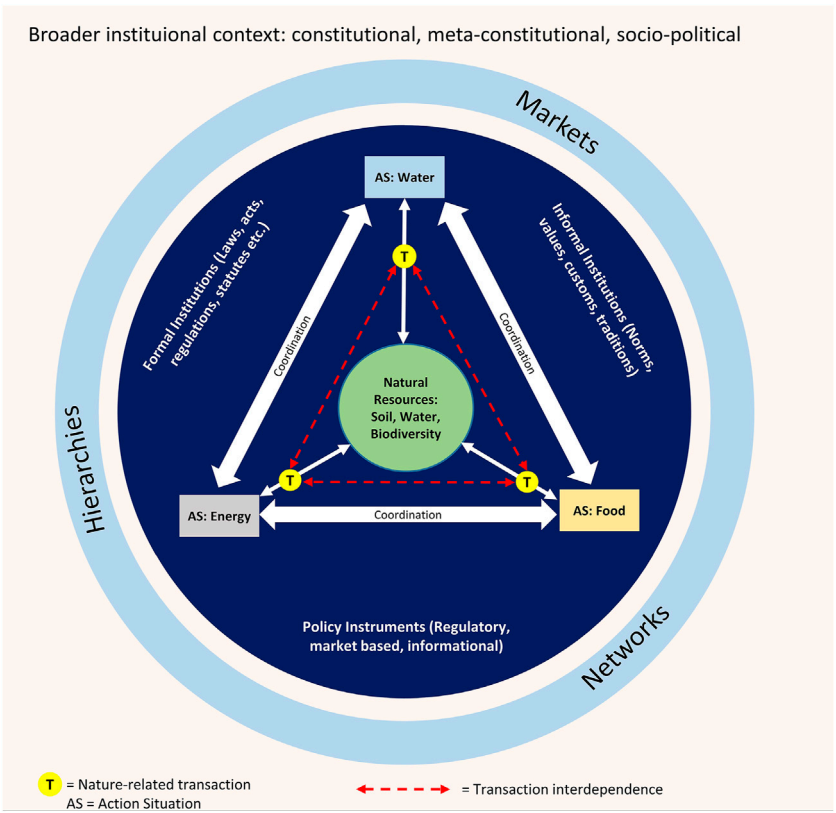

FIGURE 1 | Polycentric view of water-energy-food (WEF) nexus governance. Source: Authors.

For analysing WEF governance, we propose to start with an ontological description of different elements that are to be included in the analysis: namely, key decision-making units/centres; key resources of focus; institutions (formal and informal rules); possible modes of governance (hierarchies, markets, networks); and how these elements are related with each other. These elements form the constituents, or building blocks, of the analytical framework that could be applied as a heuristic to assess the performance of the various arrangements in the governance as observed in various empirical settings according to desirable performance/evaluative criteria. We believe that the provision of WEF securities is generally organised in different sectors with differing and sometimes overlapping sets of actors, who organise and make decisions in different, but interdependent, action situations on the use and management of natural resources, especially water, soil and biodiversity, for either independent or joint provision of water, food or energy. Although, these action situations are formally independent, their dependence on the same natural resources make them functionally interdependent. Thiel and Moser (2019) mention that, in the realms of management of water or other natural resources, functional interdependence means that governance and its performance are affected by a multitude of activities. These decision-making centres and action situations for water, energy and food provision are embedded in an overarching system of constitutional and meta-constitutional rules. **Figure 1** presents a description of polycentric arrangements of WEF nexus governance.

3.1 Common Pool Resources and Interdependence of Nature-related Transactions

Natural resources (especially water, soil and biodiversity) are at the core of the nexus on which the WEF securities depend. Water in particular is crucial for the production of food and energy, as well as for fulfilling the drinking and sanitation needs of humans. Similarly, soil and biodiversity are vital inputs for food production. Generating energy requires water and, in the process, can degrade biodiversity, water and soil resources if environmental and social safeguards are not adhered to. Attributes of natural resources play a very important role in understanding the use patterns of differing actors for different purposes (Ostrom, 1990). For instance, incentives for the appropriation of resource units are based on the attributes of rivalry and excludability of the resources. Water—be it surface or groundwater—is a classic "common pool" resource where high levels of rivalry exist, meaning that one actor's use diminishes the quantity or quality

of the resource for another actor. At the same time, options for excludability are typically low. Hence, sustainable water extraction requires some institutions that increase excludability. Mentioned in the literature are several other attributes of resources—for instance, size, location, predictability, and so on—that play a crucial role in determining the type of institutions that are suitable for sustainable management and use of water with different degrees of effectiveness (Agrawal, 2003; Birner and Wittmer, 2004; Ostrom, 2005; Epstein et al., 2013).

The pursuit of WEF securities by actors in multiple, autonomous decision-making centres fundamentally involves biophysical transactions between the respective actors and natural resources for the production of water for consumption, food production or energy generation. Hagedorn (2008) considers "nature-based transactions" and the interdependence they create as crucial determinants of institutional and governance arrangements that emerge or are suitable to be designed. While the concept or the focus on transactions as a unit of analysis is borrowed from industrial organisation, originally defined by Williamson (1987), Hagedorn (2008, 360) defines nature-based transactions as "economically relevant processes by which goods and services, resources and amenities, damages and nuisances are allocated". He posits that transactions of goods caused by decisions made by actors usually also impact other actors positively or negatively, although they are not involved in the decision (Hagedorn, 2015). He further argues that, if the focus of the normative governance framework is to identify and promote institutions and governance solutions to achieve sustainability, then the physical properties of the nature-related transactions play a determining role and need to be considered in the analysis. Actors are the causal connection between transactions and institutions. Therefore, to understand the interdependence, it is important to study both the physical as well as social interdependence between actors or organisations (Hagedorn, 2015).

When the transaction of one actor affects another actor negatively, the latter actor is likely to perceive the interdependence and enter into negotiations with the actor initiating the transaction. These negotiations may then lead to the design or changing of certain rules. This means that the need for coordination among actors in interdependent action situations may arise as a result of the transaction interdependence. From a New Institutional Economics perspective, Williamson (1979) argues that complex recurring transactions require long-term relations between identified individuals. In other words, actors are more likely to engage in institution building within a hierarchical organisation rather than in an "anonymous market". He further suggests that "governance structures" are needed to "attenuate opportunism" and infuse confidence in the economic transactions among self-interested actors. However, Granovetter (1985) argues that all behaviour—including economic transactions (within and beyond organisations)—are embedded in social relations (networks). In other words, the structures of coordination in a governance system are embedded in a broader social, political, and cultural context and their effectiveness depends on such a context.

3.2 Networks of Water-Energy-Food Action Situations

In order to understand the nature of polycentricity in WEF governance, it is necessary to investigate the context under which the actors make decisions and enter into several transactions in generating WEF securities. **Figure 1** provides a simplistic presentation of three action situations for food, energy and water provision, which in reality entail several interdependent action situations. Hence, we adapt the Institutional Analysis and Development (IAD) framework developed by Ostrom (1990), which is one of the most widely used analytical framework for studying polycentric governance systems. Thiel (2016) views the IAD as a framework that operationalises polycentric governance theory through its focus on self-organisation. Self-organisation is one of the possible organisational forms in polycentric governance systems.

The analytical framework has three broad components, which further entail various sub-components. They are—1) action situations and their networks across different levels; 2) exogenous variables, providing the biophysical, socio-economic and institutional context for action situations; and 3) outcomes, which can be operational or institutional in nature and refer to the wellbeing of actors involved, their access to key resources and to the sustainability of natural resources. A further important component of the framework, which stands out of the rest, is the "evaluative criteria" by which the observed outcomes and the processes that lead to outcomes are evaluated (**Figure 2**).

An action situation in the IAD framework is "an analytical concept that enables the analyst to isolate the immediate structure affecting a process of interest to the analyst for the purpose of explaining regularities in human actions and results. . ." (Ostrom, 1990, 11). It is a situation in which two or more actors participate by taking specific positions and choosing from a set of possible actions, that lead to a particular outcome, which in turn have different pay offs for each participant in the situation. Actors may be individuals or an organized entity of individuals who participate in a given action situations. Participants act upon information available to them about costs and benefits of actions, outcomes and their individual payoffs that depend on the rules for distribution of costs and benefits (Ostrom, 2005). The information about the actions and outcomes and the rules that determine the individual payoffs in a given action situation may be generated or devised in a different action situation, which may have same, overlapping or different participants depending on the type of institutional arrangement in place. For example, different users appropriate water from a resource system in one action situation, subject to the rules designed by the same users by forming a water user association (WUA) in a functioning decentralised self-governance system. In other cases, where the authority to design rules of appropriation or management

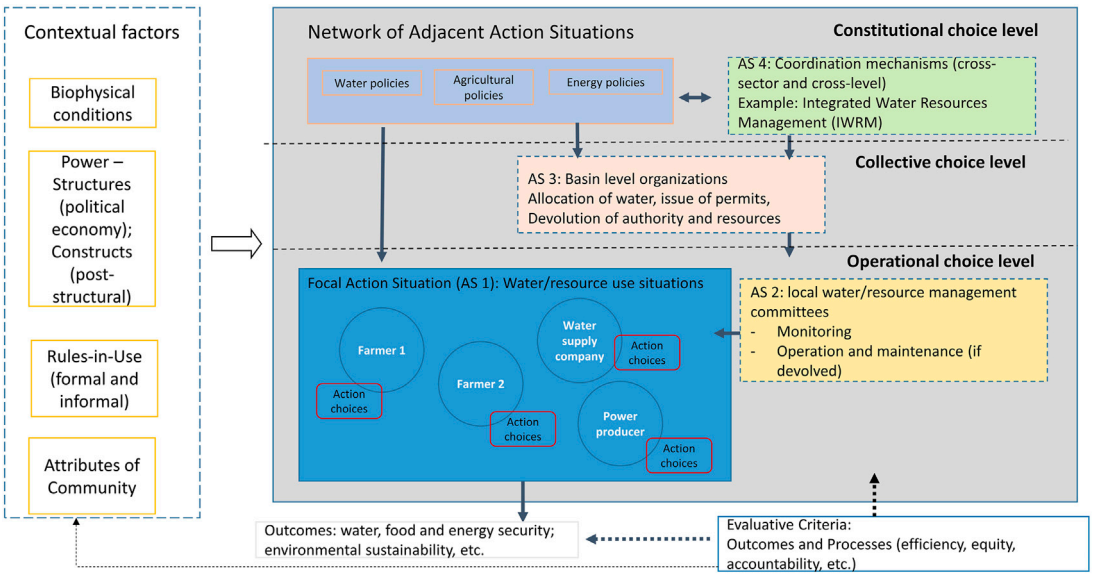

FIGURE 2 | Networks of adjacent action situations in provision of water, energy and food (WEF) securities. Source: Authors (based on Ostrom, 1990; Clement, 2010; McGinnis, 2011).

is not devolved to local communities, different set of actors, mostly from the governmental authorities participate in the action situation for designing rules.

McGinnis (2011) further elaborates the concept of action situations in the IAD framework by stating that various functions of polycentric governance such as production, provision, financing, coordination and dispute resolutions, all occur in distinct action situations adjacent to each other. He states that "an action situation Xi is adjacent to Y if the outcome of Xi directly influences the value of one or more of the working components of Y" (McGinnis, 2011). These action situations may be spread across different action arenas or conceptual levels of analysis (Ostrom, 2005, 58–62): 1) operational choice level, wherein the outcomes of action situations are more tangible, related to wellbeing of actors involved and natural resource conditions, 2) collective choice level, wherein the outcomes of action situations are institutions or rules that define the set of action choices at operational choice level, and 3) constitutional choice level, wherein the action situations result in procedures for processes or action situations at collective choice level. The outcomes of actions at this level also legitimize the participation of actors (individuals or organizations) in different action situations at collective and operational choice levels.

Actors in the action situations are influenced by the contextual factors that include biophysical, social, political and institutional conditions. Biophysical context of an action situation includes conditions of resources (land and water), their abundance, scarcity, temporal and spatial distribution, availability and access to different actors, particularly relevant to the action situations at the operational choice level. It also includes climatic conditions as well as their short and long-term variability and change. Further, the characteristics of resources explained in Section 3.1 determine the actions of actors in different situations.

Rules-in-use impose constraints on actions of actors and their mutual interactions (North, 1993). They include both formal rules (laws, regulations, statutes, etc.) and informal rules (societal norms, customs, values, beliefs etc.) and their enforcement characteristics. It is important to understand both formal and informal rules-in-use to explain the behaviour of actors in different action situations and their outcomes. Further, Ostrom (2005) identifies seven different types of rules-in-use, which correspond to different working components of the action situation. The boundary, position, choice, information, aggregation, payoff and scope rules emerge as outcomes of interactions in distinct action situations in different arenas or choice levels of analysis (ibid.).

Community attributes such as heterogeneity, size, and level of trust determine mainly the capacity to coordinate and solve social dilemmas in different action situations, especially relevant in the operational choice arena (Agrawal, 2003).

Actors within an action situation or across action situations through their actions engage in patterns of interaction with each other. Patterns of interactions within different action situations generate joint (intermediate) outcomes. They either feed into other action situations as rules, resources and information forming the feedback loops within the network of action situations. The outcomes of a resource governance system as a whole are a combined result of different intermediate outcomes of independent action situations and as affected by the contextual factors which are external to the network of action situations. Such outcomes can be both material and institutional in nature. Material outcomes may include changes in the social or economic situation of involved actors or changes in the condition of natural resources used or

managed in different action situations. Institutional outcomes include changed perceptions, values and beliefs resulting from patterns of interaction, which are further internalised by participating actors in the action situations. The institutional outcomes occur over longer time periods and therefore cannot be easily observed or measured.

Further, structures and relations of power, in which the actors in different action situations are embedded in, also constrain the choices of certain actors and determine the type of interactions between actors and their outcomes. We describe different forms of power and how they can be considered in the analysis of governance under **Section 3.4**.

In a system of nested action situations, it is important to choose a focal action situation, considered critical for the intended analysis (McGinnis, 2011). Most studies focusing on the management of common pool resources analyse behaviour of actors pertaining to use and management of natural resources, and therefore focus primarily on action situations at the operational choice level, which yield tangible outcomes.

3.3 Coordination in a Polycentric Water-Energy-Food System: Governance Modes

Scholarship relating to the WEF nexus is quite unanimous in its calls for more and effective coordination across sectors and multiple levels for governance of WEF nexus interlinkages (Pahl-Wostl, 2019). As water, energy and food are interdependent policy issues that are dealt with and are affected by actors across different policy domains, coordination is required to achieve coherence along the entire policy process (Hedlund et al., 2021). Although coordination is sometimes used interchangeably with other related terms such as cooperation in literature, we understand coordination as "the extent to which organizations attempt to ensure that their activities take into account those of other organizations" (Hall et al., 1977: 459, quoted in Bouckaert et al., 2010: 15). It is an alignment of tasks and efforts of organisations across policy sectors, which could be either forced or voluntary (Bouckaert et al., 2010). As explained below, we consider coordination as the overriding term and cooperation, competition and coercion may be principles based on which it is achieved. Polycentric systems are often associated with effective coordination in combination with the decentralisation of power. Pahl-Wostl and Knieper (2014), for example, define polycentric governance systems as "multiple centres of authority and distribution of power along with effective coordination structures." Based on the degree of centralisation of power and the degree of coordination, they categorise governance regimes into four categories: centralised-coordinated; centralised rent-seeking; fragmented; and polycentric. They then associate polycentric systems with positive outcomes, namely, increased resilience against shocks and as supporting experimentation and learning (Pahl-Wostl and Knieper, 2014). However, from a positive analytic conceptualisation, we define polycentric systems more liberally as being multiple decision-making centres with varying levels of authority and access to power resources and a variety of (coordination structure) interactions, which may, or may not, be effective and efficient in achieving social, ecological and economic outcomes.

There may be a variety of arrangements or modes of governance, which lead to coordination among decision-making centres. Governance modes are organisational solutions aimed at making the institutions or rules effective (Hagedorn, 2015) in realising different purposes of governance. The purpose of their design is to facilitate coordination of interactions among constituent autonomous decision centres. Public administration literature suggests that different governance modes such as networks, markets and hierarchies exist (Bouckaert et al., 2010) that are based on the principles of cooperation, competition or coercion (**Figure 1**).

In a hierarchical mode, a central authority may coercively devise and enforce rules for coordination. Cooperation can be understood as interaction where the agreed upon rules are jointly designed and enforced by the constituent decision-making centres to achieve shared goals. Such interaction opens up the space of governance to non-government actors who together with other actors may work together towards achieving shared goals (Koontz and Garrick, 2019). Another important contractual relationship through which different decision centres in a polycentric system take each other into account is competition. It is also argued by economic liberalists as an efficient form of interaction for producing public goods and services (in this case, water, energy and food) in a polycentric system as it results in the emergence of markets (Koontz and Garrick, 2019).

In order to internalise the externalities of nature-related transactions, specific policy instruments are required. Further, policy instruments require suitable governance modes for their effective implementation. Which modes of governance promote coordination for internalising the externality costs effectively depends on the properties of the transactions (as discussed in the earlier section) as well as on meta-institutions which create the enabling environment for actors at operational and collective choice levels to make rules. The choice of governance mode also depends on the type of goods and how the property rights to the resources and their ecosystem services are defined. In the case of high rivalry and a lack of excludability, a market mode of governance may not be a feasible option, but other forms of governance such as networks or hierarchy may work.

Pahl-Wostl (2019) argues that a combination of different governance modes—collaborative networks, market-based approaches and regulatory frameworks—is essential for achieving coordination among different decision-making centres. Hybrid governance forms, combining two or more governance modes, are purposefully designed structures and may be manifested in different types of policy instruments that are used to achieve a policy goal (Pahl-Wostl et al., 2020). Especially in irrigation management, combining hierarchical irrigation system governance with participatory irrigation management (Newig et al., 2019) or farmer-managed irrigation system (FMIS) emerged as an "institutional panacea" in the 1990s (Meinzen-Dick, 2007; Gandhi et al., 2020). Further,

Leininger et al. (2018) emphasise the role of combining various different governance modes for governing the interlinkages among WEF-related SDGs as the following three cases illustrate. A combination of voluntary agreements between water supply companies and formal regulations (namely, the German Drinking Water Directive and EU Nitrate Directive) were initially successful in adopting sustainable production practices and reducing nitrate leaching (Richerzhagen and Scheumann, 2016). Later, a parallel promotion by the European Union and Germany for biomass and renewable energies offset these positive effects. Similarly, a market-based mechanism that was implemented in the Hidrasogamoso hydropower plant in Columbia was only sufficient in compensating the upstream farmers for conservation of biodiversity as well as preventing the sedimentation of the reservoir. On the other hand, the mechanism did not compensate the losses of the downstream water users who had less water available for food production (Rodríguez-de-Francisco et al., 2019). Therefore, a hierarchical arrangement to ensure that the principle of "leave no one behind" (LNOB) would need to be integrated into the governance of water resources for energy and food production in the Columbian case. Similar observations were made pertaining to the need for the hierarchical mode for sequentially reforming the water and energy sectors in order to provide the right incentives for private actors to participate in wastewater treatment in India (Never and Stepping, 2018). Hence, it is clear from the above examples that no single mode of governance will be sufficient to achieve all the three securities of the nexus and not exclude any interest groups from the benefits.

Policy instruments to facilitate or constrain an action towards achieving a desirable outcome—in this case one of the WEF securities—need to be evaluated not only for their impact on the provision of the intended collective good but also in how far they impact the provision of other goods of interest. Going by the famous Tinbergen's (Tinbergen, 1952) rule that each policy target should be matched with one tool, there is a need to check for the interactive effects among policy goals, among tools or policy instruments that may belong to different sectors or levels of the government (Del Rio and Howlett, 2013). Del Rio and Howlett (Del Rio and Howlett) further note that it is difficult to achieve horizontal and vertical coordination at the same time. This is because of the existence of different goals at different levels of administration and is moreover a result of the non-uniform distribution of costs and benefits across levels, which creates "winners and losers" for each instrument. The different logics of policy instruments and different principles underlying the different modes of governance may sometimes lead to conflicts instead of synergies making a particular combination incompatible and thereby inefficient in achieving the policy objectives (Pahl-Wostl et al., 2020). For example, in the Indian irrigation systems, Mollinga et al. (2007) noticed that reluctance on the part of central and state agencies to devolve power to water user associations (WUAs) did not provide incentives for the participation of water users and that this explained the varied and limited success of the particular combination of hierarchy and network modes of governance. For this reason, the context-based assessment of possible interactions both within and beyond policy mixes, based on the underlying principles, is crucial for their effectiveness in achieving the intended policy goals.

Koontz and Garrick (2019) further describe three factors that provide incentives for engaging in different interactions between each other: authority, information and resources.

Authority defines the limitations of different decision centres allowing them or forbidding them to take particular actions or entering or exiting particular interactions with each other. In the public sector, authority is usually assigned or devolved by a higher constitutional authority. Devolution of authority is an essential element of various decentralisation strategies pursued in different parts of the world, involving both responsibility as well as constitutionally backed power to make decisions regarding production as well as social, political and legal transactions with respect to a specified policy area and jurisdiction. Effective decentralisation of authority may guarantee the formal autonomy of a decision-making centre, which is an important attribute of polycentric systems of governance. The distribution of authority among decision-making centres across different levels is crucial for facilitation of competitive and cooperative interactions. Which interactions emerge further depend on other conditions of access to information and resources.

Information on the costs and benefits of alternative production mechanisms for public goods, externalities, and transaction costs are crucial if actors in different action situations are to decide on alternatives of production or interaction with other actors. Information on the roles and responsibilities of the various different actors is helpful in increasing the accountability and transparency of the governance process.

Access to financial, human and natural resources is vital to carrying out the assigned or agreed upon roles and responsibilities in generating public goods or monitoring the provision of goods and services. Distribution of access to key resources also defines the power relations among actors in a governance system. Actors with a shared mandate may enter into cooperative relationships of sharing resources and complementing each other in achieving shared goals.

The types of interactions or coordination mechanisms that emerge in a given context depend on the distribution of authority, information and resources across decision centres. There are opportunities for all three kinds of interactions, competition, cooperation and coercion to occur in a system where multiple centres exist under a common set of overarching rules (Koontz and Garrick, 2019). How the three vital elements are distributed among differing actors and decision centres is further contingent on the social, political and cultural contexts.

3.4 Analysing Power in Governance Systems

Social structures, or relationships in which the interactions among actors are embedded, provide some insights into the opportunities and constraints faced by actors in making their choices between

possible interactions or coordination with other actors (Stein et al., 2018). Stein et al. (2018) assert that three forms of embeddedness create conditions for coordination and cooperation through multiple network mechanisms at different network levels—namely positional, relational and structural. While a network approach can "unpack" power relations to some extent by identifying powerful actors in terms of their centrality, it is not sufficient to explain the cultural, historical and political context crucial to the understanding of the meanings and dynamics of social networks. "Power and justice" affect interactions, outcomes and performance in a governance system. In consequence, political dimensions need to be better integrated: Skelcher (2005), for instance, suggests integrating polycentricity theory with the theory of democracy as one useful approach.

The IAD framework has been criticised for the fact that the decisions of actors and their outcomes are often explained with recourse to rules and that this often ignores the role played by power dynamics in shaping institutions (Cleaver, 2000; Clement, 2010). Although the IAD provides a solid basis for multi-level analysis through its conceptualisation of nested action arenas and governance levels, it does not sufficiently capture the influence of intra- and inter-level power distribution on institutional design and effectiveness (Clement, 2010). The effects of power asymmetries, which are more widespread in the less industrialised societies, are spread across multiple and interlinked social and political arenas (Kashwan, 2016).

Increasing efforts have been made to address this gap by integrating the approaches of political ecology to understand the critical role of power in environmental governance into the institutional analytical approaches. The broad conceptualisation of institutions as "prescriptions that humans use to organize all forms of repetitive and structured interactions including those within families, neighbourhoods, markets, firms, sports leagues, churches, private associations, and governments at all scales" (Ostrom, 2005) allows for the integration of power relations as one of the conditioning institutional processes leading to particular political outcomes (Clement, 2010; Bennett et al., 2018). Bennett et al. (2018) develop a relational typology based on the antecedent and consequent relation between power and institutions as well as political economic and post-structuralist conceptualisations of power that are prevalent in political ecology approaches. The political economic "power structures" such as capitalism, class, gender, and so on are based on the premise that power resides in stable societal structures that determine control over, and access to resources. In contrast, post-structural "power constructs," such as discourses, narratives, power/knowledge, subjectivities etcetera, influence individuals and groups in their operations as well as shaping the reality (for instance, environmental problems) (Bennett et al., 2018). The authors further mention that post-structural power constructs provide a methodological approach to studying how the social norms and internal values emerge and change. Based on the relational typology developed by Bennett et al. (2018) for understanding the relationships between power and institutions, we can formulate a range of research questions about relationships between operationalisable concepts of institutions, power structures and power constructs.

4 METHODOLOGICAL STEPS TO ANALYSE POLYCENTRIC WATER-ENERGY-FOOD SYSTEMS

A wide variety of methods—namely small-N case studies; comparative field-based research; meta-analysis; laboratory and field experiments; agent-based modelling—have been used in combination with the IAD framework (Poteete et al., 2010). Almost all of the studies focused on single action situations and single collective/public good of interest.

Following the enhancement of the IAD framework to include the adjacent action situations along with the focal action situation (McGinnis, 2011), a few authors have started to explore new combinations of methods to analyse the interactions among different action situations and thereby offer a more complete explanation of the choices and outcomes of the focal action situation. Kimmich (2013) employs a combination of NAAS and Ecology of Games (EG) frameworks to understand the coordination dilemmas of the interlinked energy and water systems in India. Villamayor-Tomas et al. (2015) employ a combination of NAAS and value chain frameworks to understand similar interlinkages in Spain. Both studies relied on quantitative and qualitative data obtained from primary and secondary sources. Both Ecology of Games and NAAS approaches go beyond the normative focus about the virtues of polycentric governance and mere descriptions of action situations (in NAAS) or policy games (in Ecology of Games). They are helpful in generating empirically testable hypotheses about the structure of the game or action situations, analysing the drivers of individual behaviour and institutional change and showing how these lead to policy outputs and outcomes (Lubell, 2013).

One of the initial and crucial tasks in a WEF nexus study is to identify the relevant focal action situation and adjacent action situations. This essentially depends on the research question and the WEF issues that the research project is focusing on. There can be numerous adjacent action situations surrounding the focal action situation. However, the selection should depend on the theoretical proposition and the empirical knowledge (Kimmich, 2013) gained through exploratory field research approaches such as secondary data, review of the literature, and interviews with key actors.

Stein et al. (2018) use the concept of "problemshed and issue network," originally proposed by Mollinga et al. (2007) in selecting a unit of analysis. This concept moves beyond a pre-defined geographical unit of analysis (such as a watershed) or a sectoral focus (for instance, water) to include a broad set of issues that are linked to the context of a problem. "Problemshed" is framed through an iterative process by the researcher, or co-constructed with stakeholders. The

specific issues of WEF nexus interlinkages as a framework can guide in framing the problemshed. In the understanding of this paper, a problemshed would entail networks of adjacent action situations.

Network theory and analysis is increasingly being used to disentangle the complex interdependencies in polycentric systems. Social network analysis (SNA) is a tool to understand the characteristics or structure of a network by identifying the actors involved in a network and their relationships. This approach helps to understand how social relationships shape governance processes and provide opportunities and constraints for addressing complex and interconnected sustainability challenges (Stein et al., 2018). The centrality of different actors and actor groups is determined and influential actors with a bridging position are identified. Whether the understanding could be extended to the functionality of the networks is a question that is not fully explored in current studies (Lubell, 2013). Relational data generated from the network survey can be transferred into adjacency matrices representing various issue networks identified on the basis of the concept of problemshed and issue networks (Mollinga et al., 2007) mentioned above.

SNA relies on primary data collected from actors who are participants in selected action situations through a structured network survey questionnaire, which focuses on the positional, relational and structural attributes of the network embeddedness. Alternatively, "NetMap" is a method to identify the action situation network following a participatory approach (Schiffer and Hauck, 2010).

Going beyond the quantitative SNA, semi-structured interviews with actors participating in action situations are useful to understand the considerations behind the decisions of actors as well as the structure of the action situation. Further, focus groups with groups of actors within an action situation is a useful technique to gather data on group dynamics and elicit particular kinds of historical or recent data, which are often found to be more reliable if they emerge out of a discussion among actors with similar interests.

5 CONCLUSION

The majority of the scholarship on the WEF nexus focuses on substantiating the biophysical interlinkages among the related sectors of water, food and energy. These help in understanding the magnitude of the problem in different contexts and in strengthening the case for integrated governance of the WEF systems. However, social, political and institutional interlinkages, crucial for understanding and evolving an integrated governance approach, have received less attention. This is the result of the dominant technical-managerial view of the WEF nexus problem. The recent surge in analyses of the WEF nexus using the analytical approaches of environmental governance has emphasised the need for more and effective horizontal (cross-sectoral) and vertical (cross-level) coordination in order to avoid trade-offs and to achieve synergies in realising WEF securities. However, prior literature falls short of explaining the conditions under which such coordination occurs.

In our effort to further the WEF nexus governance research, we have conceptualised WEF nexus governance as a polycentric system. Further, we have argued that analysis of a polycentric WEF nexus governance system would help, first, to understand the relations and interactions among the constituent decision centres which we have conceptualised as networked adjacent action situations; and, subsequently, to investigate the conditions under which different types of interactions emerge among the decision centres. We then proposed a conceptual framework covering various components of WEF governance systems and their logical interrelations. The conceptual framework highlighted the need for coordination arising out of the interdependence of WEF-related transactions by actors in various different interlinked action situations.

Various forms of coordination—namely cooperation, coercion and competition to manage the interdependencies in WEF nexus—are achieved through various means. Which type of interactions different decision centres engage in to coordinate their transactions is dependent on the way authority, information and resources are distributed among the decision centres. It was further argued that WEF nexus governance requires a combination of differing coordination mechanisms or modes in order to manage the cross-sector and cross-scale interlinkages. The coordination mechanisms of hierarchies, markets and cooperation are further embedded in the social structure or relationships, which facilitate or constrain coordination.

The proposed analytical framework based on the concept of network of adjacent action situations (an extension of the IAD framework) has the potential to operationalise the analysis of polycentric WEF nexus governance systems. The analytical framework provides a heuristic for formulating research questions relevant to the context and hypotheses related to conditions affecting the action situation and the interactions among action situations. Further, integrating the approaches from political ecology to understand the role of power structures and power constructs will support the inquiry into how power relations shape, and are shaped by, rules-in-use at various levels. The framework also allows one to assess the performance of the governance system based on outcome and process criteria defined in the respective context and the indicators suggested by theory.

Methodological innovation is called for in operationalising the analysis of polycentric governance systems in the context of WEF nexus. Instead of delineating action situations based on sectoral boundaries, we propose the application of the "problemshed" concept so that the analysis can be focused on the actual issues facing the coordination problem and so that the coordination can be assessed for its conditions and performance in solving the problem. A combination of approaches that study social networks as well as institutions, actors, and resource characteristics may complement each other in providing a holistic

understanding of how a specific situation of WEF nexus governance is organised and performs.

Finally, it is important to note that issues and problems of WEF nexus interdependencies vary across different biophysical, political and economic contexts. For example, not all the elements of the nexus may be relevant in all contexts. In some river basins, energy may be generated entirely from other sources than water and in other contexts, water in agricultural sector may be prioritized for non-food crops, for which there exists a comparative advantage and importing food may be cheaper than domestic production. Moving beyond the given nexus elements of water, energy and food and conceptualising context relevant nexuses in different case studies may be one option. Common reference point for comparison would then be a resource management unit such as watershed, or river basin or sub-basin.

AUTHOR CONTRIBUTIONS

SS and ID jointly conceived the idea for the paper. SS conducted the literature review on WEF nexus governance and elaborated the conceptual framework in **Sections 3.1**, **3.2**, **3.4**. SS and ID jointly wrote the **Section 3.3** on coordination and governance modes. SS wrote the **Section 4** on methodological steps. SS and ID together jointly wrote the conclusion.

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