



Scale-related governance challenges in the water–energy–food nexus: toward a diagnostic approach

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Abstract

The notion of a water–energy–food (WEF) nexus was introduced to encourage a more holistic perspective on the sustainable development of natural resources. Most attention has been directed at identifying potential synergies and trade-offs among sectors that could be addressed with improved technologies and management. The governance of the WEF nexus more broadly has received comparatively little attention, and the importance of scale in space and time has been largely ignored. Inspired by scholarship on multi-level governance in individual sectors, this paper identifies four scale-related governance challenges in the WEF nexus, namely: (1) *scalar fit*, which arises when planning and operating procedures work at different levels along the scales of space and time in different sectors; (2) *scalar strategies*, wherever the levels at which actors have influence and in which action takes place are contested and negotiated; (3) *institutional interplay*, where rules and norms in different sectors influence each other at different levels; (4) *scalar uncertainty*, arising out of the complexity of multi-level and multi-scale interactions. The relevance of these four challenges is illustrated with case studies from developed and developing countries. These examples show the importance of considering multiple levels and scales when assessing the likely effectiveness of WEF nexus governance mechanisms or proposals. The cases underline the need to pay close attention to issues of power, contestation, and negotiation, in addition to the analysis of institutional design. Thus, this paper recommends that nexus governance efforts and proposals be scrutinized for scale assumptions. The four identified challenges offer a suitable starting point for diagnosis.

Keywords Water–energy–food nexus · Multi-level governance · Scalar governance challenges

Introduction

Sustainability challenges far too often have been dealt with in isolation, ignoring the interdependencies between resource systems. Many decisions affecting the sustainable management of water resources are taken not within the water sector but are, for example, determined by agricultural policies. In many regions, agricultural productivity depends

increasingly on irrigation, but agricultural policies do not take into account constraints imposed by the availability of water. Climate change may increase the severity of conflicts between different water uses. The promotion of energy crops has often ignored potential competition with food production. The notion of a water–energy–food (WEF) nexus was introduced to encourage a more holistic perspective on natural resource development. A nexus perspective shifts emphasis to the interdependence of resources and has helped better understand and address synergies and trade-offs among resource systems (Liu et al. 2018; Pahl-Wostl 2019; Hoff 2011; Gleick 2018). Water, energy, and food resource systems are multi-level, and thus, attention to scale issues in the nexus and multi-level governance is critical (Bijl et al. 2018; Johnson and VanDeveer 2017). Despite ensuing calls for more integration and coordination of sectoral policy and management, research into WEF nexus governance remains largely detached from governance practice. One reason is

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that a ‘technical and administrative’ view on governance prevailing in much of the WEF nexus literature (Cairns and Krzywoszynska 2016) is not conducive to overcoming the barriers to effective governance in practice, as it does not take into consideration the political negotiations required among stakeholders with different interests (Allouche et al. 2015; Weitz et al. 2017; Morrison et al. 2019). Another reason is the strong focus on integration across sectors, that is, horizontal coordination of actors and interplay of institutions at similar administrative levels, which has meant that insufficient attention has been given to the vertical relationships among actors working at different administrative levels (Benson et al. 2015; Pahl-Wostl 2019). Furthermore, the focus on policy objectives has overshadowed the importance of implementation and outcomes, and thus issues of accountability. Therefore, it often remains unclear at which governance level and when in the policy cycle specific types of interventions might be most effective (Weitz et al. 2017).

The main contribution of this paper is to address these governance gaps related to selection of levels and phase of the policy cycle by offering a pragmatic starting point for assessing how space and time scales matter for the effective governance of the WEF nexus. Our simple diagnostic framework consists of four scale-related governance challenges that we expect to be often important for WEF nexus situations, and a corresponding set of queries to determine when they are critical (Table 1). The challenges were purposively selected to span different governance dimensions—processes/structures (*scalar fit*), actors (*scalar strategies*), institutions (*interplay*), and interactions (*uncertainty*). The four challenges were identified by building on the combined understanding of multi-level governance of individual resource (i.e., water, energy, and food) systems insights on cross-sector policy coordination and work on the politics of scale. In the next subsection, after defining core terms, we briefly summarize key points of this foundation.

Multi-level and multi-scale governance

Following Cash et al. (2006), we use *scale* to refer to the dimensions (e.g., space or time) used to measure and study a phenomenon, and *levels* to refer to the units of analysis that are located at different positions on a scale. Thus, levels on a *spatial scale* might be local, provincial, and national; whereas on a *temporal scale*, the levels might be seasonal, annual, and multi-year. *Governance* here refers to efforts to steer how society interacts with the WEF nexus, and thus includes decisions and actions of both state and non-state actors.

So far, progress in understanding multi-level governance and the importance of scale have been driven by sectoral studies, including large bodies of work on water, energy, and food systems. Throughout this literature, various archetypical scale challenges emerged (see, e.g., Moss and Newig 2010; Young 2002). These center around the scalar compatibility of different resource and governance systems (*scalar fit*), and the processes through which these scalar differences are accommodated (*interplay*). While these cover the structural and procedural governance dimensions, a wide debate emerged around the politics of scale (e.g., Bulkeley 2005) and the ways in which scales are constructed and taken advantage of through political actors (*scalar strategies*). Finally, considering different scales, levels and the dynamics between these inevitably require accounting for the complexity and *uncertainty* inherent in the system (Kok and Veldkamp 2011). Based on the insights found in the various sectoral studies, these archetypical challenges are shown to be of pivotal importance also when it comes to the analysis of the WEF nexus.

On which spatial scale water should be governed has received some attention and debate (Pahl-Wostl et al. 2008; Vörösmarty et al. 2015; Hering et al. 2015). Gupta

Table 1 Four core scale-related nexus governance challenges

Nexus challenge	Description of challenge	Diagnostic queries
Scalar fit	Processes in water, energy, and food systems operate on different scales and levels, and these do not correspond to the structural levels of governance at which they are currently dealt with	What are the most important scale mismatches in the nexus, and which can be ignored?
Scalar strategies	Key actors in water, energy, and food sectors are strategic in how they engage with issues on different scales and levels, reflecting interests, competency and opportunities to exercise power	How are actors contesting and negotiating levels and scales in the nexus? Which actors have agency?
Institutional interplay	Key institutions in water, energy, and food sectors may respond to, or drive changes in, other institutions in the same sector at other levels, and in different sectors	Is vertical or horizontal interplay in the nexus present, and if so, is it constructive or disruptive?
Uncertainty	Uncertainties arise from how resource processes, actor strategies, and institutions interact on different scales and levels across the nexus	How do interactions increase the uncertainty of the outcomes from efforts to govern the nexus?

and Pahl-Wostl (2013) applied a politics of scale perspective to understand the diverse motivations of actors for defining a water-related problem at the global or local levels, and showed that the multi-level approach to water governance was evolving and inevitable. Regardless, actors are strategic in how they engage multi-level systems like transboundary river basins, for example, by shifting issues and attention to those levels where they have greater capacity to pursue their interests (Lebel et al. 2005; Guerrin et al. 2014). Such observations are example of *scalar strategies*. Studies of the management and development of water resources suggest that polycentric systems (decentralized and coordinated) with multi-level governance arrangements often perform better than decentralized or centralized arrangements hindered by problems of coordination and fragmentation (Pahl-Wostl and Knieper 2014). One reason is that they foster constructive forms of *institutional interplay*; another is they can improve the *fit* between governance and natural resource system processes (Lebel et al. 2013). Polycentric governance may thus be particularly suited to address WEF nexus challenges (Pahl-Wostl 2019).

Energy governance studies that are explicitly multi-level have creatively struggled with issues of accountability arising from the mixture of private, quasi-private, and public organizations with roles for production, distribution, and regulation in tension with each other (e.g., Dedecca et al. 2019; Marquardt 2014; McKenna 2018). In these settings, constructive *institutional interplay* is important, for instance, for the expansion of renewable energy systems (Smith 2007). Research in the field of energy also suggests that “decentralization strategies work well where improvements are based on locally available knowledge and sharing of best practices” (Hermanson 2018); while dependence on subsidies may constrain the *strategies* of subnational actors and recentralize authority (Cowell et al. 2017).

In studies of smallholder access to land to grow food, biofuels, or fiber (Morgan 2017; Larsen et al. 2014), there is often a large gap between national laws and principles on land tenure and distribution, and de facto local recognition of property rights. This applies especially to ‘frontier’ areas settled by ethnic minorities or subject to corporate land concessions (Dwyer 2015; Baird 2014) and resettlement for ‘development’ (Kura et al. 2017; Weeratunge et al. 2016). In addition, commodity chains for exported food or biofuels are often subject to private governance efforts, for example, through standards and certification schemes (Tallontire et al. 2011; Sanders 2017). In these situations, actors may resort to scale-jumping *strategies* (van Schendel 2002) to improve access to natural resources, benefits from their use or to protect them (Perreault 2005; Green 2016). Thus, a multi-level understanding of land governance needs to consider both formal and informal institutions, external institutional

processes such as trade in food and energy systems, as well as possible implications for water resources.

The importance of multi-level interactions in sectoral governance strongly suggests that the influence of such interactions may be even more pronounced in nexus governance as the number and complexity of institutions and actors multiplies (Young 2017). To understand and deal with such complexity, and the uncertainties this generates, the multi-level governance of the nexus warrants more attention in scholarly studies and policy debates.

Recent scholarship suggests that ignoring the multi-level nature of the governance systems to be coordinated is likely to be an important obstacle to successfully addressing the challenges of governing the nexus. A central issue in the discussion relates to how different actors, nested at different levels, should interact to produce desirable governance outcomes (Newig and Fritsch 2009; Hooghe and Marks 2003; Morrison et al. 2019). On one hand, excessive coordination may hinder creative self-organization (Folke et al. 2007; Pahl-Wostl 2009). On the other hand, insufficient coordination may disrupt effective implementation of policies or agreements (Pahl-Wostl 2019). Moreover, depending on the issue, some actors seek to disrupt coordination, whereas others to facilitate it, at particular levels (Haas 1992; Di Gregorio et al. 2019). When horizontal policy integration occurs not at a single level of governance, but is carried across vertical tiers of governance, one can also speak of diagonal policy integration (Berger and Steurer 2009). Such integration has received increasing attention in public policy in recent years (Trein et al. 2019). To date, however, fragmentation in multi-level governance efforts for solving environmental problems frequently prevails (Wever et al. 2012; Young 2006; Märker et al. 2018; Venghaus et al. 2019).

The quest for such a holistic perspective and coordination across sectors does not necessarily coincide with the perspectives of the actors within the different sectors—a shared nexus perspective does not exist. Rather, the actors in each domain may pursue their narrow sectoral and organizational agendas and economic interests, and perceive the need for interaction and coordination to govern the nexus in an integrated way very differently (Allouche et al. 2015; Di Gregorio et al. 2019; Middleton et al. 2015). Hence, we agree with Weitz et al. (2017) that more emphasis needs to be given to processes of negotiation and the role of power constellations, and would add—across scales and levels.

Methods

In March 2019, a 1-week expert workshop bringing together an interdisciplinary group of researchers working on the WEF nexus took place in Germany. The purpose of the workshop was to advance research on the governance

dimension of the WEF nexus. Participants came from diverse scientific disciplines and worked on different WEF nexus sectors. During group discussions, the authors shared experiences from their research and empirical findings from their respective case studies. A significant outcome of this deliberation process was the observation that, whilst scale challenges are inherent to many nexus challenges, surprisingly little attention has been paid to scale-related challenges in the WEF nexus debate. To further explore to what extent and how scale challenges have been analyzed in the context of the WEF nexus, an explorative literature review was conducted. This review confirmed the strong emphasis on sectoral interdependencies. Relatively few studies explicitly addressed how scale matters for the governance of the WEF nexus. A notable exception is the research by Johnson and VanDeveer (2017) who point out that “the concept of scale is inherent to nexus thinking and necessary for any fruitful nexus-based analysis”, but that there is a need for more systematic inclusion of scalar thinking in nexus analyses and governance. To address this gap, the authors examined the literature on multi-level governance and on cross-sectoral policy coordination of individual resource systems in breakout groups. Based on this literature review and face-to-face discussions during the 4-day workshop, the authors co-produced four scale-related challenges. The challenges were purposively selected to address different governance dimensions—(1) processes (*scalar fit*), (2) actors (*scalar strategies*), (3) institutions (*interplay*), and (4) interactions (*uncertainty*).

To demonstrate the usefulness of these dimensions as a diagnostic approach, several empirical case studies were examined by undergoing multiple critiques by the authors. This allowed setting into communication the scale-related nexus governance challenges identified in the literature with empirical research on the WEF nexus in different parts of the world. At least one of the four identified challenges (cf. Table 1) was found to be present in all cases (regions) where the authors did empirical research. To further examine the scale-related challenges, four case studies were selected for a more in-depth analysis.

Cases were selected based on the authors’ recent or ongoing research. Having worked on those cases for several years, the authors were able to draw on extensive empirical data and knew the policy settings. All cases are characterized by sectoral interdependencies that constitute the core of a WEF nexus perspective (cf. Table 2). This enabled an empirical grounding of the scale-related challenges in specific nexus interdependencies and governance dynamics. Another case selection criterion was the objective to cover a diversity of geographic regions in both developed and developing countries. Empirical cases were chosen from Sub-Saharan Africa, Europe, South Asia, and Southeast Asia. A detailed description of the case studies Blue Nile in Ethiopia, the

Weser-Ems region in Germany, the Lower Mekong river basin in Cambodia, Laos, Thailand, and Vietnam, and the Mahaweli river basin in Sri Lanka can be found in the Supporting Information.

The analysis underlying this initial scoping paper was explorative and primarily based on expert judgement, which combined a good understanding of the literature with an in-depth understanding of the empirical case studies. The intention is not to systematically apply a diagnostic approach across case studies, but to offer a pragmatic starting point and to demonstrate its merits. In the following sections, we will discuss each of the four challenges presented in Table 1. After summarizing the core arguments, examples from the selected case studies will illustrate the value of diagnosing these challenges in many nexus governance settings.

Scalar fit

Scalar fit is the match between the scalar configurations of key institutions and the characteristics of the interacting bio-geophysical systems (Folke et al. 2007; Young 2002). Water, energy, and food systems display various peculiarities of *scalar fit* (Bijl et al. 2018). In water governance, misfit challenges mainly concern the mismatch between hydrological and political-administrative scales (Moss 2003, 2012), and resulting difficulties of aligning administrative structures to the scale of river basins and aquatic ecosystems. In agricultural and energy systems, misfits occur between the location of authority and the scalar configurations of problems to be addressed. For instance, multiple studies stress the misfit between top-down agricultural policies, such as the EU Common Agricultural Policy, and the local realities of farmers and farming landscapes, leading for example to distorted incentives for unsustainable practices, or the disregard of ecological matters, ecosystem health, or biodiversity (see, e.g., Leventon et al. 2017; Bergsten et al. 2019). In the energy sector, major challenges of fit have emerged through the reorganization of energy systems due to the expansion of renewables and the related shifts from centralized production toward more decentralized structures (Eitan et al. 2019), which may provide considerable benefits locally, but run counter to the requirements of large-scale energy networks (McKenna 2018).

Those sectoral misfit challenges are amplified when taken together under the WEF nexus. Structures in different sectors adhere to distinct multi-level logics, aggravated by new cross-cutting governance challenges—e.g., the one between the preservation of favorable agricultural land and the rapid expansion of renewable energy production in rural areas (Poggi et al. 2018). The sectoral and institutional fragmentation under the WEF nexus, thus, may highlight situations of particularly pronounced temporal misfits. Institutions,

Table 2 Concise summary of key features of the four case studies

Case	Nexus interactions	Scale-related governance challenges
Weser–Ems region, Germany land-use, renewable energy and groundwater interactions	Intensified agriculture and livestock (F) degraded groundwater (W) Subsidies for renewable energy (E) increase competition for land (F) Residues from bioenergy plants (E) add to groundwater pollution (W)	Water (s): EU (Water Framework Directive) —Germany—Lower Saxony—Weser and Ems Basins—Sub-basin area (cooperation) Water (t): six-year planning cycles (currently 2015–2021) Food (s): EU (Common Agricultural Policy) —Germany—Lower Saxony
Mekong river basin International assessment and planning activities	Diversion of water (W) for irrigation of food crops impacts fisheries (F) Flow regulation (W) for hydropower (E) impacts fisheries (F) Expansion of irrigation areas (F) and hydropower generating capacity (E) increase competition for water (W) Reliance on traditional biomass energy (E) adversely impacts agricultural production (F) and degrades watersheds (W)	Food (t): seven-year budget cycles (currently 2013–2020) Energy (s): Germany (Renewable Energy Act)—municipal level Energy (t): 20-year feed-in tariff guarantees Water (s): Mekong Region (Mekong Agreement)—member states (water resource development plans)—River sub-basin or province (plans)—individual projects (impact assessments)
Upper Blue Nile (Abay) Ethiopia Water-related infrastructure development	Impact of flow regulation (W) of the multi-purpose water reservoirs (E) on downstream agriculture (F) Water allocation and distribution (W) for agriculture (F) depends on climate and weather conditions	Water (s): Ethiopia (Growth and Transformation Plan)—Abay basin (River Basin Master Plan)—regional level (water resources development plans)—municipal level
Sri Lanka Mahaweli Development Program		Water (s): Sri Lanka (National Water Supply and Drainage Board)—River basin and Mahaweli Management Units (Mahaweli Development Program)—Local Government Units, Regional agrarian units Food (t): <i>Yala</i> and <i>Maha</i> cultivation seasons —project management periods under the Mahaweli Development Program

Nexus interactions between water (W), energy (E), and food (F) systems. Examples of spatial (s) and temporal (t) scale-related nexus governance challenges

projects, and plans in different sectors have different histories and temporal patterns, creating additional challenges for the integration and synchronization of plans and policies (Galaz et al. 2008; Munck af Rosenschöld et al. 2014). Hence, it is pertinent to consider the challenges of *scalar misfit*, as these are inherent to the WEF nexus and generate systemic barriers for coordinating policies and management decisions.

Experience from cases In the Mahaweli River Basin in Sri Lanka's dry zone, rural dwellers face multiple, partly overlapping or contradictory incentives for agricultural activities from various governance levels and sectors, leading to malfunctions in the water allocation system and detrimental effects for rural livelihoods (Perrone and Hornberger 2016; Withanachchi et al. 2014; Paranage 2019). These conflicting incentives, on one hand, stem from the already fragmented governance system for the water allocation and the management of environmental issues. This system, based on Agricultural Service Regions, involves a number of actors from various branches and levels of government, including representatives from the village level to those from the central administration (e.g., centrally appointed village officers), each being accountable to different governmental bodies and levels. On the other hand, in this basin, conflicts over the allocation of water are exacerbated by the Mahaweli Development Program (MDP), the largest multi-purpose water management project in Sri Lanka, aiming to establish human settlements in dry zone areas, to increase agricultural production, and to boost hydropower generation (Perrone and Hornberger 2016; Withanachchi et al. 2014). This system follows its distinct spatial logic of 'development zones', again bringing diverse actors and interests to the table. Spatially, this scalar patchwork of different units is only loosely coupled, but forms a complex bureaucratic governance structure (Withanachchi et al. 2014; Paranage 2019).

The Moragahakanda–Kaluganga Development Project (MKDP) under the Mahaweli Development Program aims to provide water to agriculture, as well as drinking water supply to the Northern and North Central Provinces in Sri Lanka. The management of drinking water is a responsibility of the National Water Supply and Drainage Board (NWSDB), which is a central government agency. However, local governments demand more power to manage drinking water in the areas under their administrative control. The research findings indicate that local communities in the Northern Province are more connected with their respective local authorities than with the central government. In the Northern and North Central Provinces, the presence of the central government, acting through the NWSDB or the Agrarian Services, has the potential to discourage active civic engagement in local-level water resource management. In consequence, this leads to a situation where the WEF nexus is not only fragmented, but where we see a

scalar mismatch between local needs and accountability structures, and the institutional regime set out to govern these, with detrimental implications for local users and the environment.

Such challenges of spatial misfit often go in hand with a temporal misfit between different planning routines and time frames, as the case of the Weser–Ems region exemplifies. The region is a European hotspot for intensified agriculture and biogas energy production, with severe detrimental effects for regional water resources. Fragmentation of decision-making centers across levels has significantly contributed to this situation, setting conflicting incentives for local and regional actors (Pahl-Wostl 2019). Whereas the agricultural sector is completely communitarized through the EU's Common Agricultural Policy (CAP), responsibilities in the energy and water sectors are shared between the EU and its member states. This leaves the right to determine the nature of energy exploitation and supply to the respective member states, i.e., the German federal government (Venghaus and Hake 2018).

Competences in the water sector are further scaled down with the federal state of Lower Saxony as the regional authority for water management (Newig et al. 2016). The case additionally exemplifies an often-overlooked temporal misfit arising from conflicting time frames and planning cycles. While water management follows 6-year planning cycles (Jager et al. 2016) with the next one ending in 2021, the priorities of the CAP are re-evaluated every 7 years together with the overall EU budget, the next period starting again in 2020 (Pe'er et al. 2019). Biogas plants, as additional driver of agricultural activity and pollution, used to be subsidized through a guaranteed feed-in tariff issued for 20 years (Schomerus and Maly 2018). Given these asynchronous procedures, coordination becomes additionally complicated, as suitable times for action and change in one sector may be inhibited by pre-set decisions and plans in another, culminating in a temporal nexus trap.

As these examples highlight, challenges of misfit are diverse and occur on different dimensions. Whereas, in sectoral studies, misfits between resources and the responsible institutional structures are already widely regarded, these challenges are multiplied when considered in the context of the WEF nexus, leading to various circumstances of ineffective management and unclear accountability structures. Aspects of temporal misfit, often difficult to grasp, add additional complexity to the spatial picture, further complicating coordination and coherent sequencing of interrelated nexus governance activities.

Scalar strategies

Non-state and governmental actors may operate more effectively in particular roles at different levels, and thus choose to strategically act at the level where they see the best chance to push their agendas (Gupta 2008). They may also

strategically upscale or downscale a problem to extend their power to other levels (Gupta and Pahl-Wostl 2013; Hüesker and Moss 2015). Mandates may constrain what they can formally do and what they cannot avoid; nevertheless, some will endeavor to work across levels (Hüesker and Moss 2015). Furthermore, research has shown that “organizations at the same level of governance have a strong tendency to interact primarily among themselves”, proposing that political boundaries create barriers to cross-level interaction (Di Gregorio et al. 2019, p. 68). This creates challenges for creating and maintaining arenas of engagement, whether it is in the form of consultations or advocacy and protest (Cox 1998). It also creates challenges for sustaining processes of learning that are inevitably required to do justice to different values and world views that underlie preferences for different policy objectives and claims for the scale at which a problem should be addressed (Lebel et al. 2005; Gupta and Pahl-Wostl 2013). Differences in actor objectives, scope of influence in planning hierarchies, and roles in building and operating critical infrastructure in water, energy, and food sectors multiply the opportunities for following divergent strategies. Learning, the co-production and contestation of knowledge, takes place at multiple levels with individual, communal, organizational, and national or international actors having relevant experience and disparate power to influence others’ ideas at different levels (Hoolohan et al. 2018). Thus, the *scalar strategies*, or levels at which stakeholders claim action are needed or prohibited, and to which they commit resources or shift responsibilities, should be mapped to understand the evolving interests behind scaling dynamics, as this can help to identify obstacles and entry points for deliberation, learning, and negotiation (Dore and Lebel 2010).

Experience from cases In the Lower Mekong River Basin, the four riparian states (Cambodia, Laos, Thailand, Vietnam), driven by concerns of transboundary impacts, have jointly undertaken a series of multi-year assessment and planning activities to support the development of water resources for food and energy production. In the ensuing deliberations, a common, *scalar strategy* of hydropower development proponents has been to scale up the benefits of particular projects to the region, and scale down the area adversely affected, for instance, to just the reservoir area (Lebel et al. 2005; Baird and Quastel 2015). Thus, proponents celebrate that most of the electricity produced by a dam in Laos is destined for export to Vietnam and Thailand. Critics, in contrast, scale up the area in which fisheries are likely to be adversely affected to include areas downstream, even reaching into lower riparian states—a transboundary issue—and because of impacts on fish migration, also further upstream.

Scalar strategies are also apparent with respect to temporal scales. Hydropower proponents, for instance, dismiss the flow impacts of catering to daily and day of the week peaks in electricity consumption, whereas those with river-bank gardens and fishers bemoan the disruption of their livelihoods from ‘unnatural’ flow fluctuations (Cochrane et al. 2014; Baird and Quastel 2015). At the seasonal level, hydropower dam operations tend to increase dry season flows—euphemistically called ‘new water’—while reducing the seasonal flood pulse important to the productivity of fisheries (Baran and Myschowoda 2009; Keskinen et al. 2015). Over the decades, the basin planning exercises have manipulated the duration and starting times of infrastructure scenarios; thereby including or excluding projects from ‘baseline’ conditions, and thus the size of apparent impacts on flow changes (Lebel 2013). Discursive and material *scalar strategies* are a critical feature of the nexus insecurities and trade-offs in the Lower Mekong (Pittock et al. 2016; Intralawan et al. 2018).

In the Weser–Ems region in Northern Germany, non-state, state, and international actors also adopted different *scalar strategies*. In this case, agricultural actors came under pressure due to the severe nitrate pollution inflicted on regional water resources through activities of intensified agriculture for food and bioenergy production. Pressure was executed by the EU, with the European Commission opening an infringement procedure against Germany for failing to comply with the EU Nitrate Directive (Meergans and Lenschow 2018).

While opponents to the current agricultural practices try to upscale competences and decisions, as the EU infringement procedure highlights, regional proponents try to keep major competences within their sphere of influence. Traditionally, the regional agri-food system was characterized by a close network between business and governmental actors, forming the basis for the collective organization of different associations and the development of strong collective power, which are used to influence political institutions on the local and regional levels (Franz et al. 2018). To prevent stricter legislation at higher levels with less favorable political climate, additional, privately organized measures have been taken, such as a costly manure export program, aiming to redistribute manure from areas with high agricultural intensity to those with less (Franz et al. 2018). The agency of private actors to rescale issues in this case is noteworthy.

These two illustrations of *scalar strategies* at work underline that interests are neither fixed nor scale-free, but vary with competence and are influenced by negotiations. Efforts to understand and diagnose obstacles and opportunities to more effective governance of the WEF nexus should scrutinize the discursive and material *scalar strategies* of both public and private actors.

Institutional interplay

Institutional interplay refers to the basic idea that “the effectiveness of specific institutions often depends not only on their own features but also on their interactions with other institutions” (Young et al. 1999, p. 49). The prevailing, largely disconnected governance of water, energy, and food resource systems are a legacy of historically evolved roles and responsibilities among different governmental authorities and self-organizing non-state actors (Märker et al. 2018; Venghaus et al. 2019). Within each resource system, there are often complex layers of institutions operating at different levels of social organization (Young 2006; Venghaus and Hake 2018) and in the context of different normative frames (Gillard et al. 2017), thus creating challenges for multi-level governance (Young 2011). Decisions regarding energy supply in Europe, for example, have long been in the hands of large (publicly or privately owned) companies and government actors at the national level supported by policies, regulations, and planning procedures that make small, independent energy production difficult. Recent shifts toward renewable energies, however, have significantly increased the role of small-scale private actors, including households or communities in energy production at the local level (e.g., Goldthau 2014; Kubli and Ulli-Ber 2016).

The interplay among institutions in such energy system transitions is complex and context-dependent. Thus, in much of the developing world, decision-making in the energy sector remains highly centralized, with key operations controlled by state enterprises; on the other hand, numerous decentralized energy systems, typically off-grid, fill gaps in service provision and are governed primarily by community-based institutions. As the number of institutions in a given social space grows, it is likely that interplay between and among them will increase (Young 2011).

The ambition to govern the WEF nexus across multiple levels and sectors adds additional complexity to this existing fabric of regulatory frameworks and formal and informal institutional interactions. When horizontal policy integration occurs not at a single level of governance, but is carried across vertical tiers of governance, one refers to ‘diagonal policy integration’ (Berger and Steurer 2009). Such cross-scale, diagonal interplay, however, is always the negotiated outcome of power relations generating relative winners and losers, which in turn influence the effectiveness of *institutional interplay* and has important consequences for nexus governance (Adger et al. 2005; Young 2006; Stein and Jaspersen 2018; Gillard et al. 2017). Thus, developing effective coordination structures for multi-level cross-sectoral nexus challenges requires a careful understanding of horizontal (across sectors) and vertical (across levels of social organization) *institutional interplay*.

Experience from cases The Blue Nile river basin in north-western Ethiopia is a region undergoing rapid change in the water, energy, and agricultural sectors. The implementation of Ethiopia’s Growth and Transformation Plan (GTP) (FDRE 2010, 2015) has given rise to numerous ambitious development projects, including the construction of dams, inter-basin water transfers, expansion of irrigation areas, and hydropower developments. These investments in infrastructure projects require an integrated policy framework and effective institutional interactions to yield sustainable and equitable growth (Calow and Mason 2014; Parker et al. 2016). However, coordination and information sharing between planning units at different levels and across sectors remain limited (Hailelassie et al. 2012; Stein and Jaspersen 2018; Parker et al. 2016; Oates et al. 2015; Mosello et al. 2015). Although various policies in Ethiopia emphasize coordination, in practice, such coordination remains limited (Mosello et al. 2015). In Ethiopia, policy design and decision-making have historically been characterized by a top-down approach and a largely authoritarian culture within government agencies (Keeley and Scoones 2003; Ludi et al. 2013; Snyder et al. 2014). As a consequence, the behavior of (local) actors continues to be driven by the aim to meet targets set at the top, because that is how their performance is evaluated (Merrey and Gebreselassie 2011). National-level policy targets, such as the ones formulated in the GTP, are supposed to be broken down for each sector and at each administrative level, taking into account the specific local context. However, in practice, there is often a lack of institutional capacity to adapt policy targets, and in the absence of effective cross-level coordination, policies risk being poorly suited to local circumstances (Ludi et al. 2013; Mosello et al. 2015). This undermines the sustainability, equity, and effectiveness of interventions (Snyder et al. 2014; Parker et al. 2016). Challenges of cross-scale *institutional interplay* are not confined to interactions among institutions within countries, but can also be transboundary.

In the Lower Mekong River Basin (SI Table 1), the assessment and planning activities, in principle, add an international level to the existing national planning processes. As these basin planning activities involve the allocation of water for irrigation and hydropower, with consequence for flows and thus water for fisheries, locally and transboundary, they potentially triggered both *horizontal* and *vertical institutional interplay* around the nexus.

Vertical institutional interplay, in practice, has been very limited. The regional plans simply aggregated the individual projects submitted by the member states; their inclusion in regional plans, however, had no influence on state decisions to proceed or delay projects. Moreover, some large planned irrigation diversion projects that would have significant impacts on flows were not submitted, and thus not included. One way to maintain this gap between the Mekong

Agreement Plans and Procedures and national decisions on projects was by sending representatives to meetings or nominating members of national committees who had little influence on national planning agendas (Hirsch et al. 2006). Constructive *horizontal interplay* within the public administrations of each country has also been limited and unrelated to nexus discourse (Lebel and Lebel 2018; Middleton et al. 2015). The challenges were acknowledged early on in the basin planning process; the “BDP group also thought that transboundary multisector dialogues were more difficult to conduct than those within a country about a single sector” (Dore and Lebel 2010, p. 69). At the regional level, the Council Study represents another effort at a more integrative perspective (MRC 2016), but does not appear to have had much influence on individual state decisions to proceed with construction of large-scale hydropower projects. Future nexus coordination efforts in the Mekong will soon not be about planning new infrastructure, but rather be about coordinating their *operations* (Piman et al. 2016; Hecht et al. 2019).

The above cases illustrate how *institutional interplay* may undermine the effectiveness and sustainability of nexus governance. The reasons range from institutional legacies of top–down policy and planning practices that impede synergistic interaction to resistance of powerful players to cooperate when it is not in their self-interest. These barriers are context-specific. However, an understanding of *institutional interplay* across both sectors and levels of social organization is critical in efforts to improve nexus governance and to shape interplay of synergistic rather than conflicting nature.

Uncertainty

Much has been written on the implications of complexity in environmental governance and management (Pahl-Wostl 2007a; Folke 2006; Renn 2008), which have often been ignored by technical interventions (Gleick 2003; Pahl-Wostl 2007b). Given the complexity of nexus interactions, the need and effectiveness of coordination measures are difficult to predict. On one hand, kind and outcomes of nexus interactions may change over time due to factors largely external to the WEF nexus governance system (e.g., climate change and socio-economic developments). On the other hand, *uncertainty* may arise from unexpected developments in nexus interactions themselves. The energy sector, for example, is currently in a phase of transition. The increased importance of decentralized local energy production increases complexity and asks for new approaches to govern multi-level and multi-actor energy production systems. Furthermore, actors may choose different *scalar strategies* to respond to interventions. Interventions at one level may lead to unexpected repercussions in the multi-level governance system.

A holistic nexus perspective that asks for systemic transformation cannot ignore such complexity (Pahl-Wostl 2019; Liu et al. 2018).

Nexus interventions thus require adaptive governance and management at different levels and during different phases of the policy cycle. Adaptive governance and management entails claims on governance capacity, the need to tailor solutions to context and to comply with good governance principles (Folke et al. 2005; Pahl-Wostl 2009, 2015). Otherwise, flexibility in negotiating goals, the means how to achieve them, and space for interpretation of agreements might be abused by powerful actors pursuing their vested interests (Pahl-Wostl 2015; Duit and Galaz 2008; Pahl-Wostl et al. 2007). Sources and nature of uncertainties relevant for multi-level WEF nexus governance, their perceptions by different actors, and strategies on how to deal with them need to be determined and made transparent. This is essential for evaluation and enhancement of governance capacity for addressing uncertainties.

Experience from cases In the Blue Nile region, livelihoods and economic development are vulnerable to climate variability. Climate change is expected to lead to more *uncertainty* and extremes in weather patterns, such as floods and droughts, with potential implications for water, energy, and food security (Conway and Schipper 2011; Demekie et al. 2011; Awulachew et al. 2012; McCartney and Menker Girma 2012). The Ethiopian government has embarked on a series of ambitious infrastructure projects to develop the Blue Nile’s substantial water resource potential for irrigation and hydropower expansion. Allocating water between different sectors as well as upstream and downstream users requires the coordination among planning units from different levels of governance. Uncertainties associated with climate change further amplify the challenges of governing the WEF nexus in the Blue Nile. Investments in water storage infrastructure can help to mediate some of the effects of hydrological variability. However, there are also limitations to control oriented, top–down infrastructure-based solutions (Allouche et al. 2019). Investments in infrastructure such as dams and irrigation schemes need to be accompanied by parallel investments into soft infrastructure (Parker et al. 2016), especially coordination and negotiation mechanisms between sectors and planning units at different levels (Mosello et al. 2015).

In the Blue Nile, the capacity to govern nexus interactions is hindered by a lack of adequate financial, human, and technical resources, as well as the disruptive reorganization of government organizations, which has produced uncertainties about institutional responsibilities, compromised institutional memory and thus institutional learning (Merrey and Gebreselassie 2011; Hagos et al. 2011; Mosello et al. 2015). *Uncertainty* also arises from inadequate meteorological and hydrological data, which is collected by different organizations and not shared

effectively across different sectors and levels of governance (Hagos et al. 2011; Mosello et al. 2015). Ethiopia's Climate Resilient Green Economy strategy alongside the multi-sectoral Growth and Transformation Plan provides an opportunity for addressing interconnected nexus challenges (Okereke et al. 2019). However, this would require creating policy space for alternative more bottom-up understandings of nexus relationships, which are resilient in the face of *uncertainty* and change (Allouche et al. 2019).

In the Mahaweli River Basin in Sri Lanka, inter-sectoral water allocation constitutes a complex multi-level governance challenge that is exacerbated by the expected increase in climate variability due to climate change. The central government authorities, such as the Mahaweli Authority, interfere in water management processes by implementing ad-hoc policies that are not derived through a careful planning process considering key uncertainties in the management of water resources at different levels of management or across sectors (Samad et al. 2017). Agricultural water allocation is based on the availability of upstream water, including water released by upstream reservoirs. One of the key tasks of these multi-purpose water reservoirs is hydropower generation. During low precipitation periods, water availability in water reservoirs declines, and meeting the needs of hydropower generation becomes a controlling factor for downstream water allocation. Under the Mahaweli Development Program (MDP), water distribution for farmers is managed by mainly the Bulk Water Allocation (BWA) system. This system requires farmers to restructure their farming activities (Wong and Herath 2014; Aheeyar et al. 2007). Furthermore, seasonal cultivation systems (*Yala* and *Maha*) in accordance with Monsoon rains drastically vary in their impacts depending on the highly fluctuating rainfall variability (Chandrasiri et al. 2020). This approach inheres a significant risk, as water allocation and distribution needs cannot be fully pre-planned, given climate variability and management decisions in the upstream part of the river. In WEF nexus interactions, climate change and weather uncertainties amplify the authoritative power of the central government, further marginalizing the local- and regional-level bodies' roles in water allocation and distribution.

These case examples illustrate that the impacts of uncertainties, for example arising from climate change, exacerbate the challenges of dealing with nexus interactions. Governance capacity and flexible vertical coordination that produces the desired outcomes are essential for nexus governance under such conditions.

Discussion and conclusion

The nexus approach aims at holistically approaching different policy fields with an integrated perspective to secure the sustainable provision of water, energy, and food in times of

global change. Previous research on the governance of the WEF nexus has primarily focused on the integration across sectors (Pahl-Wostl 2019) and, with a few notable exceptions, has largely overlooked issues of scale. The objective of this study was to provide a simple diagnostic framework for assessing when and how space and time scales matter for effective nexus governance. We identified and illustrated a small set of diagnostic queries to help ascertain the scale-sensitive analysis of WEF nexus governance around the dimensions of scalar fit, scalar strategies, institutional interplay, and uncertainty.

Challenges of *scalar fit* are both spatial and temporal. The distinct administrative hierarchies around the management of water, energy, and food systems often seem to neither match each other spatially, nor the key biophysical processes that underlie their provision. The temporal dimension also presents severe, yet often unrecognized nexus governance challenges. As the Mekong case and the Weser-Ems case suggest, differences in planning cycles generate procedural misfits and other obstacles to coordinating multi-level planning across sectors. Moreover, infrastructures in the water, energy, and food sectors have different investment horizons and lifespans, making their integrated planning and operation an institutional design challenge. This can result in locked-in, asynchronous patterns where political reform and institutional change become hard to time and implement.

Scalar strategies may create additional nexus governance difficulties, challenging the critical assumption that interests are scale-free and fixed. The discursive strategies of actors in the Mekong case and the German case suggest an awareness of the importance of actors framing problems (and solutions) at the particular temporal and spatial levels in which they are most competent or influential. These multi-level and cross-scale interactions in the WEF nexus are not only discursive, and they are also relational and material, as actors manifest power inequality through institutionalized procedures and the long-term control of water or energy flows with infrastructure.

Institutional interplay may be constructive, disruptive, or inconsequential. In the Blue Nile, large-scale water infrastructure investments within Ethiopia are being made to produce energy and grow food with, in practice, limited coordination and sharing of information among levels or across scales (sectors). In the Mekong case, similar infrastructure-led development is taking place at a transboundary level with institutionalized sharing of information and cooperation on assessments, but key decisions still being made a sector-at-a-time by states.

High *uncertainty* results from multi-scalar and multi-level interdependencies. As particularly evident from the Ethiopian case and the Sri Lankan case, governance actors not only face the problem of anticipating the potential local and regional impacts of global climate change, but

struggle to consider multi-level repercussions of nexus governance interventions. The lack of capacity to deal with the vagaries of climate change exposes the weaknesses of the prevailing governance system.

With these diagnostic queries, we do not claim to have provided an exhaustive list of scale-related issues for WEF nexus governance; rather, the four identified challenges serve as an important starting point to better understand the plethora of scale-related difficulties for developing effective nexus governance. The value of such a diagnostic approach to the WEF nexus is that it includes queries that help probe structural (fit), agency (strategies), procedural (interplay), and complexity (uncertainty) dimensions of governance without becoming overly complicated. This enables systematic analyses going beyond the question of whether policy objectives across sectors are aligned to better acknowledge the multi-level nature of the WEF nexus.

The relevance of the identified scale challenges may also extend beyond the sphere of WEF nexus governance. We expect similar challenges to arise on the implementation of the sustainable development goals (SDG) and other efforts that consider the interdependent nature of natural resource systems. In particular, the SDGs are formulated as individual goals and targets, but they can only be achieved if the numerous interdependencies are taken into account. Liu et al. (2018) conclude in this regard that achieving the SDGs requires a collection of holistic nexus governance strategies that recognize the importance of sectoral interdependencies, synergies, and trade-offs. We recommend using diagnostic queries like those suggested in this paper for scrutinizing proposals for the governance of such nexus situations to uncover their underlying scalar patterns and dynamics.

This study goes beyond many previous discussions around scale by putting special emphasis on the importance of temporal scales and multi-level power relations. Including these aspects may be of high relevance for the wider nexus governance literature, and enriches the more conventional emphasis on spatial scales and administrative hierarchies.

In conclusion, the paper demonstrates that the WEF nexus is an inherently multi-level perspective raising a host of neglected governance issues related to scale. The four identified challenges, which, as a set of queries, make a useful diagnostic framework for assessing the likely implications of proposed or in progress WEF nexus governance interventions. Insights from the case studies demonstrate the usefulness of an analysis along these dimensions. We thus argue that the framework offers an important starting point to gain a more profound understanding of the scale-related challenges in nexus governance and to develop adequate responses to them.

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