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Interrelated transformative process dynamics in the face of resource nexus challenges: an invitation towards cross case analysis

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ABSTRACT
The need for more attention to the social and human dimensions in global change sciences and natural resources management requires in-depth understandings of transformative approaches and processes. More inclusive and systemic approaches are needed that embrace complexity and support transformative learning, shifts in power relations, collective and relational agency and structural transformations for adaptive and innovative governance. Scientific understanding of how such change can be brought about is still limited. In this paper, which sets the scene for this Special Issue, we develop a conceptual framework for analyzing transformative processes across a range of diverse cases. Aspects of the conceptual framework are applied, tested and elaborated in three following papers in the Special Issue, deepening understanding of how transformative change in complex social-ecological systems may originate at nexus boundary zones such as that portrayed by the water-food-energy nexus. Specifically, the paper conceptually elaborates four iteratively related dynamics of *transformative learning, transforming power relations, transformative agency and transforming structures* which intersect in transformation processes. The perspectives offer tools for cross case analysis in the longer term, but also tools for supporting co-engaged, generative research processes.

1. Introduction

This paper was developed through an extended co-engaged process in an international collaboration between researchers in Germany and South Africa. The collaboration was to deepen our collective understanding of transformation processes at the Water-Energy-Food (WEF) nexus and involved a number of workshops and a summer school series on 'Analysing Transformative Approaches for the Management of the WEF Nexus and the Advancement of the SDGs'. Through our workshops, we co-developed and then elaborated a conceptual framework that could be iteratively applied to a variety of WEF or broader social-ecological systems (SES) cases of transformative change (for examples in water management landscapes). This conceptual framework was applied iteratively to analysis of a diversity of contexts and cases via the ongoing workshop sessions and summer school, some of which were later developed into papers that form part of this Special Issue (SI) (Pahl Wostl et al. 2023; Pringle et al. 2023; Weaver et al. 2023). It gave rise to this SI, and a wider related collection of papers in the SI (Haider and Cleaver 2023; Manlosa et al. 2023; Munera-Rolden 2023; Pereira-Kaplan and Erwin 2023; Raschke et al. 2023; Shackleton et al. 2023; Sonetti-González et al. 2023) that all offer additional insights on the social dimensions of transformative processes within social-ecological systems research from post-colonial and global South contexts. These are referred to where relevant to aid inter-textual reading across the SI in relation to the conceptual framing of transformative processes outlined in this paper.

As a conceptual paper, it principally offers an invitation to authors working in various WEF and/or SES contexts to critically consider and further develop the conceptual framework introduced by the paper. Locating our shared interest in nexus concerns and complex SES landscapes and boundary zones, the paper introduces and deliberates vantage points from social theory. The aim of this is to deepen possibilities for interpreting and understanding interrelated dynamics of transformative processes in SES research in diverse case contexts to support cross case analysis in the longer term. We were not aiming to produce a typology or methodology for cross case

analysis, rather we were seeking out starting points for deliberating the potentials of analysing complex transformative process dynamics in contexts such as the boundary zones found in WEF nexus and SES.

At the outset we recognise that there is an emerging and fast-growing body of research that applies social theory to SES contexts (e.g. Barnes et al. 2017; Menzel and Buchecker 2013; Stojanovic et al. 2016; Westley et al. 2013; Fritz and Meinherz 2020; Shackleton et al. 2022 cf. below). This body of work has played a critical role in opening up a more inter- and transdisciplinary understanding of natural resource management issues, more recently often framed as WEF and SES issues (Cote and Nightingale 2012). Many of these authors highlight the origins of scholarly work in this field in the natural sciences, noting that this has resulted in knowledge asymmetries and superficial engagements with human and social dimensions (e.g. Cote and Nightingale (2012), Stone-Jovicich (2015)). By drawing more deeply on social theory research, SES research is beginning to shine a light on the need for more nuanced and critical engagement with issues such as power and politics (e.g. see Boonstra (2016), Brisbois and de Loë (2016)), social change and transformation processes (e.g. Cote and Nightingale (2012)), learning (Krasny et al. 2010; Suškevičs et al. 2018), and human agency (Westley et al. 2013; Charli-Joseph et al. 2018). The framework we propose here seeks to contribute to this field, offering advancements on existing work related to:

(i) integrating a range of social theories in a conceptually rigorous, inter- or transdisciplinary manner to enable in-depth analysis,
(ii) specifically applying social theory to *transformation processes* in WEF and SES contexts, and
(iii) addressing the need to look at different social processes together or more iteratively in a way that can address the complexities of time, space and context which are so challenging to work with in comparative SES research on transformation (Cockburn et al. 2020).

It is not our intention to systematically review this body of work here, although we have drawn some of it into our deliberations. Rather, for the purposes of deepening understanding of transformative process dynamics, we follow Stojanovic et al. (2016) who recommend depth engagement with wider traditions in the social sciences. Thus, our intention was to seek out relational depth across a number of social theoretical perspectives on transformation processes, which we sought to link to the emerging body of work in applied SES studies where nexus concerns

arise in boundary zones, as illuminated in accompanying papers in this SI (cf. Pringle et al. 2023; Weaver et al. 2023; Pahl Wostl et al. 2023). Each paper that worked with the conceptual framework in the SI reviews associated literature from the SES, and thus further critically engages and contextualises the conceptual framework into this field. While the framework was initially aimed specifically at addressing WEF nexus issues, it is also generally applicable in a diversity of SES contexts, as the accompanying papers in the SI illustrate.

2. Introducing nexus concerns as potential space for transformative process analysis

A vast collection of literature exists that deals with complex, open systems, especially in the social-ecological systems sciences (e.g. Folke et al. 2016; Preiser et al. 2018). Complex interdependencies and openness to external influence imply that system change is difficult to understand and even more so to govern. Scientists have advocated several frameworks of how such complex, open social-ecological systems can be conceptualized (Binder et al. 2013). These frameworks have been helpful for theory development, empirical research, and the analysis of interacting relations and processes from a systemic perspective (Pahl-Wostl 2015). Increasingly, scientists and civil society alike are using such systemic approaches for mobilizing transformative processes that support new concept formation, as well as novel social practices, management approaches and governance interventions (Pahl-Wostl 2015).

Recent critically important emphasis on social and human dimensions in sustainability and natural resource management science (Pahl-Wostl 2017) points to the need for more in-depth understandings of transformative approaches and processes (Lotz-Sisitka et al. 2015, 2017). Moving from top-down technocratic approaches (Popkewitz 2012) towards adaptive and innovative driven governance (Pahl-Wostl 2020) requires more in-depth knowledge of transformative processes, as is argued by authors across this SI.

Nexus approaches (e.g. the Water-Energy-Food (WEF) nexus) are being advocated by science, policy, and business as potentially path-breaking new perspectives with respect to climate change and natural resources management (Albrecht et al. 2018; Morandín-Ahuerma et al. 2019; Pahl-Wostl 2019; Rasul and Sharma 2016). Perspectives emerging on the WEF nexus at the livelihood and community scale raise the need to consider provisioning of services from a higher scale (i.e. economy, policy), but also to consider actual *transformative processes* and how they emerge on a localised and even individual or household scale. Nexus approaches argue in favour

of systemic perspectives and a focus on interdependencies of issues that have so far often been dealt with in isolation (Albrecht et al. 2018; Hoolohan et al. 2018). They are also by definition, focussed on boundary concerns.

In the social-ecological systems, WEF nexus approaches are not uncontested. Some view them as too narrow and propose including climate change, arguing in favour of a 'Water-Food-Energy-Environment-Climate Change' nexus (Mohtar and Bassel 2016). Others argue it is more appropriate to talk about the Water-Energy-Land-(Food) nexus, as Food is not a resource (Ringler et al. 2013). Further arguments highlight that the WEF nexus discourse has been embedded in over-emphasis on technocratic solutions for complex sustainability, not paying sufficient attention to the political, social justice nature of transformative change (Allouche et al. 2019), i.e. the social transformation processes that are embedded in the social-ecological WEF nexus. WEF nexus concerns are complex, and require social transformations to dislodge contradictions, unlearning normalised practices and assumptions (e.g. de Loë and Patterson 2017) hence we argue in this paper that further understanding of transformation processes is necessary, particularly given the increased awareness of deepening social transformation understandings in the SES noted above.

Figure 1 provides a conceptual view of the WEF nexus, and different groupings in society who have an interest in the WEF nexus and need to be connected to address WEF nexus challenges, which is not dissimilar to other SES contexts. The figure uses areas of overlap with diffuse boundaries, rather than arrows, to represent interdependencies among sectoral domains. This is to emphasize that boundaries drawn are artificial. Hotspots, interlinkages and tensions relate to contradictions and trade-offs that

might arise at such 'interfaces' or in boundary zones. Innovation often relates to these and therefore, also happen at these in these 'boundary zones', and could be facilitated by boundary organizations, -agents or -objects (Mattor et al. 2014; Kirchhoff et al. 2015; Nel et al. 2016). By boundary zones we mean the many different interfaces, interactions and relations which characterise SES and WEF issues, including the sometimes imagined and or/arbitrary boundaries between for example organisations (emphasised in Figure 1), scales, ecosystems or resource systems (Figure 1), and knowledges (e.g. see Poteete (2012); Stone-Jovicich (2015); Velempini et al. (2022)). A key point here is that nexus concerns provide productive points for the emergence of transformative processes.

Drawing on work that we are variously engaged in, and based on our observations in the social-ecological and sustainability sciences, we have observed that a wide range of case studies of emerging landscape and system level transformations exist and are being produced in both the Global North and the Global South as people try to 'work out' how to respond to the complexity of sustainability challenges, WEF nexus concerns, and just transitions in open systems (van Mierlo and Beers 2020; van Mierlo et al. 2020). However, not enough is known about the nature of these SES transformations and in particular how they occur and arise in nexus contexts, making this a productive area of enquiry and practice. As indicated above, we propose that such analyses might be productively undertaken in boundary zones, providing an interesting unit of analysis for transformative processes.

In her 2015 work, Pahl Wostl argues that 'Comparative analyses of transformative change pose considerable challenges due to the need for analysis over longer time scales and the limited
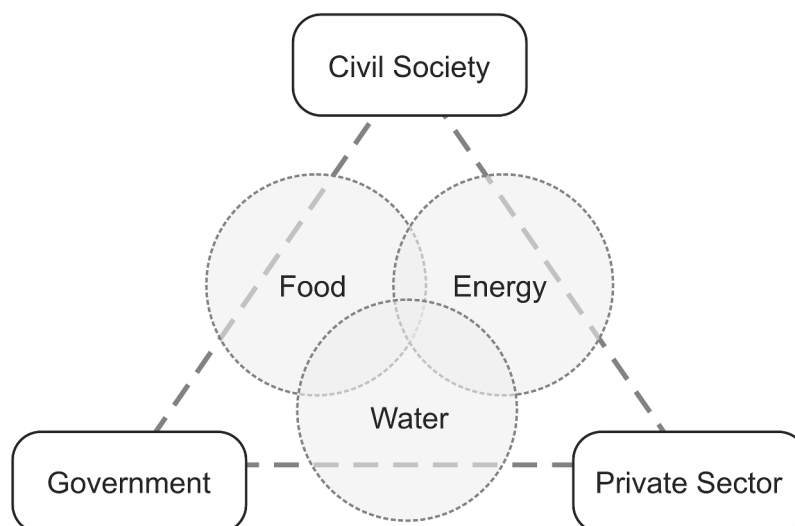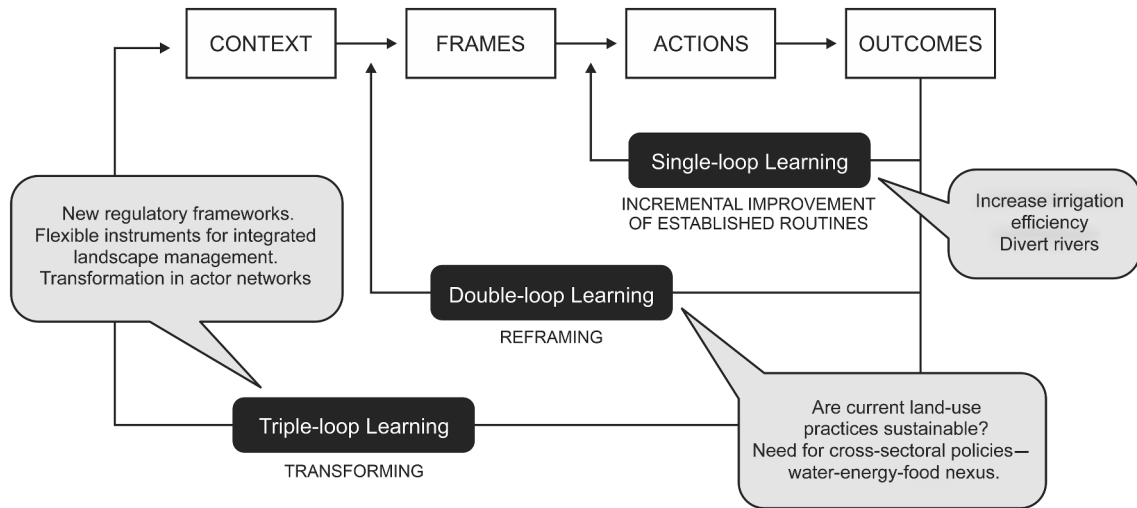

Figure 1. The water-energy-food (WEF) nexus and different societal groupings.

Figure 2. The triple-loop learning concept (Pahl-Wostl 2009) illustrated with examples of what the different learning loops might imply when dealing with water scarcity and water-Energy-Food (WEF) nexus challenges.

comparability of transformation processes' (pg. 232). We consider the latter, namely how one might think about and respond to the problem of the 'limited comparability of transformation processes', by offering a conceptual framework that can aid development of perspective on these processes in case study analysis, for possible longer term comparative perspective. For this, the conceptual framework itself will need to be elaborated through iterative applications and critical analysis and elaborations in case study contexts, as shown by the three accompanying papers in this special issue that pioneered engagement with the emerging conceptual framework (Pringle et al. 2023; Weaver et al. 2023; Pahl-Wostl et al. 2023).

Hence, the elaborations below (cf. also Figure 3) were offered invitationally to researchers to critically consider, elaborate and/or revise via their case analyses.

3. Towards a conceptual framework for analysis of interrelated transformation process dynamics

To understand when change becomes transformative, we orient our discussion around the concept of triple loop learning (Pahl-Wostl 2009, 2015), within a normative commitment to social justice and sustainability. We recognise that SES transformations
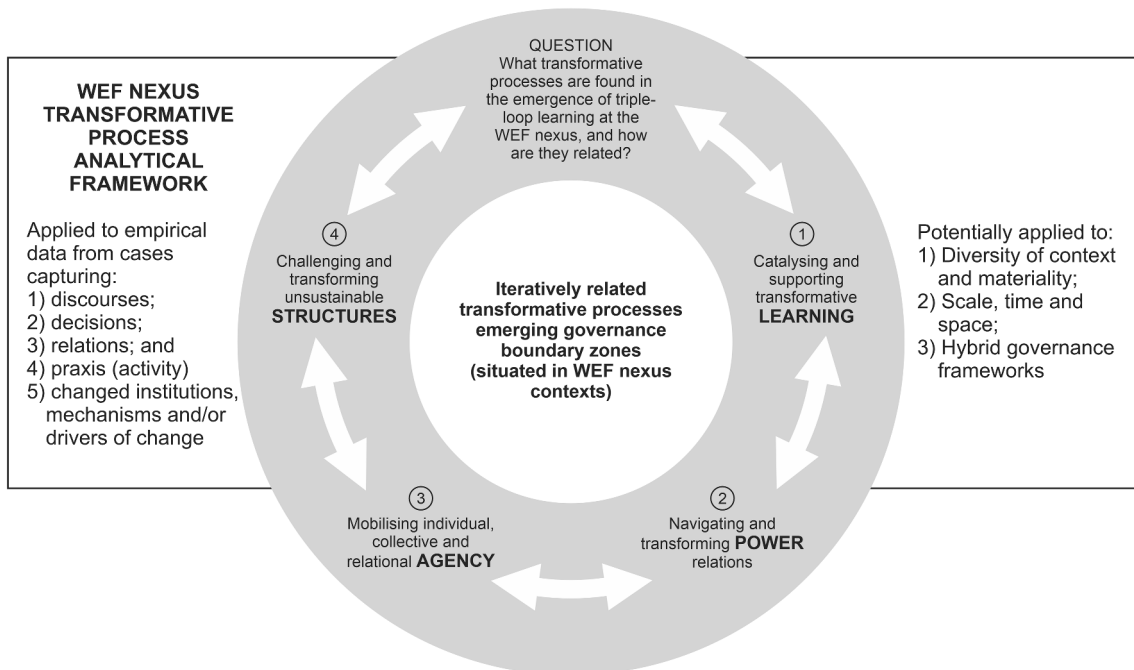
Figure 3. Conceptual framework to guide analysis of emergence of transformative processes at the Water-Energy-Food (WEF) nexus in diverse case contexts and social-ecological systems (SES).

are complex and emergent, and may be identified at local and or other scales. Within the SES, the concept of triple loop learning has offered an emergent and developing process framework that reflects more sophisticated forms of learning as well as more transformative outcomes from a collective, reflexive and structural transformation perspective. As portrayed in Figure 2, the concept and outcomes range from improvements within established paradigms (single loop learning) towards reframing challenging established beliefs (double loop learning) to structural change and new ways of knowing and meaning (triple loop learning) (Pahl-Wostl 2009). Depth deliberation is thus especially useful within the triple-loop learning trajectory. New coalitions start to emerge at in boundary zones, where contradictions arise, and where different discourses co-exist and compete for attention. The challenge is to understand when discourse leads to transformative change. Such change requires transformative agency (Sannino 2020) and the transformation of power relations, actors or agencies who experiment with innovative practices and new forms of human activity while meeting and overcoming structural constraints (Engeström 2016). New practices and activity may emerge at in boundary zones, where different (often contradictory) beliefs and practices co-exist and compete for attention, potentially leading to structural transformations (Yamazumi et al. 2006; Engeström 2016).

In developing our conceptual framework for transformative process analysis, we thus pursue development of the triple loop learning framework from a transformative process point of view. We do this by illuminating in more detail social (structure-agency-learning) and political (power relation) nuances that may lead to triple loop learning outcomes, as elaborated below. The focus on transformative process dynamics therefore informs *how* triple loop learning and its outcomes may become possible. While we do not analyse it as such in this paper in via triple loop learning cases, we propose that **the following four interrelated transformative process dynamics are necessary for understanding triple loop learning and** transformative change **in process terms**. Each of these processes is complex and requires depth analysis in its own right, but they are also iteratively and ontologically related to one another:

(1) Catalysing and supporting transformative **learning**
(2) Navigating and transforming **power** relations
(3) Mobilizing individual, collective and relational **agency**
(4) Challenging and eventually replacing unsustainable **structures**

These four interrelated, emergent processes are elaborated below (cf. also Figure 3), to illuminate possible ways of coming to understand such processes as they may advance understanding of multi-loop learning outcomes, but especially those most difficult to achieve, namely triple loop learning outcomes. Thus, the conceptual framework we are elaborating offers tools for deepening understanding of triple loop learning (i.e. transformative learning), as illuminated in the accompanying papers by Pahl Wostl et al. (2023), Weaver et al. (2023) and Pringle et al. (2023).

Theoretical perspectives that offer much in terms of dealing with the depth and complexity of the types of transformative outcomes that the WEF nexus demands informed the elaborations in the section below. The elaborations draw mainly on theoretical perspectives from the field of social sciences and where relevant, applied insights from SES research. As indicated above, the development of this conceptual framework was to provide an invitation to SES case researchers to consider and interpret how transformative processes may arise in complex nexus contexts and landscapes. It was not meant to be a definitive set of perspectives or a fixed conceptual framework to apply to each context, rather to open the landscape for such analysis.

3.1 Catalysing and supporting transformative learning

There is an emerging body of research on transformative learning in the SES, especially as this relates to social learning (e.g. Wals 2007; Lotz-Sisitka 2012; Berkes 2017; Macintyre et al. 2018; Souza et al. 2019; Rodríguez Aboytes and Baarth 2020). Inspiring some of this literature and considering the concept of transformative learning from the learning sciences, Jack Mezirow indicates that a defining condition of the human experience is that we have to make meanings of our lives (Mezirow 1997), as humans we form and reform this meaning in relation to contexts, influences and challenges. In Mezirow's framing, transformative learning theory focuses on the individual as a reflective learner (along the lines of single and double loop learning) and requires the learner to acquire information that upsets prior knowledge and triggers a changing of ideas and perceptions (Davis 2006, cf also; Rodríguez Aboytes and Baarth 2020). 'Transformative learning involves critical self-reflection of deeply held assumptions' (Davis 2006, p. 16). Mezirow explains that it requires the learner to 'interpret past experiences from a new set of expectations about the future, thus giving new meaning perspectives to those experiences' (cited in Davis 2006). This shift can be gradual or sudden, as the individual moves through the stages and in doing so

experiences a cognitive restructuring of experience and action (Stansberry and Kymes 2007).

However, Mezirow's framing does not always provide enough insight into how the individual's transformative experiences are related to social context and/or how these are connected to the transformative experiences of others in collective social transformations. This involves more than individuals each learning something new and transforming their frames of reference, hence also an interest in social learning theory in SES. Social learning theory can relate to learning from modelling (after Bandura 2006), or learning in communities of practice (after Lave and Wenger 1991; Wenger 1998) and can be explained in some depth by the post-Vygotskian learning theory of Yjrö (Engeström [1987] 2014) (Engeström and Sannino 2010; Engeström et al. 2016)., Vygotsky's psychological work (1978) was revolutionary as it demonstrates so clearly how everything that we learn or internalise, exists in the social realm first (via language and artefacts that are culturally, socio-materially and historically imbued). This socio-cultural approach inspired the social learning work of Lave and Wenger (1991, 1998) and was also developed into cultural historical activity theory by (Engeström [1987] 2014; Engeström 2016). Engeström's work helps to explain collective learning and agency as it develops around transforming human activity, including at the WEF or SES nexus (e.g. Mukute and Lotz-Sisitka 2012). (Engeström [1987] 2014; Engeström 2016) built on Vygotsky's understanding of human learning, explaining it as a process that emerges from shared activity (meaning the full scope of material and socially dimensioned human activity such as that found in the WEF nexus or wider SES contexts).

This shifts our explanation and understanding of transformative learning from a focus on individual cognition and mental model 'shifts' as per Mezirow's work (which are needed for double and triple loop learning), to a focus on how people learn from and with each other, and via their cultural histories and ecological contexts, to socio-materially transform their collective activity (especially required for triple loop learning). Transforming human activity most often involves more than one person and is a collective, boundary crossing social endeavour (Engeström [1987] 2014; Akkerman and Bakker 2011; Mukute and Lotz-Sisitka 2012; Engeström et al. 2016; Pesanayi 2019). And, it also involves deeply critical engagements with structures and the status quo, as argued by Souza et al. (2019) who point to such criticality being extended to our relationality with the living world as well as social and historical structures. They see transformative learning as a process of transforming our relations with the each other and the world, or 'a process of

transformation in co-existence' (p. 1609). It is interesting to note that authors Pringle et al. (2023); Weaver et al. (2023), Raschke et al. (2023), Manlosa et al. (2023), Pereira-Kaplan et al. (2023), Sonetti-González (2023), and Schackelton et al. (2023) all draw attention to the importance of transforming relations, especially also relations of trust, in transformative processes related to WEF and SES concerns. Sonetti-González (2023) and Pereira-Kaplan et al. (2023) argue that this is and must be a decolonial process of unlearning and solidarity building.

Given the complexity of WEF nexus concerns, transformative learning processes therefore need to be constituted in such a way as to engage a diversity of actors (Figure 1) all of whom need to engage in individual cognitive development (as per Mezirow), but who also need to engage in collective social engagement (Berkes 2017) around developing a shared concept of their WEF nexus boundary-zone activity. This process is also referred to as 'expansive learning' after Engeström ([1987] 2014, 2016). Such processes ought to facilitate the types of transformations in activity (cf. Engeström [1987] 2014, 2016), and critically engaged co-existence referred to by Souza et al. (2019), drawing on the theories of Maturana and Freire.

New concepts and relations with the world and each other are formed in and via activity, as decisions and praxis shift and develop in materially and culturally interconnected ways as people grapple together with arising contradictions and challenges in transforming their shared activity (e.g. food production in the face of social inequalities, water and energy challenges) (Mukute and Lotz-Sisitka 2012). There are also significant relational changes that take place, people form deeper or new relations with each other and the world, and are often more willing to work together in ways that also support trust building (Engeström 2009) and sustainability. At times deep cultural and social-ecological relational transformations occur (Pesanayi 2019; Manlosa et al. 2023). Such forms of relational, co-engaged expansive learning create the possibility for transformation of collective activity, especially if people can also navigate power relations, discussed next, and as also surfaced in the political education of Freire (1970), which brought transformative learning as a 'freedom seeking' process into view. In our research, we have also seen such transformative learning processes as transgressing of unsustainable norms in society as collective activity is transformed in more sustainable directions (Lotz-Sisitka et al. 2015, 2017; Wals and Peters 2017). An example comes from the work of Pesanayi (2019) which shows how farmers and college lecturers were able to transgress the norm of large-scale irrigation in support of smallholder

farmers practices where rainwater harvesting and conservation practices were applied instead, in both practice and training.

3.2 Navigating and transforming power relations

In coming to understand how people navigate power relations, we can turn to existing analyses of power in SES research which offers insight into the role of power and politics in transformative pathways to sustainability and in resilience building (e.g. Leach et al. 2018; Cinner and Barnes 2019). Fritz and Meinherz (2020) and Fritz and Binder (2020) draw on relational theories of power to develop analytical categories of *power over*, *power to*, and *power with*, to empirically explore power relations in transdisciplinary research. In articulating analytical tools for power analysis in polycentric governance contexts in the SES, Morrison et al. (2019) produce a typology of power relations that influence such governance arrangements via *power by design*, *pragmatic power* and *framing power*, which they articulate as three 'types of power'. Like others analysing power in the SES, Shackleton et al. (2022) draw on social theory to identify four substantive approaches to conceptualizing power including; (1) actor-centered power, (2) institutional power (institutions and policies), (3) structural power (political-economic structures in society), and (4) discursive power (knowledge and discourses), which we also point to below, but relationally. Their work deepens power relations analysis in conservation settings and offers useful process possibilities for power analysis at the WEF nexus. They also discuss non-human and Indigenous forms of power. From this one can see that there are many ways to approach power relations analysis in the SES.

As Fritz and Meinherz (2020) and Shackleton et al. (2022) do, we turn to the wider field of social theory for opening up possibilities for relational power analyses at the WEF nexus. Interestingly and linked to the section on transformative learning above, Fritz and Meinherz (2020) argue that our capacity to learn together is a form of 'power with'. Whilst power analysis is a huge field of research in its own right, here we briefly illuminate some useful starting points for surfacing ways of analysing power for WEF nexus transformations and triple loop learning outcomes in different contexts, drawing on social theory.

The most widely used theoretical tools for power analysis in the social sciences emerge from the work of Michel Foucault, who developed both an archaeological and genealogical method for power analysis (Ball 2012). His methodology offers ways of deconstructing present power relations and the way in which they structure internal and external governing processes. Such analysis is clearly useful for

understanding the current structuring of WEF nexus concerns, as this deconstructive approach helps to reveal the present situation as it is, and it helps to surface knowledge-power relations, and how they become legitimated and/or entrenched in discourses (e.g. policy discourses). In a WEF nexus context, we could examine the discourse of those who are responsible for governance in the WEF nexus (e.g. local government integrated development plans or SDG reporting) to establish governance discourses and how the institutions of power are operating via these discourses. For example, governments can hold power via their particular chosen discourse in reporting systems. Such analysis is helpful for tracking absences and problems in a system and is the foundation of critical theoretical analysis of power relations. As Fritz and Meinherz (2020) argue, it offers a perspective of 'power over' others.

However, one of the problems with this framework of power analysis is that it fails to take the power of the agent/agents fully into account, or to consider 'power to' as this type of power is referred to in the Fritz and Meinherz (2020) paper. While discourses (e.g. policy discourses) hold power, they are also produced, resisted, transformed or transgressed. Here it is worth noting that Foucault's concepts of subjectification and resistance have received attention after his death signalling that a more extended framework for analysing power is required that takes account of the power of agents to think and do (individually or collectively as per the above section on transformative learning), i.e. it is not only the structural aspects of discourses that control all agents; they do have powers to resist, shift and change these discourses as well as their shared activity (Hartmann 2003) as has also been shown in activity theoretical studies inspired by the work of Engeström noted above, and in the studies in this SI by Pringle et al. (2023); Manlosa et al. (2023). Thus in WEF nexus research, it may be helpful to consider theories of power that articulate how people resist, shift and change such discourses in double and triple loop learning processes.

One such perspective is provided by Bhaskar, who suggests that in analysing power we need to take full and critical account of the powers of oppression and domination (e.g. how power structures work as per Foucault's work), and we also need to take account of how agency operates to transform power structures. To analytically engage with this, he offers the tools of Power 1 and Power 2[1] (Bhaskar 2008). Power 2 refers to oppressive and/or domination forms of power and Power 1 refers to the transformative power of the agent (i.e. his or her ability to think, learn, act and do, to challenge forms of power, to resist, and to transform activity with others in a social context). Power 1 relates strongly to the concept of

'empowerment', and brings the importance of relationality to the fore in analysing transformative processes, an interest which is reflected in the work of Fritz and Meinherz (2020) as noted above. Munera-Roldan et al. (2023) for example show how peoples motives drive their commitments to SES changes showing an important connection between motive and agency in transformative processes.

Other theorists of power relations such as Galbraith (1983) also surface the dialectical relations that exist between structures and agents in transforming power relations. Galbraith particularly also refers to how collectives can challenge institutional powers (which are sedimented cultural powers). This in turn requires forms of collective agency, i.e. people being able to mobilise their agency together in response to the sedimented nature of Power 2 relations, a transformative process dynamic we discuss next. As argued by Fritz and Meinherz (2020) forms of *power over, power with,* and *power to* are not ontologically separate, although they can be analytically useful for unravelling how transformative processes emerge.

3.3 Mobilising individual, collective and relational agency

Agency has also emerged as an area of inquiry in the SES with works such as Reyers et al. (2018) drawing attention to the opportunities, agency and capacity needed for SES transformations, and Westley et al. (2013) who develop a theory of transformative agency in adaptive systems that emphasises links between strategies and phases of system change. Pearse (2021) also argues for giving attention to agency in energy transitions. In our conceptual inquiry, and building on understandings of collective transformative learning, and navigating power relations outlined above, we sought insights from social theory into potential ways of understanding agency. We highlighted individual agency, collective agency and relational agency (Cleaver 2007; Edwards 2011; Sannino 2020), and how agency is dialectically related to structure. Working out whether this agency is transformative or not, can also introduce the concept of transformative agency, and its dynamics (Sannino 2020). Transformative agency can manifest at the individual level, in a collective set up (e.g. an organisation or institution), or in a relational formation (i.e. in new network links and actions), which can also be seen as outcomes of double and triple loop learning.

Importantly for our interest in transformation processes at the WEF nexus, is the insight that the most complex form of transformative agency is agency that can dislodge structures or structural forces and this is most often collective and/or relational in form. Archer (2000) refers to 'corporate agency' to denote collective forms of agency, and she argues that corporate agency most often leads to structural transformations over time, a point elaborated by Karlsson (2020). The field of agency studies is also vast, but orienting to the field of collective agency requires that researchers consider the relation between structure and agency. Some theories of agency treat the human agent as operating outside of structures (the 'free agent'), while others treat the human agent as victim of structures (the 'determined agent'). Besides these two views on agency, there is much work that considers how agents are influenced by, and can also transform structures. There is, however, is a question of 'what comes first' – does the agent start in existing structures to change them, or are structures changed by agents in undetermined reflexive relations. The most famous and substantive of these theories in the social sciences are those of Giddens (1984) and Archer (1982, 1995, 2000, 2007).

Archer, in particular via her elaborated social realist theory of agency provides useful analytical tools to elaborate on this relation, and argues that structures precede agents' abilities to act, but do not fully determine them. Archer (1995, 2000; Fuchs and Archer 1997) elaborates how structures predate actions of agents at Time 1 (T1), but don't determine them. She therefore argues for analytically looking at what happens at Time 2 – Time 3 in terms of social interaction (i.e. learning and activity development, how power relations are engaged etc.) and then analytically looking at what emerges in terms of structural changes at Time 4. Here T1 and T4 lenses focus on structures that pre-date and follow action, but also give space for analysis of human agency, reflexivity, learning and power engagements at T2–3, and in this way she does not conflate structure and agency in an under-determined reflexive relation. Her research offers the tool of analytical dualism for observing the relationship between structure and agency, and therefore offers a fuller way of examining agency and the structural relations that may emerge in triple loop learning (cf. for example Belay 2016; Lindley and Lotz-Sisitka 2019 as applied to the SES).

Given the complex interactions between different agents and their institutions or activity systems at the nexus, relational agency is also important for WEF nexus studies. Donati and Archer (2015) argue that 'relational goods' can emerge from the contributions of individuals who bring their various skills, competences and resources into collective settings in order to produce something new together (Cf Lotz-Sisitka 2018), which helps to explain the processes involved in corporate agency formation at T2-T3 referred to above. In such a process, transformative agency emerges via dialectical engagement with contradictions and conflicts of motive in the formation of shared activity (new activity being developed by

people together), catalysed by expansive learning (Sannino 2020). Engeström and Sannino (2010; Sannino 2020) have developed useful analytical tools for examining how expansive, collective learning around transforming activity can lead to collective transformative agency. They explain that collective transformative agency can become visible via observing expansions that arise from processes that catalyse a response to conflicts of motive. Evidence of resistance, commissive talk, explicating possible solutions to problems and/or taking action offer evidence of transformative agency. Giving attention to power relations, politics and agency power as people reframe their understandings and activity is therefore also an important part of the emergence of collective transformative agency (Lotz-Sisitka et al. 2017; Jalasi 2020). Such forms of agency can also assist people in transgressing taken for granted norms that hold unsustainability practices in place in the SES (Lotz-Sisitka et al. 2017), which are critical for achieving desired transformations emerging at the WEF nexus for movement towards sustainability.

Importantly for agency analysis at the WEF nexus, is the need to think not only about agency, but also agential power, which is a form of institutionalised corporate power, the power of an organisation or individual actor to determine and implement policy in the absence of interference from others or structural inhibitions (Hobson 2000; Meissner and Ramasar 2015). According to Meissner and Ramasar (2015), agential power should not be confused with the term 'agency' as used by Giddens (1984) and Long (1990). When talking about agency, both these authors refer to it in relation to social experiences and how people cope with their daily lives, even in the face of coercion. Hobson's (2000) conceptualisation of agentive power places policies at the centre whereas agency speaks of policies more subliminally.

Importantly for WEF nexus analysis which focusses on governance processes, agential power entails an actor's governing capacity and is the frontier where governance and policy meet in a form of institutionally structured relational agency; a perspective that Pringle et al. (2023) deepen through considering phases of change in relation to dynamics of transformative processes. Linking to the section on navigating power relations above, it is for this reason that politics should not solely be conceptualised or equated to 'power'. When we describe politics in terms of power and power wielder, we can distort what scientists think of politics; where they might develop an image of politics as the sole domain of a struggle for power by power hungry self-centred individuals (Meissner and Ramasar 2015). An accepted definition of politics in Political Sciences is that politics is the authoritative allocation of resources in society (Easton 1985) and where society

is not synonymous with government (Meissner and Ramasar 2015). Where governance is synonymous with interaction, politics' claim lies with authority (Rosenau 1990) with authority not resting on the shoulders of government officials, the leaders of states or international organisations such as the United Nations only (Meissner and Ramasar 2015). From this, we can detect that agency analysis is a critically important dimension of transformation processes, but that there is need to give attention to the sophisticated understandings of this that have emerged over time in the social sciences, some of which we have touched on above.

3.4 Challenging and transforming unsustainable structures

The three inter-related transformation process dynamics are all implicated in the complex transformation of structures in social-ecological system and WEF nexus contexts. We have argued that human beings are able to learn new things together individually, collectively and relationally, and that they can mobilise their agency power to change the existing situations that oppress them, at least to some extent. However, this is difficult to do in contexts where agentive powers are contradictory, or where structures are highly oppressive or destructive as revealed in the Anthropocene/Capitalocene literatures (Moore 2015). Thus, there is a move towards developing and theorising collective forms of transformative learning, agency and power shifts (e.g. via social movement learning and agency) (Engeström et al. 2016; Sannino 2020).

In an attempt to deepen understanding of the social dynamics of transformation processes, we have focussed mainly on the social side of the social-ecological system in our four iteratively related transformative process dynamics. We can, however, recognise that there is need to give as much attention to socio-material relations in the transformative process relationship, as human beings are not the start and end point in transformative process analysis. Material environments co-define or at times define our capabilities to act, as ecological infrastructure research illuminated by three associated papers in this Special Issue elaborate (cf. Pringle et al. 2023; Weaver et al. 2023; Pahl Wostl et al. 2023; Manlosa et al. 2023).

In defining context and structures, we therefore need to take the fuller socio-materiality of life into account (e.g. the influence of drought, climate, crisis, landscapes etc. as elaborated in the accompanying papers by Pringle et al. 2023; Weaver et al. 2023; and Pahl Wostl et al. 2023). We have learned from hydro-social work but also in everyday engagement in the WEF nexus context, that the environment in general (e.g. poor water quality creating skin rashes,

the constant stench from overflowing sewers or a regular burning dumps creating toxic fumes), but also with its individual elements (e.g. a tree for the elders to meet) influences people's relations, their self-worth and how they think about and experience the world, thus also their learning and agency. While we are conscious of the need for this wider framing in transdisciplinary research, we are also aware that not all concepts can be included at one time. Hence we have explicitly chosen to focus more into the social dynamics in this paper.

In the social realm, we can give attention to social structures that need to be shifted (Barnes et al. 2017) and this requires critical depth analysis as well as scalar analysis at multiple levels because collective learning and transformative agency are required at multiple levels (cf. for examples Weaver et al. 2023; Pahl Wostl et al. 2023; Manlosa et al. 2023). We see consciousness of this in theories such as transition theory (Geels 2002) that articulates shifts at three levels namely niche level, regime level and landscape level (cf. Weaver et al. 2023 for scale analysis). Bhaskar (2016) describes structural change in terms of underlying mechanisms that intersect to produce structural changes, ultimately necessary at all scalar levels for triple loop learning outcomes. For example Pesanayi (2019) in his study was able to explain that it was the underlying mechanisms of apartheid power relations and racist prejudice (social structural powers) that exacerbated supremacist tendencies amongst predominantly white people who held power. These intersected with associated capitalist interests in controlling land and resource flows (from colonial extractivist and supremacist ideologies) and exacerbated effects of poor quality Bantu Education, capability deprivation, and a lack of land and resourcing for black small holder farmers. This produced contradictions in the WEF nexus context in his study. These social structural dynamics were also shaped and exacerbated by droughts, and dryland conditions related to climate change and ecological dynamics (Pesanayi 2019).

When social structural dynamics (e.g. power relations, capitalist tendencies etc.) intersect with ecological dynamics (e.g. recurring drought conditions), the generative complexes referred to by Bhaskar (2008, 2016) become social-ecological in nature. Engaging social structural dynamics is difficult due to the way in which structures sediment into institutional cultures that govern and control agentive power. Hence the need for collective transformative learning, collective agency formation, navigation of power relations, and transformation of human activity. In their paper, Manlosa et al. (2023) argue for relationality between community level institutions with power to influence and create hybrid governance arrangements creating new institutional formations or boundary crossings between state and community institutions as one way of dislodging the lock in power of institutions. All authors contributing to this SI in some way or other recognise that it is extremely tough to dislodge and transform sedimented institutional cultures, structures and forms of agentive power, hence also their interest in transformative process research.

Engeström (2016), in his transformative expansive learning theory, notes that it is deep seated structures in society (as these interface with the material world) that produce contradictions and tensions such as those found at the WEF nexus. He proposes that it is such contradictions that produce the possibility for collective learning, and the learning of 'what is not yet there', as envisaged in double and triple loop learning, hence we can see how the above transformative process dynamics are iteratively related (cf. also Weaver et al. 2023; Pringle et al. 2023; Pahl Wostle et al. 2023; Haider and Cleaver, 2023).

4. Conclusion: conceptual framework guiding case analysis in diverse SES contexts

As indicated above, our interest was to 'tease out' dimensions of interrelated transformative process dynamics in relation to ambitions in WEF nexus sciences to more deeply and fully engage such transformative processes, especially where these arise in boundary zones in ways that can potentially result in triple loop learning outcomes. This, we reasoned, could help develop a conceptual framework for beginning such an inquiry. We are cognisant that a paper of this scope cannot cover the full history of learning theory, or all that is known about power analysis, or structure and agency. We have therefore surfaced some perspectives that appear to be useful for WEF nexus concerns in boundary zones, with an invitation to researchers to elaborate, enrich, and critically engage these starting points in their case analyses, via which we may be able to generate more systematic insights into the interrelated dynamics of transformative processes, or at least appreciate the diverse ways in which they arise and play out in the longer term as more case analyses emerge.

To aid this process, from an empirical data perspective, we propose that evidence for the first three of these transformative processes dynamics and how they emerge is found in nexus-related **discourses, decisions, relations and praxis**. For analysis of changes in structures, we propose that these may be evidenced in **changed institutions, mechanisms and drivers OR drivers of change** (e.g. policies, socio-technical innovations etc.) (cf. papers by Pringle et al.

2023; Weaver et al. 2023; Pahl Wostl et al. 2023; Manlosa et al. (2023), for further insight).

We therefore, in our deliberations, settled on Figure 3 as a broad conceptual framework for guiding further case analyses (Note: we unpack the components of the diagram in further detail below). As readers of the Special Issue will see in the accompanying papers, the conceptual framework offered useful lenses and 'ways in' to analysis of transformative process dynamics in at least three of South Africa's catchments: the uMngeni (Pringle et al. 2023), the Tsitsa (Weaver et al. 2023) and the Berg-Breede (Pahl Wostl et al. 2023). In all cases, researchers have elaborated this initial conceptual framework via contextual engagements, as well as elaborations with other models and approaches useful in the SES such as resilience modelling (Pringle et al. 2023), scalar analysis (Weaver et al. 2023) and considering the way in which crisis produces a catalyst for transformative processes enriching understandings of triple loop learning (Pahl Wostl et al. 2023). In all cases, researchers elaborated on the relational process and starting views offered above, captured in brief in Figure 3. We argue that this may well be the most useful way of 'putting the framework to work' in SES research.

Figure 3 offers a 'matrixed' perspective for researching transformative process dynamics, with the four transformative processes at the centre of analysis. Transformative processes can be captured via discourses, decisions, relations, praxis and/or changed institutions, mechanisms or drivers of change, as shown in accompanying papers in this special issue. Figure 3 offers a way of framing analysis starting points in and potentially thereafter, across cases.

In its application, Pahl Wostl et al. (2023); Pringle et al. (2023), Weaver et al. (2023) show that analytical differentiation of transformative processes does not replace the iterative, relational and ontologically embedded nature of these transformative processes. Application of the Figure 3 framework offers diverse perspectives on how these transformation process dynamics are iteratively related, but all show them to be present and the framework to be helpful in understanding transformation process dynamics in SES contexts (cf. Pahl Wostl et al. 2023; Pringle et al. 2023; Weaver et al. 2023). In Figure 3 we therefore emphasise how the four processes are situated and related to each other.

The accompanying papers illuminate how contexts and scales also shape the emergence of transformative process dynamics, and possibilities for their expansion and engagement empirically and analytically (e.g. Pringle et al. 2023; Weaver et al. 2023).

We noted above that the framework is also potentially useful for deepening understanding of triple loop learning, which is a more complex, structurally challenging process of learning, that extends across scales, time and space in order to gain deep deliberation on, and potentially also transformation of unsustainable structures (Pahl-Wostl 2009). Thus, as also reflected in Figure 3, it is also helpful to consider the following in our descriptions, an insight that also comes to the fore in various of the papers in this Special Issue (e.g. Pahl Wostl et al. 2023; Pringle et al. 2023; Weaver et al. 2023):

- **Context**, which includes: histories, ecologies, social-ecological relations, political economy dynamics, cultures, norms, governance modes (e.g. networking – interactive, hierarchical, market oriented) and governance formations (as these may either be embedded and structurally constraining, or in transformation i.e. new hybrid forms of governance – see below) - here it would be important to keep focussed on the WEF nexus.
- **Scale, time and space**: Scale refers to the dimensions (e.g. time or space) used to study a phenomenon (cf. Cash et al. 2006). Time refers to temporal dimensions, with temporary scales being seasonal, annual, and multi-year (shorter and longer term windows). Space refers to place, as well as spatial scales such as local, provincial and national; including mismatches between temporal and spatial changes, and how time-space dynamics relate (see also Pahl Wostl et al. 2023; Weaver et al. 2023)
- **Hybrid governance formations**: Such formations connect civil society, the private sector and/or government. The transformation of actor networks, the linking across scales (e.g. upscaling of innovative approaches), the stabilization of informal agreements is supported by hybrid governance formations that connect the logics of informal networks, market-based settings and hierarchical governmental intervention (Pahl Wostl 2015, 2019). We propose that case analysis identifies such hybrid formations and the potential role they play in transformative change. *Some* examples of such hybrid formations include *inter-alia*, co-operative payment schemes, platforms connecting communities, business and government, relational hubs, learning networks and more. We see these as critically important emerging platforms for transformative processes (cf. also Manlosa et al. 2023).

Regarding triple loop learning, one would expect a dominance of hierarchical governance for single loop learning, a focus on established practice and expert knowledge, actors remaining largely within

their established networks. Higher levels of learning would involve formation of new actor coalitions and polycentric networks, integration of different kinds of knowledge, challenging of established and experimentation with new practices, formation of hybrid governance arrangements (Pahl-Wostl 2009), hence we emphasise these, perhaps as a starting 'unit' or 'point' of analysis for transformative processes research (i.e. if one finds them present somewhere they may be a good indicator of transformative processes that can be further a) analysed, and b) advanced, as shown in the paper by Pahl Wostl (2023) and also Pringle et al. (2023). Pringle et al. (2023) put forward an analysis of the uMngeni Ecological Infrastructure Programme (UIEP) transformation processes which is a good example of how a hybrid governance arrangement can be used as a unit of analysis for transformative processes.

And finally, as can be seen from the above, and carrying forward works that draw on social theory in the SES, there are useful perspectives from the social and learning sciences that can be applied to analysis of transformative processes at the WEF nexus which arise from years of theory development and research, and some recent applications in the SES, including the papers in this SI.

That which was overviewed above, can be viewed as largely introductory given the enormous complexity of the interrelated transformative process dynamics outlined above. The four transformation process dynamics highlighted can also be extended and enriched with further perspectives and theories from the wider social science and SES landscape. For example, de Sousa Santos (2014) argues for ecologies of knowledge and broadening the scope of analysis of structures to include analysis of coloniality, patriarchy and capitalism as mechanisms that hold inequality and exclusion in place, including in many transformatively oriented processes. There is also related work on values and the role of values and motives in shaping transformations and associated power relations (e.g. Lotz-Sisitka et al. 2017; Fritz and Binder 2020). These would shape and influence the above mentioned transformative process dynamics directly in different ways, as also discussed in Munera-Roldan (2023). Therefore, in case analysis (and potentially also longer term cross case analysis work), researchers could also consider these additional dynamics, in addition to the four interrelated processes outlined above. We decided to focus on these initial four as other transformation dynamics tend to relate to these (e.g. ecologies of knowledge are necessary for transformative learning, values shape power relations and our agentive choices or how structures are formed etc.).

As can be seen from the three accompanying papers in this Special Issue (Pahl Wostl et al. 2023; Pringle et al. 2023; Weaver et al. 2023), and some of the other related papers (e.g. Manlosa et al. 2023; Weaver et al. 2023) it is through actual case analysis in empirical social-ecological system landscape contexts that the significance of these and other transformative process dynamics will come to the fore. The accompanying studies also show that, as indicated above, and in Figure 3, the four transformative process elements outlined in this paper are analytically distinct and related, but not ontologically distinct, in reality they are deeply intertwined. This requires researchers to apply the lenses and perspectives outlined above situationally and critically, and with due regard for the 'messy realities' of social-ecological systems and social life, especially in complex and emergent contexts such as the WEF nexus (cf. Clifford-Holmes et al. 2016, 2018). This does not mean that researchers are unable to undertake such analysis, it simply means that they need to take adequate account of the difference between analysis and the realities that are being analysed.

Additionally, analysis on its own is often inadequate in transformatively oriented research as it helps one to describe the situation, yet we often need means to also contribute to changes via our research, i.e. to use our analyses in the co-engaged unfoldings of ongoing transformative processes. Thus, there is also transdisciplinary, generative potential in undertaking such analysis, i.e. with a view to co-reflecting on these dynamics in change processes in open-ended ways with others in WEF nexus contexts. Researchers are thus cautioned against turning the above transformative process dynamics conceptual framework into an instrumental framework to be applied to real life situations. In addition to analysis and description, we encourage consideration of the co-engaging, generative potential of such work in ongoing transformative processes of change that are emergent at the WEF nexus and in SES settings more broadly.

Note

1. **Power$_2$** relations = 'expressed in structures of domination, exploitation, subjugation and control, which I will thematize as generalized master – slave (–type) relations' ... **Power$_1$** = 'the transformative capacity analytic to the concept of agency' (Bhaskar 2008, pg. 55)

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