Bottom-up sustainability transformations:

Supporting local actors fostering change towards sustainability

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List of papers

Paper 1:

Scaling the impact of sustainability initiatives: a typology of amplification processes

David P. M. Lam, Berta Martín-López, Arnim Wiek, Elena M. Bennett, Niki Frantzeskaki, Andra I. Horcea-Milcu, Daniel J. Lang (2020)

Urban Transformations

Paper 2:

Indigenous and local knowledge in sustainability transformations research: a literature review

David P. M. Lam, Elvira Hinz, Daniel J. Lang, Maria Tengö, Henrik von Wehrden, Berta Martín-López (2020)

Ecology and Society

Paper 3:

Three principles for co-designing sustainability intervention strategies: Experiences from Southern Transylvania

David P. M. Lam, Andra I. Horcea-Milcu, Joern Fischer, Daniel Peukert, Daniel J. Lang (2019)

Ambio

Paper 4:

A leverage points perspective on social networks to understand sustainability transformations: evidence from Southern Transylvania

David P. M. Lam, Berta Martín-López, Andra I. Horcea-Milcu, Daniel J. Lang (2020)

Sustainability Science

Additional publications

Values in transformational sustainability science: four perspectives for change

Andra I. Horcea-Milcu, David J. Abson, Cristina I. Apetrei, Ioana A. Duse, Rebecca Freeth, Maraja Riechers, **David P. M. Lam**, Christian Dorninger, and Daniel J. Lang (2019)

Sustainability Science

Balance Brings Beauty: Strategies for a Sustainable Southern Transylvania

Joern Fischer, Andra-Ioana Horcea-Milcu, Daniel J. Lang, Lennart Thale-Bombien, David J. Abson, Cristina I. Apetrei, Elizabeth Clarke, Pim Derwort, Christian Dorninger, Ioana A. Duse, Rebecca Freeth, Nicolas W. Jager, Kathleen Klaniecki, **David P. M. Lam**, Julia Leventon, Jens Newig, Daniela Peukert, Maraja Riechers, Tamara Schaal (2019)

Pensoft

Research pathways to foster transformation: linking sustainability science and social-ecological systems research

Andra I. Horcea-Milcu, Berta Martín-López, **David P. M. Lam**, Daniel J. Lang (2020)

Ecology and Society

Leverage points for sustainability transformation: a review on interventions in food and energy systems

Christian Dorninger, David J. Abson, Cristina I. Apetrei, Pim Derwort, Christopher D. Ives, Kathleen Klaniecki, **David P. M. Lam**, Maria Langsenlehner, Maraja Riechers, Nathalie Spittler, Henrik von Wehrden (2020)

Ecological Economics

From niche to mainstream: the dilemmas of scaling up sustainable alternatives

Karoline Augenstein, Boris Bachmann, Markus Egermann, Verena Hermelingmeier, Annaliesa Hilger, Melanie Jaeger-Erben, Alexandra Kessler, **David P. M. Lam**, Alexandra Palzkill, Paul Suski, Timo von Wirth (2020)

GAIA

Indigenous and local knowledge in environmental management for human-nature connectedness: a leverage points perspective

Aracely Burgos-Ayala, Amanda Jiménez-Aceituno, Aura Marcela Torres-Torres, Daniel Rozas-Vásquez, **David P. M. Lam** (2020)

Ecosystems and People

List of abbreviations

ILK	Indigenous and local knowledge
IPLC	Indigenous peoples and local communities
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
NGO	Non-governmental organisation
P	Paper (e.g. P1 stands for Paper 1)
PECS	Programme on Ecosystem Change and Society
PhD	Doctor of Philosophy
SRQ	Sub-research question

Summary

Despite growing research on sustainability transformations, our understanding of how transformative transdisciplinary research can support local actors who foster change towards sustainability is still somewhat limited. To contribute to this research question, I conducted research in a transdisciplinary case study in Southern Transylvania, where non-governmental organizations (NGO) drive sustainability initiatives to foster desired changes (e.g., supporting small-scale farmers or conserving natural and cultural heritage). Interactions with these local actors and reflections on my research question shaped the research of this dissertation, which I present in four papers.

In paper 1, I[1] conducted a literature review on amplification processes that describe actions, which local actors can apply to increase the impact of their sustainability initiatives. This is of interest in sustainability transformations research and practice because the impact of initiatives challenges incumbent regimes and consequently prepares transformations. I developed an integrated typology of amplification processes, which introduces new and innovative ways to conceptualize and study how initiatives increase their impact. The typology integrates theoretical insights on amplification processes from different frameworks that draw on diverse theories, such as resilience theory on transformations of social-ecological systems or sustainability transitions theory on transitions of socio-technical systems. This typology combines contemporary conceptualizations of amplification processes, informs transdisciplinary researchers working with local actors on increasing impact from initiatives, and has inspired debate and empirical research which contributes to theory development concerning amplifying impact of initiatives in diverse contexts.

In paper 2, I conducted a literature review on the application of indigenous and local knowledge (ILK) in sustainability transformations research to understand whether this research engages with the conceptualization of transformations from local actors. The results show that ILK is generally applied to confirm and complement scientific knowledge in contexts of environmental, climate, social-ecological, and species change. Only four out of 81 papers (5%) applied ILK to conduct research on transformations. In addition, I identified four research clusters that apply ILK in contexts of transformation, transition, or change in Arctic, terrestrial, coastal, and grass and rangelands environments. Consequently, the review shows that only few empirical studies apply ILK to understand transformations. This indicates that sustainability transformations research lacks to include knowledge from local actors to conceptualize transformations, such as in the case of ILK. This has the potential to question scientific conceptualizations of transformations for theory development (e.g., resilience theory on

[1] For the purpose of my dissertation I use the I-perspective. However, where I use “I” or “my” in relation to my four papers (P1-P4) I deeply acknowledge the work and contributions from my co-authors.

transformations of social-ecological systems) and to enrich transformative transdisciplinary research.

In paper 3, I derived principles that provide guidance for how to integrate sustainability initiatives from local actors in transformative transdisciplinary research. Based on my transdisciplinary research with the NGOs in Southern Transylvania and by using systems and futures thinking as an approach for analysis, I derived three principles that provide guidance for the co-design of sustainability intervention strategies that build on, strengthen, and complement existing initiatives from local actors. These principles contribute to transformative transdisciplinary research by highlighting and operationalizing the need to integrate initiatives from local actors to foster bottom-up, place-based transformations.

In paper 4, I explored empirically how to identify relevant local actors for collaborations that seek to intervene in specific characteristics of a system (e.g., parameters or design of a system). I applied a leverage points' perspective to analyse the social networks of the NGOs in Southern Transylvania that amplify the impact of their initiatives. My results suggest that there are two types of local actors for potential collaborations: local actors who have the ability to intervene in both shallow (i.e., parameters and feedbacks of a system) and deep (i.e., design and intent of a system) system characteristics, and local actors who have the ability to intervene only in specific system characteristics. In addition, my results indicate that the application of specific amplification processes is associated with the positions of local actors in their networks. Thus, paper 4 provides a novel methodological approach and first empirical insights for identifying potential relevant partners for specific system interventions. This supports in transformative transdisciplinary research the categorization of relations and networks of local actors according to the system characteristics that they address, and the selection of relevant partners for specific system interventions.

This dissertation as a whole contributes insights to three recommendations of how transformative transdisciplinary research can support local actors fostering change towards sustainability: First, by conducting research that studies and supports local actors who increase the impact of their sustainability initiatives via amplification processes (Paper 1 and 4); Second, by engaging specifically with the initiatives, networks, and knowledge from local actors, who foster bottom-up, place-based transformations (Paper 1-4); Third, by identifying and collaborating with local actors that are relevant for strategic systems interventions that build on, strengthen, and complement existing initiatives (Paper 3-4). These three recommendations pave the way for an enhanced transformative transdisciplinary research that can potentially support local actors who with their initiatives, networks, and knowledge foster bottom-up, place-based sustainability transformations.

Zusammenfassung

In den vergangenen zehn Jahren hat die wissenschaftliche Auseinandersetzung mit Nachhaltigkeitstransformationen stetig zugenommen. Dennoch fehlt es weiterhin an einem grundlegenden Verständnis, wie eine transformative transdisziplinäre Forschung lokale Nachhaltigkeitsakteure[2] bei ihren Aktivitäten und in ihrer Wirkung unterstützen kann. Um in diesem Thema zu einem verbesserten Verständnis beizutragen, habe ich in einer transdisziplinären Fallstudie in Südtranssilvanien zu der Frage „Wie kann transformative transdisziplinäre Forschung lokale Nachhaltigkeitsakteure unterstützen?“ geforscht. In dieser Fallstudie habe ich mit Nichtregierungsorganisationen (NGO) zusammengearbeitet, die mit ihren Initiativen nachhaltige Veränderungen in Südtranssilvanien fördern, beispielsweise durch Initiativen zur Unterstützung von kleinbäuerlicher Landwirtschaft oder zum Schutz von natürlichem und kulturellem Erbe. Durch die Zusammenarbeit mit den NGOs und meiner Forschungsfrage hat sich die Forschung meiner Dissertation in einem transdisziplinären Prozess geformt. Die Ergebnisse meiner Forschung habe ich in vier wissenschaftlichen Artikeln publiziert, welche ich im Folgenden vorstelle.

In meinem ersten Artikel habe ich[3] eine Literaturanalyse zu Verstärkungsprozessen (*amplification processes*) durchgeführt. Verstärkungsprozesse beschreiben Handlungen von lokalen Akteuren, die die Wirkung ihrer Nachhaltigkeitsinitiativen verstärken können. Dies ist interessant für die Forschung und Praxis zu Nachhaltigkeitstransformationen, weil die Wirkung von Initiativen vorherrschende Regime beeinflusst und folglich Transformationen vorbereiten kann. Basierend auf meiner Literaturanalyse habe ich eine integrierte Typologie von Verstärkungsprozessen entwickelt, welche neue und innovative Wege ermöglicht, die Wirkungsverstärkung von Nachhaltigkeitsinitiativen zu konzeptualisieren und zu beforschen. Die Typologie integriert theoretische Erkenntnisse zu Verstärkungsprozessen aus unterschiedlichen Bereichen der Transformationsforschung, beispielsweise aus dem Forschungsbereich zu Resilienz und Transformation von sozial-ökologischen Systemen (*resilience thinking*) oder aus dem Forschungsbereich zu nachhaltiger Transition von sozio-technischen Systemen (*sustainability transitions research*). Dadurch integriert meine Typologie aktuelle Erkenntnisse zu Verstärkungsprozessen aus unterschiedlichen Bereichen der Transformationsforschung. Des Weiteren kann die Typologie insbesondere transdisziplinär Forschende bei ihrer Arbeit mit lokalen Akteuren zur Wirkungserhöhung von Nachhaltigkeitsinitiativen konzeptionell unterstützen. Außerdem kann die Typologie die

[2] In der deutschen Zusammenfassung wird aus Gründen der besseren Lesbarkeit ausschließlich die männliche Form verwendet. Sie bezieht sich auf Personen aller Geschlechter.

[3] Zum Zwecke meiner Dissertation habe ich die Ich-Perspektive gewählt. An Stellen, in denen ich „ich” oder „meine” in Zusammenhang mit meinen vier Artikeln (P1-P4) verwende, verweise ich hiermit auch auf die Arbeit und Beiträge meiner Ko-Autorinnen und Ko-Autoren.

Debatte und empirische Forschung zu Verstärkungsprozessen inspirieren, was zur weiteren Theorieentwicklung bezüglich der Wirkungsverstärkung von Nachhaltigkeitsinitiativen in diversen Kontexten beitragen kann.

In meinem zweiten Artikel habe ich eine Literaturanalyse zur Anwendung von indigenem und lokalem Wissen (*indigenous and local knowledge*) von lokalen Akteuren in der Transformationsforschung durchgeführt. Ziel dieser Literaturanalyse war es zu verstehen, ob sich diese Forschung mit den Transformationsverständnissen von lokalen Akteuren auseinandersetzt. Meine Ergebnisse zeigen, dass indigenes und lokales Wissen in der Transformationsforschung vorwiegend angewendet wird, um wissenschaftliches Wissen im Zusammenhang mit Umweltveränderungen, Klimaveränderungen, Artenveränderungen und sozial-ökologischen Veränderungen zu bestätigen und zu vervollständigen. Nur vier von 81 Artikeln (5%) wendeten indigenes und lokales Wissen speziell zur Beforschung von Transformationen an. Des Weiteren habe ich vier Forschungscluster identifiziert, welche zeigen, dass mit indigenem und lokalem Wissen zu Transformationen, Transitionen und Veränderungen in arktischen Gebieten, terrestrischen Gebieten, Küstengebieten und Graslandgebieten geforscht wird. Insgesamt zeigt meine Literaturanalyse, dass nur wenige empirische Studien indigenes und lokales Wissen anwenden, um Transformationen zu beforschen oder zu verstehen. Dies weist daraufhin, dass die Forschung zu Nachhaltigkeitstransformationen unzureichend Wissen von lokalen Akteuren einbindet, um Transformationen zu konzeptualisieren. Die Einbindung von Transformationsverständnissen von lokalen Akteuren hat das Potential die wissenschaftlichen Transformationsverständnisse in Frage zu stellen und somit zu einer weiteren Theorieentwicklung beizutragen (z.B. im Forschungsbereich zur Resilienz und Transformation von sozial-ökologischen Systemen). Des Weiteren kann die Einbindung von Transformationsverständnissen von lokalen Akteuren die transformative transdisziplinäre Forschung bereichern.

In meinem dritten Artikel habe ich aus meiner transdisziplinären Forschung mit NGOs in Südtranssilvanien Prinzipien abgeleitet, die Anleitung geben, wie in der transformativen transdisziplinären Forschung Nachhaltigkeitsinitiativen von lokalen Akteuren integriert werden können. Dazu habe ich System- und Zukunftstheorien als Analyseansätze verwendet und drei Prinzipien entwickelt, welche speziell Anleitung für das Ko-Design von Nachhaltigkeitsinterventionsstrategien geben, die insbesondere auf existierenden Initiativen von lokalen Akteuren aufbauen, sie stärken und komplementieren. Diese Prinzipien heben die Notwendigkeit hervor Initiativen von lokalen Akteuren zur Förderung von bottom-up, ortsbezogenen Transformation zu integrieren. Des Weiteren beschreiben sie, wie dies in der transformativen transdisziplinären Forschung operationalisiert werden kann.

In meinem vierten Artikel habe ich empirisch exploriert, wie man relevante lokale Akteure für Kollaborationen identifizieren kann, um in spezifischen Systemcharakteristika (z.B. die

Parameter oder das Design eines Systems) zu intervenieren. Ich habe die *Leverage Points*-Perspektive angewendet, um soziale Netzwerke von den NGOs in Südtranssilvanien zu analysieren, welche die Wirkung ihrer Initiativen verstärken. Meine Ergebnisse zeigen, dass es zwei Typen von lokalen Akteuren für potentielle Kollaborationen gibt: (1) lokale Akteure, die die Fähigkeit haben in Systemcharakteristika mit wenig (d.h. *shallow leverage points*; z.B. die Parameter und Feedbacks eines Systems) und hoher (d.h. *deep leverage points*; z.B. das Design und die Intention eines Systems) Hebelwirkung zu intervenieren und (2) lokale Akteure, die die Fähigkeit haben nur in spezifische Systemcharakteristika zu intervenieren. Des Weiteren zeigen meine Ergebnisse, dass die Anwendung von ausgewählten Verstärkungsprozessen einen Zusammenhang mit den Positionen von lokalen Akteuren in ihren Netzwerken hat. Daher bietet mein vierter Artikel einen neuartigen methodologischen Ansatz und erste empirische Erkenntnisse zur Identifizierung potentiell relevanter Partner für spezifische Systeminterventionen. Dies unterstützt in transformativer transdisziplinärer Forschung die Auswahl von relevanten Partnern für spezifische Systeminterventionen und die Kategorisierung von Beziehungen und Netzwerken von lokalen Akteuren gemäß den Systemcharakteristika, welche sie adressieren.

Insgesamt trägt die vorliegende Dissertation Erkenntnisse für drei Empfehlungen bei wie transformative transdisziplinäre Forschung lokale Akteure, die Nachhaltigkeitsveränderungen fördern, unterstützen kann. Erstens, indem man Forschung betreibt, die gemeinsam mit lokalen Akteuren forscht, welche die Wirkung ihrer Nachhaltigkeitsinitiativen mit Verstärkungsprozessen erhöhen und sie dabei unterstützt (Artikel 1 und 4). Zweitens, indem man sich insbesondere mit den Initiativen, Netzwerken und dem Wissen von lokalen Akteuren beschäftigt, die bottom-up, ortsbezogene Nachhaltigkeitstransformationen fördern (Artikel 1-4). Drittens, indem man lokale Akteure identifiziert und mit lokalen Akteuren kollaboriert, die relevant sind für strategische Systeminterventionen. Diese Systeminterventionen sollten auf existierenden Initiativen aufbauen, sie stärken und komplementieren (Artikel 3-4). Diese drei Empfehlungen ebnen den Weg für eine verbesserte transformative transdisziplinäre Forschung, die potentiell lokale Akteure unterstützt, die mit ihren Initiativen, Netzwerken und Wissen bottom-up, ortsbezogene Nachhaltigkeitstransformationen fördern.

1. Introduction

1.1. Sustainability transformations research

The urgency of social injustice, poverty, biodiversity loss, and climate change calls for ambitious sustainability transformations (Steffen et al. 2015, Scoones et al. 2020). In the sustainability literature, sustainability transformations are differently conceptualised (Walker et al. 2004, Olsson et al. 2014, Feola 2015, Patterson et al. 2017, Loorbach et al. 2017, Horcea-Milcu et al. 2020, Scoones et al. 2020). However, they are generally defined as "*fundamental changes in structural, functional, relational, and cognitive aspects of socio-technical-ecological systems that lead to new patterns of interactions and outcomes*" (Patterson et al. 2017 p. 2). Examples for systems of interest are mobility, energy, fishery, agriculture, forestry, or water systems (Loorbach et al. 2017).

Sustainability transformations research examines transformations through three approaches: structural, systemic, and enabling (Scoones et al. 2020). Structural approaches investigate changes in underlying foundations of politics, economy, and society. They highlight the need to change the ideological underpinnings of the current social system (Scoones et al. 2020). Social movements play a crucial role in structural approaches, because they, for instance, demand alternative economic models (e.g., zero growth (Jackson 2009), or de-growth (Martínez-Alier et al. 2010)) in moments of crises and tensions when the relationships between economies and societies shift (Scoones et al. 2020). Structural approaches often provide detailed analysis of past transformations but are limited in their appreciation of environmental aspects and future orientation (Scoones et al. 2020).

In contrast, systemic approaches are grounded in systems thinking from the 1980s and aim to identify and understand particular parts of systems that need to change (e.g., system elements) (Meadows et al. 1972, Scoones et al. 2020). Change is typically induced through interventions (e.g., policy), while recognizing the inherent complexity, uncertainty, and non-linearity of responses of system interactions (Meadows 1989, Scoones et al. 2020). Systemic approaches focus on understanding system dynamics and states through the interdependencies of social, ecological, institutional, and technological elements (Scoones et al. 2020). Two prominent perspectives that emerged from this approach are transformations of social-ecological systems (Berkes et al. 2003, Olsson et al. 2014) and socio-technical systems through strategic interventions (Geels 2002, Grin et al. 2010).
Due to the focus on systems as a whole, systemic approaches have tended to diminish the role of individual agency and the complexity of politics, power issues, and human-environment

dynamics (Meadowcroft 2011, Brown 2014, Scoones et al. 2020). They are also mainly based on experiences from researchers from the Global North and have often "*implicitly presumed the embrace of Western ideals of deliberative democracy, pre-existing capacities for collective action, and general support for change that will result in enhanced equity, environmental integrity and improved public welfare*" (Scoones et al. 2020 p. 3). Needless to say, there is a substantial lack of research examining whether these ideals are applicable to other parts of the world, such as the Global South.

Recent sustainability literature that applies systems thinking has drawn on the notion of leverage points (Abson et al. 2017, Fischer and Riechers 2019, Dorninger et al. 2020). Leverage points are places to intervene in systems where a relatively small intervention in one part of the system can lead to relatively big changes in the whole system (Meadows 1999). The notion of leverage points stems from the seminal work on complex systems from Donella Meadows (Meadows et al. 1972). Leverage points can be separated into "shallow" leverage points at which interventions are rather easy, but have limited potential to foster transformative change, and "deep" leverage points at which interventions are rather difficult, but have greater potential to foster transformative change (Meadows 1999). Leverage points can be categorised by the system characteristics that they target: parameters, feedbacks, design, and intent of a system (Abson et al. 2017). The leverage points perspective is a hitherto under-recognized heuristic and practical tool for studying how to bring about transformative change (Fischer and Riechers 2019).

Enabling approaches draw insights from structural and systemic approaches but highlight the individual agency of actors at the local level and the uncertainties in navigating directions of transformative change (O'Brien 2015, Scoones et al. 2020). Enabling approaches focus less on desired system configurations (i.e., structural approaches) and management of system dynamics (i.e., systems approaches) (Scoones et al. 2020). Instead, they emphasize "*creating the social attributes — capacities — that empower individuals and communities to take action on their own behalf*" (Scoones et al. 2020 p. 3). Enabling approaches often highlight especially the most excluded interests. They are based on optimism and activism while focusing on processes and capacities instead of mere outcomes (Pereira et al. 2018c). Transformative change is seen as fostered collectively through smaller individual actions in networks that over time transform systems from below in directions which maybe unexpected, but which reflect the values and visions of involved local actors (Stirling 2015, Horcea-Milcu et al. 2019, Scoones et al. 2020). By putting less focus on "*grand theoretical frameworks or pre-decided categories of phenomena, enabling approaches focus on the values, agency, relations and processes that underlie both structures and systems*" (Scoones et al. 2020 p. 4).

Researchers working with this approach specifically work on emancipatory, bottom-up transformative change with local actors by engaging with their networks, knowledge and sustainability initiatives while often applying a transformative transdisciplinary research practice (Wiek and Lang 2016, Pereira et al. 2018b, 2020). Enabling approaches try to understand how local actors with their networks, knowledge, and initiatives can be supported to foster transformative change (Moore and Westley 2011, Moore et al. 2018). The amplification of impact from sustainability initiatives that local actors apply to intervene in their systems is regarded as crucial but still insufficiently understood (Pereira et al. 2018a). Nevertheless, enabling approaches are criticized because of their biased focus on local actors and their perspectives in a globalized world (e.g., the risk of the localism trap), or their insufficient attention on how local actors could induce required structural and systemic changes (Born and Purcell 2006, Scoones et al. 2020).

This dissertation studies sustainability transformations by applying an enabling approach, which draws on insights from systemic and structural approaches. Thus, the emphasis is on local actors who try to transform systems with their networks, knowledge, and initiatives through interventions targeting shallow to deep leverage points. Such sustainability transformations emerge from the bottom-up and are induced by local actors with their networks, knowledge, and initiatives of which the impact needs to be amplified to achieve desired changes (Stirling 2015, Pereira et al. 2018a). Transformative transdisciplinary research is an often applied research practice in enabling approaches that investigate and aim to support local actors fostering transformative change (Pereira et al. 2020, Scoones et al. 2020). In the following, I introduce three topics that are relevant in enabling approaches to study sustainability transformations (Figure 1) (Pereira et al. 2018b, 2020, Scoones et al. 2020): (1) Sustainability initiatives and amplification processes, (2) local actors and knowledge, and (3) transformative transdisciplinary research.

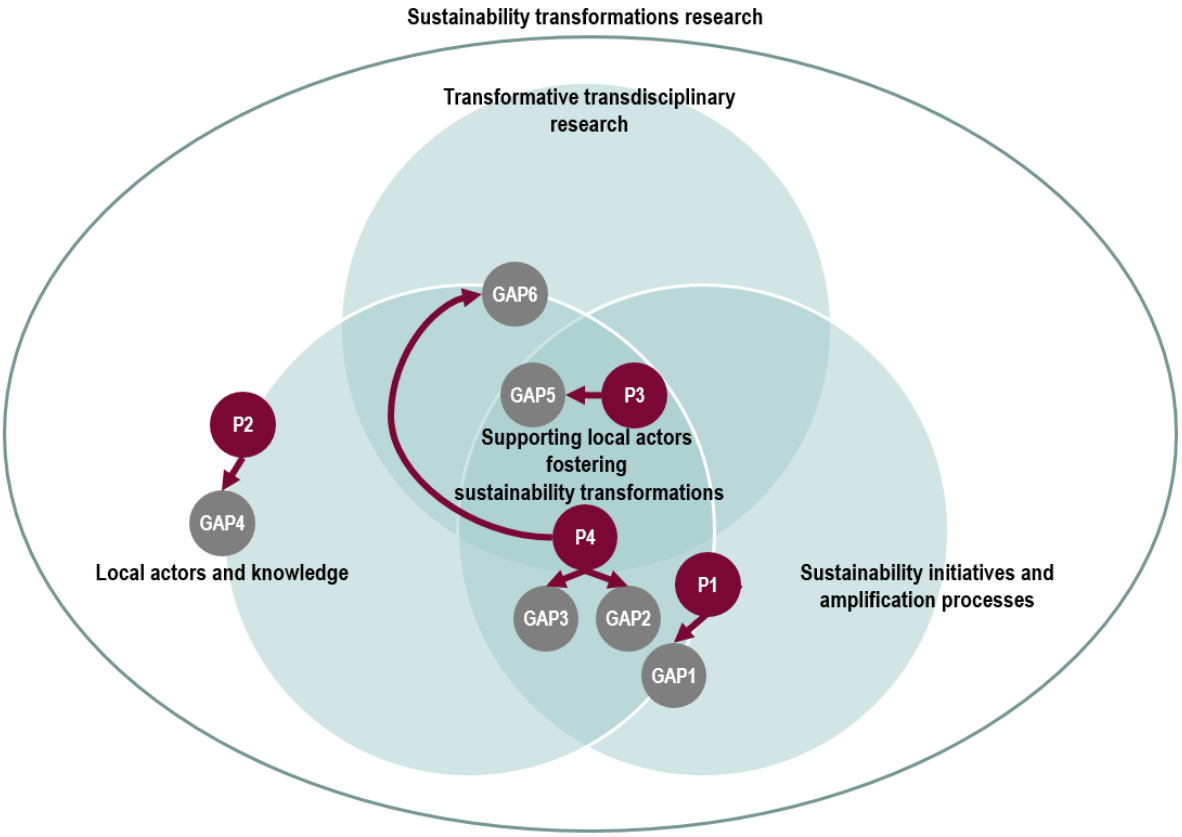

Figure 1: Overview of three relevant topics to study sustainability transformations while applying an enabling approach (turquoise circles): (1) sustainability initiatives and amplification processes, (2) local actors and knowledge, and (3) transformative transdisciplinary research. Grey dots indicate six identified research gaps. Red dots indicate the four papers of this dissertation and how they address the research gaps (red arrows).

1.2. Sustainability initiatives and amplification processes

Despite the intensity of current sustainability problems that require transformative change, the future does not have to be dystopic as dominantly communicated by popular and scientific forecasts (Pereira et al. 2018a). All over the world, there are many sustainability initiatives from local actors, which are examples of new ways of thinking, doing, living, and connecting people and nature that address at least parts of local and global sustainability problems and that contribute to achieving desired futures (Bennett et al. 2016).

Sustainability initiatives from local actors play an important role for transformations because they can over time coalesce to shift dominant regimes onto more desired pathways and thus foster transformative change (Pereira et al. 2018a). They provide positive narratives for people to live and act differently in times of seemingly overwhelming global problems (Pereira et al. 2018a). Such initiatives inform novel positive scenarios and visions (Bennett et al. 2016). They also contribute to a better understanding of how transformative change theoretically occurs and how to support such change towards desired futures (Pereira et al. 2018a).

Sustainability initiatives are especially important in the beginning of transformations to prepare them as described in the theory of change used in the project Seeds of good Anthropocenes (Olsson et al. 2006, Bennett et al. 2016, Pereira et al. 2018a). In this theory of change, initiatives emerge at the micro-scale as a response to local and global sustainability problems and provide potential solution options from local actors that challenge incumbent unsustainable regimes at the meso-scale (Pereira et al. 2018a). They can build collaborations and networks to jointly foster transformative change with their knowledge and initiatives. These collaborations can lead to the building of proto-regimes (Pereira et al. 2018a). Proto-regimes are connected and organized initiatives, emerging from the micro-scale, and are amendable to become institutionalized at the meso-scale (Geels 2002, Pereira et al. 2018a). The amplification of impact from initiatives is a crucial element to foster transformations in the beginning to gather momentum but still insufficiently understood (Moore et al. 2015, Olsson et al. 2017, Pereira et al. 2018a).

Amplification of impact from initiatives has received increased interest in sustainability transformations research and practice during the last years (Moore et al. 2014, Olsson et al. 2017, Loorbach et al. 2020). This led to the discussion of diverse amplification processes that describe how initiatives increase their impact in different research projects and frameworks, such as seeds of good Anthropocenes (Bennett et al. 2016) or acceleration mechanisms (Gorissen et al. 2018). Amplification processes describe *"diverse actions deployed by sustainability initiatives together with other actors (e.g., from government, business, or society) to purposively increase their transformative impact"* (Lam et al. 2020c p. 3). One example of an amplification process is *replicating* that describes the creation of new initiatives in different places to reach more people (Moore et al. 2015). Another example is *scaling deep* that describes the change of underlying values and mind-sets due to the impact from initiatives (Moore et al. 2015).
One key element highlighted in literature to apply such processes are the relations of local actors and their initiatives, hence, their social networks (Moore et al. 2015, Hermans et al. 2017, Gorissen et al. 2018, Garrah et al. 2019). Social networks of sustainability initiatives are important, for instance, for focused collaborations, pooling of resources, extending the sphere of influence, developing unusual alliances, and creating coherence through strategic interventions (Moore et al. 2015). They are also important to understand how novel ideas and solutions are generated, selected, and institutionalized (Olsson et al. 2017).

However, due to the diverse theoretical backgrounds of frameworks that discuss amplification processes it is difficult to advance the scientific understanding of such processes and research that supports initiatives to increase their impact (Pereira et al. 2015, Fazey et al. 2018). This

depicts research gap 1 that this dissertation seeks to explore conceptually by conducting a review and developing an integrative typology of amplification processes (Table 1, Figure 1). This will potentially facilitate an enhanced dialogue in sustainability transformations research on how initiatives increase their impact.

In addition, despite the intense work on understanding the role of social networks for fostering sustainability transformations (e.g., Ernstson 2011, Moore and Westley 2011, Barnes et al. 2017, Hermans et al. 2017, Langle-Flores et al. 2017), empirical studies that investigate social networks of local actors that apply amplification processes remain scarce. This depicts research gap 2 that this dissertation seeks to explore empirically (Table 1, Figure 1). I will do this by conducting social network analyses that includes applied amplification processes from local actors (i.e., attributes), and by trying to find associations between applied amplification processes by local actors and their network positions (i.e., centrality metrics).

1.3. Local actors and knowledge

Local actors play a key role for sustainability transformations because they are often one of the most affected ones by impacts from, for instance, climate change, deforestation, biodiversity loss, and depletion of fish stocks (IPBES 2019a). At the same time, they are regarded as key actors to foster transformative change from the bottom-up in place-based contexts (Stirling 2015, O'Brien 2015, Mehmood et al. 2020). Bottom-up, place-based transformations are fostered by local actors in a specific place context which is defined by the local sustainability problem (Stirling 2015, Horlings et al. 2020). Local actors have agency to act and are affected at the local scale and can be, for instance, individuals or groups of persons (e.g., initiatives, projects, communities, organizations, companies, or governments) (Liehr et al. 2017, Schlüter et al. 2019). They develop novel ideas and initiatives that can weaken broader structures which prevent the amplification of new ways of thinking, doing, or organizing (Westley et al. 2013, Pereira et al. 2018a). Particularly the social networks and the diverse knowledge of local actors are regarded as crucial for transformative change towards sustainability (Gelcich et al. 2010, Westley et al. 2013, Olsson et al. 2014, Blythe et al. 2018, Scoones et al. 2020).

Social networks of local actors generate, protect, support, and share novel ideas, initiatives, knowledge, practices, and approaches that potentially contribute to transformative change (Moore and Westley 2011, Smith and Raven 2012). They are real observable phenomena that can be measured by quantitative methods and analysed by social network analysis (Marsden 1990, Wasserman and Faust 1994, Borgatti et al. 2013). They consist of relations between local actors (e.g., giving informal advice or sharing material resources) which constitute different networks (e.g., trust network or knowledge exchange network) (Salpeteur et al. 2017).

Social networks have been in focus of research in various contexts, such as physics, biology, and history (Borgatti et al. 2009, 2013). The theoretical advancements that this research has provided are of specific interest, for instance, for researchers studying the governance of natural resources because they investigate social-ecological systems in which complex social dynamics and interactions take place (Salpeteur et al. 2017). For example, social-ecological systems research investigates the transformation of governance systems for natural resources, or the transmission of local ecological knowledge (Bodin et al. 2006, Salpeteur et al. 2017).

Social networks are regarded as crucial for the transformation of governance systems to new adaptive models (Folke et al. 2005), and to understand transformation and adaption in social-ecological systems (Barnes et al. 2017). Drawing on these insights, sustainability transformations research has created a sophisticated understanding of why social networks from local actors are important to foster transformative change. For example, to bridge similar or different actors across and within scales, to diffuse new ideas and innovations, to support the take up of alternative visions for the future, or to disseminate and exchange diverse knowledge from local actors (Gelcich et al. 2010, Moore and Westley 2011, Westley et al. 2013, Frantzeskaki et al. 2014, Hermans et al. 2017, Langle-Flores et al. 2017).

The diverse knowledge from local actors has recently been highlighted crucial for fostering transformative change (Scoones et al. 2020, Mehmood et al. 2020, Rebelo et al. 2020). Diverse knowledge stems from different knowledge systems, which describe "*agents, practices and institutions that organize the production, transfer and use of knowledge*" (Cornell et al. 2013 p. 61). Engaging with the diverse knowledge systems from local actors is an important requirement for successful transformative change because transformations are political, contested, and driven by different competing interests rooted in diverse worldviews, values, and knowledge systems (Pereira et al. 2020, Scoones et al. 2020). Engaging with diverse knowledge systems can enrich our understanding and actions for sustainability transformations by overcoming the risk of neglecting non-academic knowledge systems and the risk of maintaining the supremacy of Western scientific knowledge systems (de Sousa Santos 2008, Tengö et al. 2017, Scoones et al. 2020).

One specific group of local actors are indigenous peoples and local communities (IPLC). The United Nations recognizes no need for a formal definition of who IPLC are, and regards self-identification as the key requirement (Hill et al. 2020). Thus, Hill et al. (2020) provide the following description as guidance to understand who IPLC are: "*Indigenous peoples include communities, tribal groups and nations, who self-identify as indigenous to the territories they occupy, and whose organization is based fully or partially on their own customs, traditions, and laws. Indigenous peoples have historical continuity with societies present at the time of*

conquest or colonisation by peoples with whom they now often share their territories. Indigenous peoples consider themselves distinct from other sectors of the societies now prevailing on all or part of their territories. Local communities are groups of people who maintain inter-generational connection to place and nature through livelihood, cultural identity, worldviews, institutions and ecological knowledge. Local communities may be settled together, or they may be mobile depending on seasons and customary practices. Communities who come together in urban or peri-urban settings around common interests, such as beekeeping or tree-planting, are considered here to be 'communities of interest' or 'communities of practice' rather than local communities." (Hill et al. 2020 p. 9).

Although, IPLC are one of the most vulnerable local actors due to effects of climate change and resource depletion, their indigenous and local knowledge (ILK) potentially holds valuable insights to better understand and foster transformative change (Mastrángelo et al. 2019, Scoones et al. 2020). ILK is described as a "*cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment*" (Berkes 2018 p. 8). The valuable insights that ILK can contribute to understanding sustainability problems and developing solutions has recently received increased interest, especially by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Díaz et al. 2015, Mistry and Berardi 2016, Tengö et al. 2017, Díaz-Reviriego et al. 2019, Mastrángelo et al. 2019, Hill et al. 2020). Examples that show the contributions of ILK are the improvement of environmental governance systems for ecosystems and biodiversity (Brondizio and Tourneau 2016), or the exchange of ILK and scientific knowledge for pollinator conservation (Hill et al. 2019).

However, despite the widely acknowledged importance of social networks and diverse knowledge from local actors in sustainability transformations research, two research gaps are apparent to which this dissertations seeks to contribute. First, although research has created a sophisticated understanding why social networks are important for sustainability transformations, a systemic perspective on how local actors with their relations to other actors intervene in different characteristics of a system is still missing. This depicts research gap 3 that this dissertation seeks to explore conceptually and empirically by applying a leverage points perspective in social network analyses (Table 1, Figure 1). Second, even though many positive examples of how ILK can contribute to sustainability exist, research on and understanding of transformations tends to be dominated by Western scientific knowledge systems and thus determine resulting research and actions (Scoones et al. 2020). Studies that investigate the role of ILK in sustainability transformations research are scarce. This depicts research gap 4 that this dissertation seeks to explore conceptually by conducting a systematic

literature review on the representation of ILK in sustainability transformations research (Table 1, Figure 1).

1.4. Transformative transdisciplinary research

Over the last three decades, alternative research practices have emerged that are democratic, inclusive, action-oriented and integrate different forms of knowledge, such as mode 2, participatory, action, and transdisciplinary research (Fazey et al. 2018). These research practices seek to produce knowledge in ways that bridge the divide between science and practice, and can potentially uncover complementarities across different knowledge systems (van Kerkhoff and Lebel 2006, Cornell et al. 2013, Tengö et al. 2014, Clark et al. 2016). Yet, insights of these research practices have not specifically been used to support researchers who aim to inform and support transformative change (Fazey et al. 2018).

The involvement of local actors with their initiatives, networks and diverse knowledge to foster sustainability transformations requires new ways forward in research (Scoones et al. 2020). It calls researchers to critically reflect on their way of conducting research, and on their own possibilities to contribute and support transformative change towards sustainability (Fazey et al. 2018). The typical role of the researcher solely as a knowledge provider becomes expanded as recent sustainability transformations research shows an increased interest of researchers in the application of produced knowledge and its outcomes as well as impacts (Wiek et al. 2012, Wittmayer and Schäpke 2014, Schäpke et al. 2018b, Frantzeskaki and Rok 2018, Pereira et al. 2020, Sellberg et al. 2020).

Transformative research frameworks seek to meet the aim of producing knowledge with local actors that informs and supports the resolution or at least mitigation of sustainability problems by developing evidence-based solution options (Wiek and Lang 2016, Pereira et al. 2020). They are combinations of different methods in a meaningful sequence to produce evidence-based solution options (Wiek and Lang 2016). Transformative research frameworks generally comprise of three generic stages: (1) creating an understanding of system dynamics; (2) assessing current system state(s) against sustainability principles and developing a vision of the desired future state(s); and (3) developing and testing sustainability intervention strategies to foster change towards the desired vision (Wiek and Lang 2016). Examples of transformative research frameworks are transition management (Loorbach 2010), the three horizons technique (Sharpe et al. 2016), the seeds of good Anthropocene scenario methodology (Bennett et al. 2016, Pereira et al. 2018c, Sellberg et al. 2020), or transformative transdisciplinary research (Lang et al. 2012, Wiek and Lang 2016, Pereira et al. 2020).

Sustainability intervention strategies are a crucial element of transformative research frameworks because they seek to bridge the gap between the present and desired future

state(s) of a system by answering the question of “How do we get there?” (Raskin et al. 2002, Wiek and Kay 2012). A sustainability intervention strategy is an adaptive and coordinated set of prescriptive and evidence-based actions that ought to be executed by various actors to move a system from a current to a sustainable system state (Wiek and Kay 2012). Intervention strategies initiate, coordinate, and integrate contributions from local actors involved, such as their sustainability initiatives and diverse knowledge. Integrating initiatives and knowledge from local actors is essential for the success and contextualization of intervention strategies (Westley et al. 2006, Lang et al. 2012). However, it also depicts a challenge due to the complexity of transformations and of engaging with diverse actors, their initiatives and knowledge (Olsson et al. 2006, Kay 2012, Tengö et al. 2017, Scoones et al. 2020).

During the last years, the framework of transformative transdisciplinary research has received increased interest in sustainability transformations research because of its transdisciplinary research practice (Wiek and Lang 2016, Roux et al. 2017, Pereira et al. 2020, Scoones et al. 2020, Norström et al. 2020). It follows the principle of transdisciplinarity which is a “*reflexive, integrative, method-driven scientific principle aiming at the solution or transition of societal problems and concurrently of related scientific problems by differentiating and integrating knowledge from various scientific and societal bodies of knowledge*” (Lang et al. 2012 pp. 26–27). The involvement of relevant academic and non-academic actors into the research process is key to reconcile values and preferences, and to create legitimacy and ownership for problems, solutions, and intervention strategies (Lang et al. 2012, Roux et al. 2017). Examples of methods to identify relevant actors for such research are stakeholder mapping and social network analysis (Bodin and Prell 2011, Reed and Curzon 2015, Hauck et al. 2016, Newton and Elliott 2016).

Integrating knowledge from academic and non-academic actors to generate solution options is described as knowledge co-production and at the centre of transformative transdisciplinary research (Lang et al. 2012, Wiek and Lang 2016). Knowledge co-production can be defined as “*[i]terative and collaborative processes involving diverse types of expertise, knowledge and actors to produce context-specific knowledge and pathways towards a sustainable future*” (Norström et al. 2020 p. 2). Over the past decade, knowledge co-production has raised expectations in international science and policy fora to enable science to have greater impact for transformative change towards sustainability (Lemos et al. 2018, Scoones et al. 2020, Norström et al. 2020). For example, the Programme on Ecosystem Change and Society (PECS) explicitly applies a transdisciplinary research practice to study social-ecological systems transformations (Carpenter et al. 2012, Balvanera et al. 2017).

Despite the increasing amount of literature about transformative transdisciplinary research, two research gaps still exist that are also relevant for other transformative research frameworks. First, general guidance and empirical examples for how to integrate local actors with their initiatives and knowledge into sustainability intervention strategies remain scarce. This depicts research gap 5 that this dissertation seeks to address empirically by deriving guiding principles from research in a transdisciplinary case study (Table 1, Figure 1). Second, despite the diversity of methods to identify relevant actors in transformative transdisciplinary research, these methods provide less support to identify relevant actors for collaborations to develop and implement interventions that target specific system characteristics, such as the parameters, feedbacks, design, or intent of a system. This depicts research gap 6 that this dissertations seeks to address empirically by exploring the application of a leverage points perspective in social network analyses (Table 1, Figure 1).

1.5. Research aim and objectives

The aim of this dissertation is to contribute to research on sustainability transformations that are fostered by local actors with their initiatives, networks, and knowledge by providing insights for the aforementioned six research gaps (Table 1, Chapters 1.2.-1.4.). I seek to reach this aim by improving our understanding of sustainability transformations fostered by local actors (theoretical objective), and by rethinking how to do transformative transdisciplinary research with local actors (methodological objective) (Figure 2). In the following, first, I describe my research approach (Chapter 2). In Chapter 3, I provide the four papers of my dissertation. In Chapter 4, I synthesize the main findings of my dissertation for each research gap, followed by a reflection on limitations, research process, and implications. Finally, I draw conclusions (Chapter 5).

Table 1: Theoretical and methodological research gaps that this dissertations contributes to with conceptual and empirical work. P1 to P4 indicate which papers address the research gaps (P= Paper).

Research gaps (theoretical and/or methodological)	**Applied approach (conceptually and/or empirically)**	**P1**	**P2**	**P3**	**P4**
Sustainability initiatives and amplification processes					
Gap 1: Understanding of amplification processes that increase the impact of sustainability initiatives from local actors (**theoretical**).	**Conceptually** by conducting a literature review and developing an integrative typology of amplification processes.	x			
Gap 2: Understanding of and approaches to study the role of networks for amplification processes (**theoretical, methodological**).	**Empirically** by conducting social network analyses that include amplification processes as attributes of local actors.				X

Local actors and knowledge					
Gap 3: Understanding of and approaches to study how networks of local actors and their initiatives foster sustainability transformations (**theoretical, methodological**).	**Conceptually** by applying a leverage points' perspective to sort relations of local actors and **empirically** by conducting social network analyses.				x
Gap 4: Understanding of the role of indigenous and local knowledge in current sustainability transformations research (**theoretical**).	**Conceptually** by conducting a systematic literature review.		x		
Transformative transdisciplinary research					
Gap 5: Methodological guidance for the integration of local actors with their initiatives and knowledge in sustainability intervention strategies (**methodological**).	**Empirically** by deriving principles from a transdisciplinary case study that support the integration of local actors in sustainability intervention strategies.			x	
Gap 6: Approaches to identify relevant local actors for collaborations to intervene in specific system characteristics (**methodological**).	**Empirically** by exploring the application of a leverage points' perspective to sort relations of local actors and conducting social network analyses.				x

2. Research approach

2.1. Research questions

To address the six research gaps that I have identified in literature of sustainability transformations research (Chapters 1.2.-1.4., Table 1), I seek to answer the following main research question (Table 1, Figure 2):

How can transformative transdisciplinary research support local actors who foster change towards sustainability?

By answering this main research question, I seek to contribute to the theoretical and methodological research gaps, which I derived from three topics relevant for enabling approaches that study sustainability transformations (Table 1, Chapter 1.1.). These topics are sustainability initiatives and amplification processes (Chapter 1.2.), local actors and knowledge (Chapter 1.3.), and transformative transdisciplinary research (Chapter 1.4.). To cope with the complexity of these three topics, I developed four sub-research questions (SRQ), which are more tangible and can successively be answered (Figure 2):

- SRQ 1: How does sustainability transformations research discuss about amplifying the impact of sustainability initiatives driven by local actors?
- SRQ 2: How is indigenous and local knowledge represented in sustainability transformations research?
- SRQ 3: How to better integrate sustainability initiatives from local actors in transformative transdisciplinary research?
- SRQ 4: How to identify relevant local actors who amplify the impact of their sustainability initiatives in networks that intervene in specific system characteristics?

SRQs 1 and 2 are driven by the theoretical research objective that seeks to improve our understanding of sustainability transformations fostered by local actors (Figure 2). By answering SRQ 1, I seek to advance our understanding of amplification processes that are currently discussed in sustainability transformations research (Research gap 1). By answering SRQ 2, I seek to advance our understanding of the role of ILK in sustainability transformations research (Research gap 4). SRQ 3 is driven by the methodological objective that seeks to rethink how to do transformative transdisciplinary research with local actors (Figure 2). By answering SRQ 3, I seek to make a methodological contribution to transformative transdisciplinary research by exploring how to integrate local actors with their initiatives and knowledge in sustainability intervention strategies (Research gap 5). SRQ 4 is mainly driven by the methodological objective but also contributes partly to the theoretical objective (Figure 2). By answering SRQ 4, I seek to make a methodological contribution to transformative transdisciplinary research by exploring how to identify relevant local actors for collaborations to intervene in specific system characteristics (Research gap 6). In addition, I seek to make a theoretical and methodological contribution concerning the role of networks for amplification processes (Research gap 2) and sustainability transformations (Research gap 3). The answers to these four SRQ will inform my main research question.

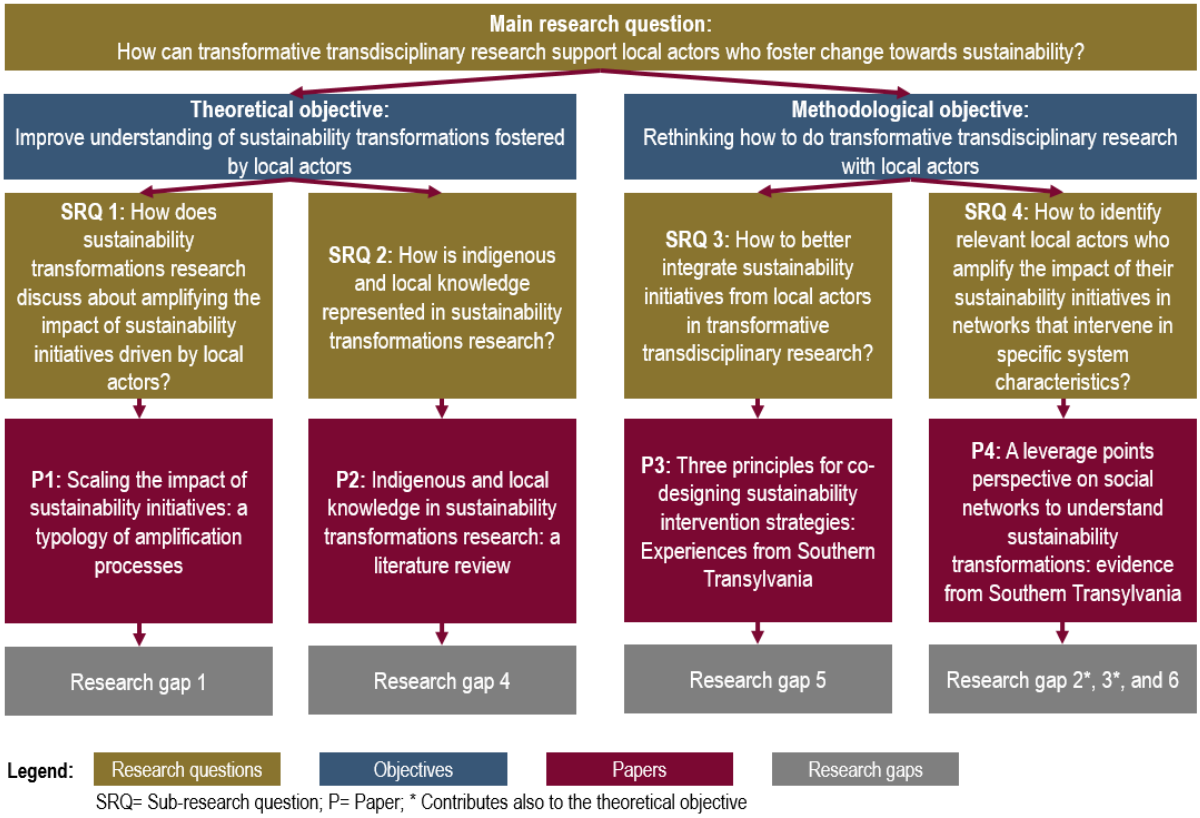

Figure 2: Overview of main research question, objectives, sub-research questions, papers, and research gaps (from the top). The main research question follows two objectives that each lead to two sub-research questions. The four sub-research questions are answered with four papers that address the six research gaps identified in sustainability transformations literature (Chapter 1.)

2.2. Research design and overview of papers

To answer my SRQs, I conducted conceptual and empirical work that contributes to sustainability transformations research, which applies enabling approaches (Figure 1, Table 1 and 2). To answer SRQ 1, I did a conceptual study that contributes to the topic of sustainability initiatives and amplification processes (Figure 1, Chapter 1.2.). Amplification processes are currently discussed in different amplification frameworks that have different theoretical backgrounds and use diverse terms to describe such processes. Examples for such frameworks are the acceleration mechanisms framework, which stems from socio-technical systems research (Gorissen et al. 2018) or the seeds of good Anthropocenes framework, which stems from social-ecological systems research (Bennett et al. 2016). I conducted a selective literature review of amplification processes discussed in such frameworks from sustainability transformations research. The selective review followed the principles of a scoping study (Table 2) (Arksey and O'Malley 2005, Wigboldus et al. 2016). Scoping studies map "*the key concepts underpinning a research area and the main sources and types of evidence available, (…) especially where an area is complex or has not been reviewed comprehensively before*" (Mays et al. 2001, p. 194). In addition, I analysed the amplification processes that I have identified through the scoping study and derived an integrated typology

of amplification processes (Table 2). The results of this conceptual study have been published in the following paper (Chapter 3.1.):

> **P1: Scaling the impact of sustainability initiatives: a typology of amplification processes**
> David P. M. Lam, Berta Martín-López, Arnim Wiek, Elena M. Bennett, Niki Frantzeskaki, Andra I. Horcea-Milcu, Daniel J. Lang (2020)
> *Urban Transformations*

To answer SRQ 2, I carried out a conceptual study that contributes to the topic of local actors and knowledge (Figure 1, Chapter 1.3.). I conducted a systematic literature review of peer-reviewed scientific papers on ILK in sustainability transformations research followed by qualitative and quantitative data analysis (Table 2) (Hill and Gauch 1980, Pullin and Stewart 2006, Abson et al. 2014, Mayring 2014, Luederitz et al. 2016, Partelow et al. 2018). Conducting a systematic literature review seemed most suitable to identify peer-reviewed scientific papers with the relevant information (Pullin and Stewart 2006). In addition, I conducted a qualitative content analysis to code and categorize the information from the papers (Mayring 2014). Finally, I conducted a detrended correspondence analysis to visualize the principal gradients found within the abundance of words in the papers (Hill and Gauch 1980). Detrended correspondence analysis is a standard ordination analysis predominantly used in ecology with sparse datasets, extracting main gradients out of multivariate datasets based on reciprocal averaging (Hill and Gauch 1980). The results of this conceptual study have been published in the following paper (Chapter 3.2.):

> **P2: Indigenous and local knowledge in sustainability transformations research: a literature review**
> David P. M. Lam, Elvira Hinz, Daniel J. Lang, Maria Tengö, Henrik von Wehrden, Berta Martín-López (2020)
> *Ecology and Society*

To answer SRQ 3, I conducted an empirical study that contributes to the topic of transformative transdisciplinary research (Figure 1, Chapter 1.4.). I derived guiding principles from my transformative transdisciplinary research with local non-governmental organizations (i.e., local actors) (NGO) in Southern Transylvania, Romania (Table 2, Chapter 2.3.) (Wiek and Lang 2016). My research in Southern Transylvania was part of a transdisciplinary case study from the research project Leverage Points for Sustainability Transformation (www.leveragepoints.org) (Lang et al. 2012, Abson et al. 2017). I used systems and futures

thinking as an analytical approach to derive guiding principles for transformative transdisciplinary research on how to better integrate local actors and their sustainability initiatives that change system elements towards desired states (Meadows 1989, 1999, Andrachuk and Armitage 2015, Abson et al. 2017). The results of this empirical study have been published in the following paper (Chapter 3.3.):

> **P3: Three principles for co-designing sustainability intervention strategies: Experiences from Southern Transylvania**
> David P. M. Lam, Andra I. Horcea-Milcu, Joern Fischer, Daniel Peukert, Daniel J. Lang (2019)
> *Ambio*.

Finally, to answer SRQ 4, I conducted a study that combined conceptual and empirical work. It contributes insights to the three topics sustainability initiatives and amplification processes, local actors and knowledge, and transformative transdisciplinary research, which are especially relevant for enabling approaches studying sustainability transformations (Figure 1, Chapters 1.2.-1.4.). Relations between local actors that drive sustainability initiatives are regarded as crucial to foster sustainability transformations and to apply amplification processes (Moore and Westley 2011, Frantzeskaki et al. 2014, Moore et al. 2015). I conducted social network analyses of relations between NGOs in Southern Transylvania to identify relevant local actors with high centrality metrics (Chapter 2.3.) (Bodin and Prell 2011, Prell 2011a, Hauck et al. 2016). I collected data on the relations between NGOs via an online survey (Bryman 2012). I used the leverage points perspective to sort their relations according to the leverage points and systems characteristics that they address. The results of this empirical and conceptual study have been published in the following paper (Chapter 3.4.):

> **P4: A leverage points perspective on social networks to understand sustainability transformations: evidence from Southern Transylvania**
> David P. M. Lam, Berta Martín-López, Andra I. Horcea-Milcu, Daniel J. Lang (2020)
> *Sustainability Science*

Collectively, this conceptual and empirical work will potentially advance our understanding of sustainability transformations fostered by local actors, and rethink how to do transformative transdisciplinary research with local actors (Table 2, Figure 2).

Table 2: Overview of the four papers of my dissertation (P= Paper)

Sub-research question	Approach and methods	Main results	Addressed research gaps and contribution
P1: Scaling the impact of sustainability initiatives: a typology of amplification processes			
1. How does sustainability transformations research discuss about amplifying the impact of sustainability initiatives driven by local actors?	Conceptual study: - Selective literature review following the principles of a scoping study - Conceptual analysis and integration of amplification processes	- P1 provides an integrated typology of amplification processes. - P1 identified eight amplification processes that can be grouped in three categories.	Research gap 1: P1 advances our **theoretical** understanding of amplification processes applied by local actors to increase the impact of their sustainability initiatives.
P2: Indigenous and local knowledge in sustainability transformations research: a literature review			
2. How is indigenous and local knowledge represented in sustainability transformations research?	Conceptual study: - Systematic literature review - Qualitative content analysis and quantitative detrended correspondence analysis	- P2 shows that indigenous and local knowledge is mainly applied to confirm and complement scientific knowledge in contexts of environmental, climate, social-ecological, and species change. Only four papers (5%) applied indigenous and local knowledge to study transformations. - P2 shows four research clusters that apply indigenous and local knowledge in contexts of transformation, transition, or change in (1) Arctic, (2) terrestrial, (3) coastal, and (4) grass and rangelands environments. - P2 indicates that indigenous and local understandings of transformations are currently neglected in the scholarly transformations discourse.	Research gap 4: P2 advances our **theoretical** understanding of how indigenous and local knowledge is applied in sustainability transformations research and indicates a gap in understanding transformations from the perspective of indigenous peoples and local communities.
P3: Three principles for co-designing sustainability intervention strategies: Experiences from Southern Transylvania			
3. How to better integrate sustainability initiatives from local actors in transformative transdisciplinary research?	Empirical study applying a transdisciplinary research practice: - Transformative transdisciplinary research (TRANSFORM framework (Wiek and Lang 2016)) - Transdisciplinary case study research with local actors - Participant observations - Scoping meetings - Semi-structured interviews - Workshop - Systems and futures thinking as an approach for analysis	- P3 derives from work in a transdisciplinary case study three principles to facilitate the process of co-designing intervention strategies that integrate sustainability initiatives from local actors. - P3 exemplifies the application of the three principles in a transdisciplinary case study carried out in Southern Transylvania, Romania.	Research gap 5: P3 contributes **methodologically** to transformative transdisciplinary research by providing guidance for how to integrate sustainability initiatives driven by local actors in intervention strategies.
P4: A leverage points perspective on social networks to understand sustainability transformations: evidence from Southern Transylvania			
4. How to identify relevant local actors who amplify the impact of their sustainability initiatives in networks that intervene in specific system characteristics?	Conceptual, empirical study applying a transdisciplinary research practice: - Transformative transdisciplinary research (TRANSFORM framework) - Transdisciplinary case study research - Application of a leverage points perspective - Collection of social network data via an online survey - Social network analyses - Mann-Whitney U test	- P4 applies a leverage points perspective on relations of local actors intervening in system characteristics and who apply amplification processes. - P4 provides empirical insights on the application of a leverage points perspective in social network analysis, and the role of networks for applying amplification processes. - P4 reveals which local actors have high centrality metrics in networks that intervene in different system characteristics. - P4 shows differences in the centrality metrics when local actors applied amplification processes.	Research gaps 2, 3, and 6: P4 advances our **theoretical** understanding of the role of networks for amplification processes and sustainability transformations. P4 contributes **methodologically** by exploring the application of a leverage points perspective in social network analyses to identify relevant local actors for collaborations who apply amplification processes.

2.3. Transdisciplinary case study: Sustainability initiatives in Southern Transylvania

The research of this dissertation was developed in the context of a transdisciplinary case study in Southern Transylvania, Romania; hence, an iterative process. The case study was part of the research project Leverage Points for Sustainability Transformation (Abson et al. 2017) and was a suitable opportunity to follow my research interest on how transformative transdisciplinary research can support local actors in fostering change towards sustainability for three reasons. First, the case study focused on how sustainability initiatives from local actors can foster transformative change in the region (www.leveragepoints.org). Second, the case study built on previous research that conducted social-ecological system analysis and scenario building (Hanspach et al. 2014), which is essential to conduct transformative transdisciplinary research that supports local actors in fostering change (Wiek and Lang 2016). Third, the case study applied a transformative transdisciplinary research practice (Abson et al. 2017).

The work in Southern Transylvania builds on five years (2011-2015) of place-based inter- and transdisciplinary research investigating the issues of change and sustainability. Previous research framed Southern Transylvania as a social-ecological system. This research developed an in-depth, empirically grounded understanding of system structures and dynamics, components of the ecological and social subsystems, interrelations between the two subsystems, and direct as well as indirect drivers of change (Berkes et al. 2000, Hanspach et al. 2014, Loos et al. 2014, Mikulcak et al. 2015, Dorresteijn et al. 2016, Horcea-Milcu et al. 2018). The social subsystems and dynamics are challenged by weak governance structures, corruption, low social capital, and low profitability of small-scale farming (Hanspach et al. 2014), while the ecological subsystems and dynamics are heavily influenced by landscape heterogeneity, cultural land ties, and traditional practices (Dorresteijn et al. 2015). In addition, the influence of global market dynamics and supra-national policies of the European Union are one of the strongest drivers of change leading to the regional challenge of conserving the unique natural and cultural heritage of Southern Transylvania. In response to these challenges, local actors, especially NGOs foster change towards sustainability through numerous sustainability initiatives. They focus on various topics, such as nature and cultural heritage conservation, supporting small-scale farming, eco-tourism, or rural community development.

At the end of 2012, researchers and local actors co-developed and co-validated in a scenario building exercise a widely agreed on and shared sustainable future for Southern Transylvania, named Balance Brings Beauty (Hanspach et al. 2014). Balance Brings Beauty describes a future in which national and supra-national policies have a pro-environmental emphasis that creates a context in which local actors can capitalize on opportunities through collaboration

and shared sustainability initiatives (Hanspach et al. 2014). It reflects a system constellation that balances economic prosperity with social and ecological sustainability (Hanspach et al. 2014, Nieto-Romero et al. 2016).
The aim of the transdisciplinary case study from 2016-2019 was to facilitate changes towards the sustainable future of Southern Transylvania that are driven by the numerous initiatives from the local actors. Two topics arose among scoping meetings with the local actors as important to foster such changes. First, the amplification of impact from their sustainability initiatives. Second, better understanding their networks. These two topics influenced the development of my sub-research questions at the science-society interface.

Through SRQ 1, I aimed to understand a real-world question posed by local actors (i.e., amplification of impact) from a scientific perspective and translate scientific insights back to society. This translation was done by co-developing a practitioners book about how to amplify the impact of sustainability initiatives to reach Balance Brings Beauty with the local actors (Fischer et al. 2019). With SRQ 2, I stepped one step back and aimed to understand whether scientific and local understandings of transformation differ. This may pose challenges (e.g., normative, epistemological, or ontological) in conducting transformative transdisciplinary research with local actors that fosters change towards sustainability. In sustainability transformations research, different scientific understandings of transformations (e.g., social-ecological transformations or socio-technical transitions) also lead to different understandings of amplification processes (Bennett et al. 2016, Gorissen et al. 2018, Scoones et al. 2020).
Through SRQ 3, I aimed to understand how science and society can better work together to foster transformative change (Wiek and Lang 2016). I derived guiding principles from the case study on how to integrate sustainability initiatives from local actors in transformative transdisciplinary research. In this way, the guiding principles constitute empirically grounded insights from a transdisciplinary research setting, in which scientists and local actors aim to foster transformative change. With SRQ 4, I aimed to understand the network of local actors, which was mentioned by the local actors as important to foster transformative change. In this way, I tried to find answers for local actors and their real-world problem by applying a scientific method (e.g., social network analysis).
This illustrates how the transdisciplinary case study and my research interest shaped my dissertation. My dissertation addresses research questions that are scientifically relevant because they provide insights for research gaps identified in sustainability transformations research (Table 1 and 2, Chapters 1.2.-1.4.). In addition, my dissertation is potentially relevant for the local actors in Southern Transylvania because their interest in how to foster transformative change influenced my sub-research questions.

3. Results

3.1. Scaling the impact of sustainability initiatives: a typology of amplification processes

David P. M. Lam, Berta Martín-López, Arnim Wiek, Elena M. Bennett, Niki Frantzeskaki4, Andra I. Horcea-Milcu, Daniel J. Lang (2020)

Urban Transformations

Picture shows a graphical illustration of my speed talk about the amplification typology at the Transformations Conference 2017 in Dundee, Scotland. It was drawn by an anonymous person.

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Urban Transformations

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Scaling the impact of sustainability initiatives: a typology of amplification processes

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Abstract

Amplifying the impact of sustainability initiatives to foster transformations in urban and rural contexts, has received increasing attention in resilience, social innovation, and sustainability transitions research. We review the literature on amplification frameworks and propose an integrative typology of eight processes, which aim to increase the impact of such initiatives. The eight amplification processes are: stabilizing, speeding up, growing, replicating, transferring, spreading, scaling up, and scaling deep. We aggregated these processes into three categories: amplifying within, amplifying out, and amplifying beyond. This integrative typology aims to stimulate the debate on impact amplification from urban and rural sustainability initiatives across research areas to support sustainability transformations. We propose going beyond an understanding of amplification, which focuses only on the increase of numbers of sustainability initiatives, by considering how these initiatives create transformative change.

Keywords: City, Urban, Rural, Scaling, Transition initiative, Transformation, Transition

Science highlights

- We suggest a typology of processes amplifying the impact of sustainability initiatives that exist and have impact in urban and rural contexts
- Eight amplification processes are identified in the scientific literature
- Amplification processes are grouped into three categories: amplifying within, out, and beyond
- The typology conceptually bridges research areas with the aim to initiate dialogue on sustainability transformations

Practice recommendations

- Sustainability initiatives in urban and rural contexts increase their impact through one or more of our eight identified amplification processes

– Sustainability initiatives should apply a set of amplification processes to foster transformative change
– Increasing impact can also be achieved by changing values and mind-sets, referred to as 'scaling deep'

Introduction

Scientists, politicians, entrepreneurs, and civil society are increasingly calling for sustainability transformations.[1] This is to ensure that society can operate within the earth's biophysical limits while simultaneously fostering justice and wellbeing (Raskin et al. 2002; Rockström et al. 2009; Westley et al. 2011; Olsson et al. 2014). Sustainability transformations are fundamental changes of interactions and feedbacks in, for example, social-ecological or socio-technical systems towards sustainability (Gunderson and Holling 2002; Walker et al. 2004; Grin et al. 2010; Olsson et al. 2014). Examples are the shift from cattle ranching to ecotourism based on wildlife in Zimbabwe (Cumming 1999), or Germany's energy transition (Geels et al. 2016). Over the last two decades, sustainability transformations have been addressed in a variety of research areas including resilience (Gunderson and Holling 2002), social innovation (Westley et al. 2006), and sustainability transitions studies (Grin et al. 2010). During the last years, these research areas have come closer together, as they all have a joint interest in societal change towards sustainability. We refer to this emerging literature here as sustainability transformations research (Olsson et al. 2014; Pereira et al. 2015; Loorbach et al. 2017; Avelino et al. 2019; Horcea-Milcu et al. 2020).

Sustainability transformations research is heterogeneous, because of the diverse above-mentioned research areas that investigate transformations with different theories and methods (Loorbach et al. 2017). Despite this heterogeneity, the literature is predominantly led by researchers in the Global North, often with technocratic and positivistic paradigms of what transformations are and how they emerge (Ramos-Mejía et al. 2018; Köhler et al. 2019; Lam et al. 2020). A recent study from the Global South emphasises that transformations are highly contested and an integral part is to consider conflict and dilemmas in the research design early on (Pereira et al. 2020). Furthermore, the normative goal of sustainability is sometimes critiqued to be dominated by Western worldviews, mind-sets, and values, which may not apply to contexts in the Global South (Kothari et al. 2014; Scoones et al. 2020).

In this paper, we examine the literature on sustainability transformations, but do not take any single theoretical or normative concept as the only truth. Instead, we argue that there are multiple understandings of transformations, for example, from different research areas, or different knowledge systems (e.g., scientific, indigenous and local knowledge systems) (Blythe et al. 2018; Lam et al. 2020). Therefore, we highlight that urban and rural sustainability transformations may be best understood when considering them as place-based societal changes driven by local actors. This includes the development and implementation of sustainability initiatives by local actors that realise local and global worldviews, mind-sets, and values (Horcea-Milcu et al. 2019; Lam et al. 2019).

[1]Here, we use the term sustainability transformations also as a synonym for sustainability transitions, such as in Loorbach et al. (2017). Although both terms refer to large-scale societal change, we are aware of the nuanced differences that they entail. For a detailed analysis of the similarities and differences of these terms, see Hölscher et al. (2018).

Sustainability initiatives are potential local solutions to sustainability problems with global relevance (e.g., biodiversity loss, health, mobility). These are often designed, carried out, and led by local actors. Sustainability initiatives provide new ways of thinking, doing, and organising (e.g., social, technological, economic, socio-technical, or social-ecological). This may be, for example, projects, products, practices, approaches, or technologies (Bennett et al. 2016; Gorissen et al. 2018). Their focus depends on the context and agency (e.g., individual or collective), and can be, for example, on urban agroecology, climate smart cities, or green design (Pereira et al. 2018). Sustainability initiatives are crucial for transformations because they can over time coalesce to shift dominant regimes onto more sustainable pathways and thus foster transformative change (Pereira et al. 2018; Lam et al. 2019). Different research areas refer to sustainability initiatives with unique terms such as grassroots innovations (Seyfang and Smith 2007), seeds of a good Anthropocene (Bennett et al. 2016), social innovations (Westley and Antadze 2010; Moore et al. 2015), transition experiments (Caniglia et al. 2017; Sengers et al. 2019), and transition initiatives (Frantzeskaki et al. 2016; Gorissen et al. 2018). In this paper, we use the term "sustainability initiative" as an umbrella concept for all.

With regard to initiatives, sustainability transformations research generally discusses the beneficial context-settings through which they emerge and flourish (Leach et al. 2012; Smith and Raven 2012), and the approaches of "scaling", i.e., amplification processes that increase their impact (Westley et al. 2011; Moore et al. 2015; Gorissen et al. 2018). Amplification processes describe diverse actions deployed by sustainability initiatives together with other actors (e.g., from government, business, or society) to purposively increase their transformative impact (e.g., initiating a new initiative in another city). The emphasis is thus on the extended impact of initiatives, which is created when new ways of thinking, doing, and organizing things (e.g., practices, processes, or products) get adopted and amplified (Leach et al. 2012; Wigboldus et al. 2016). Understanding amplification processes sheds light on the conditions required, and thus options for purposive interventions, to support such processes (Wiek and Lang 2016). In this paper, we deliberately use the term *amplification* instead of "scaling" to reduce confusion, because "scaling" suggests the involvement of a "scale" or "higher level" to increase impact (Cash et al. 2006). However, increasing impact of initiatives does not exclusively involve levels or scales (e.g., of governance or quantity). It can, for example, also involve changing values and mind-sets (Horcea-Milcu et al. 2019).

We aspire to bring coherence to the dispersed literature on amplification processes applied by sustainability initiatives to foster transformations. Additionally, we hope to stimulate debate by providing an integrative typology of amplification processes. Scholars from diverse research areas have advanced our understanding of such processes by applying different theories and focusing on different systems of interest, in both urban and rural contexts (van den Bosch and Rotmans 2008; Moore et al. 2015; Olsson et al. 2017). Although some research areas have moved closer to a shared understanding of such processes (Olsson et al. 2017), there is still considerable diversity in how they describe and understand them (Pereira et al. 2015). Diversity is both positive and a challenge. It contributes substantially to diverse debates and empirical insights, but also reduces comparability to draw conclusions, in part, due to a lack of a common language. For example, while certain research areas use similar terms for amplification processes (e.g., *scaling out*, *outscaling*) they, in fact, often refer to different processes to

increase impact. This lack of clarity hinders the advancement of the debate across research areas and the support of sustainability initiatives in selecting processes that increase their impact.

An integrative typology of amplification processes is therefore an important next step for three reasons. First, it will conceptually bridge insights from different research areas. Second, the typology can provide potential insights regarding commonalities and learning within and between research areas, to discuss amplification processes. Third, it can support reflection on current processes with the aim to uncover gaps and challenges as well as points of overlap or divergence in the literature. For example, scholars using different theories and methods could learn from each other. Local actors could inform themselves about how modifying their actions could lead to increasing their impact. Furthermore, policymakers could use the typology to develop policies and institutional spaces that can enable initiatives to amplify their impact.

In this paper, we aim to provide a typology of amplification processes identified in the sustainability transformations literature. First, we introduce the frameworks that discuss amplification processes. Second, we present an integrative typology of amplification processes. We further explain it with examples of sustainability initiatives from urban and rural contexts. Finally, we discuss the relevance, limitations, and implications of the typology for future research.

Amplification frameworks

Amplification frameworks focus on identifying actions that increase the impact of sustainability initiatives via specific processes. These processes may be referred to as strategies (Moore et al. 2015), mechanisms (van den Bosch and Rotmans 2008; Bennett et al. 2016; Gorissen et al. 2018) or patterns (Naber et al. 2017). Due to the heterogeneity and breadth of the literature, we conducted a selective review that follows the principles of a scoping study (Arksey and O'Malley 2005). Scoping studies map "the key concepts underpinning a research area and the main sources and types of evidence available, (…) especially where an area is complex or has not been reviewed comprehensively before" (Mays et al. 2001). Thus, the review was not exhaustive, but covers contemporary frameworks commonly engaged within the literature (Loorbach et al. 2017).

The selection of frameworks followed two steps. First, based on an explorative reading of relevant literature, we identified sustainability transitions, resilience, and social innovations studies as the three most prominent research areas discussing amplification processes (Olsson et al. 2014; Pereira et al. 2015; Loorbach et al. 2017; Hölscher et al. 2018). Second, by analysing relevant scientific papers from these research areas, we identified frameworks that had a transformative amplification purpose. Due to the scope of the review we excluded frameworks that were mainly descriptive-analytical (e.g., Multi-Level perspective) and only included transformative frameworks (Geels and Schot 2007; Wiek and Lang 2016; Hölscher et al. 2018). While descriptive-analytical frameworks are primarily used to analyse and describe transformations, transformative frameworks are applied to support transformative change (Wiek and Lang 2016). It is important to note that the purpose of the review was not to analyse and compare all amplification frameworks available, but to selectively review those that focus on sustainability transformations (Wigboldus et al. 2016). We intentionally excluded frameworks that did not explicitly focus on

sustainability, such as diffusion of innovations in general (Rogers 2003) or in organizations (Greenhalgh et al. 2004).

As a result, we identified six frameworks: (1) Strategies for social innovation (Moore et al. 2015), (2) Seeds of a good Anthropocene (Bennett et al. 2016), (3) Scale dynamics (Hermans et al. 2016), (4) Acceleration mechanisms (Gorissen et al. 2018; Ehnert et al. 2018), (5) Transition management (Rotmans and Loorbach 2008; Frantzeskaki et al. 2018), and (6) Strategic niche management (Naber et al. 2017) (Fig. 1, Table 1). Although these frameworks have been used to investigate the amplification of initiatives' impacts in diverse contexts, they are often used to derive empirical insights from initiatives that foster sustainability transformations in urban and rural contexts. For instance, by using the framework of acceleration mechanisms, Gorissen et al. (2018) investigate how diverse types of initiatives (e.g., community currency or bee-friendly city initiatives) contribute to accelerating urban transformations in the City of Genk. Hermans et al. (2016) apply the framework of scale dynamics to discuss the amplification of sustainable agricultural innovations in the Dutch rural region of the Northern Frisian Woodlands. Other frameworks derive insights from initiatives that exist in both urban and rural contexts (Rotmans and Loorbach 2008; Moore et al. 2015; Bennett et al. 2016; Naber et al. 2017). For example, Naber et al. (2017) applied the strategic niche management framework to understand energy initiatives in the city of Zwolle and municipality of Texel in the Netherlands.

The six frameworks derive from three different research areas: social innovations research (Westley et al. 2006), social-ecological transformations research (Gunderson and Holling 2002), and socio-technical transitions research (Grin et al. 2010). These research areas are neither mutually exclusive nor have they been developed separately, and often explicitly refer to or draw from each other (Moore et al. 2015; Hermans et al. 2016; Bennett et al. 2016). *Social innovations research* focuses on social and institutional entrepreneurship, where leaders of social innovations (e.g., non-profit organizations) try to increase their impact to induce large systems change (Westley et al. 2006;

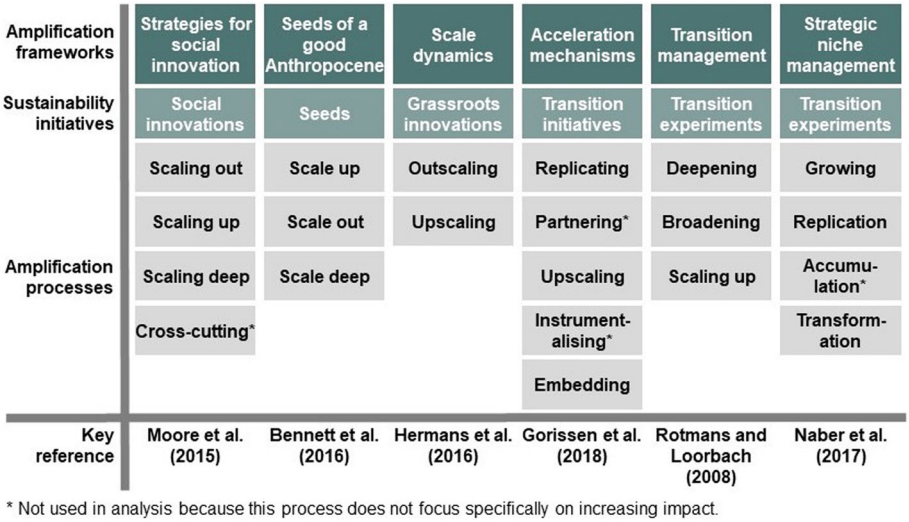

Fig. 1 Overview of amplification frameworks used in sustainability transformation research and their conceptualization of sustainability initiatives and amplification processes. Note that these are examples of key references that describe the amplification processes of each framework, but there are many others discussing the respective processes in the literature (see main text, Tables 1 and 2 for further references)

Table 1 Amplification frameworks

Framework	Theoretical background	Sustainability initiative	Amplification purpose
Strategies for social innovation	Social innovations research (Westley et al. 2006)	Social innovations, i.e. "initiative, product, program, platform or design that challenges, and over time changes, the defining routines, resource and authority flows, or beliefs of the social system in which the innovation occurs" (Moore et al. 2015, p. 69).	To "achieve systemic impacts" and "large systems change" (Moore et al. 2015, p. 69). The latter requires combining different types of scaling (Table 2).
Seeds of a good Anthropocene	Social-ecological transformations research (Gunderson and Holling 2002)	Seeds, i.e. "initiatives (social, technological, economic, or social–ecological ways of thinking or doing) that exist, at least in prototype form, and that represent a diversity of worldviews, values, and regions, but are not currently dominant or prominent" (Bennett et al. 2016, p. 442).	To "have transformative impacts beyond initial localities and sectors" (Bennett et al. 2016, p. 443).
Scale dynamics	Social-ecological transformations research (Gunderson and Holling 2002) and socio-technical transitions research (Grin et al. 2010)	Grassroots innovations, i.e. "networks of activists and organizations generating novel bottom-up solutions for sustainable development; solutions that respond to the local situation and the interests and values of the communities involved. […] [G] rassroots initiatives operate in civil society arenas and involve committed activists experimenting with social innovations as well as using greener technologies." (Seyfang and Smith 2007, p. 585).[a]	To "enact transformative change across scales and have a wider impact beyond the people directly involved in their initial development." (Hermans et al. 2016, p. 285).
Acceleration mechanisms	Socio-technical transitions research (Grin et al. 2010)	Transition initiatives, i.e. "locally-based (…) actor-networks that start-up, adopt and/or engage with new practices, technologies and experiments that seek to profoundly change established unsustainable routines and perceptions towards more sustainable ones." (Gorissen et al. 2018, p. 172).	To "accelerate sustainability transitions [in city-regions]" (Gorissen et al. 2018, p. 173).
Transition management	Socio-technical transitions research (Grin et al. 2010)	Transition experiments, i.e. innovation projects "with a societal challenge as a starting point for learning aimed at contributing to a transition." (van den Bosch and Rotmans 2008, p. 12).	To "make a potentially large innovative contribution to a transition process" (Loorbach 2010, p. 176). This encompasses changing "established ways of thinking (culture), doing (practices) and organizing (structure)" (van den Bosch and Rotmans 2008, p. 5).
Strategic niche management	Socio-technical transitions research (Grin et al. 2010)	Transition experiments, i.e. "inclusive, practice-based and challenge-led initiative designed to promote system innovation through social learning under conditions of uncertainty and ambiguity" (Sengers et al. 2019, p. 161).	To "scale-up and diffuse innovative solutions" in order to increase "the potential of the niche to influence the current regime and eventually achieve a transition." (Naber et al. 2017, p. 344).

[a]Hermans et al. (2016) address specifically agricultural grassroots innovations

Westley et al. 2014; Moore et al. 2015). This research area focuses on social problems, such as homelessness, poverty, and mental illness (Westley and Antadze 2010). *Social-ecological transformations research* is based on social-ecological systems and resilience studies (Berkes et al. 2000; Gunderson and Holling 2002; Berkes et al. 2003). This research area is concerned about fundamental shifts of human and environmental interactions in complex social-ecological systems (Gunderson and Holling 2002; Berkes et al. 2003; Walker et al. 2004; Olsson et al. 2014), emphasising transformations of governance structures. *Socio-technical transitions research* is based on science and technology studies as well as evolutionary economics. It is concerned with the replacement of socio-technical regimes, which emerge around dominant technologies, through radical niches, i.e. protected spaces in which path-breaking innovations develop (Grin et al. 2010; Smith and Raven 2012). This research area focuses mainly on transitions towards more sustainable water, mobility, and energy systems in urban and rural contexts (Loorbach et al. 2017).

Former reviews and interdisciplinary work provide detailed insights on commonalities and differences of these research areas (Pereira et al. 2015; Feola 2015; Patterson et al. 2017; Loorbach et al. 2017; Hölscher et al. 2018; Horcea-Milcu et al. 2020; Scoones et al. 2020). For instance, one difference is how these research areas frame their system of interest (Loorbach et al. 2017). Social innovations research focuses on how leaders induce change in social systems (e.g., health care, education, and labour system). Social-ecological transformations research is concerned with the capacity of social-ecological systems (e.g., forestry, fisheries, and agriculture system) to respond to disruptive change. Socio-technical transitions research investigates non-linear change in socio-technical systems (e.g., energy, mobility, and water system).

Despite the different theoretical backgrounds, the three research areas all describe sustainability transformations as multilevel, multiphase, and cross-scale processes (Olsson et al. 2014). Commonalities can be found in notions such as path dependencies, regimes, niches, experiments, and governance (Loorbach et al. 2017; Pereira et al. 2018). Furthermore, they all strive to understand how to increase the impact of sustainability initiatives via amplification processes to foster transformations. In the following, we briefly introduce the six frameworks (Fig. 1), with further information for each framework in Table 1, and the process descriptions of each framework in Table 2.

1. *Strategies for social innovation* research discusses processes to increase the impact of social innovations (Moore et al. 2015). Its main question is how social innovations can contribute to systemic impacts and large systems change (Moore et al. 2015). Large systems change requires a combination of different processes. Moore et al. (2015) describe these processes as *scaling out*, *scaling up*, and *scaling deep* (Table 2).
2. *Seeds of a good Anthropocene* research discusses processes to spread seeds, which are social, technological, economic, or social-ecological initiatives (Bennett et al. 2016). The purpose for seeds is to spread and have transformative impact beyond their initial context (location or sector) (Bennett et al. 2016). Bennett et al. (2016) describe spreading processes of seeds as *scale up, scale out,* and *scale deep* (Table 2). These spreading processes build up on Moore et al. (2015), use similar terms, but describe processes differently since this framework has a different understanding of sustainability initiatives.

Table 2 Amplification processes from the different frameworks (*Not used in analysis because this process does not focus specifically on increasing impact)

Framework	Amplification process
Strategies for social innovation	**Scaling out** To impact greater numbers of people or communities. Scaling out consists of two strategies: 1. "Deliberate replication. Replicating or spreading programmes geographically and to greater numbers while protecting the fidelity and integrity of the innovation" (Moore et al. 2015, p. 77). 2. "Spreading principles. Disseminate principles, but with an adaptation to new contexts via co-generation of knowledge, leveraging social media and learning platforms: 'open scaling'" (Moore et al. 2015, p. 77). Open scaling means spreading "the core principles and approach of the innovation […], leaving it to the local community to adapt it to local conditions" (Moore et al. 2015, p. 78). **Scaling up** To impact "higher levels of institutions through policy change" (Moore et al. 2015, p. 79) by codifying innovative approaches into law, policy and institutions. Scaling up consists of one cross-scale strategy with two approaches: "Policy or legal change efforts. New policy development, partnering, advocacy" (Moore et al. 2015, p. 77). 1. Shifting "work to higher levels in government in order to address root causes in larger-scale institutions" (Moore et al. 2015, p. 79) that affect an entire population. This often entails "leaving behind the initial innovative initiative, and starting an entirely new initiative focused on policy change" (Moore et al. 2015, p. 79). 2. Linking "together community-level policy interventions into a more coherent movement" (Moore et al. 2015, p. 79). **Scaling deep** To impact cultural roots. This is based "on the recognition that culture plays a powerful role in shifting problem-domains, and change must be deeply rooted in people, relationships, communities and cultures" (Moore et al. 2015, p. 77). Scaling deep consists of two strategies: 1. "Spreading big cultural ideas and reframing stories to change beliefs and norms. Intensively share knowledge and new practices via learning communities, distributed learning platforms and participatory approaches" (Moore et al. 2015, p. 77). 2. "Invest in transformative learning, networks and communities of practice" (Moore et al. 2015, p. 77). Learning is "a specific strategy used to build shared mindsets across a range of sectors and organizations, to ensure the impact of […] initiative is scaled deep into the defining routines and practices and beliefs of partners and collaborators. […] [L] earning processes […] can be supported by a range of methods, including: mentorship, deliberate transfer of practices, capturing and sharing organizational or community culture, and shared reflection and evaluation practices" (Moore et al. 2015, p. 80). **Cross-cutting*** *Broaden the problem frame*: To adopt "a systems-change perspective" is critical to build "consciousness and intention to change" (Moore et al. 2015, p. 76). This strategy reveals systemic or root causes of problems, leads organizations to re-conceptualize their goals, and enables "organizational leaders to consider different types of scales (e.g. organizational scales, temporal scales, political scales), and to understand the complex interrelated layers of variables and phases of change" (Moore et al. 2015, p. 76). *Seek alternative resources*: To find "new funding, or entirely new funding models" because it is "a necessary precursor to scaling" (Moore et al. 2015, p. 76). *Build networks and partnerships*: To network across sectors is specifically "valuable for focused collaboration, resource-pooling, extending the organization's sphere of influence, and developing unusual alliances." (Moore et al. 2015, p. 75). Networks are also important to generate coherence (Moore et al. 2015).
Seeds of a good Anthropocene	**Scale up** To "grow to involve more people and places" (www.goodanthropocenes.net). **Scale out** To reproduce "in different places" (www.goodanthropocenes.net). **Scale deep** To "change underlying values to inspire people to live in a different way" (www.goodanthropocenes.net).
Scale dynamics	**Outscaling** To "replicate and disseminate programs, products, ideas or innovative approaches in order to affect more people or to cover a larger geographical area" (Hermans et al. 2016, p. 287). **Upscaling** To embed or institutionalize "an innovation and changing the 'institutional logics' of

Table 2 Amplification processes from the different frameworks (*Not used in analysis because this process does not focus specifically on increasing impact) *(Continued)*

Framework	Amplification process
	an incumbent regime" (Hermans et al. 2016, p. 287). This is done by being concerned with "identifying opportunities and barriers within institutional structures to properly embed an innovation and the actions that niche actors employ to achieve that, such as creating and fine-tuning technologies, linkage building through intermediation activities, advocacy and lobbying, mobilizing powerful 'patrons', and creating alternative visions, framings and discourses" (Hermans et al. 2016, p. 287).
Acceleration mechanisms	**Replicating** To "take up […] new ways of [thinking, doing and organizing] of one transition initiative by another transition initiative or different actors in order to spread out these new ways." (Gorissen et al. 2018, p. 173).
	Partnering* To pool and/or complement "resources, competences, and capacities in order to exploit synergies to support and ensure the continuity of the new ways of [thinking, doing and organizing]." (Gorissen et al. 2018, p. 173).
	Upscaling To increase the number of "members, supporters or users of a single transition initiative in order to spread these new ways of [thinking, doing and organizing]." (Gorissen et al. 2018, p. 173).
	Instrumentalising* To tap into and capitalize on "opportunities provided by the multi-level governance context of the cityregion in order to strengthen new ways of [thinking, doing and organizing] locally." (Gorissen et al. 2018, p. 173).
	Embedding To align "old and new ways of [thinking, doing and organizing] in order to integrate them into city-regional governance patterns." (Gorissen et al. 2018, p. 173).
Transition management	**Deepening** To learn "as much as possible from a transition experiment" (Rotmans and Loorbach 2008, p. 27) within a specific context. Learning in deepening "includes (local) shifts in ways of thinking, values and perspectives (culture), shifts in doing things, habits and routines (practices) and shifts in organizing the physical, institutional or economic context (structure). […] The outcome of deepening is a (local) constellation of culture, practices and structures that fulfills a societal need in a fundamentally different way." (van den Bosch and Rotmans 2008, p. 29–30).
	Broadening To repeat and link "an experiment in a different context" (Rotmans and Loorbach 2008, p. 27). "What is repeated or linked is the new or deviant constellation of culture, practices and structure, which is the outcome of innovation and learning processes (deepening). […] The result of broadening can be distinguished in: (1) the new or deviant culture, practices and structure get diffused or adopted in a variety of contexts or (2) the new or deviant culture, practices and structure fulfill a broader function." (van den Bosch and Rotmans 2008, p. 32).
	Scaling up To "apply a successful experiment at a higher scale level" (Rotmans and Loorbach 2008, p. 27). This means "embedding a transition experiment in –new- dominant ways of thinking (culture), doing (practices) and organizing (structure), at the level of a societal system. […] The outcomes of scaling up are fundamental changes in the dominant way societal needs are fulfilled, which extend the scale of the initial innovation project." (van den Bosch and Rotmans 2008, p. 33–34).
Strategic niche management	**Growing** To grow means that "[t] he experiment continues and more actors participate, or the scale at which technologies are used increases" (Naber et al. 2017, p. 344).
	Replication To replicate means that "[t] he main concept of the experiment is replicated in other locations or contexts" (Naber et al. 2017, p. 344).
	Accumulation* To accumulate means that the "[e] xperiments are linked to other initiatives" (Naber et al. 2017, p. 344).
	Transformation To transform means that "[t] he experiment shapes wider institutional change in the regime selection environment" (Naber et al. 2017, p. 344).

3. *Scale dynamics* research discusses impacts of grassroots innovations across scales enacting transformative change (Hermans et al. 2016). Its purpose is to better understand how grassroots innovations can lead to transformative change across scales and impact beyond their initial context (Hermans et al. 2016). Hermans et al. (2016) describe scaling processes as *outscaling* and *upscaling* (Table 2).
4. *Acceleration mechanisms* research discusses processes that represent means through which transition initiatives can accelerate urban sustainability transitions (Valkering et al. 2017; Gorissen et al. 2018). The objective is to understand how accelerating the accumulation of change and feedback loops in urban sustainability transitions occurs (Gorissen et al. 2018; Ehnert et al. 2018). Gorissen et al. (2018) and Ehnert et al. (2018) describe processes for acceleration as *replicating, partnering, upscaling, instrumentalising,* and *embedding* (Table 2).
5. *Transition management* research discusses processes to increase the impact of transition experiments especially in urban contexts in which small-scale innovations, if successful and combined with others, are tested to move a transition forward (van den Bosch and Rotmans 2008; Loorbach 2010). Rotmans and Loorbach (2008) consider the processes of *deepening, broadening,* and *scaling up* to increase the impact of transition experiments (Table 2).
6. *Strategic niche management* research discusses upscaling processes of transition experiments (Naber et al. 2017). The purpose is to increase the potential of niches to influence regimes (Naber et al. 2017). According to the Multi-Level Perspective (Geels 2002), niches are protective spaces for radical innovations to develop (Smith and Raven 2012), whereas regimes are incumbent socio-technical configurations to realize societal needs (Smith et al. 2010). Naber et al. (2017) describe upscaling processes as *growing, replication, accumulation,* and *transformation* (Table 2).

Typology of amplification processes

To further unpack the commonalities and differences between frameworks, we developed an integrative typology of amplification processes in three steps: identification, comparison, and aggregation of processes. In the first step, we identified in each framework those processes that specifically focused on increasing the impact of sustainability initiatives by analysing the process descriptions (Table 2). Here, we followed Moore et al. (2015), who differentiates between amplification processes and enabling factors. Amplification processes specifically aim to increase impact while enabling factors support this and are relevant across different processes (Moore et al. 2015). Enabling factors are, for instance, *cross-cutting, partnering, instrumentalising*, and *accumulation* (Table 2). We excluded these enabling factors from our analysis because they are relevant for all processes (Moore et al. 2015).

In the second step, we compared the identified processes to uncover similarities and differences (Table 2). We found that the frameworks often describe different processes with similar terms and similar processes with different terms. While comparing the different processes, we gained four insights. First, all frameworks share processes aiming to impact more people and places by increasing, for example, the number of sustainability initiatives through new initiatives (i.e., *scaling out, scale out, scale up, outscaling, upscaling, replicating, broadening, growing, replication*; Table 2). However, the descriptions of these processes differ in level of detail and focus, especially concerning the dependency of new initiatives to existing ones, and the similarity of the context to which

new initiatives are amplified. Furthermore, some of them contain additional descriptions of other processes that actually focus on the stability of initiatives to have long-term impact (i.e., *scale up, upscaling, growing*; Table 2). Second, most of the frameworks share processes that aim to impact higher institutional levels (i.e., *scaling up, upscaling, embedding, transformation;* Table 2). These processes pursue the goal of impacting the societal system by, for instance, changing rules and laws. Third, only the framework of acceleration mechanisms addresses the speed of impact (Gorissen et al. 2018). Fourth, only few frameworks discuss processes that address the change of values and mind-sets (i.e., *scaling deep, scale deep, deepening*; Table 2).

In the third step and based on the aforementioned comparison, we identified eight generic and unique types of amplification processes (Fig. 2): *stabilizing, speeding up, growing, replicating, transferring, spreading, scaling up,* and *scaling deep*. Table 3 shows how each process of the six frameworks is allocated to our eight amplification processes and vice versa. Table S1 provides the exact quotes that we referred to for the allocation (see Additional file 1). It is crucial noting that these processes are not mutually exclusive and that one initiative can deploy diverse processes to increase its impact. In the following, we describe each amplification process and provide examples of initiatives from diverse urban and rural contexts (e.g., social-ecological and socio-technical, Global North and Global South) that illustrate these processes (Table 4 for overview of examples).

We derived *stabilizing* from processes that mainly focused on prolonging the impact of an initiative (Table 3 and S1). *Stabilizing* involves strengthening and more deeply embedding initiatives in their context, making them more resilient to up-coming challenges and ensuring that they last longer. This means that initiatives employ actions that capitalize on existing opportunities, increase the number of members, supporters, or users, and also professionalize their practice to ensure a lean procedure and clear

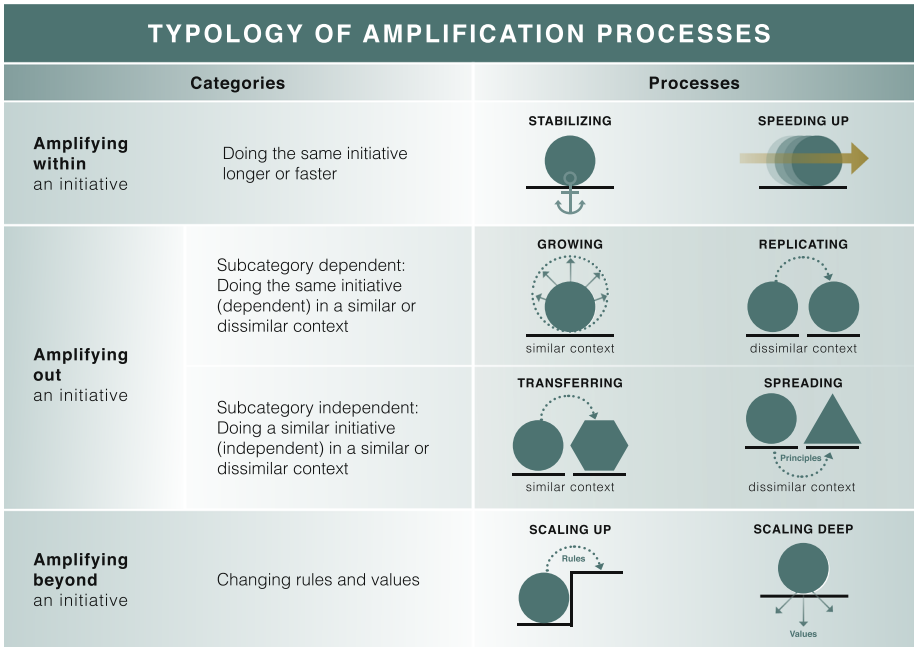

Fig. 2 Illustration of the eight amplification processes grouped into three categories. Note that there is no vertical correspondence between the eight illustrations intended

Table 3 Overview of how the amplification processes of different frameworks overlap and differ as well as how we grouped them under the amplification processes. We only analysed processes that focus on increasing impact and therefore excluded cross-cutting, partnering, instrumentalising, and accumulation in this analysis (Table 2; *Speeding up is based on the idea of acceleration mechanisms which processes can increase the pace of a transformation. Italics indicate not perfect matches. A more detailed overview of the integration of amplification processes is provided in Table S1)

Amplification processes	Amplification frameworks					
	Strategies for social innovation	Seeds of good Anthropocene	Scale dynamics	Acceleration mechanisms	Transition management	Strategic niche management
Stabilizing		*Scale up*		Upscaling		Growing
Speeding up				**all processes*		
Growing		Scale up	*Outscaling*	*Upscaling*		Growing
Replicating	Scaling out	Scale out	Outscaling		Broadening	
Transferring				*Replicating*	Broadening	Replication
Spreading	Scaling out			Replicating	Broadening	Replication
Scaling up	Scaling up		Upscaling	Embedding	Scaling up	Transformation
Scaling deep	Scaling deep	Scale deep			Deepening	

communication of purpose and mission (Bennett et al. 2016; Valkering et al. 2017; Gorissen et al. 2018). One example is the Alam Sehat Lestari (ASRI) organization (www.alamsehatlestari.org), an Indonesian non-governmental organization in West Kalimantan, whose name means "healthy nature everlasting". ASRI stabilized its impact by involving and getting support from communities and organizations around the Gunung Palung National Park to assist the conservation and reforestation programs. ASRI also facilitated knowledge sharing about sustainable farming and secured the support from other non-governmental organizations (e.g., Health in Harmony; www.healthinharmony.org) and universities to increase ASRI's capacity to adapt to new challenges (Shetty 2009; Pohnan et al. 2015).

Speeding up is based on the framework acceleration mechanisms which aims to accelerate transformations (Gorissen et al. 2018; Ehnert et al. 2018). Although none of the processes from the frameworks specifically addressed the speed of impact as such, *speeding up* is important because current sustainability challenges demand faster impact of initiatives. *Speeding up* involves increasing the pace by which initiatives create impact or are brought to fruition (Frantzeskaki et al. 2017; Valkering et al. 2017; Gorissen et al. 2018). The aim is that initiatives create change faster, for example, by increasing the efficiency of organisational or implementation procedures to have more impact over time (Rosenthal et al. 2017). The role of time and pace with regards to impact of initiatives is essential because current sustainability challenges (e.g., climate change and biodiversity loss) require immediate and fast actions to avoid irreversible change (Olsson 2017). One example is Alberta's Unleashing Local Capital initiative, which provides capital to finance local business development and foster community ownership in urban and rural contexts (www.acca.coop/unleashing). The Unleashing Local Capital initiative was restructured after a first evaluation to increase the efficiency of procedures. This restructuring led to speed up the procedures from proposal to investment to impact (Gismondi et al. 2015).

We derived *growing, replicating, transferring,* and *spreading* from processes that seek to impact more people and places, often by increasing the impact range or number of

Table 4 Overview of examples that illustrate the amplification processes. For each example, we describe what the impact is and how it is amplified

Amplification processes	Example	What is the impact and what is amplified?
Stabilizing	Alam Sehar Lestari, non-governmental organization in Indonesia	- Impact: Restoring forest areas and reducing illegal logging in Gunung Palung National Park in West Kalimantan, Indonesia. - Amplification: Stabilizing impact through getting support from communities and other organizations.
Speeding up	Unleashing Local Capital, local financing program from Alberta Community and Co-Operative Association in Canada	- Impact: Providing capital to finance local business development and foster community ownership. - Amplification: Speeding up impact through restructuring processes to provide capital faster after submitting proposals.
Growing	Public Lighting Authority, state-created authority in the city of Detroit, U.S.A	- Impact: Providing LED street lights to the whole City of Detroit. - Amplification: Growing of impact by installing LED street lights in the whole City of Detroit from 2014 until 2017. - Similar context: Socio-technical context (LED street lights) and geographical context (City of Detroit) did not change.
	Slow Food Italy, food movement in Italy	- Impact: Promoting local food cultures and traditions through locally acting groups. - Amplification: Growing of movement through establishing more than 290 locally acting groups. - Similar context: Socio-cultural context (Italy) did not change.
Replicating	The Nature Conservancy, global non-governmental organization	- Impact: Protecting ecologically-valuable land. - Amplification: Replicating local chapters to different countries and states with place-based missions. - Dissimilar context: Socio-ecological context (ecosystems) changed.
	Alnatura, organic grocery store in Germany	- Impact: Providing organic local food products. - Amplification: Replicating stores to different cities in Germany. - Dissimilar context: Socio-economic context (locally produced food) changed.
Transferring	Water-independent house concept, Tucson, Arizona, U.S.A.	- Impact: Reducing water demand from houses in cities. - Amplification: Transferring the concept from Tucson, Arizona to Phoenix. - Similar context: Socio-technical context (water-independent house concept) did not change.
	Ciclovía, car-free city initiative in Bogotá, Colombia	- Impact: Providing car-free streets in cities for the public, especially cyclists. - Amplification: Transferring of the initiative to more than 100 cities. - Similar context: Socio-cultural context (car-free streets in cities) did not change.
Spreading	Transition Town Network, global network of transition initiatives	- Impact: Supporting communities to reimagine and rebuild their cities, villages or districts. - Amplification: Spreading of key principles to different communities all over the world. - Dissimilar context: Context to which the key principles are applied changed.
Scaling up	Planned Lifetime Advocacy Network, family-led charitable organization in Canada	- Impact: Supporting parents of children with disabilities to provide a good life and future

Table 4 Overview of examples that illustrate the amplification processes. For each example, we describe what the impact is and how it is amplified *(Continued)*

Amplification processes	Example	What is the impact and what is amplified?
		for their children. - Amplification: Changing financial regulations concerning savings and benefits for people with disabilities.
	Ciclovía, car-free city initiative in Bogotá, Colombia	- Impact: Providing car-free streets in cities for the public, especially cyclists. - Amplification: Becoming an official program of the city government.
Scaling deep	Time banks, United Kingdom	- Impact: Providing services in communities. - Amplification: Changing values through increasing social inclusion in communities by promoting reciprocal altruism. -
	City-community initiative in Burgas, Bulgaria	- Impact: Renaturation of city districts. - Amplification: Regarding nature as a solution instead of a risk in the context of urban flood protection.

initiatives (Table 3 and S1). These four processes are characterised by two aspects (Fig. 2): (1) the dependency of the amplification (e.g., new initiative elsewhere) to the existing initiative and (2) the similarity of the context to which an initiative has been amplified. A new initiative is dependent when it, for instance, belongs to the existing initiative (e.g., an initiative opening another office in another city). The context to which an initiative is amplified is similar, when essential social, ecological, political or technical structures and dynamics do not substantially differ between the old and new contexts. The relevant context of an initiative is characterised by the type of initiative. For example, the relevant context of a green energy initiative can be the access to technology (Zemp et al. 2011; Lutz et al. 2017); whilst the relevant context for an initiative that aims to promote locally and sustainably produced food can be the food system.

Growing entails the expansion of the impact range (Bennett et al. 2016; Naber et al. 2017). Here, an initiative works in the same way across a geographical location, organization, or sector. As a result of a growing process, an initiative covers more of its potential impact range by reaching out with its program, product, solution or service, or by opening affiliates which are dependent on the existing initiative. One example is the City of Detroit becoming the first large city in the U.S.A. to deliver 100% public lighting through energy-saving LED lights. The growing process took 3 years from 2014 to 2017 within the socio-technical context of providing public lighting in the geographical context of Detroit (www.pladetroit.org). Another example is the growth of the Slow Food movement in Italy, which is now a global grassroots organization that supports local food cultures and traditions, provides an alternative to hectic life styles, and fights people's decreasing interest in the food they eat (Chaudhury and Albinsson 2015). Since its foundation in 1989, Slow Food grew to a movement with more than 290 locally acting groups ('convivas') in the socio-cultural context of Italy. The 'convivas' are dependent to each other through the coordination and support by Slow Food Italy on the national level (www.slowfood.com). The expansion of Slow Food beyond Italy does not fall under the amplification process *growing* but refers to *transferring* (see below).

Replicating involves the copying of an initiative to a dissimilar context (Moore et al. 2015; Hermans et al. 2016; Bennett et al. 2016; Naber et al. 2017). One example is the branch structure of The Nature Conservancy (TNC), which allows TNC to act responsively in different local contexts dependent on a centrally coordinated conservation strategy (Dees et al. 2004). Another example from TNC is its land acquisition program as a principal tool to conserve nature in different parts of the world. Through this program, TNC identifies ecologically valuable land in different social-ecological contexts, conducts professional appraisals, and publicly markets the property in order to find conservation-minded buyers. TNC has supported to protect 21 million acres in the U.S.A. and approximately 103 million acres globally (www.nature.org). Another example for *replicating* is the rise of the German organic grocery store chain Alnatura in urban contexts (e.g., Hamburg or Munich) where each new local store is dependent on the headquarters, but functions in dissimilar socio-economic contexts, which means sourcing different locally produced products. Alnatura opened the first store in Mannheim in 1987 and replicated after 30 years 125 stores all over Germany (www.alnatura.de).

Transferring involves taking an initiative and implementing a similar but independent one in a different place, adapted to the new but similar local context (Rotmans and Loorbach 2008; Withycombe Keeler et al. 2016). In comparison to the *growing* process, a similar but independent initiative emerges. One example is the transfer of a water-independent house concept from Tucson (Arizona, U.S.A.) to Phoenix (Arizona, U.S.A.), a similar socio-technical context (Forrest et al. 2020). Another example is the transfer of the Ciclovía initiative of Bogotá in Colombia, which offers car-free corridors on Sundays and holidays for cyclists and runners in urban contexts (Zieff et al. 2013). Ciclovía was transferred to more than 100 cities around the world through the Open Streets Project, initiating more than 100 independent initiatives in similar socio-cultural contexts (www.openstreetsproject.org).

Spreading involves disseminating core principles and approaches to other places with a dissimilar context (Rotmans and Loorbach 2008; Moore et al. 2015). In comparison to *replicating*, a similar but independent initiative emerges, that is *informed* by principles or approaches from an existing initiative. One example for spreading is the Transition Town Network disseminating its principles through a website, publications, and personal exchange to inspire local transition initiatives globally (Feola and Butt 2017). The transition initiatives share the same principles (Hopkins 2008); however, they conduct different and independent projects which are strongly adapted to their social, ecological, political or technical context (Shawki 2013).

We derived *scaling up* from processes that aim to impact higher institutional levels by changing the rules or logics of incumbent regimes (Table 3 and S1). This means codifying the impact of initiatives into law, policy, or institutions by, for instance, advocacy, lobbying, networking, or supporting alternative visions and discourses (Rotmans and Loorbach 2008; Moore et al. 2015; Hermans et al. 2016; Naber et al. 2017). One example is the work of the Planned Lifetime Advocacy Network (PLAN) in Canada (Moore et al. 2015). PLAN is a family-led charitable organization founded by parents of children with disabilities. PLAN's work led to a Registered Disabilities Savings Plan for people with disabilities to avoid financial state dependency (Moore et al. 2015). Another example is the Ciclovía initiative (see above) as it started in Bogotá in the early 1970s

through the efforts of cycle activists and became an official program of the city government in 1982 (Díaz del Castillo et al. 2011).

We derived *scaling deep* from processes that address the change of values and mind-sets (Table 3 and S1). *Scaling deep* aims to change people's values, norms, and beliefs through the work of the initiative by fostering new mind-sets, changing perceptions, and introducing new ways of relating and knowing as well as new value systems (Rotmans and Loorbach 2008; Moore et al. 2015; Bennett et al. 2016; Loorbach et al. 2017; Horcea-Milcu et al. 2019). An example are time banks in the United Kingdom where people earn a time credit for the time they spent helping another person. The accrued credits are, in turn, spent on services received from other members of the time bank (Seyfang 2004). Time banks increase social inclusion in communities by promoting reciprocal altruism and provide an alternative way to value work within the hegemonic understanding of work and welfare (Seyfang 2004; Bellotti et al. 2013). Another example is the city-community initiative from the city of Burgas, Bulgaria, in which citizens together with the city unsealed soil and planted trees as a nature-based solution for urban flood protection (Frantzeskaki 2019). By introducing nature-based solutions and by including citizens into urban planning, nature can be recognized as a source of solutions instead of a risk.

To reduce the complexity of amplification processes, we aggregated the eight processes in three categories based on their underlying rationale: *amplifying within, amplifying out,* and *amplifying beyond* (Fig. 2). *Amplifying within* consists of processes which generally seek to increase the impact of one specific initiative by, for instance, *stabilizing* its existence (i.e., prolonging impact) or *speeding up* the way it impacts (i.e., accelerate impact). *Amplifying out* consists of processes, which generally seek to increase the impact of initiatives by involving more people and places through a greater impact range and a higher number of initiatives. We use the dependency of the amplification (e.g., new initiative) to the existing initiative to divide *amplifying out* into two subcategories (Fig. 2). The first subcategory (*amplifying out dependent*) refers to processes that create initiatives, which are dependent on existing ones. This subcategory includes *growing*, when an existing initiative's impact range increases in a similar context, and *replicating,* when the existing initiative is replicated in a dissimilar context. The second subcategory (*amplifying out independent*) refers to processes that create independent initiatives either by *transferring* an initiative to another place with a similar context, or by *spreading* the principles of an existing initiative to a similar initiative in another place with a dissimilar context. *Amplifying beyond* consists of processes that generally seek to increase their impact by *scaling up* to reach higher institutional levels or by *scaling deep* to change values. Processes of *amplifying beyond* are different from the other categories in that they suggest a reconsideration of how initiatives create impact.

Relevance of the typology

Our typology serves to integrate existing literature on amplification processes from sustainability transformations research. We hope this will (1) bring more coherence into the dispersed literature on such processes, (2) encourage dialog across research areas to support reflection on these processes, and (3) be of practical assistance to sustainability initiatives in striving to increase their transformative impact by exploring the spectrum of amplification processes.

First, with our typology we aspire to bring more coherence into the dispersed literature by aggregating the different amplification processes discussed into three categories (i.e., *amplifying within, amplifying out, amplifying beyond*). This reveals that amplification includes increasing the impact range and number of initiatives in urban or rural contexts (*amplifying out*), the stabilization and acceleration of impact (*amplifying within*), and rethinking how initiatives create impact (*amplifying beyond*). Furthermore, the typology disentangles the different amplification processes grouped under *amplifying out* (i.e., *growing, replicating, transferring, spreading*) based on the dependency of new initiatives to existing initiatives, and the similarity of the context to which new initiatives are amplified to. The variety of processes grouped under *amplifying out* indicates that most studies assume that more initiatives will foster transformations. This assumption mirrors orientations derived from modernist and growth-centred paradigms, which are often found in the discussion on scaling technological innovations. Yet, recent literature highlights a need to leave this perspective behind through processes that change institutional structures, values, or mind-sets (i.e., *amplifying beyond*) (Olsson et al. 2017). These insights add clarity across research areas on how initiatives in urban and rural contexts can amplify their impact to foster sustainability transformations and can inform future creation of new initiatives that have an amplification purpose. These can also guide future research development about the drivers, barriers, mechanisms, and institutions required for sustainability initiatives to amplify their impact.

Second, this typology considers diverse ideas regarding amplification by integrating existing work from three research areas. It provides a common language for amplification processes that can facilitate dialogue between scholars of different research areas, potentially helping to enable inter- and transdisciplinary collaborations. In our review, we realized that a big share of current work focuses on increasing the range and number of sustainability initiatives in urban or rural contexts (i.e., *growing, replicating, transferring, spreading*) and impacting higher institutional levels (i.e., *scaling up*). However, less studies describe how the impact of initiatives can be stabilized or accelerated (i.e., *stabilizing, speeding up*) or how initiatives can change values and mind-sets (i.e., *scaling deep*). Therefore, our typology also contributes to rethink which processes require more attention in future research.

Third, our typology can provide guidance for the design of urban and rural sustainability initiatives that have an amplification purpose. For example, to foster large-scale systemic change, most probably a combination of different amplification processes is needed, some of which are more suitable to perform in the beginning (e.g., *stabilizing, replicating*) and some require a more advanced development of an initiative or even a new initiative (i.e., *scaling up*) (Moore et al. 2015). Designing initiatives which target system-wide sustainability problems need to take into account challenges and requirements of future amplification (Ghiron et al. 2014).

Considerations and limitations

Amplification of impact from promising sustainability initiatives are complex, non-linear, context-specific, and place-based processes, which may even lead to negative, unanticipated, social and environmental side effects, such as bad labour conditions, environmental degradation, or reduction of diversity which increases vulnerability (Leach et al. 2012; Gee et al. 2013; Olsson et al. 2017). Therefore, we consider amplification of

impact not per se as positive or negative, nor do we claim that the processes described apply to all contexts and places. For example, some processes stem from frameworks that focused only on either urban or rural contexts (Gorissen et al. 2018) and most of the reviewed frameworks stem from research conducted in the Global North. Future research needs to show how applicable our insights are for research on transformations in the Global South, especially in contexts of indigenous peoples and local communities as they may have different understandings of amplification and transformations (Lam et al. 2020).

Amplification entails considerable responsibility challenges, for instance, with regard to anticipating positive and negative outcomes, responding to societal needs and concerns expressed by different stakeholders, being reflexive and adaptive to changing circumstances and contexts, and being inclusive in terms of collaboration and who benefits (Wigboldus et al. 2016). Furthermore, amplification poses questions of power and justice. For instance, it should take into account procedural justice: Who has the power to foster change and decide the direction of change? (Avelino and Rotmans 2011; Boonstra 2016); Who has the ability and responsibility to revoke initiatives that have been amplified and caused negative effects? (Wigboldus et al. 2016); Or who selects which initiatives should be amplified? In addition, amplification of initiatives should also deal with distributive justice by reflecting on who will benefit and lose if initiatives get amplified. For example, one contested sustainability initiative in terms of justice is the production of biofuels and its undesirable impacts on food security and equity of often marginalized actors (Tilman et al. 2009; Blaber-Wegg et al. 2015; Renzaho et al. 2017).

The typology has some limitations, for instance, as it represents a snapshot of current literature, it contains overlaps between processes, and it might miss other processes. Due to the dispersed literature on processes that specifically aim to foster transformations, we did not conduct an exhaustive systematic review, but we selectively reviewed those frameworks from different research areas that target sustainability transformations. Furthermore, we do not regard our amplification processes as completely excluding each other, especially with regard to the processes of *amplifying out*. Here, the processes described in the literature often seemed overlapping, but we tried to make differences clear (i.e., dependence of the new initiative on the existing initiative and the similarity of the context). Due to our selection of amplification frameworks, our typology might miss other processes, but we are confident that we have covered the ones most dominantly discussed in the scientific literature at the moment.

Future research

Future research should focus on (1) in-depth understandings of less explored amplification processes, (2) interactions and consequences of processes, (3) differences of amplifying initiatives in urban or rural contexts, and (4) skills and agency of actors.

First, we need to further investigate amplification processes that are less covered in the scientific literature, especially which aim to achieve greater speed of impact (*speeding up*) and to change values and mind-sets (*scaling deep*). Accelerating the impact of sustainability initiatives is of high importance (e.g., through more efficiency), because research highlights the need to act with greater speed against sustainability challenges to not cross any points of no return (e.g., climate change, biodiversity loss) (Rockström

et al. 2009; Russill and Nyssa 2009; Smith et al. 2016; Olsson et al. 2017). Investigating how initiatives can change or activate values and mind-sets is of interest because it is one way to target deep leverage points (i.e., places to intervene in systems) which can lead to fundamental transformations of systems (Meadows 1999; Abson et al. 2017; Horcea-Milcu et al. 2019).

Second, research needs to investigate the interactions and consequences of amplification processes. Knowing which combinations (i.e., which processes together) and sequences (i.e., which processes when in time) of processes are most supportive for transformations can help initiatives to amplify their impact and to better design new urban or rural initiatives that have an amplification purpose (Moore et al. 2014; Moore et al. 2015). Investigating the consequences of processes, such as long-term, cross-scale (e.g., institutional, temporal, or spatial) and domain (e.g., agriculture and labour conditions) effects could unravel unanticipated and undesired outcomes (Moore and Westley 2011).

Third, our typology builds on amplification frameworks that focus on initiatives in urban and rural contexts fostering sustainability transformations. Future research may investigate which processes and which combinations of processes are more or less applied by initiatives that exist and have impact in either urban or rural contexts, or in both. Furthermore, it would be interesting to investigate how initiatives from urban contexts amplify their impact to rural contexts and vice versa, for instance, via processes of *amplifying out* or *amplifying beyond*.

Finally, it is important to investigate which skills and agency actors need to pursue amplification processes drawing from the discussions on agency from the different research areas. Building up on resilience and social innovations literature, it is interesting to explore the skills that actors need for different processes and during different phases of sustainability initiatives (Moore et al. 2015). Examples for skills are cultural skills (e.g., visioning, framing, motivating), leveraging and brokering skills (e.g., identifying windows of opportunity, networking, connecting ideas and resources), and political-interactional skills (e.g., coalition forming, bargaining, leveraging resources) (Westley et al. 2013). It is necessary to understand how skills for amplification processes are connected to the notions of transformative agency, distributed agency, and system entrepreneurship (Riddell 2013; Westley et al. 2013; Olsson 2017). Connecting to discussions in the sustainability transitions literature, it is interesting to explore the different roles that actors can play (e.g., from the lens of intermediaries), which values drive them, and how they build alliances to foster transformative change (de Haan and Rotmans 2018; Kivimaa et al. 2019).

Conclusion

Based on a literature review, we developed a typology of amplification processes to increase the impact of sustainability initiatives that exist in urban or rural contexts. Amplification processes are *stabilizing, speeding up, growing, replicating, transferring, spreading, scaling up*, and *scaling deep*. We aggregated amplification processes into three categories: *amplifying within, amplifying out*, and *amplifying beyond* an initiative. This typology integrates work on amplification processes across different research areas and from studies in urban and rural contexts to unveil how different frameworks working on sustainability transformations conceptualize amplification. Our typology of amplification processes views amplification as threefold: Increasing the impact (1) by

prolonging or accelerating the impact of one specific initiative (*amplifying within*), (2) by impacting more people and places (*amplifying out*), and (3) by changing how initiatives create impact (*amplifying beyond*). We believe that our typology can stimulate the debate on amplification, by bringing coherence into the dispersed literature on amplification processes, encouraging dialogue across research areas to support reflection on amplification processes, and being of practical use for sustainability initiatives. Scientists and non-academic actors could benefit from this typology in enhancing dialogues, coordinating efforts, and eventually increasing the impact of sustainability initiatives to foster urban and rural transformations.

Supplementary information

Supplementary information accompanies this paper at https://doi.org/10.1186/s42854-020-00007-9.

Additional file 1: Scaling the impact of sustainability initiatives: a typology of amplification processes.

Abbreviations

ASRI: Alam Sehat Lestari; PLAN: Planned Lifetime Advocacy Network; TNC: The Nature Conservancy; U.S.A.: United States of America

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Publisher's Note

3.2. Indigenous and local knowledge in sustainability transformations research: a literature review

David P. M. Lam, Elvira Hinz, Daniel J. Lang, Maria Tengö, Henrik von Wehrden, Berta Martín-López (2020)

Ecology and Society

Picture shows things that mean resilience for indigenous and local leaders who met at a workshop in Ixtlán, Mexico in 2017. The workshop was part of the second international conference from the Programme on Ecosystem Change and Society (PECS).

Lam, D., E. Hinz, D. Lang, M. Tengö, H. von Wehrden, and B. Martín-López. 2020. Indigenous and local knowledge in sustainability transformations research: a literature review. *Ecology and Society* 25(1):3. https://doi.org/10.5751/ES-11305-250103

Research

Indigenous and local knowledge in sustainability transformations research: a literature review

David P. M. Lam [1], Elvira Hinz [1], Daniel J. Lang [1], Maria Tengö [2], Henrik von Wehrden [1] and Berta Martín-López [1]

ABSTRACT. Scholars, politicians, practitioners, and civil society increasingly call for sustainability transformations to cope with urgent social and environmental challenges. In sustainability transformations research, understandings of transformations are often dominated by Western scientific knowledge. Through a systematic literature review, we investigated how indigenous and local knowledge (ILK) is represented in peer-reviewed empirical scientific papers that apply ILK in contexts of transformation, transition, and change. Our results show, first, that all papers applied ILK to confirm and complement scientific knowledge in contexts of environmental, climate, social-ecological, and species change. Only four papers (5%) applied ILK to conduct research on transformations. Second, we identified four research clusters that apply ILK in contexts of transformation, transition, or change in (1) Arctic, (2) terrestrial, (3) coastal, and (4) grass and rangelands environments. These clusters are located along two axes: tropic to Arctic and marine to terrestrial. Finally, our results indicate that indigenous and local understandings of transformations are currently neglected in the scholarly transformations discourse. The reviewed papers do not focus on how indigenous peoples and local communities understand transformations, instead they focus on what changes indigenous peoples and local communities observe and describe, resulting from their daily experiences and activities. We argue that because of its in-depth local, place-based character, ILK can substantially contribute to a more plural understanding of transformations and the assessment of transformative change. We conclude that future research needs to investigate how to gain a more plural understanding of transformations that leads potentially to more inclusive actions toward more just, equitable, and sustainable futures on a local and global level.

Key Words: *indigenous and local knowledge; knowledge system; multiple evidence base approach; traditional ecological knowledge; transformation; transition*

INTRODUCTION

For more than two decades, sustainability transformation research has sought to better understand how large system changes toward just, equitable, and sustainable futures can be fostered (Loorbach et al. 2017). Diverse definitions of and approaches to transformation exist in the literature (Patterson et al. 2017, Blythe et al. 2018). They are decisively influenced by Western scientific knowledge because it is currently the dominant knowledge system that sets prevailing standards for research (Davis and Ruddle 2010). Knowledge systems exist through "agents, practices and institutions that organize the production, transfer and use of knowledge" (Cornell et al. 2013:61). Knowledge from other knowledge systems, such as indigenous and local knowledge (ILK) systems are rarely involved in research, especially in transformation research (Blythe et al. 2018).

The contributions of ILK for sustainability and research are increasingly considered in sustainability science (Mistry and Berardi 2016, Tengö et al. 2017). Indigenous and local knowledge is defined as a "cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment" (Berkes 2018:8). Its contributions are especially highlighted by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). For example, Brondizio and Le Tourneau (2016) argued that involving indigenous peoples and local communities is essential to develop and implement more effective environmental governance systems for ecosystems and biodiversity. Another example is the exchange of ILK and scientific knowledge in the case of pollinator conservation (Hill et al. 2019). Indigenous peoples and local communities practice biocultural approaches to pollinator conservation in all continents, except Antarctica, which maintain biodiversity and Nature's contributions to people (Díaz et al. 2018, Hill et al. 2019). The contribution of ILK is also exemplified by the combination of observations from Tibetan pastoralists and scientific knowledge on climate change to support the hypothesis of delayed summers on the Tibetan Plateau (Klein et al. 2014, Mistry and Berardi 2016). Reasons for this growing interest are the long-standing relationships of indigenous peoples and local communities with their surrounding environments, the holistic knowledge accumulated in centuries to govern social-ecological systems, and the ability of these communities to overcome crisis and changes of all different types (e.g., livelihood change, climate and ecosystem change, availability of resources; Pearce et al. 2015, Berkes 2018).

Despite these positive examples of how ILK can contribute to sustainability and research, studies that investigate how indigenous and local understandings of transformation can support working toward just, equitable, and sustainable futures are less abundant. In fact, the transformation discourse seems to pay insufficient attention to social differentiation, issues of power and plurality which threatens the legitimacy of the discourse (Blythe et al. 2018). To overcome some of these challenges, we argue that a more inclusive and plural understanding of transformations is needed, which views transformations from the perspective of diverse knowledge systems.

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The aim of this study is to review to what extent indigenous and local understandings of transformation are represented in the scientific sustainability transformation literature. To reach this goal, we conducted a systematic literature review of ILK in contexts of transformation, transition, and change. The findings intend to stimulate the debate on transformations to enable a more plural and comprehensive understanding of transformations, which includes insights from diverse knowledge systems.

SUSTAINABILITY TRANSFORMATION RESEARCH

The interest in sustainability transformations is increasing among scholars with different theoretical backgrounds and has led to the emergence of different conceptual approaches to transformations (Olsson et al. 2014). Reviews from Feola (2015), Loorbach et al. (2017), and Patterson et al. (2017) provide detailed overviews and discussions of these conceptual approaches to transformations that show the diversity of how transformations can be understood within the Western scientific knowledge system. Following Patterson et al. (2017), we briefly introduce how four prominent conceptual approaches to transformations from the global sustainability literature understand transformations: (1) social-ecological transformations, (2) sustainability transitions, (3) transformative adaptation, and (4) sustainability pathways (Table 1).

Table 1. Overview of four prominent conceptual approaches to transformation based on Patterson et al. (2017). These conceptual approaches to transformation have different perspectives, foci, and aims, which show the plurality of how sustainability transformations are understood within research.

Approach to transformation	Perspective	Focus	Aim
Social-ecological transformations	Place based	Social-ecological systems	Resilient natural resource use and management
Sustainability transitions	Sectoral	Social-technical systems	Sustainable production and consumption
Transformative adaptation	Systemic and structural	Power issues in transformative processes	Opportunities and possibilities for vulnerable groups
Sustainability pathways	Contextually grounded sustainable development	Human development	Sustainable and just pathways of change

First, the social-ecological transformations approach focuses on social-ecological systems (e.g., forest, fishery, agriculture systems) while often taking a place-based research perspective (Berkes et al. 2002, Gunderson and Holling 2002; Table 1). Its disciplinary roots are in ecology but are strongly widened by social sciences (Patterson et al. 2017). Social-ecological transformations literature is based on complex adaptive systems theory that discusses resilience, adaptability, and transformability as key properties of social-ecological systems (Berkes et al. 2002, Gunderson and Holling 2002, Walker et al. 2004). This approach understands transformations as "shifts that fundamentally alter human and environmental interactions and feedbacks" (Walker et al. 2004, Olsson et al. 2014:1).

Second, the sustainability transitions approach generally focuses on social-technical systems while often taking a sectoral perspective (e.g., energy, water, waste, food systems; Grin et al. 2010, Köhler et al. 2019; Table 1). This approach investigates long-term societal change toward sustainability. Its disciplinary roots are in innovation studies, complex systems theory, technology studies, institutional analysis, and evolutionary as well as institutional economics (Patterson et al. 2017). This approach understands transformations as transitions (see Hölscher et al. 2018 for a comparison of the terms transformation versus transition) and thus as "co-evolution processes that require multiple changes in socio-technical systems or configurations," "multi-actor processes," "radical shifts from one system or configuration to another," "long-term processes," and "macroscopic" (Grin et al. 2010:11-12).

Third, the transformative adaptation approach focuses on power issues within transformative processes as an adaptive response to climate change (Pelling et al. 2015; Table 1). It takes a systemic and structural perspective on human vulnerability and equity concerns linked to climate change (Pelling 2010, O'Brien 2012). Transformative adaptation aims to change fundamental systemic structures and paradigms that produce vulnerability for people. Its disciplinary origins are in development studies, human geography, and political ecology (Patterson et al. 2017). This approach understands transformations, for instance, as "physical and/or qualitative changes in form, structure or meaning-making (…). It can also be understood as a psycho-social process involving the unleashing of human potential to commit, care and effect change for a better life" (O'Brien 2012:670).

Fourth, the sustainability pathways approach focuses on human development while often taking a contextually grounded sustainable development perspective (Leach et al. 2007, Scoones et al. 2015; Table 1). This approach investigates the governance aspects of transformations and highlights the role of citizens at the same time (Scoones et al. 2015). Its disciplinary roots are in development studies, political science, complex systems theory, anthropology, and economics (Patterson et al. 2017). This approach does not relate to one specific definition of transformation due to the differences of context and perspectives (Scoones et al. 2015). However, this approach highlights the role of pathways to sustainability in which a pathway is "the way in which a given system changes over time, depending on the issue in question, several different scales may be important, sometimes simultaneously and in overlapping ways" (Leach et al. 2007:12).

This brief overview does not claim to be exhaustive, but shows how transformation is understood differently within the Western scientific knowledge system. Scholars with different theoretical backgrounds have different foci in transformations (e.g., social-ecological, social-technical systems), apply different perspectives (e.g., place-based, sectoral), and pursue different aims (e.g., resilience and sustainable production and consumption; Table 1). Despite these differences, they jointly contribute to a more comprehensive understanding of what a transformation in the sense of a large system change means. They all call for large-scale societal change toward sustainability while understanding transformations as nonlinear, complex, long-term, multilevel, multiphase, and cross-scale processes (Olsson et al. 2014, Loorbach et al. 2017). Indigenous and local knowledge systems

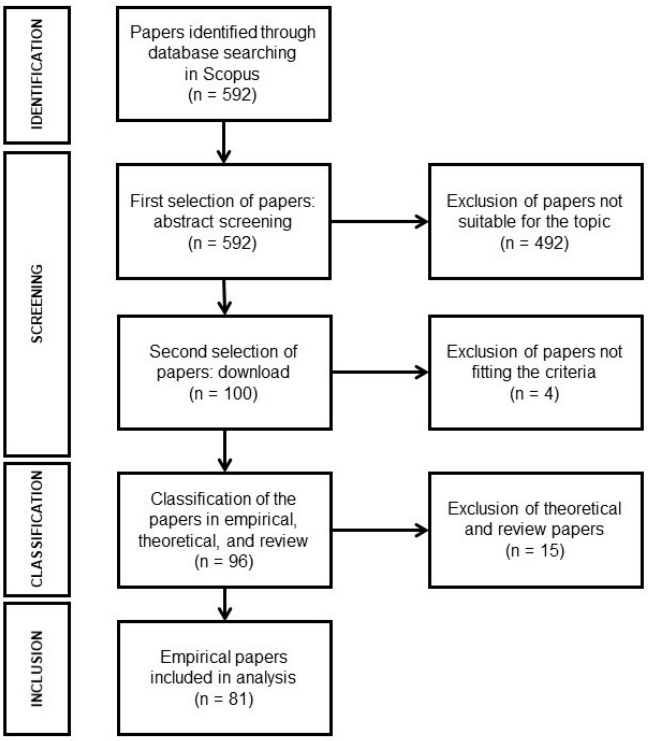
may contribute different insights to the scientific understandings of transformations because of their (1) accumulation of knowledge, practices, and beliefs; (2) strong connection to the environment of indigenous peoples and local communities; and (3) emphasis on relationships of living beings with another and with their environment (Berkes 2018).

METHODS

Systematic literature review

To identify the existing body of research on ILK in sustainability transformation research, we conducted a systematic literature review (Pullin and Stewart 2006, Luederitz et al. 2016; Fig. 1). First, we searched for primary research articles on ILK and sustainability transformations in the Scopus database. The search string used for the review comprised two main elements: (1) transformation (e.g., transformation, transition, or change) and (2) ILK (e.g., indigenous ecological knowledge, local ecological knowledge, or traditional ecological knowledge). The terms "transition" and "change" were selected because of their possible interpretation in the sense of transformation (i.e., large system change; Appendix 1). The search was applied to abstracts, titles, and keywords of published papers written in English between 2000 and 2016. The year 2000 was set as the starting date because at this time research in combination with ILK was becoming ubiquitous in different scientific fields, such as resource management (Cruikshank 2001).

Fig. 1. Flow diagram of the selection process used in the systematic literature review.



The search returned 592 papers (Fig. 1), of which 492 were disregarded after the screening of titles and abstracts because they did not meet the following criteria: (1) they did not apply or observe indigenous, traditional, or local knowledge; and (2) they were not connected to transformation, transition, or change. We also excluded papers that were not published in English (n = 4).

Then, we classified the remaining papers (n = 96) into the groups of review, theoretical, and empirical papers to filter only empirical papers for our literature review (n = 81; Appendix 2 for complete list of reviewed empirical papers). We excluded review and theoretical papers because we were only interested in empirically supported evidence for indigenous and local understandings of transformations.

Data analysis

We conducted qualitative content analysis and coded the content of the final set of 81 papers using the software MAXQDA 12 (Mayring 2014). We developed the coding scheme (Appendix 3) according to the research aims and the variables that help to answer the research questions. Main categories of the coding scheme were general paper characteristics, methodological approach, location of case study, the occurrence and use of the terms transformations and ILK and their synonyms, and the connection of ILK and transformations in the reviewed literature. We continuously adapted and refined the coding variables during the iterative process of coding the papers until we reached a consistent information level.

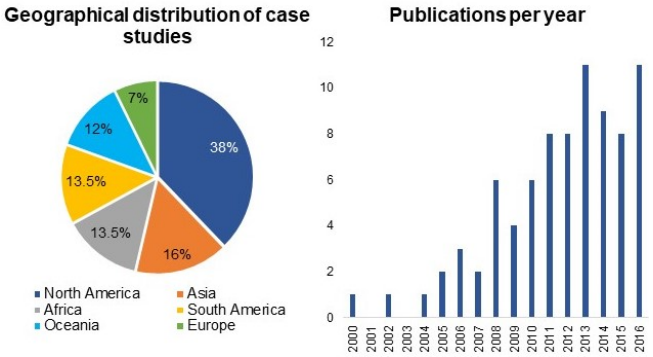
In addition, we quantitatively analyzed the full text of the final set of 81 papers. All words that appeared in at least one of the papers were extracted to examine the abundance of the individual terminologies across all papers (Abson et al. 2014, Partelow et al. 2018). The extracted list contained n = 5570 unique words, which was further reduced by excluding adjectives, pronouns, articles, numbers, and abbreviations that were content-wise not relevant to the topic. In addition, words with ambiguous meaning that had no connection to the topic were excluded (e.g., background or cycle). Our final list contained n = 842 words. With the final multivariate word by paper matrix, we conducted a detrended correspondence analysis with R software to derive a visualization of the principal gradients found within the abundance of words in the papers (Hill and Gauch 1980). Using the detrended correspondence analysis to visualize the first two axes of the multivariate space, we in addition clustered papers into groups that shared the same wording, using Wards clustering (Abson et al. 2014). Different groups were visualized within the ordination by different colours. Detrended correspondence analysis is a standard ordination analysis predominantly used in ecology with sparse datasets, extracting main gradients out of multivariate datasets based on reciprocal averaging (Hill and Gauch 1980). Statistical significance of cluster groups was supported by an indicator species analysis, which allowed the identification of words that were significantly occurring and hence indicating a specific cluster group.

RESULTS

Geographical and temporal distribution

The 81 papers investigated 82 case studies (1 paper with 2 case studies). The biggest part of the research was conducted in North America with 31 papers (38%), followed by Asia with 13 papers (16%), Africa with 11 papers (13.5%), South America with 11 papers (13.5%), Oceania with 10 papers (12%), and Europe with only 6 papers (7%; Fig. 2). We also identified a general increase in publications per year, especially since 2008 (Fig. 2).

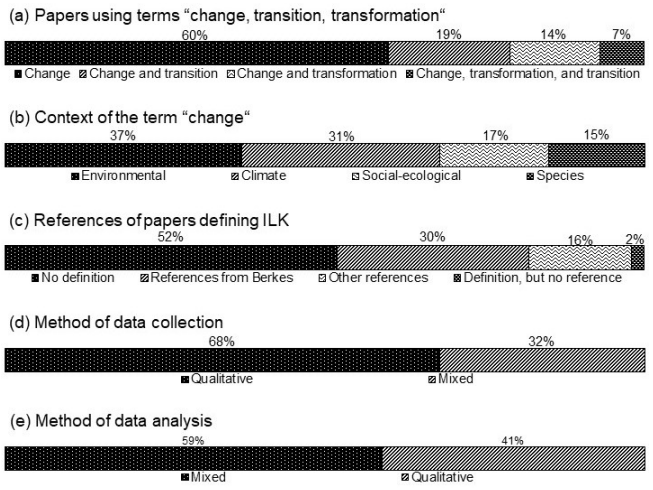
Fig. 2. Geographical distribution of case studies (n = 82, because one paper investigated two case studies) and temporal distribution of publications (n = 81).



Understandings of transformations

We found few empirical papers that included ILK to understand transformations among the reviewed scientific papers. The application of the words "transformation," "transition," and "change" in the reviewed papers showed a clear focus on the use of the word "change" in combination with ILK. In all 81 papers (100%) the word "change" was mentioned, "transition" in 21 papers (26%), and "transformation" in 17 papers (21%; Appendix 4). In 49 papers (60%), only "change" was used (Fig. 3a). The combination of "change" and "transition" was used in 15 papers (19%). The words "change" and "transformation" were used together in 11 papers (14%). Six papers (7%) used all three words.

Fig. 3. Overview of results (n = 81). Note ILK = indigenous and local knowledge.



Only four papers (5%) used the term "transformation" in the sense of a social-ecological system change (i.e., Kassam 2009, Andrachuk and Armitage 2015, Apgar et al. 2015, Jandreau and Berkes 2016). Eleven papers (14%) used "transformation" or "transition" in the sense of a system change, but did not define it, such as a transition of a pastoral system (Homann et al. 2008). Furthermore, 11 papers (14%) used these terms in ecological contexts, such as "transition of temperature and landscape" or "environmental transformations" (e.g., Chalmers and Fabricius 2007, Fernández-Llamazares et al. 2015, de Almeida et al. 2016). Additionally, the "transformation of living conditions" was researched in four papers (5%; e.g., Klein et al. 2014, Herman-Mercer et al. 2016).

Regarding the term "change" the predominant focus of the analyzed literature body lies in observations and perceptions of environmental (n = 30, 37%) or climatic (n = 25, 31%) changes by ILK holders (Fig. 3b). The papers dealing with environmental changes focus, for instance, on marine (e.g., Taylor et al. 2011, Moshy and Bryceson 2016) or terrestrial environments (e.g., Paré et al. 2010, Kgosikoma et al. 2012). Papers focusing on climatic change often investigated indigenous and local perceptions of climate change and interpretations of climate variables, such as temperature or precipitation (e.g., Boillat and Berkes 2013, Boissière et al. 2013). Fourteen papers (17%) dealt with social-ecological changes, for example, changing livelihood circumstances due to environmental alterations (e.g., Ford et al. 2006, Kassam 2009). The remaining 12 papers (15%) dealt with change in terms of changes in species abundance and behavior (e.g., Kendrick et al. 2005, Carter and Nielsen 2011).

Conceptualization of indigenous and local knowledge

The term of ILK summarizes all the different descriptions of indigenous, traditional, or local knowledge systems occurring in the reviewed literature body. Some authors constrain to one description, for instance, traditional ecological knowledge (Gill and Lantz 2014) or indigenous knowledge (Wilson et al. 2015), but most of the papers (n = 60, 74%) used the different terms synonymously.

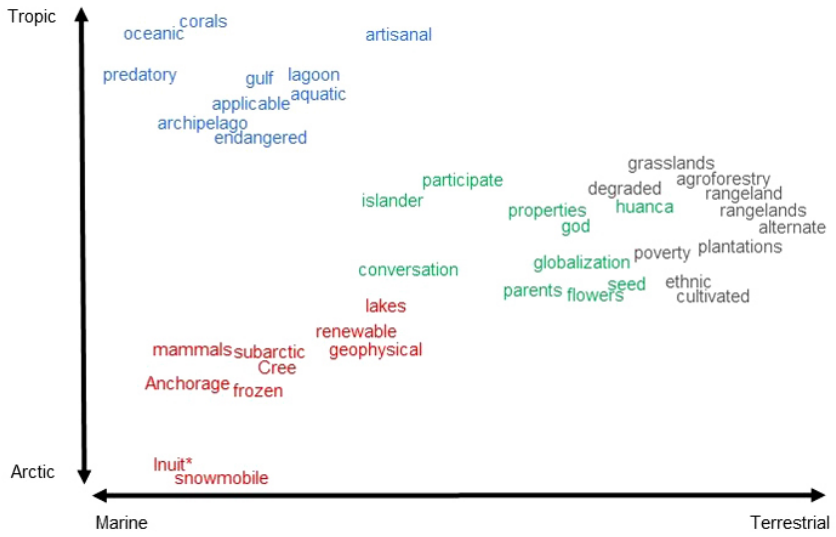
Only 39 papers (48%) explicitly defined ILK (Fig. 3c), of which 24 papers (30%) referenced literature from Fikret Berkes who defined ILK (or traditional ecological knowledge) as "a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment" (Berkes 2018:8). Thirteen papers (16%) used other definitions and references to define ILK, for instance, ILK defined as "place-based knowledge that is rooted in local cultures and generally associated with long-settled communities which have strong ties to their natural environments" (Orlove et al. 2010:244). Two papers (2%) did not link their definition of ILK to other literature.

Methodological approach in indigenous and local knowledge research

The methodological approach of the data collection in the reviewed literature showed a strong tendency to qualitative methods (Fig. 3d). Fifty-five papers (68%) used qualitative methods exclusively, particularly semistructured interviews and focus-group discussions, and 26 papers (32%) conducted a mix of qualitative and quantitative methods.

In 48 papers (59%), data analysis included both qualitative and quantitative methods, indicating that data collected through qualitative methods often were analyzed through statistical methods (Fig. 3e). In 33 papers (41%), solely qualitative methods were used, such as content analysis of the interviews (e.g., McCarthy et al. 2012, Altschuler and Brownlee 2016).

Fig. 4. Research clusters resulting from detrended correspondence analysis: research in Arctic environments (red), research in terrestrial environments (green), research in coastal environments (blue), and research in grass and rangeland environments (gray). *wording adjusted.



Clusters of scientific literature on transformations and indigenous and local knowledge

The cluster analysis, which is visualized in the detrended correspondence analysis of the words used in the reviewed papers, yielded four distinct research clusters: (1) research in Arctic environments (red), (2) research in terrestrial environments (green), (3) research in coastal environments (blue), and (4) research in grass and rangeland environments (gray). These clusters were distributed along two axes: (1) marine vs. terrestrial environments (X-axis) and (2) Arctic vs. tropic climatic conditions (Y-axis; Fig. 4). Appendices 5 and 6 present more information for each research cluster (e.g., geographical distribution of case studies, key research aspects) and a complete list of significant indicator words, respectively.

The cluster of research in Arctic environments comprised 26 papers (32%; red). This cluster focused solely on case studies in Arctic environments, including Alaska, the Canadian Arctic, and Siberia. Actors involved in the research were members of different indigenous communities in Arctic regions, such as the Inuit, the Cree, or the Chipewyan Dene. The key research aspects of this cluster were observations and understandings of changing climatic and environmental conditions. Because of the widespread subsistence activity of hunting mammals on land and ice, especially changes in sea ice and the distribution and abundance of different animal populations in the Arctic regions were objects of research in this cluster.

The cluster of research in terrestrial environments included 22 papers (27%; green). The spatial focus of this cluster lay mostly in case studies in Oceania and South America. Actors involved in this research cluster were either from indigenous communities or local communities. The research focused on the perception of climatic changes and the adaptive capacity of the local communities to these changes. Unlike the other clusters, this cluster paid high attention to societal aspects and culturally important issues in the communities, such as education, globalization, government, beliefs, spirituality, and traditions.

The cluster of research in coastal environments comprised 14 papers (17%; blue). This cluster focused strongly on coastal and island regions of all continents. Actors involved in the research of this cluster included local fishers or divers with local ecological knowledge of the marine environments in these regions. Key research objects in this cluster were changes in marine ecosystems, such as coral reefs and lagoons, which served as habitats for endangered fish and plant species, and appropriate management strategies for a positive development of these ecosystems.

The cluster of research in grass and rangeland environments included 19 papers (24%; gray). The spatial focus of this cluster lay in Africa and Asia. Participants were predominantly actors with an agricultural background, for instance, local herders, smallholder farmers, and households owning small land areas or livestock. Hence, the research focus lay in environmental changes of grass- and rangelands and the consequences for livestock management and farming. Problematic issues mentioned in this cluster were desertification and vegetation changes as well as mitigation processes against these changes.

DISCUSSION

Three major insights gained through our literature review: (1) a lack of research to understand transformations from the perspective of ILK systems, (2) challenges of researching ILK in contexts of change, and (3) a pledge for a more plural understanding of transformation. Based on these insights we formulated relevant starting points for future research.

Lack of research to understand transformations from the perspective of indigenous and local knowledge systems

This study demonstrates a gap in understanding transformations from the perspective of ILK systems in the sustainability transformation literature. Despite our comprehensive search

string (Appendix 1), we identified only four papers (5%) in our review that applied indigenous and local observations of change to investigate transformations from social-ecological literature (i.e., Kassam 2009, Andrachuk and Armitage 2015, Apgar et al. 2015, Jandreau and Berkes 2016). This result might be explained by two main reasons: (1) potential caveats of this study, and (2) an actual lack of consideration of ILK in sustainability transformation research.

The first explanation relates to an important caveat of this research, which is that we only sampled peer-reviewed papers published in English referenced on Scopus. This sampling method can lead to a systematic sampling bias because the consideration of ILK to foster sustainability transformations could mostly appear outside of this body of academic literature and in languages other than English (Vinyeta and Lynn 2013). Research on ILK with a focus on understanding transformations, for instance, from cultural anthropology or ethnobiology may exist in other sources, such as books or papers that are not accessible through Scopus and are written in other languages. A similar sampling bias has previously been reported in systematic reviews of ILK with regard to conservation initiatives (Benyei et al. 2020). Furthermore, most of the case studies of the reviewed papers conduct research in North America, which might also be a bias. This would be true if the reason for this is the fact that North America is generally the continent with the highest amount of academic literature worldwide (King 2004), which therefore may also lead to more research in this area. However, another possible reason for this focus could be that the regions of Alaska and the Canadian Arctic are some of the most affected regions by global climate change worldwide (Hinzman et al. 2005). The loss of sea ice due to climate change has an especially strong impact on the livelihood of indigenous peoples and local communities in Arctic regions. Because indigenous and local observations of climate change and its consequences are treated a lot in the reviewed literature body, it could be a logical outcome that case studies in these affected regions dominate the reviewed literature.

The second explanation could be that sustainability transformation research has indeed not engaged thoroughly with ILK yet despite the recognition that more plural perspectives and worldviews need to be considered to advance sustainability transformation research (Loorbach et al. 2017). We only found four papers from social-ecological transformations literature that investigated transformations with ILK. Indigenous and local understandings of transformation have the potential to relate the values, contexts, worldviews, and cultures of indigenous peoples and local communities to the transformations discourse (Apgar et al. 2015), such as in environmental governance (Brondizio and Le Tourneau 2016), climate change (Savo et al. 2016), conservation (Benyei et al. 2020), and resource management research (Ban et al. 2018). The engagement of ILK in sustainability transformation research is still emerging and in its infancy. Including more than simply Western scientific knowledge systems to change perspectives and find solutions for sustainability challenges still gets relatively little attention (Golden et al. 2015). However, the number of recent papers that showcase the value of bridging ILK and scientific knowledge for climate change mitigation and biodiversity conservation is increasing (Gavin et al. 2015, Brondizio and Le Tourneau 2016, Garnett et al. 2018, Hill et al. 2019). A challenge is that in contrast to scientific knowledge, ILK is often regarded as "subjective, arbitrary, and based on qualitative observations of phenomena and change" (Mistry and Berardi 2016:1275). Also, current research approaches that try to apply ILK are often driven by Western research methods and political agendas, such as predominant conservation and development approaches, which is questionable because all knowledge is value driven and linked to socially situated actors (Weiss et al. 2013, Mistry and Berardi 2016). For example, the perception and interpretation of climate change is very different whether the observation approach is local or global, or from an ILK or scientific knowledge perspective (Byg and Salick 2009). Another example is from Golden et al. (2014), who presented the challenge of mutual understanding and negative connotations to Western terms and concepts. In their study, they described the absence of the word or concept "adaptation" in the culture of First Nations in Canada and argued that it makes a common approach to research on adaptation almost impossible.

Challenges of researching indigenous and local knowledge in contexts of change

Our results support the trend of increasing research that engages with ILK in contexts of environmental, climate, social-ecological, and species change in different environments (Figs. 2, 3, 4). However, our results indicate three challenges that accompany research with ILK in contexts of change: (1) the added value of ILK, (2) the use of qualitative methods, and (3) the focus on change and adaptation.

First, understanding the added value of ILK for sustainability research is difficult because ILK is very different from scientific knowledge (Berkes 2018) and in our review, 42 papers (52%) did not even provide a definition for ILK. Indigenous and local knowledge is "local and context-specific, transmitted orally or through imitation and demonstration, adaptive to changing environments, collectivized through a shared social memory, and situated within numerous interlinked facets of people's lives" (Mistry and Berardi 2016:1274). However, the trend is still to assimilate ILK within scientific knowledge instead of acknowledging ILK as an equally relevant knowledge system (Tengö et al. 2014, Mistry and Berardi 2016). Hence, engaging with ILK means encountering different worldviews, practices, ethics, identities, power relations, and rights (Tengö et al. 2017). The results from the detrended correspondence analysis also show that the green cluster (i.e., terrestrial environments) was the only one that presented social aspects of ILK, such as belief, culture, and language (Fig. 4; Appendix 5).

Second, the different methodological approaches used in the reviewed papers show the predominant use of qualitative methods both in data collection and data analysis, which indicates the complexity involved in investigating and understanding ILK. Csonka (2005) mentioned the mostly oral character of these knowledge systems, which requires the use of qualitative methods and the contribution of "qualitative, historical field data" (Vinyeta and Lynn 2013:14). However, Davis and Ruddle (2010) criticized that the standards of accountability and transparency for research on ILK need to be improved, starting with "the requirement that researchers provide descriptions of research designs and methodologies sufficient to enable assessment of the reliability and representativeness of findings, and to facilitate comparison, generalization, and evidence-based conclusions"

(Davis and Ruddle 2010:892). Others see great potential in the open and qualitative character of research on ILK because of the "readiness, reliability and low cost" of associated methods (Hallwass et al. 2013:402) and the possibility to support and complement the usually more quantitative data of Western scientific research (Moshy and Bryceson 2016). Furthermore, qualitative approaches may also be more likely to capture and articulate aspects of ILK systems that are holistic and not directly commensurable with reductionist science (Whyte et al. 2016).

Third, the detrended correspondence analysis revealed four research clusters that generally focus on observing changes with indigenous peoples and local communities in Arctic, terrestrial, coastal, and grass and rangeland environments (Fig. 4; Appendices 5, 6). Research on change that includes ILK can be better differentiated by the environments in which the research is conducted than by the theoretical or methodological approaches used. This indicates greater diversity of the biophysical conditions studied compared to the theoretical and methodological approaches used. The focus of observing change lays with natural phenomena, such as melting of ice, change of flora and fauna, and climate variations. This research on change in different environments tends to be driven more by natural science research, such as ecology or biology, with less focus on social aspects. Additionally, the research clusters generally focus on the practices of indigenous peoples and local communities in their respective environments and how these practices have adapted to changes. One example is the change in hunting practices of the Inuvialuit people in Canada's Western Arctic due to climate change (Berkes and Jolly 2002). However, none of the research clusters indicates a focus on understanding which practices or strategies indigenous peoples and local communities apply to navigate and manage their environments toward desired states, i.e., often breaking out of and transforming negative situations.

Summing up, future sustainability transformation research that engages with ILK should be transparent about how ILK is understood and which research designs and methodologies are applied. Research, which engages with ILK, needs to also apply different innovative methods to deal with the complexity of ILK and to make insights from local and place-specific ILK useful for other regions of the world that also undergo processes of change. Possible methods could include the analysis of stories and songs that are a repository of ILK (Fernández-Llamazares and Cabeza 2018, Fernández-Llamazares and Lepofsky 2019). Additionally, insights from more contextualized and place-based research modes such as transdisciplinary research might provide helpful approaches (Lang et al. 2012, Balvanera et al. 2017*a*). With the societal problems or phenomena as a point of departure and not a specific theory or methodology, transdisciplinarity can serve as a research practice that allows for collaboration between ILK systems and scientific knowledge systems on equal footing. Transdisciplinary research highlights close collaboration between scientific as well as societal actors and is therefore promoted by global sustainability research initiatives (e.g., IPBES, Future Earth) to cocreate knowledge for sustainability transformations (Mauser et al. 2013, Pascual et al. 2017).

Need for plural understanding of transformations

Sustainability transformation research and practice aims at changing how people interact within the systems they live in, such as food or energy systems. For transformative change to improve the living conditions for people from different knowledge systems, it becomes critical to connect with their view on how the world works and changes, how to act for transformations (i.e., what to do to foster change), and what just, equitable, and sustainable futures could be (Braun 2015, Blythe et al. 2018). Thus, we argue for a plural understanding of transformations because this (1) could substantially improve understandings of transformations, (2) is ethically required, (3) could increase agency for contributing to sustainability transformations, and (4) could support research on transformative change.

First, we believe that including people with different knowledge systems can improve the sustainability transformation discourse and practices because it potentially widens the conceptual understanding and provides more variety for actions to foster just, equitable, and sustainable futures. The scientific sustainability transformation discourse has its own understandings or approaches to transformations (Feola 2015), such as social-ecological transformations, sustainability transitions, transformative adaptation, and sustainability pathways (Table 1). Due to different disciplinary roots, they apply different perspectives on transformations (e.g., place-based, sectoral), foci (e.g., social-ecological systems, human development), and pursue different aims (e.g., resilience, sustainable pathways; Table 1; Patterson et al. 2017). What unites them is their call for large-scale societal change toward the normative goal of sustainability and a scientific approach to transformations by viewing transformations as nonlinear, complex, long-term, multilevel, multiphase, and cross-scale processes (Olsson et al. 2014, Loorbach et al. 2017). Indigenous and local understandings of transformation could bring additional perspectives, foci, and aims concerning transformations due to alternative normative goals and emotional as well as spiritual connections to nature (Reid et al. 2006, Gray 2016).

The dominant sustainability transformation discourse aims for the normative goal of sustainability (Loorbach et al. 2017), which is primarily influenced by Western worldviews, values, and knowledge systems (Kothari et al. 2014). A plural understanding of transformation could carefully consider and reflect on alternative normative goals, such as "Buen Vivir," which is a concept that captures a culture of life for collective well-being of people and nature together with different interpretations across South America (Gudynas 2011, Monni and Pallottino 2015), or "Ubuntu," which is a moral concept of caring that connects humanity and has origins in South Africa (Metz 2011). Normative goals of transformations vary between people in different places and from diverse knowledge systems and worldviews. They may also vary among different actors within a place. Perceptions of the normative goal shape possible and preferred actions that may foster change toward a desired direction. Engaging with indigenous peoples and local communities for transformation can therefore be a promising endeavor to collaboratively explore alternative actions for and desired directions of transformations. A reflexive view on the normative aspect of transformations is critical to consider for scholars conducting social-ecological transformations, sustainability transitions, transformative adaptation, or sustainability pathways research in places where indigenous peoples and local communities live, to avoid repeating or reinforcing previous or existing patterns of injustice and marginalization.

Indigenous and local knowledge systems can also provide guidance for how to include emotional and spiritual aspects into the often very positivistic sustainability transformation discourse because ILK systems are knowledge-action-belief complexes and entail different conceptualizations of human-nature connectedness (Gadgil et al. 1993, Reid et al. 2006, Gray 2016, Berkes 2018). Recent literature highlights that successful transformations will not only rely on changing structures and practices, but also on the change of human-nature connectedness as well as values and mindsets (Abson et al. 2017, Horcea-Milcu et al. 2019, Ives et al. 2020). The sustainability transformation literature discusses the need to change people's connection to nature as well as values and mindsets instead of only developing and scaling out new social-technical innovations, such as new technologies (O'Brien 2016, Olsson et al. 2017). However, discussions on how to achieve these changes for transformations at the societal level are still in its infancy. Indigenous peoples and local communities have very different connections to nature and worldviews than do Western societies. Some of them regard themselves as one unit with nature with deep relations to their place and all living beings, which includes mountains, rivers, lakes, and animals (Berkes 2018). These different human-nature connections and worldviews might provide critical reflections for the current Western scientific approaches to transformations (Table 1). A possible reflection could be on how to understand relations between people and nature (e.g., one unit versus divided, or as biocultural relations; Sterling et al. 2017), or the systems of interest (e.g., social-technical systems), which in science often separate people from nature and thus insufficiently recognize the relations and patterns between living beings. Finally, such reflections could lead to new actions to foster transformations that go beyond scaling out of new technologies (e.g., renewable energies) and changing dominant practices by including, for instance, spiritual and emotional values of nature (i.e., scaling deep) or by emphasizing local identity, place, and kinship relations (i.e., scaling down).

Second, there is a strong ethical imperative for engaging with different people and actors concerned with transformations and their aspirations, knowledge, and conditions (Castree et al. 2014, Daedlow et al. 2016). A more collaborative approach to working with indigenous peoples and local communities as partners, might dismantle the power imbalance between ILK and scientific knowledge concerning the notion of transformations (Tengö et al. 2017). This is particularly important in engagement with indigenous peoples and local communities, who have often been marginalized and deprived of livelihoods and self-governance in the name of development and change (Smith 2012). Working toward a plural understanding of transformations might acknowledge cognitive justice, which legitimizes the existence of different knowledge systems, suggests going beyond epistemic supremacy, and is part of processes of decolonizing knowledge (de Sousa Santos 2008, Rodriguez 2017). Cognitive justice "demands recognition of knowledges, not only as methods but as ways of life. This presupposes that knowledge is embedded in an ecology of knowledges, where each knowledge has its place, its claim to a cosmology, its sense as a form of life. In this sense knowledge is not something to be abstracted from a culture as a life form; it is connected to a livelihood, a life cycle, a lifestyle; it determines life chances" (Shiv Visvanathan in Rodriguez 2017:2). A rewarding yet challenging endeavor for sustainability transformation researchers is to reach out to indigenous peoples and local communities and learn from their worldviews and knowledge systems what transformations possibly mean for them, and from there to explore a common ground for transformations to sustainability or any other normative goal. Working with indigenous peoples and local communities as partners can be key to better understand and act for transformations. For instance, the collaboratively developed fire management system in the Canaima National Park in Venezuela shows how ILK and practices of fire management from the Pemon indigenous peoples informed a counter narrative of landscape change that led to a shift in the environmental discourse and policy making regarding fire management in the park (Rodriguez 2017). Another example is related to effective environmental governance (Brondizio and Le Tourneau 2016, Garnett et al. 2018). Indigenous peoples and local communities manage vast areas of land, ecosystems, and biodiversity, and in many cases, their governance systems are sources of sustainable practices, developed and implemented by communities with limited external involvement and embedded in their worldviews (Berkes 2018, Mistry and Berardi 2016, Timoti et al. 2017).

Third, by involving people with diverse knowledge systems, we hope to also draw attention to the challenges related to agency in transformations (Westley et al. 2013, Olsson 2017). Understanding the creation and distribution of agency between different people across scales is key to work collectively and inclusively toward just, equitable, and sustainable futures (Moore 2017). The notion of transformation in sustainability science is currently promoted dominantly by Western scientific knowledge systems, which limits the distribution of agency. A plural understanding of transformations, should involve a more diverse and inclusive set of actors representing diverse knowledge systems, and it should lead to more diverse actions to solve current sustainability problems, other than the often applied approach of solving problems with technological innovations.

Fourth, plural understandings of transformations could contribute to research on transformative change that specifically collaborates with indigenous peoples and local communities. The number of studies investigating transformations is increasing and predicted to grow in the future (Köhler et al. 2019). Most recently, the IPBES outlined, in its next work program until 2030, to assess "factors in human society, at both the individual and collective levels, that can be leveraged to bring about (...) transformative change in favour of biodiversity while taking into account broader social and economic imperatives in the context of sustainable development" (IPBES 2019:18). One explicit ambition from IPBES is to include knowledge from natural sciences, social sciences, humanities, and ILK systems in its assessments through participation and inclusiveness (Díaz et al. 2015, Díaz-Reviriego et al. 2019). Assessing factors that lead to transformative change in favor of biodiversity with ILK systems will entail understanding transformation and transformative change from the perspective of indigenous peoples and local communities as a prerequisite. However, our results show that this is currently neglected in research. We therefore see epistemological, ontological, and methodological challenges that an assessment of transformative change, which includes ILK, could face if it considers cognitive justice and wants to avoid the supremacy of Western scientific knowledge systems.

In summary, we need a plural understanding of transformations because the sustainability challenges we face are as diverse as people are. It is important to be inclusive to different kinds of engagement with sustainability transformations to avoid a supremacy of Western scientific knowledge systems in identifying and prioritizing ways forward. Bridging diverse knowledge systems concerning transformations, could lead to involvement of more people, increased mutual understanding, cocreation of actions across knowledge systems with stronger impact and effectiveness, and support collaborative research on transformative change. As the urgency to solve sustainability problems increases, collaborations between diverse knowledge systems may provide helpful ways of thinking about how to foster transformations.

Future research

Our literature review reveals that the discourse on sustainability transformations lacks understandings of transformations from ILK systems. To address this gap, we suggest two concrete research activities to move forward toward a more plural understanding of transformations: (1) exploring other sources to understand sustainability transformations from an ILK perspective through consultations and collaborations with experts on ILK (i.e., researchers who have studied ILK systems) and ILK holders (i.e., knowledge holders representing their knowledge system, its integrity, and rights), and (2) active engagement of ILK holders and ILK experts in research processes (Tengö et al. 2017). These two research endeavors could also reveal more local understandings of transformations, which in return can potentially contribute to a better understanding of global transformations (Balvanera et al. 2017*b*).

First, consultations and collaborations with experts on ILK and ILK holders who are familiar with the concept of sustainability transformation and who have worked with indigenous peoples and local communities for a long time in their research and other activities can reveal other sources and existing work on different understandings of transformations. The experts on ILK and ILK holders should be used to seeing ILK and scientific knowledge as both legitimate and complementary. Particularly important persons to consult are indigenous scholars and ILK holders with experience in interacting with science and policy, for example in the Convention on Biological Diversity and IPBES. The consultations and collaborations could provide entry points to potential alternative understandings, concepts, and ways to describe and talk about transformation among indigenous peoples and local communities. This could provide insights about diverse views on human-nature connections and alternative perspectives on time, future, change, scale, and amplification (i.e., a different scaling understanding to foster transformations), which are fundamental elements of the Western scientific understanding of transformations.

Second, active engagement with ILK holders and experts on ILK could deepen and broaden the understanding of practices and strategies for transformation as well as contribute to shifting the power dynamics between knowledge systems and addressing the ethical requirements in sustainability transformations research. Tengö et al. (2017) emphasized the need to engage with the actors and institutions that represent ILK systems, rather than scientist interpreting ILK and the main interfaces with scientific and other knowledge systems (Tengö et al. 2017). One possible approach to bridge different understandings of transformations is the multievidence base approach, which recommends five tasks for successful collaborations across knowledge systems: to mobilize, translate, negotiate, synthesize, and apply (Tengö et al. 2017). This set of tasks can guide a knowledge collaboration to facilitate mutual respect and understanding, usefulness for all actors involved and thus both expand the joint knowledge base for transformation as well as strengthen the ethical practices in sustainability transformation research. Joint and deepened understanding can also create a foundation for agency for transformation. Such an encounter of knowledge holders would contribute to going beyond the dichotomy and power asymmetry of ILK versus scientific knowledge (Agrawal 1995). It would help to see the different knowledge systems as equally relevant and complementary, to bridge them (rather than integrate), and hopefully at the end enable them to work together. Furthermore, it would also increase cognitive justice concerning transformations to avoid suppressing nonscientific knowledge systems and amplifying epistemic supremacy of Western knowledge systems (de Sousa Santos et al. 2008, Rodriguez 2017). As discussed, fostering sustainability is only one possible goal besides others that could arise from traditionally marginalized groups, such as Buen Vivir or Ubuntu. By going beyond acknowledging ILK systems within their own frames and worldviews and treating them as an equally relevant and parallel type of knowledge with differing fundamentals (Berkes et al. 2002, Leonard et al. 2013, Tengö et al. 2014), a basis for true collaboration could be built for an enhanced understanding and fostering toward just, equitable, and sustainable futures.

CONCLUSION

This systematic literature review investigated the current role of ILK in sustainability transformation literature. Our study reveals a research gap in understanding transformations from the perspective of ILK systems. We gained an understanding of how ILK is studied in different contexts of change, which is currently applying ILK to confirm and complement scientific knowledge on environmental, climate, social-ecological, or species change. We propose future research endeavors that could yield a plural understanding of transformations and hence, provide an enriched picture of how we could foster inclusive transformations in times of pressing sustainability challenges. Collaborating with indigenous peoples and local communities for transformations has the potential to substantially enrich and question scientific approaches to transformations by providing, for instance, alternative and complementary goals to sustainability, such as Buen Vivir or Ubuntu. Sustainability transformation research needs to avoid the risk of neglecting nonscientific knowledge systems and the risk of perpetuating the supremacy of Western scientific knowledge systems as we endeavor to foster transformations toward just, equitable, and sustainable futures.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/11305

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3.3. Three principles for co-designing sustainability intervention strategies: Experiences from Southern Transylvania

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Picture shows representatives from NGOs discussing how their sustainability initiatives contribute to reaching a more sustainable future for Southern Transylvania.

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PERSPECTIVE

Three principles for co-designing sustainability intervention strategies: Experiences from Southern Transylvania

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Abstract Transformational research frameworks provide understanding and guidance for fostering change towards sustainability. They comprise stages of system understanding, visioning and co-designing intervention strategies to foster change. Guidance and empirical examples for how to facilitate the process of co-designing intervention strategies in real-world contexts remain scarce, especially with regard to integrating local initiatives. We suggest three principles to facilitate the process of co-designing intervention strategies that integrate local initiatives: (1) Explore existing and envisioned initiatives fostering change towards the desired future; (2) Frame the intervention strategy to bridge the gap between the present state and desired future state(s), building on, strengthening and complementing existing initiatives; (3) Identify drivers, barriers and potential leverage points for how to accelerate progress towards sustainability. We illustrate our approach via a case study on sustainable development in Southern Transylvania. We conclude that our principles were useful in the case study, especially with regards to integrating initiatives, and could also be applied in other real-world contexts.

Keywords Leverage points · Place-based · Social-ecological system · Transdisciplinarity · Transformation · Transition

INTRODUCTION

Discussions have intensified around the question how science can contribute to finding solutions to complex sustainability challenges such as climate change or biodiversity loss. Scholars argue that sustainability transformations are urgently needed to ensure justice and wellbeing to the global society while operating within earth's biophysical limits (Raskin et al. 2002; Rockström et al. 2009). Sustainability transformations are desirable, radical and non-linear societal changes often entailing fundamental changes of system interactions and feedbacks, which lead to more sustainable system constellations (Gunderson and Holling 2002; Walker et al. 2004; Olsson et al. 2014). Examples of such transformations are the emergence of an adaptive co-management system to govern wetland landscapes in southern Sweden (Olsson et al. 2004), or the energy transition in Germany (Geels et al. 2016).

Transformational research frameworks have advanced theoretical and empirical understanding of how to foster sustainability transformations in different contexts (Olsson et al. 2014; Wiek and Lang 2016), including urban (Frantzeskaki et al. 2017) and rural contexts (Nieto-Romero et al. 2016), or in social–ecological (Berkes et al. 2000) and socio-technical systems (Grin et al. 2010). Transformational research frameworks are combinations of different methods in a meaningful sequence that seek to produce actionable knowledge to advance sustainability (i.e. to develop evidence-supported solution options) (Wiek and Lang 2016). Solution options are often complex, require long-term processes and involve real-world experimentation, collective learning and continuous adaptation (Wiek and Lang 2016). Various fields have developed transformational research frameworks such as backcasting

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(Robinson 2003), the compram methodology (Complex Problem Handling) (DeTombe 2001), transition management (Loorbach 2010), transdisciplinary case study (Lang et al. 2012), the TRANSFORM methodology (Wiek and Lang 2016), the three horizons technique (Sharpe et al. 2016) and creating transformative spaces applying future methods such as used for the seeds of a good Anthropocene project (Pereira et al. 2018b).

These frameworks have their origins in different bodies of literature, such as social-ecological systems research (Berkes et al. 2000) or sustainability transitions (Grin et al. 2010). They vary in scope including management and governance approaches (e.g. transition management), methodological frameworks (e.g. transdisciplinary case study), strategic planning tools (e.g. backcasting), intervention frameworks (e.g. compram) or future techniques (e.g. the three horizons technique). Despite these differences, they share the common aim of producing actionable knowledge that can be used by actors to mitigate sustainability challenges. Many existing frameworks comprise three generic stages: (1) creating an understanding of system dynamics; (2) assessing current system state(s) against sustainability principles and developing a vision of the desired future state(s) and (3) developing and testing intervention strategies to foster change towards the desired vision (Wiek and Lang 2016). Despite the essential role of this last, interventional stage, the first two stages have been addressed more deeply in the literature (Brandt et al. 2013). Transformational research frameworks define the interventional stage slightly differently, via terms such as *intervention design* (DeTombe 2017), *transition strategy design* (Loorbach 2010) or *backcasting pathway* (Robinson 2003). However, while acknowledging this existing work, both general guidance and empirical examples for how to facilitate the process of co-designing intervention strategies in specific, real-world contexts that build on work, experiences, knowledge and initiatives from local actors remain scarce.

Co-design typically refers to the initial phase of a knowledge co-production process in transdisciplinary research (Lang et al. 2012), in which "researchers and non-academic partners jointly develop a research project and define research questions that meet their collective interests and needs" (Moser 2016, p. 108). Accordingly, we understand the co-design of intervention strategies as a process consisting of diverse facilitated activities (e.g. open discussions, workshops) geared at jointly developing intervention strategies that meet the interests and needs of researchers and non-academic actors involved (e.g. local actors and their initiatives).

Local initiatives by local actors play an important role in fostering context-specific sustainability transformations (Nightingale 2017). They are deeply embedded in the context where they try to foster change, provide insights to the local sustainability challenges and show with their work, goals and missions how these challenges could be approached (Bennett et al. 2016). Integrating existing local initiatives—that is, involving local actors and building on their experience and knowledge when co-designing intervention strategies—is therefore essential for contextualising intervention strategies because they provide relevant local knowledge, experiences and social relations to foster change towards sustainability (Westley et al. 2006; Lang et al. 2012). However, integrating local initiatives into intervention strategies remains a challenge in theory and practice due to the complexity of transformations (Olsson et al. 2006; Kay 2012). Change towards sustainability is often fostered by local initiatives with different approaches and narratives of transformation pathways (e.g. green economy, ecotopian solutions), making it difficult to understand complementarities between seemingly conflicting local initiatives (Luederitz et al. 2017). Additionally, research processes that involve collaborations between academic and non-academic actors pose among other things epistemological and methodological challenges (Lang et al. 2012). One way to facilitate collaboration between researchers and local initiatives is place-based research that employs a transdisciplinary research mode (Lang et al. 2012; Balvanera et al. 2017b). Place-based research highlights the role of a place as a navigation space for different actors to overcome epistemological, methodological and problem framing differences (MacGillivray and Franklin 2015).

In this paper, we aim to advance the theory and practice of developing a process for co-designing intervention strategies to foster transformations in contexts where local actors with their initiatives act for sustainability. We propose three guiding principles that shed light and add depth to the interventional stage of transformational research frameworks, while highlighting the role of contextualisation. We exemplify the three principles using a concrete transdisciplinary case study carried out in Southern Transylvania, Romania. We first present a general formulation of the three guiding principles. Second, we illustrate the principles by presenting how they played out empirically in Southern Transylvania. Finally, we discuss implications of our findings for research and practice.

THREE PRINCIPLES TO FACILITATE THE PROCESS OF CO-DESIGNING INTERVENTION STRATEGIES THAT INTEGRATE LOCAL INITIATIVES

Intervention strategies seek to bridge the gap between the present and desired future state(s) of a system (Wiek and

Kay 2012). We propose three principles that facilitate the process of co-designing sustainability intervention strategies which integrate local initiatives in place-based research (Table 1). We derived the principles from literature in dialogue with our own experiences especially derived from the later presented case study in Southern Transylvania. For each principle, we give a short description and outline possible approaches. In combination, the principles provide guidance for co-designing more effective intervention strategies. Their operationalization will be dependent on the local context, including previous work by the academic and non-academic actors involved, such that different principles may be more or less important in particular situations. Several iterations between principles may be necessary. Yet, Principle 1 is generally the starting point.

Principle 1 Explore existing and envisioned initiatives fostering change towards the desired future.

We argue that designing durable and effective intervention strategies should build on existing momentum and acknowledge existing efforts and experiences in a given place. Existing initiatives working in the desired direction create a solid starting point for possible interventions. Where existing initiatives and local knowledge align with the envisioned transformation, drawing on these initiatives and knowledge can greatly improve take-off and successful implementation of any new interventions. Building on existing initiatives also acknowledges that it is the people living and engaging in the concrete context who will be responsible for fostering the transformation process in the long run. Exploring existing and envisioned initiatives working towards the desired future implies three steps that build on insights and participation of local actors from the previous stages of system analysis and visioning (Table 1).

First, it is necessary to identify existing initiatives and knowledge working towards sustainability to create inventories of initiatives at local, regional or global scales. Two examples are the projects *seeds of a good Anthropocene* with a global perspective on initiatives (i.e. "seeds") that have a local or regional scope (Bennett et al. 2016) and *Accelerating and Rescaling Transitions to Sustainability*, which takes a local urban perspective (Gorissen et al. 2018). Second, it is necessary to identify who is involved and leading different existing initiatives. Actors could be, for example, communities (Barr and Devine-Wright 2012), (non-)governmental organisations (Moore et al. 2015; Langle-Flores et al. 2017) or grassroots innovation groups (Seyfang and Smith 2007). Third, it is necessary to analyse how existing and possible future sustainability initiatives from local actors contribute to changing the state of system elements that need to change for reaching the desired vision or up to an intermediate state. In particular, which system elements need to change can be revealed by revealing the status quo dynamics of a given system (Hanspach et al. 2014). System elements characterise the identity of a system, can be characterised by different states and altering their states determines whether the system has changed or not (Andrachuk and Armitage 2015). For example, the cultivation of crops in the agricultural sector could change from conventional to organic. Another example is the amount of poverty in a region, which could change from high to low. An intermediate state is a tangible moment on the pathway towards the desired vision, for instance, the year 2030 if the desired vision describes the year 2050. Considering an intermediate state for the identified system elements on the pathway towards the desired vision could have a multi-fold purpose. In general intermediate states serve as tangible moments in the future that can be regarded as reachable, mid-term milestones that are less uncertain and, compared to the desired vision can thus be better appraised (Loorbach

Table 1 Three guiding principles for co-designing intervention strategies in transformational research

Principles	Steps
Principle 1. Explore existing and envisioned initiatives fostering change towards the desired future	1.1. Identifying existing initiatives and knowledge working towards sustainability
	1.2. Identifying who is involved and leading different existing initiatives
	1.3. Analysing how existing and possible future sustainability initiatives from local actors contribute to changing the state of system elements that need to change for reaching the desired vision or up to an intermediate state
Principle 2. Frame the intervention strategy to bridge the gap between the present state and desired future state(s), building on, strengthening and complementing existing initiatives	2.1. Analysing which initiatives are missing to change neglected system elements of a sustainability vision
	2.2. Framing the intervention strategy in a way that bridges the gap between the present state and desired future state(s)
Principle 3. Identify drivers, barriers and potential leverage points for how to accelerate progress towards sustainability	3.1. Relying on the experience and knowledge of identified local actors of change in their present and envisioned efforts to attain the desired vision
	3.2. Drawing out envisioned drivers, barriers and potential leverage points for the co-designed intervention strategy

2010). Furthermore, they support the development of relevant intermediate actions, interventions and goals along the pathway towards the desired vision and serve as a potential milestone for evaluating and adapting transformative actions.

Principle 2 Frame the intervention strategy to bridge the gap between the present state and desired future state(s), building on, strengthening and complementing existing initiatives.

First, this principle implies analysing which initiatives are missing to change neglected system elements of a sustainability vision (Table 1). Missing initiatives are those that could address system elements of the desired vision that are currently not (sufficiently) addressed by existing and envisioned initiatives. Second, this principle involves framing the intervention strategy in a way that bridges the gap between the present state and desired future state(s). Such a framing should take into account the temporality of initiatives identified in Principle 1 and the choice of the intermediate state (if any) (Weiser et al. 2017). The temporality of initiatives refers to the lifetime of initiatives during which they influence system elements. In this way, the intervention strategy takes into account possible starting points of envisioned future initiatives, their rhythms including peak times of activities as well as times of inactivity and ending points of existing as well as envisioned initiatives. Consequently, the intervention strategy will build on and strengthen ongoing initiatives from local actors. This could include various types of amplifying and scaling, such as replicating initiatives to other places to reach more people, or scaling up to change policies and rules (Moore et al. 2014; Bennett et al. 2016). More importantly the strategy also entails to co-design new initiatives which complement existing initiatives, specifically focusing on system elements that are currently not (sufficiently) addressed by existing initiatives.

Principle 3 Identify drivers, barriers and potential leverage points for how to accelerate progress towards sustainability.

Investigating drivers that foster and enable, as well as barriers that prevent change towards the desired vision entails two things (Table 1). First, relying on the experience and knowledge of identified local actors of change in their present and envisioned efforts to attain the desired vision. Second, drawing out envisioned drivers, barriers and potential leverage points for the co-designed intervention strategy. Drivers of change push and protect sustainability initiatives by, for instance, supporting or accelerating an emerging favourable broader societal context (Loorbach et al. 2017), or providing protective space for these initiatives to develop, act and flourish (Smith and Raven 2012). On the contrary, barriers hinder change, can create path dependency and could lead to lock-in situations if responses fail to address feedbacks in systems, such as environmental feedbacks in agricultural systems (Geels 2002; Allison and Hobbs 2004). Barriers often have their roots in "culture and cognition and [are] expressed through economic and social policies, land-use legislation, resource management practices, and other institutions and social practices" (O'Brien 2012, p. 671). Examples for the identification of drivers and barriers can, for instance, be taken from the implementation of nature-based solutions for climate change adaptation and mitigation in urban areas (Kabisch et al. 2017), or from the energy transitions in the United Kingdom (Foxon et al. 2005).

Leverage points are places to intervene in a system where a small shift can lead to fundamental changes in the system as a whole and thus help to overcome barriers and identify the sub systems, issues, areas, times, places and sectors for effective interventions (Meadows 1999). For developing an effective and viable strategy it is useful to differentiate between shallow leverage points which are tangible, but rather weak in fostering change such as parameters or feedbacks, and deep leverage points which are less obvious, but more powerful such as the design of the system, or its intent (Abson et al. 2017). Identifying those system properties where intervening may trigger change across various drivers and barriers increases the potential for fundamental versus incremental change (Abson et al. 2017). Managing drivers for the co-designed intervention strategy, while recognising places to intervene to overcome barriers is key to effectively moving in the desired direction. The overall goal of Principle 3 is to understand the supportive and unsupportive context of change dynamics for existing and envisioned contributions (Principle 1) and for interventions (Principle 2) fostering transformation.

EXPERIENCES FROM A TRANSFORMATIONAL CASE STUDY IN SOUTHERN TRANSYLVANIA

In this section we exemplify the principles in presenting how we applied them in our transdisciplinary case study in Southern Transylvania (Table 1). In line with many of the transformational research frameworks, within our case study, we initially carried out an extensive stage of system analysis, followed by a stage of scenario building and selection of the desired vision for the future of the system. Both stages included a high participation of local actors.

System understanding and visioning

Our understanding of the current state in Southern Transylvania is drawing on evidence from 5 years (2011–2015)

of place-based inter- and transdisciplinary research addressing issues of change and sustainability. We framed Southern Transylvania as a social-ecological system (Berkes et al. 2000). Social-ecological systems are complex systems that exhibit critical thresholds, multiple drivers of change and reciprocal feedbacks between social and ecological components. We studied components of the ecological subsystems, components of the social subsystems, interrelations between the two and direct as well as indirect drivers of change (Loos et al. 2014; Mikulcak et al. 2015; Dorresteijn et al. 2016). Weak governance, corruption, low social capital and profitability of small-scale farming underlie social feedbacks (Hanspach et al. 2014), while landscape heterogeneity, cultural land ties and traditional practices heavily influence the ecological dynamics (Dorresteijn et al. 2015). Supra-national policies of the European Union and the influence of global markets are some of the most important drivers of change outlining the regional challenge of conserving the unique cultural and natural heritage of Southern Transylvania. In response to these challenges and as part of the social subsystem, non-governmental organisations foster and act towards sustainability through numerous local initiatives. Our empirically grounded, social–ecological system knowledge, allowed us to thoroughly characterise system structures and dynamics, such as describing ecosystems and value change in local communities (Hanspach et al. 2014; Horcea-Milcu et al. 2018).

Departing from this system knowledge, we worked with stakeholders using a transdisciplinary research mode and following the TRANSFORM framework designed for developing solution options and eventually for transforming the status quo towards sustainability (Lang et al. 2012; Wiek and Lang 2016). Our aim was to facilitate moving the social-ecological system towards a widely shared vision for the future of Southern Transylvania. This vision was documented in previous work (Hanspach et al. 2014; Nieto-Romero et al. 2016), and reflects a system constellation that balances economic wealth with social and ecological sustainability. It was co-developed and co-validated in a scenario building exercise at the end of 2012 together with local actors. The exercise involved building four different alternative scenarios for the future of Southern Transylvania in 2050 (Hanspach et al. 2014). One scenario, named "Balance Brings Beauty" (Appendix S1 for vision description), was widely agreed upon as the most preferred alternative by a range of local actors (Nieto-Romero et al. 2016). A preference that was later (re-)confirmed and validated during our outreach activities with local communities in 2014. Balance Brings Beauty describes a future where locals are able to capitalise on opportunities through collaboration and shared initiatives, in a context of a pro-environmental emphasis of national and supra-national policy. The Balance Brings Beauty narrative breaks down the "problem solved" vision into system elements and their characterisation (Appendix S1) (Wiek et al. 2011).

The theory of change that underlies our work in Southern Transylvania assumes that existing diverse local sustainability initiatives emerged as a response to the challenges that Southern Transylvania is facing (e.g. weak governance, low social capital, competing land uses), and that together, these initiatives can help foster change towards the Balance Brings Beauty vision through their actions, passion and values. The initiatives thus need to build collaborations to influence the current state of the system (i.e. dominant regimes). This is in line with theory of change used in the seeds of a good Anthropocene project, where social-ecological systems change occurs on the micro, meso or macro level (Geels 2002), and comprises of a preparation, navigation and consolidation phase (Olsson et al. 2004; Pereira et al. 2018a). Seeds, in that case, were defined as "initiatives (social, technological, economic, or social-ecological ways of thinking or doing) that exist, at least in prototype form, and that represent a diversity of worldviews, values and regions, but are not currently dominant or prominent in the world" (Bennett et al. 2016, p. 442). They occur at the micro-level in the preparation phase, and can lead to transformative change by providing potential solutions in times of (anticipated) crisis that destabilises existing regimes and creates possibilities for institutional change (Pereira et al. 2018a). A co-designed intervention strategy that builds on the work, experience and knowledge of local initiatives can gather momentum, build capacity and create ownership for change towards a desired vision (Wiek and Lang 2016; Pereira et al. 2018a).

Co-designing an intervention strategy

In Southern Transylvania, facilitating the process of co-designing an intervention strategy took place from January 2016 until approximately October 2016 with intermittent fieldwork of 11 weeks in total. This research was part of the "Leverage Points for Sustainability Transformation" project, which gathered an interdisciplinary team of 23 researchers. Five researchers continuously engaged in this particular case study. They had backgrounds in transdisciplinary sustainability research, landscape ecology, design methods, sustainable development, sustainability science and human-nature relationships research. During fieldwork, we conducted field observations, scoping meetings, ten semi-structured interviews with core non-governmental organisations implementing local sustainability initiatives and a final joint workshop with the core non-governmental organisations actively working on sustainable development in Southern Transylvania. Throughout the duration of the project, our team of researchers prioritised a facilitating

role. The intent of our work was to enable the ongoing deliberate changes fostered by the local actors and their initiatives (Wittmayer and Schäpke 2014).

Principle 1 Exploring existing and envisioned initiatives fostering change towards the desired future in Southern Transylvania

The tentative question at the start of the interventional stage in January 2016 was "What can stakeholders do to reach Balance Brings Beauty?". At the end of our social-ecological appraisal of Southern Transylvania in 2015, we knew the region has vibrant local sustainability initiatives seeking to shape the pathway to a sustainability transformation. Although these initiatives are numerous and locally relevant, they lack in consistency and coordination (Nieto-Romero et al. 2016). To systematically explore existing and envisioned sustainability initiatives, we conducted interviews with main local actors that were already fostering change towards sustainability (Step 1.1.; Table 1). To this end, we identified approximately 30 non-governmental organisations (Step 1.2.; Table 1). We interviewed a core group of ten organisations because we knew from our previous research that they are the main local actors working on sustainable development in Southern Transylvania. The interviews focused on: (1) characterising a given initiative and its sustainability contributions, (2) describing experiences with carrying out a given initiative and (3) identifying barriers, drivers and relevant actors for amplifying the impact of their initiatives. We than analysed how these initiatives contribute to making change towards Balance Brings Beauty, and drawing upon our previous research, compared the results with current and future desired states of the system elements (Step 1.3.; Tables 1 and 2).

Applying the steps laid out above for Principle 1 provided a solid basis for "what is there", "what is needed", and hence, gave an overview of the fabric of existing actors and initiatives that an intervention strategy could build on. Following this principle also helped to deepen science-society relationships and to empower local actors by acknowledging their work and knowledge. Interviews and iterative transdisciplinary interactions with local actors allowed a solid appraisal of their concrete day-to-day work and an increased awareness of their different goals, mandates and aspirations (Stauffacher et al. 2008).

Principle 2 Frame an intervention strategy to bridge the gap between the present state and the desired vision for Southern Transylvania

This principle was translated in Southern Transylvania into amplifying the impact of sustainability initiatives through what we termed "amplification processes" (Lam et al. unpubl.). Amplification considers increasing the impact of existing and envisioned initiatives by the local actors as well as the development of new initiatives and transferring of existing initiatives to Southern Transylvania

Table 2 Overview of Southern Transylvania system elements under Balance Brings Beauty addressed by initiatives. Type refers to economic (EC), social (SO) or environmental (EN) system elements. Initiatives shows the number of initiatives addressing the respective system element

System element in Balance Brings Beauty	Type	Initiatives
Social capital through strong relations and communities	SO	15
High engagement and empowerment	SO	10
Good quality of education and research	SO	9
Local and self-sustaining economy	EC	6
High/medium human capital	SO	6
Conserved cultural heritage, identity and traditions	SO	6
High biodiversity	EN	5
Collaborative and eco-friendly rural tourism development	EC	4
Diverse, mosaic landscape	EN	4
Agriculture with small-scale farming	EC	3
Tourism with locally manufactured handicrafts	EC	3
Sustainable use of resources for handicrafts	EC	3
Agriculture oriented on landscape	EC	3
High diversification of income	EC	3
High/medium ethnic integration	SO	3
Lifestyle balanced between modern (individualism) and traditional	SO	3
Conserved nature	EN	3
Improved life quality	SO	2
Agriculture balanced towards organic agriculture	EC	1
Low corruption level	SO	1
High enforcement of local law	SO	1
Protected Natura 2000 areas	EN	1
Economy with high diversification	EC	0
Small-scale farming with high/medium profitability	EC	0
High/medium amount of small-scale food processing	EC	0
Shared management of commons	EC	0
Sustainable use of forest	EC	0
Training for handicrafts	EC	0
Developed service industry	EC	0
Low amount of poverty	EC	0
Maintained and developed infrastructure	EC	0
High equity	SO	0
Migration with stable young population, less people leaving villages	SO	0
Positive role of foreigners (supporting BBB rather than land-grabbing)	SO	0
Low amount of abandoned land	EN	0

(Fischer et al. 2019). We derived this idea from our interviews and participant observations and substantiated it with a literature based understanding of what amplification processes are (Lam et al. unpubl.). Despite the existing variety of amplification processes (e.g. scaling up, scaling deep), they can be allocated to three groups of amplification processes: (1) *Amplifying within* entails processes to increase the impact of a specific sustainability initiative by, for instance, *stabilising* its existence or *speeding up* the way it impacts; (2) *Amplifying out* consists of processes which rely on involving more people and places, for example, by *growing* an existing initiative's impact reach in a similar context, or by *replicating* the existing initiative in a dissimilar context. *Amplifying out* can also happen by creating similar, independent initiatives either by *transferring* an initiative to another place with a similar context, or by *spreading* the principles of an existing initiative to a similar initiative in another place in a dissimilar context; (3) *Amplifying beyond* consists of processes that seek to increase impact by *scaling up*, i.e. changing policies and rules, or by *scaling deep*, i.e. changing mind-sets or transcendental values (Lam et al. unpubl.).

The chosen framing based on a combination of amplification processes for Southern Transylvania was further elaborated during the joint workshop entitled "Co-creating the desired future of Southern Transylvania". We used the term "co-creating" instead of "co-designing" in the workshop title, because it was the main term used by local actors in our case study when they refer to the scientific understanding of co-design. We invited the core of approximately 30 non-governmental organisations acting for sustainable development in the region and previously involved in our work. In total 27 people representing 18 organisations participated. Choosing design prototyping as a method to stimulate dialogue, we moderated the workshop in a non-confrontational and playful way that balanced differences and increased exchange among our partner practitioners (Peukert and Vilsmaier 2019). By using the overarching guiding question of "How to get there?" we jointly produced knowledge that targeted the visioning stage as well as each of the three principles of the interventional stage.

First, we reiterated and re-validated the characterisation of system elements according to the desired vision for Southern Transylvania in 2050 (Table 2). We complemented the Balance Brings Beauty scenario for 2050 with a more tangible intermediate state for 2030. Second, we prompted our participants to present their sustainability initiatives and their contributions to reach the intermediate state. The participants realised during the discussions that not all system elements of the Balance Brings Beauty scenario were addressed by existing and envisioned initiatives by the local actors, and that therefore, new initiatives are needed. After the workshop, we used content analysis of the workshop and interview data on existing and envisioned sustainability initiatives to identify which system elements are or are not addressed by current initiatives (Step 2.1.; Tables 1 and 2). The analysis revealed system elements that are addressed by few or none of the local initiatives despite their importance for the desired future of Southern Transylvania, such as "Improved life quality", "Small-scale farming with high/medium profitability" or "Agriculture balanced towards organic agriculture" (Principle 1, Tables 1 and 2). Third, we discussed the amplification idea as an underlying framing of the intervention strategy, i.e. that the numerous local sustainability initiatives need to amplify within, out and beyond in order to increase their impact (Step 2.2.; Table 1). Fourth, we discussed perceived drivers and potential leverage points that could foster change towards Balance Brings Beauty (Principle 3; Table 1). Finally, at the end of the workshop, the participants discussed with us possible ideas for interventions as next steps, such as (1) a workshop on the values and mind-sets that underlie the different initiatives, (2) an analysis of the relations between the actors and desired relations to other actors and (3) an outreach event to connect to other actors, such as other non-governmental organisations or politicians.

To follow Principle 2, it was useful to choose a portfolio of approaches for "how to intervene in the system". In our case, this was a transparent discussion of the different groups of amplification processes that engaged local actors during a workshop. The local actors highlighted the importance of understanding the mind-sets and values underpinning different local initiatives to improve collaboration, as well as the importance of building new relations to other non-governmental organisations and governmental actors to amplify their impact (i.e. *Amplifying beyond*). The open dialogue was helpful and appreciated by the local actors because everyone could share their understanding of how all the different sustainability initiatives could fit together in order to foster change in Southern Transylvania. Additionally, applying Principle 2 helped the local actors to see which work is missing to reach their vision and to understand how they can overcome this gap. All of the three mentioned interventions were implemented in the further course of the project.

Principle 3 Identifying drivers, barriers and potential leverage points for how to accelerate progress towards sustainability in Southern Transylvania

In Southern Transylvania we operationalised Principle 3 by investigating drivers and barriers to reach the desired future in three steps (Steps 3.1. and 3.2.; Table 1). First, we built on previous work by Nieto-Romero et al. (2016) who after the scenario building exercise investigated general

barriers for action to reaching Balance Brings Beauty. Barriers were perceived on the local level (e.g. lack of entrepreneurship, lack of social cohesion) up to the global level (e.g. Western modern life-styles). Among barriers perceived at local level, the lack of collaboration between local organisations was named as a reason for the low impact of organisations (Nieto-Romero et al. 2016). Second, our interviews with the main local actors for sustainability revealed diverse individual drivers and barriers that current sustainability initiatives are facing (Table 3).

Table 3 Examples of sustainability initiatives from non-governmental organisations (NGO) and their identified drivers and barriers

NGO	Initiative and short description	Examples of identified drivers	Examples of identified barriers
1	*Farming association at village level* Maintaining and increasing the livestock as well as securing communal pasture land for peasants	Patriotism Becoming a leader Relationships in association Being constructive	Not aware of benefits of association Mistrust
2	*Community-owned micro food processing units* Promoting replicable models for food processing at village level (e.g. for vegetables, fruits)	Local political support Community engagement Creativity of small producers Collaboration with companies	Agricultural subsidies Few opportunities for small producers Different interpretation of legislation Non-authentic small-scale producers
3	*Fairs to promote cultural heritage* Promoting cultural built and natural heritage of three neighbouring regions	Common language between partners Expertise in marketing techniques Previous successes Open participation for any initiatives	Financial and administrative resources Not recognised area Bureaucracy and retail market Need to associate for small producers
4	*Rhubarb festival* Supporting small producers and women to sell local products in the yards of the fortified churches	Community engagement/volunteering Financial support, subsidies Ambition to be successful Opportunity spaces for initiatives	Financial resources Lack of outreach Lack of visibility Prejudices against NGOs
5	*Lawsuits against abusive wood harvesting processes* Organising court processes/campaigns against a company that cuts wood for a power plant	Deforestation in Romania Experiences with court processes Contacts and relationships Professional team coordination	Corruption and powerful actors Lack of funding, networking Lack of engagement, expertise, success Conservativeness and manipulation
6	*Conservation of cultural and built heritage* Revitalising traditional handicrafts and developing local entrepreneurship through workshops	Community led development Developing qualities of the people Legal structure to apply for funding	Personal fear, low self-trust, envy Uncoordinated legislation, price politics Lack of education and commitment Social aid
7	*Ecosystem services popularisation* Mapping ecosystem services and creating scenarios for local to national decision-making mechanism	Maintaining ecosystem services Credibility and continuity of activities Financial, local political support Strong relationships	Project thinking, technical difficulties Diverse ecosystem service definitions Conflicting EU regulations Lack of local/regional policy influence
8	*Biking tours:* Promoting the region as an eco-destination by combining biking tours with local food experiences (e.g. village brunches)	Capitalising on existing initiatives Societal trends Capitalising on landscape possibilities	Legal and financial requirements Lack of respect and acknowledgement Trend to eliminate small producers Ego of people
9	*Milk collection points* Supporting small-scale milk producers by providing equipment and knowledge for milk collection points	Change of EU hygiene rules for milk Education Open mind	Transparency, resistance of farmers National and EU requirements Globalisation, free market challenges Lack of trust, interest in local food
10	*Inventory of old trees of Romania* Mapping and conserving with citizens old trees due to their multiple social-ecological and cultural values	Constant financial resources	Lack of education, training, time Rigidity of institutions Loss of prominent support, funding Controversial legislations

Drivers related to financial support, engagement of communities and personal as well as professional relationships among non-governmental organisations and at community level were frequently mentioned (Table 3). Barriers such as poor local engagement, negative attitudes, lack of financial resources and constraining market dynamics were repeated (Table 3). Third, during our joint workshop, participants discussed perceived individual drivers (i.e. passion, courage, patience, inspiration, education, experience, insanity), relational drivers (i.e. trust, love, respect, common goal, solidarity, appreciation, acceptance, power of example) and system drivers (i.e. continuity, crisis).

As part of this workshop we deliberately did not discuss barriers as we aimed towards an encouraging and appreciative setting, which is in line with an appreciative inquiry approach (Cooperrider et al. 2003). We introduced instead the concept of leverage points and inquired participants about potential leverage points for the co-designed strategy. Elicited leverage points were related to underpinning normative assumptions and worldviews shaping the emergent direction of Southern Transylvania, e.g. performing within the boundaries of market economy or challenging the paradigms of the embedding system with alternative economic models. Other leverage points pointed to challenging the political structures and institutions deciding on incentive systems and funding allocation, as well as improving the functioning and understanding of relationships between organisations sharing Balance Brings Beauty as a vision through inter- and transdisciplinary collaborations.

Applying Principle 3 in the above outlined steps helped us to get an in depth understanding of general barriers, individual drivers and barriers for specific sustainability initiatives, and jointly perceived drivers and leverage points. This was important for the intervention strategy to identify "what hinders change" and "what supports change" to reach Balance Brings Beauty. We noticed from individual interviews that drivers and barriers where either related to the agency of local people and organisations (e.g. lack of engagement of local people, lack of financial resources, lack of collaboration between organisations) or to institutions and structures (e.g. life-styles, market structures). However, in the workshop the local actors mentioned more abstract drivers based on joint reflections. We observed that the lack of collaboration between organisations mentioned during previous fieldworks (2012–2014) decreased. During our interviews and workshops from 2016 to 2019 organisations mentioned various forms of local and regional collaborations, and even participation in national consultations held by state institutions. Interestingly, the perceived leverage points were often related to the design and intent of the system (e.g. normative assumptions, worldviews and structures).

DISCUSSION

In this article, we propose three principles that support a specific way of contextualised co-design of sustainability intervention strategies which integrates existing local initiatives in place-based research. We showcased their application with a transdisciplinary case study in Southern Transylvania. In the following, we discuss potential implications of the three principles for transformational sustainability research and implications for practice.

Implications for transformational sustainability research

The three principles help shedding some light onto a black box found in several transformational research frameworks, i.e. the process of co-designing context-specific intervention strategies. They are intended to inform the "how to" and contribute "actionable" knowledge to the interventional stage of transformational research frameworks, instead of creating a new overarching framework. The literature provides detailed descriptions and comparisons of the different transformational research frameworks, pointing out the fields of application, and how each framework defines the interventional stage (Foxon et al. 2009; Wiek and Kay 2012). The frameworks have different sequences of methods and put more or less emphasis on the interventional stage, while typically providing only general guidance about the practical "how to". For example, the transition management and TRANSFORM frameworks highlight generally the need to formulate common objectives and develop joint actions, projects and instruments that assist (1) to transform the current state of a problem, (2) to achieve the sustainability future and (3) to actively avoid undesired scenarios (Loorbach 2010; Wiek and Lang 2016). Almost all transformational research frameworks highlight the need to co-design intervention strategies together with different actors, preferably from multiple levels (Olsson et al. 2008) and selected based on their interests, backgrounds, knowledge and competencies (e.g. representing authority in various networks or domains, or open for innovation) (Loorbach 2010). Even though the transformational research frameworks might have different theoretical starting points (e.g. sustainability transitions, resilience, transdisciplinary research), our principles can become complementary or add nuance on the process of co-designing intervention strategies that build on work from local actors. They do not intend to downplay the importance of constant iteration and adaptation of intervention strategies as interventions and change unfold. Instead, they highlight the importance of and provide guidance for the integration of initiatives by local actors

and might be particularly useful when intervention strategies need to be updated or adjusted.

For example, through postulating that reaching a sustainable future must build on existing initiatives, Principle 1 highlights that the interventional stage needs to be context-specific and should be driven by initiatives and knowledge from local actors. Principle 1 additionally highlights the benefits of imagining contributions from existing and envisioned initiatives, actions and projects from local actors to an intermediate state. Transition management depicts the advantages of having "short and mid-term solutions, goals, and strategies" (Loorbach 2010, p. 175); whereas, the future methods used by the seeds of a good Anthropocene project provide detailed descriptions of how to envision future contributions from local initiatives (Pereira et al. 2018b). Our experiences in Southern Transylvania showed that a joint reflection with local actors about their current and envisioned initiatives and actions, projected to an intermediate state led to a better understanding of what is missing to reach the desired vision. This comes in agreement with the three horizons technique for transformations that includes identifying "pockets of the future in the present" (Sharpe et al. 2016). Linking current and envisioned actions from local actors to the system elements of the desired future state, provided in the Southern Transylvania case study insights about which system elements are currently more or less addressed (Table 2). We regard this linking of actions to system elements also as a point of iterative reflection and social learning as described in the backcasting framework (Robinson 2003).

Similarly, Principle 2 provides greater clarity and information about the framing needed for the intervention strategy to bridge the gap between the present state and desired future states (e.g. the intermediate state, desired vision). This framing builds on a theory of change underlying the transformation (Pereira et al. 2018a), which in the case of Southern Transylvania turned into the amplification of impact from local initiatives that can jointly influence dominant regimes. Transition management, backcasting and TRANSFORM, all highlight the need to co-design joint actions. Analysing which actions are missing in terms of scope to foster substantial change can lead to co-designed actions that in sum define a context-specific strategy. With the exception of transition management and seeds of a good Anthropocene scenario building, transformational research frameworks rarely discuss the issue of scaling or amplification of local initiatives to foster large-scale systems change (Rotmans and Loorbach 2008; Bennett et al. 2016). However, this issue is gaining increasing attention in discussions revolving around sustainability transformations (Olsson et al. 2017).

In the case of Southern Transylvania, we facilitated the process of co-designing an intervention strategy based on amplification processes applied to local sustainability initiatives (Fischer et al. 2019; Lam et al. unpubl.). Other authors focus on matters of accelerating momentum for action (Frantzeskaki et al. 2014, 2017), or scaling for large systems change (Moore et al. 2014; Olsson et al. 2017). Whereas the acceleration framing highlights the speed of transformations and the scaling framing highlights the cross-scale impacts in transformations, our amplification framing relies on a combination of various amplification processes in order to increase impact of local initiatives. The amplification framing stems from an integrative typology of amplification processes which we developed due to the emerging topic of scaling impact among our local actors. It capitalises on existing efforts and knowledge from local actors, which can play an important role in designing intervention strategies.

Finally, Principle 3 posits that complementing the essential understanding of drivers and barriers that support or inhibit change processes (Olsson et al. 2008; Loorbach 2010), with reflecting on leverage points reveals different insights on change dynamics and opportunity spaces for system transformation (Meadows 1999). This reflection relies on the experience and knowledge of local actors that have an in depth understanding of the system dynamics. Yet, the literature on transformational sustainability research does not provide profound conceptual and empirical insights about the relation between drivers, barriers and leverage points for sustainability transformations. We anticipate conceptual discussions could depart from defining system boundaries or from understandings of system models (Scholz and Steiner 2015). Recently there is also a body of literature emerging around the gains of considering leverage points as metaphors (Fischer and Riechers 2019). Our work with local actors in Southern Transylvania is a first explorative step to better understand leverage points in contexts of sustainability transformations. Our results reveal that potential leverage points for system change in Southern Transylvania related to the design and intent of the system (e.g. underpinning normative assumptions and worldviews, or political structures). Our future work in Southern Transylvania and future research in general could show how this might lead to new insights for the research and practice of sustainability transformations.

Implications for practice in Southern Transylvania and other real-world contexts

The three principles helped us to facilitate the process of co-designing an intervention strategy contextualised to Southern Transylvania. We argue that these principles are

applicable in other real-world contexts where local actors strive to foster change towards sustainability. In our case study, applying the principles led to a process of co-designing an intervention strategy that aims at amplifying the impact of existing and possible future initiatives from local actors.

Sustainability transformations research increasingly recognises that the agenda of navigating and fostering change should strongly involve contributions and knowledge from local actors (Olsson et al. 2006; van der Hel 2016). In Southern Transylvania, the principles enabled such a bottom up approach in agreement with the experiences and knowledge from local actors on problem constellation, potential solutions, drivers, barriers and envisaged leverage points. A bottom up approach does not aim to downplay the importance of top down approaches and cross-scale interactions to foster transformations (Moore 2017). We recognise the importance of weaving together top down and bottom up approaches for transformations (Ely et al. 2013). However, in cases where the top down institutional context is unreliable and unstable, change fostered through bottom up initiatives and niche alternatives is urgently needed (Nightingale 2017). Such is the case of Southern Transylvania, where it is the local agents of change who mostly incrementally move the system towards sustainability while navigating an often unfavourable governmental context maintaining a lock-in situation (Mikulcak et al. 2013, 2015). Hence, we regard the three proposed principles as facilitating the process of co-designing modular, organic and bottom up intervention strategies that could overcome governance or institutional shortcomings. Furthermore, the principles are supportive for processes that include diverse knowledge systems such as local, traditional and practical knowledge from different kinds of local actors (Tengö et al. 2017). Based on our discussions with local actors, we also observed that the principles helped to empower non-governmental organisations due to their strong interest in organising interventions that increase their impact and reach out to other actors, such as other non-governmental organisations or politicians (Avelino 2017). This might have contributed to social capital and capacity building (Middlemiss and Parrish 2010), strengthened legitimacy, ownership and accountability for the intervention strategy (Lang et al. 2012) and connected different local actors to think of new initiatives and to form as well as mobilise networks of change agents (Frantzeskaki et al. 2014).

The process of co-designing the intervention strategy in Southern Transylvania was an intense, challenging and rewarding endeavour. Due to our previous work in the area, we could build on the trustful relationships we developed through time with the local actors. However, the process of co-designing the intervention strategy implied several challenges that we had to navigate, such as (1) the changing constellation of researchers within the case study team, (2) the objectives of the research project, (3) the persisting tensions among local actors and (4) our roles as researchers.

New researchers joining and others leaving the case study team increased the complexity of working with the local actors. We had to introduce and build trust to new members, which also needed to develop a sense of caring and responsibility for the case study and the people working in it (Hubbard et al. 2001; Pohl et al. 2010). We managed this challenge by letting the researchers the local actors were already familiar with from previous projects to act as the main points of contact at the science-society interface.

Additionally, compared to the previous research done in Southern Transylvania, which had more descriptive objectives (i.e. systems analysis and visioning), the "Leverage Points" project had more interventional objectives and focused on the "how to" get to the Balance Brings Beauty scenario (Abson et al. 2017). This resulted in challenges to communicate the possible outcomes of our case study and its potential implications. Despite the general recognition that knowledge about the "how to" is essential for transformative change, we faced various difficulties in communicating the added value of our transformational research in a transdisciplinary setting (i.e. when facilitating the process of co-designing intervention strategies) in comparison to collecting and analysing social-ecological data that could be displayed to better understand the system (Augsburg 2014). However, local actors acknowledged the impact of our work on bringing together and creating coherence among the different initiatives by creating spaces for them to connect, discuss and reflect.

One of the biggest challenges stemmed from the local actors in Southern Transylvania pursuing different pathways to reaching Balance Brings Beauty. As transformations in real-world settings are complex, unpredictable and subject to competing views (Olsson et al. 2006), the application of the three principles had to allow for several iterations and adaptations. For example, during the workshop many actors highlighted the different pathways (e.g. green economy, ecotopian solutions) that the different initiatives are taking, and questioned whether more radical initiatives are needed (e.g. anticapitalistic, non-market conform) (Luederitz et al. 2017). In response to these emerging discussions, we planned to organise a workshop to surface and make transparent the underlying values and mind-sets underpinning each initiative.

During our continuous interactions with local actors, we had to creatively navigate our multiple roles as researchers (e.g. knowledge broker, reflective scientist) while

prioritising a facilitators' role (Wittmayer and Schäpke 2014). We strove towards a collaboration at best on equal footing, while recognising the inherent 'messiness' of transformative process is permanently jeopardising the 'equal footing' claim of transdisciplinary projects (Rosendahl et al. 2015). Similarly, sometimes the reaching of agreement was not the main sought after outcome, and the simple recognition of the diversity of transformations pathways and their underlying values was an essential step forward. At the end, these tensions brought to light the mutually transforming power of science-society relationships when jointly working on change towards sustainability.

Similar initiatives, where local actors of change are transforming real-world contexts towards sustainability are flourishing worldwide. They are described, for instance, as islands of sanity (Wheatley 2017), seeds of a good Anthropocene (Bennett et al. 2016) or pockets of the future (Sharpe et al. 2016). The transformation in Southern Transylvania can be characterised as a local and rural transformation, in which non-governmental organisations with their initiatives and knowledge play a key role to foster sustainability. We were able to pilot the implementation of the three proposed principles in Southern Transylvania. However, we did not provide a fully comprehensive inventory of all sustainability initiatives and an assessment of their contributions nor did we monitor the societal impact of applying the principles due to time constraints. Future research may investigate how the principles could support change towards sustainability that builds on initiatives and work from local actors on other scales (e.g. regional, global) and in other contexts (e.g. urban). Additionally, future research could investigate the transferability of insights from co-designed intervention strategies, such as the idea of amplification. This could clarify the potential for learning between different local transformations through lessons learned from the implementation of intervention strategies (e.g. cultural, social, economic and political challenges), and specifically from the interactions among local actors (Balvanera et al. 2017a). Such insights could unravel the local complexity of transformations, which could ultimately inform global initiatives (e.g. the Programme on Ecosystem Change and Society) to foster large-scale sustainability transformations (Balvanera et al. 2017a).

CONCLUSION

Transformational research frameworks often lack guidance on the process of co-designing intervention strategies to support change towards sustainability. We propose three principles that facilitate the process to co-design intervention strategies which build on contributions and knowledge from local actors of change: (1) explore existing and envisioned initiatives fostering change towards the desired future; (2) frame the intervention strategy to bridge the gap between the present state and desired future state(s), building on, strengthening and complementing existing initiatives and (3) identify drivers, barriers and potential leverage points for how to accelerate progress towards sustainability. These principles potentially inform diverse transformational research frameworks and can be applied in similar real-world contexts, where local actors foster transformative change towards sustainability.

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3.4. A leverage points perspective on social networks to understand sustainability transformations: evidence from Southern Transylvania

David P. M. Lam, Berta Martín-López, Andra I. Horcea-Milcu, Daniel J. Lang (2020)

Sustainability Science

Picture shows the Leverage Points case study team working with representatives from NGOs on social networks in Southern Transylvania.

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SPECIAL FEATURE: ORIGINAL ARTICLE

Leverage Points for Sustainability Transformations

A leverage points perspective on social networks to understand sustainability transformations: evidence from Southern Transylvania

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Abstract

Sustainability transformations research increasingly recognizes the importance of local actors and their networks to foster fundamental societal change. Local actors have different types of relations between each other (e.g., sharing material resources, giving advice) through which they jointly intervene in different system characteristics. We conducted social network analyses of 32 non-governmental organizations (NGOs) who drive initiatives to foster sustainability in Southern Transylvania, Romania. In so doing, we applied a leverage points perspective by differentiating between relations according to the system characteristic they address, such as the parameters, feedbacks, design and intent of the system. Additionally, we tested for differences of centrality metrics (i.e., weighted degree, betweenness, eigenvector) from NGOs that conduct different actions (i.e., amplification processes) to increase the impact of their sustainability initiatives. Our results reveal several NGOs that have central positions in their networks for intervening in both shallower (i.e., parameters and feedbacks) and deeper (i.e., design and intent of a system) system characteristics. We also identified NGOs that are only central for intervening in specific system characteristics. In addition, we found that specific groups of amplification processes (i.e., *amplifying within* and *out*) are associated with the NGOs' positions in the parameters, feedbacks, and design networks. We conclude that the leverage points perspective in social network analysis has the potential to identify key actors and shed light on the attributes of local actors for intervening in shallower and deeper system characteristics to foster sustainability transformations.

Keywords Leverage points · Romania · Scaling · Social network analysis · System change · Transformation · Transition

Introduction

Humanity is facing fundamental sustainability challenges, such as biodiversity loss and climate change (Barnosky et al. 2011; IPCC 2018). During the last 20 years, sustainability science has emerged as a well-established field aspiring to contribute to solving these pressing challenges (Kates et al. 2001; Komiyama and Takeuchi 2006). Within this field, the notion of transforming unsustainable human–environment systems has received increased interest and led to a sophisticated understanding of sustainability transformations (Loorbach et al. 2017; Horcea-Milcu et al. 2020; Scoones et al. 2020). Sustainability transformations refer to "fundamental changes in structural, functional, relational, and cognitive aspects of socio-technical-ecological systems that lead to new patterns of interactions and outcomes" (Patterson et al. 2017). Examples of these systems are mobility, energy, fisheries, agriculture, forestry, or water systems (Loorbach et al. 2017).

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Transformations are multiphase and multilevel processes where crisis can provide a window of opportunity for large-scale change (Olsson et al. 2006; Westley et al. 2011). The multiple interconnected phases they are comprised of are: preparation, navigating the transition, and consolidation. Changes in these phases can take place on multiple levels: the micro-, meso-, and macro-level of a system (Geels 2002; Olsson et al. 2004, 2006; Moore et al. 2014; Pereira et al. 2018).

Sustainability interventions are deliberate actions from people that seek to foster desired transformative change within systems of interest (Dorninger et al. 2020). Until now, many interventions have not led to the system transformations needed to cope with urgent sustainability challenges, as in the case of food or energy systems (Dorninger et al. 2020). Prevailing interventions tend to foster incremental changes with limited potential for system-wide, transformative change (Abson et al. 2017; Dorninger et al. 2020).

Interventions can be implemented through global top-down sustainability initiatives that are often led by governmental actors (e.g., Sustainable Development Goals, Convention on Biological Diversity) and through bottom-up initiatives from local actors who play a crucial role in fostering place-based transformations (Stirling 2015; Balvanera et al. 2017). Local actors, including individuals or groups of people (e.g., initiatives, projects, communities, organisations, or companies), have agency to act at a local scale and drive bottom-up initiatives as a response to environmental and social challenges (Liehr et al. 2017; Schlüter et al. 2019). Local actors and their sustainability initiatives can provide multiple and innovative ideas to address sustainability challenges and intervene in systems while representing a diversity of practices, knowledge systems, worldviews, values, and regions (Bennett et al. 2016; Lam et al. 2020a). Initiatives can focus on, for instance, sustainable production and consumption of food, energy, or water, or the conservation of biodiversity and cultural heritage (Bennett et al. 2016). Sustainability initiatives are especially important during the preparation phase at the beginning of transformations (Pereira et al. 2018). In the preparation phase, an awareness of systemic problems at the macro-level emerges, which inspires local actors to develop and implement sustainability initiatives on the micro-level as a response (Pereira et al. 2018). Initiatives can become organised into proto-regimes that develop and explore alternatives to incumbent and unsustainable regimes that local actors seek to change or replace with their interventions and initiatives' impact (Geels 2002; Pereira et al. 2018; Loorbach et al. 2020). For decades, scholars have improved our understanding of local, bottom-up initiatives in sustainability transformations (e.g., Westley et al. 2006; Hawken 2007; Hopkins 2008; Westley et al. 2017). However, research on how these initiatives can actually realise transformations with their relations and amplification of their impact beyond themselves remains limited.

Lately, the question of how sustainability initiatives can amplify their impact has received increased interest (Moore et al. 2015; Bennett et al. 2016). Lam et al. (2020b) discuss the diverse actions that initiatives can deploy to purposively increase their transformative impact as 'amplification processes'. For example, initiatives can have more impact by increasing the number of initiatives to reach more people and places (e.g., an initiative opens a new office in another region) (Moore et al. 2015; Lam et al. 2020b). Understanding amplification processes is relevant for sustainability transformations because it can provide new insights on the building of proto-regimes and changes on the micro-, meso-, and macro-levels (Pereira et al. 2018).

One key aspect of applying amplification processes are the relations among local actors; and hence, their social networks (Frantzeskaki et al. 2014; Moore et al. 2015; Garrah et al. 2019). Social networks of local actors develop, protect, support, and share new ideas, knowledge, practices, and approaches that can lead to sustainability transformations (Moore and Westley 2011; Smith and Raven 2012). Different relations between local actors, such as sharing material resources or exchanging informal advice, constitute different networks and can lead to changes in different characteristics of a system, such as the parameters, feedbacks, design or intent of a system (Table 1) (Abson et al. 2017).

However, empirical studies aiming to better understand social networks of local actors and their initiatives that foster sustainability transformations remain scarce. In this regard, three aspects are of particular interest: (1) in which system characteristics can local actors jointly intervene to foster sustainability transformations?; (2) to what extent do amplification processes conducted by local actors relate to the system characteristics targeted when intervening in the system?; and (3) to what extent is the position in the social network of local actors associated with the interventions in system characteristics, and with the amplification processes used to foster transformative change?

In this paper, we seek to explore these three research gaps by applying a leverage points perspective. This will yield new insights on how local actors in social networks jointly intervene and leverage transformative change in systems. To address these questions, we analysed the social networks of non-governmental organizations (NGO) in Southern Transylvania, Romania, who are the main local actors working towards sustainability. Our first objective is to unravel whether the position of NGOs varies between different networks, representing relations that target different system characteristics (i.e., parameters, feedbacks, design, intent) to foster transformative change. Second, we show the associations between the amplification processes the NGOs applied and the NGOs' positions in different networks.

Table 1 System characteristics within which interventions can be jointly made by local actors in networks. Parameters and feedbacks are shallower system characteristics, whereas design and intent are deeper system characteristics (Abson et al. 2017). Please see Table S2 for further explanations

System characteristic (Abson et al. 2017)	Relations between local actors to jointly intervene in a system	System characteristic networks
Parameters: Mechanistic characteristics typically targeted by policy makers	Sharing material resources and tools with other organizations (e.g., office space and equipment, cars, event spaces and venues, facilitation materials)	Parameters network
	Developing project applications and applying for funding or sponsorships together	
	Implementing projects together (e.g., organizing workshops, creating development strategies or plans)	
Feedbacks: Interactions between elements within a system of interest that drive internal dynamics	Exchanging information (e.g., by email, phone, or in person)	Feedbacks network
	Acquiring new knowledge (i.e., learned useful things) from interactions and information exchanges with the other organizations	
	Exchanging informal advice (i.e., asked for opinion) to make decisions	
Design: Social structures and institutions that manage feedbacks and parameters	Meeting each other as participants in the same policy processes (e.g., public consultations) or institutional groups (e.g., industry boards, steering committees, associations)	Design network
	Working together to change policies (e.g., through collaborative lobbying, coalitions, or joint petitions, and legislative proposals)	
	Engaging together in setting up new collaborations with other organizations or actors (e.g., state actors, businesses, research institutions, communities, and associations)	
Intent: Underpinning values, goals, and worldviews of actors that shape the emergent direction to which a system is oriented	Pursuing similar strategies in work	Intent network
	Reflecting jointly on your mission and goals	
	Engaging jointly in activities that help reconcile differences in values and worldviews	

Conceptual framework

A leverage points perspective in sustainability transformations research

Within sustainability science, research on transformative change is increasing and has led to a sophisticated understanding of sustainability transformations (Loorbach et al. 2017; Köhler et al. 2019; Horcea-Milcu et al. 2020; Scoones et al. 2020). Scoones et al. (2020) conducted a review on conceptualizations of transformations and distinguish between three prominent approaches to transformations: structural, systemic, and enabling. While structural approaches study changes in the underlying foundations of society, politics, and the economy (e.g., capitalism, growth), systemic approaches apply systems thinking from the 1980s to identify specific parts of systems (e.g., system elements, dynamics) as targets for focused change to foster sustainability (Scoones et al. 2020). Two prominent perspectives from scholarship on systemic approaches are the socio-technical and social-ecological systems perspective that study the transformation of socio-technical or social-ecological systems (Berkes et al. 2002; Grin et al. 2010). Enabling approaches draw on the former two approaches, often adopt a transdisciplinary approach, and have a focus on purposefully creating the conditions to empower individuals and communities to foster transformative change on their own behalf (Scoones et al. 2020). Our study is aligned to transformations research that applies a mix of enabling and systemic approaches because we study the relations of local actors who jointly intervene in different characteristics of a system to foster change in a transdisciplinary research setting. To better understand in which characteristics of a system local actors intervene and which potential for transformative change these interventions entail, we apply a leverage points perspective.

The leverage points perspective contains a hitherto undervalued potential as a heuristic and practical tool for sustainability science to study intervention points in complex systems that can lead to transformations (Fischer and Riechers 2019). Leverage points are places to intervene in a system where a relatively small intervention in one part of a system can lead to relatively big changes in the whole system (Meadows 1999). The concept of leverage points stems from Donella Meadows' pioneering research on complex systems (Meadows et al. 1972). Meadows articulated 12 different leverage points (e.g., structure of material stocks and flows, length of delays, structure of information flows, goal of the system) (Meadows 1999). She separated them into "shallow" leverage points at which interventions are easy but they have a limited potential to bring about transformative change, and "deep" leverage points at which interventions are difficult but have a greater potential to bring about transformative change (Meadows 1999).

To reduce the complexity posed by the 12 leverage points, Abson et al. (2017) aggregated these 12 leverage points into four system characteristics that interventions can target: parameters, feedbacks, design, and intent of a system (from shallowest to deepest) (Table 1). Parameters are relatively mechanistic and modifiable characteristics (Abson et al. 2017). They are physical system elements (e.g., sizes of stocks), such as taxes, incentives, and standards that are typically addressed by policy makers. Feedbacks represent interactions between system elements (Abson et al. 2017). They drive system dynamics (e.g., reinforcing feedback loops) or return information for desired outcomes after an intervention (e.g., the effectiveness of a subsidy). The design of a system constitutes the social structures and institutions that organize feedbacks and parameters (e.g., structure of information flows, rules, power, and self-organisation) (Abson et al. 2017). The intent of a system comprises the underlying values, goals, and worldviews of actors that together are responsible for the system orientation (Abson et al. 2017).

Applying a leverage points perspective in sustainability transformations research helps us understand which places to intervene in complex systems exist (e.g., socio-technical or social-ecological systems) to bring about transformative change. This is especially relevant for systemic and enabling approaches to study transformations and contributes to at least four advantages according to Fischer and Riechers (2019). First, a leverage points perspective can bridge causal and teleological explanations of system change. Second, it highlights that deep leverage points have greater potential to lead to transformative change. Third, it enables the study of interactions between shallow and deep system changes. Fourth, it can be a methodological boundary object for academic and non-academic actors who work together in transformative transdisciplinary research settings.

A leverage points perspective on social networks

We apply the leverage points perspective to study how local actors driving sustainability initiatives for transformative change are organised in different social networks. We use the leverage points perspective since it provides conceptual guidance to identify where local actors can jointly intervene in a system based on different relations. These relations can address specific system characteristics (i.e., parameters, feedbacks, design or intent) (Table 1). For example, relations where local actors share material resources address the parameters of a system. Exchanging information, knowledge, and informal advice are relations that intervene in the feedbacks of

a system since they represent interactions between different system elements that can drive dynamics (Table 1). When different local actors jointly try to change policies, they target the design of a system. Local actors address the intent of a system when they jointly reflect on their missions and goals, or engage in activities that help to reconcile differences in values and worldviews (Table 1).

In this study, we analyse three different relations per each system characteristic (Table 1). Here, we assume that we can aggregate the data that represent relations between local actors addressing the parameters, feedbacks, design or intent of a system. For example, since the exchange of information, knowledge, and informal advice intervenes in the feedbacks of a system, we aggregate these relations to depict the social network that targets the system characteristic of feedbacks (Table 1, Fig. 1). By depicting networks of the four system characteristics, we can gain a better understanding of which local actors are more or less relevant for intervening in deeper or shallower leverage points (Fig. 1). Earlier research has applied social network analysis to identify key actors that are relevant in natural resource governance (Prell et al. 2009; Hauck et al. 2016). In this study, we advance the application of social network analysis to study sustainability transformations by identifying key actors that intervene in specific system characteristics to foster transformative change.

Amplification processes to foster sustainability transformations

Amplification processes are relevant for sustainability transformations because they describe the diverse actions that local actors can deploy to purposively increase the transformative impact of sustainability initiatives (Lam et al. 2020b). The study of these different actions (i.e., amplification processes) can provide new insights on the role of sustainability initiatives and their impact during the preparation phase of transformations.

To characterize how local actors amplify the impact of their initiatives to foster transformative change, we analyse the role of different amplification processes in the four networks (i.e., parameters, feedbacks, design, intent). Lam et al. (2020b) have classified amplification processes into four groups (Table 2): (1) *amplifying within*, which comprises processes that increase the impact of one specific sustainability initiative by, for instance, prolonging or accelerating its impact; (2) *amplifying out (dependent)*, which are processes that involve more people and places, or replicate an initiative in another context, but keep the dependency with the initial initiative; (3) *amplifying out (independent)*, which initiates independent initiatives either by transferring an initiative to another place or by spreading the principles of an initiative to a new initiative in another place; and (4) *amplifying beyond,* which are processes that increase impact by scaling up, i.e., changing higher institutional levels such

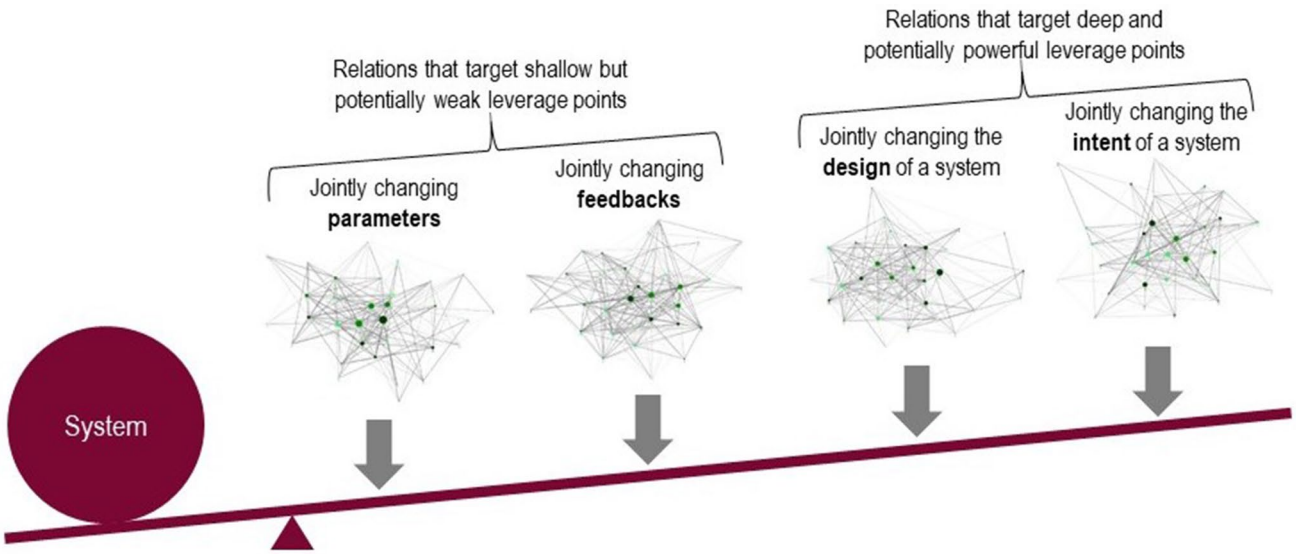

Fig. 1 A leverage points perspective on social networks based on Abson et al. (2017), Fischer and Riechers (2019), and Meadows (1999). Relations between actors in networks (green dots = actors, grey lines = relations) can have different realms of lever to change a system and can be aggregated to the system characteristics that they address (i.e., parameters, feedbacks, design, intent of a system). Each node represents an NGO and the node size represents the betweenness score. The node colour shows how many different groups of amplification processes are applied by the NGOs (i.e., dark green = 4, green = 3, turquoise = 2, light-green = 1, grey = 0). Ties represent relations between NGOs and the thickness of the ties shows the extent of the relation (i.e., very thick = high, thick = moderate, thin = low). (Figure is adopted from an earlier version with permission by David J. Abson)

Table 2 Groups of amplification processes based on Lam et al. (2020b) and corresponding survey questions

Groups of amplification processes	Survey question
Amplifying within	Have you done something to extend the lifetime of your initiatives or to speed up the way your initiatives create impact?
Amplifying out (dependent)	Have you expanded the impact of your initiatives to other places?
Amplifying out (independent)	Have your initiatives been the inspiration to create independent similar initiatives at other places?
Amplifying beyond	Have your initiatives influenced rules, laws, or underlying values, which inspire people to live in a different way?

as policies and rules, or by scaling deep, i.e., changing mindsets or values. Thus, amplification processes describe the diverse actions that local actors can deploy to increase the impact of their initiatives (Moore et al. 2015; Bennett et al. 2016; Gorissen et al. 2018; Lam et al. 2020b).

To amplify impact, initiatives can intervene in different leverage points. For instance, to protect biodiversity, a conservation initiative might aim to change policies at higher institutional level (i.e., *amplifying beyond*), which is an intervention in the design of a system. Therefore, we assume that there are associations between applied amplification processes and the central role of local actors in different networks (i.e., centrality metrics) that intervene in different system characteristics. Dismantling these associations can provide insights into which relations are potentially more relevant for the application of specific amplification processes to intervene in a specific system characteristic. For example, we hypothesise that local actors who replicate their initiatives to other places (i.e., *amplifying out (dependent)*) are presumably those in central positions in the feedbacks network since they potentially exchange information or provide informal advice (i.e., feedbacks system characteristic).

Case study: Non-governmental organizations acting for sustainability in Southern Transylvania, Romania

Southern Transylvania spreads over 270,000 ha and is home to great natural and cultural diversity, making it one of the largest areas of farmland with high natural value in the European Union. Yet, its multifunctional landscapes are threatened by numerous changes happening within and outside this region, such as draining migration, tenure changes, and the influence of the global markets. Navigating these changes while conserving the unique heritage, and responding to global pressures and local aspirations have created a delicate balancing act (Horcea-Milcu et al. 2018).

Many local NGOs have responded to the regional sustainability challenges in Transylvania, such as the loss of biodiversity or cultural heritage. They act through numerous initiatives dealing with nature and cultural heritage conservation, supporting small-scale farming, eco-tourism, or rural community development (Fig. 2) (Fischer et al. 2019; Lam et al. 2020a). For example, the Mihai Eminescu Trust is an NGO that leads different initiatives to conserve and regenerate villages and communities in Transylvania by, for instance, revitalizing traditional handicrafts, or supporting peasants to access communal pasture land for their livestock (www.mihaieminescutrust.org). Another example is Fundatia Adept, an NGO focused on biodiversity conservation and rural development which supports the production of cheese on village level, or implements bike trails to support eco-tourism in the region (www.fundatia-adept.org).

These initiatives are locally relevant and lead the local pathway to sustainability transformation according to an agreed upon target vision (Hanspach et al. 2014; Fischer et al. 2015). The target vision was co-developed and co-validated in scenario building exercises with local actors at the end of 2012. During this exercise, four alternative scenarios for the future of Southern Transylvania in 2050 were developed (Hanspach et al. 2014). The scenario named "Balance Brings Beauty" was widely agreed to be the most preferred scenario for the region by a range of local actors (Nieto-Romero et al. 2016). We have later confirmed and validated this preference during outreach activities with local communities in 2014. Balance Brings Beauty describes a target vision where local people have the possibilities to take advantage of opportunities through collaboration and joint initiatives, in a context of pro-environmental conditions through national and supra-national policy (Hanspach et al. 2014). Target visions are important to align different efforts that foster sustainability in strategies, create momentum for action, and get the attention of and commitment from diverse actors (Frantzeskaki et al. 2014; Wiek and Lang 2016).

Yet, a study on the role of visioning in fostering collective action for sustainability in Southern Transylvania highlighted the lack of collaboration between organisations and lack of information exchange as barriers to reaching the vision (Nieto-Romero et al. 2016). Hence, supporting and enabling the actions and initiatives spearheaded by these local actors of change is a matter of networking and amplifying the impact of their initiatives (Fischer et al. 2019; Lam et al. 2020a). For this study, we explore the relations

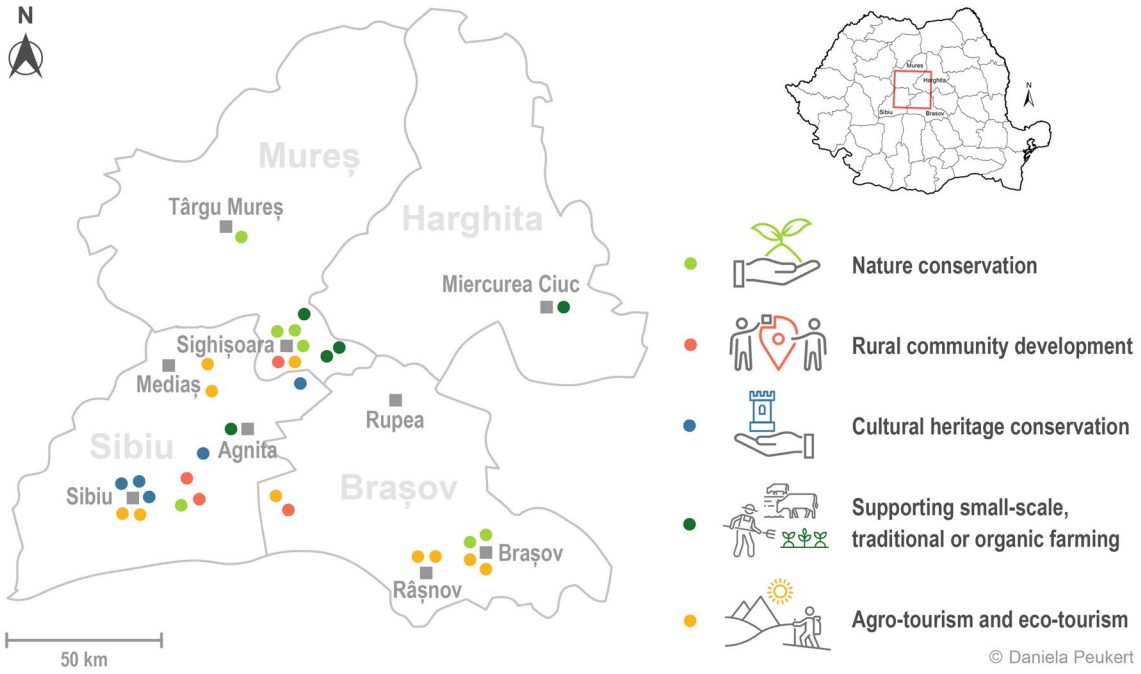

Fig. 2 Map showing the main location of 31 non-governmental organizations (NGO) trying to foster sustainability in Southern Transylvania (one main location of an NGO is not in Southern Transylvania) in the fields of nature conservation, rural community development, cultural heritage conservation, small-scale farming, and agro-tourism/eco-tourism (Map from Daniela Peukert in Fischer et al. (2019)). The colours indicate the main domain of activity of each initiative

between 32 NGOs who lead sustainability initiatives in Southern Transylvania (Fig. 2; Table S1 provides anonymous information about the work of the 32 NGOs).

Methods

Social network analysis

Social network research defines relations as ties, actors as nodes, and characteristics of actors as attributes (e.g., number of members in an organization, geographical regions in which an organization is working) (Prell 2011). This field of research is manifold, but generally provides insights on three levels: the individual level (e.g., looking at how central an actor is in a network), the dyadic level (i.e., identifying microstructures of groups of actors in a network), and the network level (i.e., analysing network properties, such as density) (Borgatti et al. 2009; Salpeteur et al. 2017).

Social network analysis has been used to gain understanding of natural resource governance and human-nature relations. Some examples include identifying key actors for the management of natural resources (Bodin and Prell 2011; Hauck et al. 2016), following the transmission of local ecological knowledge (Salpeteur et al. 2017), and identifying telecoupled processes by which some actors exert more power than others in ecosystem service management (Martín-López et al. 2019). So far, the application of social network analysis has brought four major contributions to the understanding of natural resource governance (Salpeteur et al. 2017). First, social network analysis identifies the characteristics of actors that are relevant to create the network structures (i.e., centrality, brokering ability) (Prell et al. 2009). Second, social network analysis reveals the relations and processes that can connect actors in a network (e.g., collaboration, decision making) (Rico García-Amado et al. 2012). Third, social network analysis identifies structural network characteristics that connect actors which lead to different natural resource management regimes (Bodin and Crona 2009). Finally, social network analysis reveals the multi- and cross-scale relations between actors that occur in natural resource governance and management of human-nature relations (Cohen et al. 2012).

We explored the potential of social network analysis for sustainability transformations research to generate new insights, such as the identification of key actors for collaborations and interventions to address different characteristics of a system. For this, we created four depictions of social networks that illustrate the relations between sustainability initiatives through which they jointly intervene

in the four system characteristics parameters, feedbacks, design, and intent (Table 1).

Data collection

We collected data from 32 NGOs that seek to foster sustainability in Southern Transylvania by realizing diverse sustainability initiatives (Fig. 2; Table S1). We invited 32 NGOs to participate in an online survey from December 2017 until February 2018 of which 30 NGOs responded. The survey was sent in almost all cases to persons with who we had working experiences and who participated in previous meetings. From 26 NGOs, we received one survey back. For the remaining four NGOs, we received two or three surveys that we aggregated into one dataset representing one NGO. Therefore, the final dataset contained information collected from 30 NGOs.

The online survey comprised questions about (1) the NGOs' relations to other NGOs according to the different leverage points (see "A leverage points perspective in sustainability transformations research" and "A leverage points perspective on social networks", Table 1, Table S2) and (2) the amplification processes they apply to increase the impact of their initiatives to foster sustainability (see "Amplification processes to foster sustainability transformations", Table 2).

To examine the networks from a leverage points perspective, we developed 12 questions that referred to the four system characteristics that leverage points can address (Meadows 1999; Abson et al. 2017) (Table S2). These 12 questions on relations were contextualized through our previous work and long-term experience with the NGOs in Southern Transylvania (Table 1) (Hanspach et al. 2014; Nieto-Romero et al. 2016; Horcea-Milcu et al. 2018). For example, the question "To what extent have you shared material resources and tools with the following organizations (e.g., office space and equipment, cars, event spaces and venues, facilitation materials)?" referred to a shallower leverage point of parameters since it refers to *constants, parameters, and numbers* of the system. Table S2 outlines the questions used in the survey. Each question asked the NGOs to rate the strength of their relations to the other NGOs over the past 5 years concerning their work on sustainability in Southern Transylvania with the following response options: not at all (0), low extent (1), moderate extent (2), high extent (3), and "I don't know" (Table S2). We developed all questions in accordance to the four types of system characteristics (i.e., parameters, feedbacks, design, and intent), which means that we clustered the answers into the four system characteristics (Table 1).

To examine the node attribute "applied amplification processes", we asked four questions related to the NGOs' actions to increase the impact of their sustainability initiatives. The four questions used asked about the four groups of amplification processes that can be applied by local actors to purposively increase the transformative impact of their initiatives, including *amplifying within*, *amplifying out (dependent)*, *amplifying out (independent)*, and *amplifying beyond* (see "Amplification processes to foster sustainability transformations". and Table 2 for the specific questions).

Data analysis

We used Gephi and NodeXL software to conduct the network analysis and visualisation (Bastian et al. 2009; Smith et al. 2010). We created four networks, one for each of the four system characteristics, i.e., parameters, feedbacks, design, and intent network (Fig. 1). We aggregated the answers of three questions related to each system characteristic by taking the highest perceived relation between NGOs. For instance, if the answers to three questions associated with a particular system characteristic were "1", "1", and "3", then the highest perceived relation between NGOs to accomplish this system characteristic was "3". We chose this approach because calculating an average would display false relations and taking the lowest would underestimate the extent of the relations. However, we are aware that taking the highest perceived relation might mean relations are overstated.

We calculated the weighted degree, betweenness, and eigenvector centrality for each of the NGOs (i.e., nodes) in the four networks (Table S3). Weighted degree measures the relations of one node to other nodes in the network (Freeman 1978), pondered by the weight of the relations (Barrat et al. 2004; Newman 2004). Thus, it provides information about the individual interconnectedness of each node to the network. Betweenness measures how often a node links other nodes that would otherwise be disconnected (Freeman 1978; Wasserman and Faust 1994). Nodes with higher betweenness exert more control over the network (Freeman 1978). Finally, eigenvector centrality measures the influence of a node in the network, weighted by the influence of its adjacent nodes (Bonacich 1972; Borgatti and Everett 1997). Because eigenvector takes into account the degree centrality of its adjacent nodes, this centrality metric can be interpreted as the future influence of a node (Prell 2011).

We tested whether differences in the centrality metrics (i.e., weighted degree, betweenness, eigenvector) occurred due to the different groups of amplification processes (i.e., *amplification within, out (dependent), out (independent), beyond*) applied by the NGOs in the four networks of parameters, feedbacks, design, and intent. We used the non-parametric Mann–Whitney U test to compare the centrality metrics between those NGOs that apply a particular group of amplification processes and those that do not apply them in each of the four networks. This provides insight into whether the centrality metrics of NGOs who applied

a particular group of amplification processes were significantly different to those who did not apply this particular group of amplification processes. Prior to the Mann–Whitney U test, data on centrality metrics were screened for outliers based on z-scores. Because only 30 of 32 NGOs participated in the survey, we kept the two NGOs that did not respond when calculating the centrality metrics and creating the networks, but left them out when we tested for differences of the centrality metrics among the four groups of amplification processes.

Results

Social networks of NGOs working on sustainability in Southern Transylvania

We created four networks that represent the relations between 32 NGOs when realizing actions to foster sustainability in Southern Transylvania (Fig. 3). Each network represented relations that target different system characteristics, i.e., parameters, feedbacks, design, and intent. We found that while some NGOs had high centrality metrics across all four networks (e.g., N18 and N20 for weighted degree and betweenness), other NGOs had high weighted degree, betweenness, or eigenvector in one particular network. Table S3 presents all centrality metrics (i.e., weighted degree, betweenness, eigenvector) for each NGO in the four networks of parameters, feedbacks, design, and intent.

Concerning weighted degree (see "Data analysis"), N18 and N20 were among the NGOs with the highest weighted degree scores in all four networks (Table S3). Thus, N18 and N20 had a high interconnectedness in all four networks, meaning that they had a key role when intervening in the system to foster transformative change in Southern Transylvania. Three NGOs had highest weighted degree scores in three networks, which were N19 in feedbacks, design, and intent; N24 in parameters, feedbacks, and design; and N29 in parameters, feedbacks, and intent.

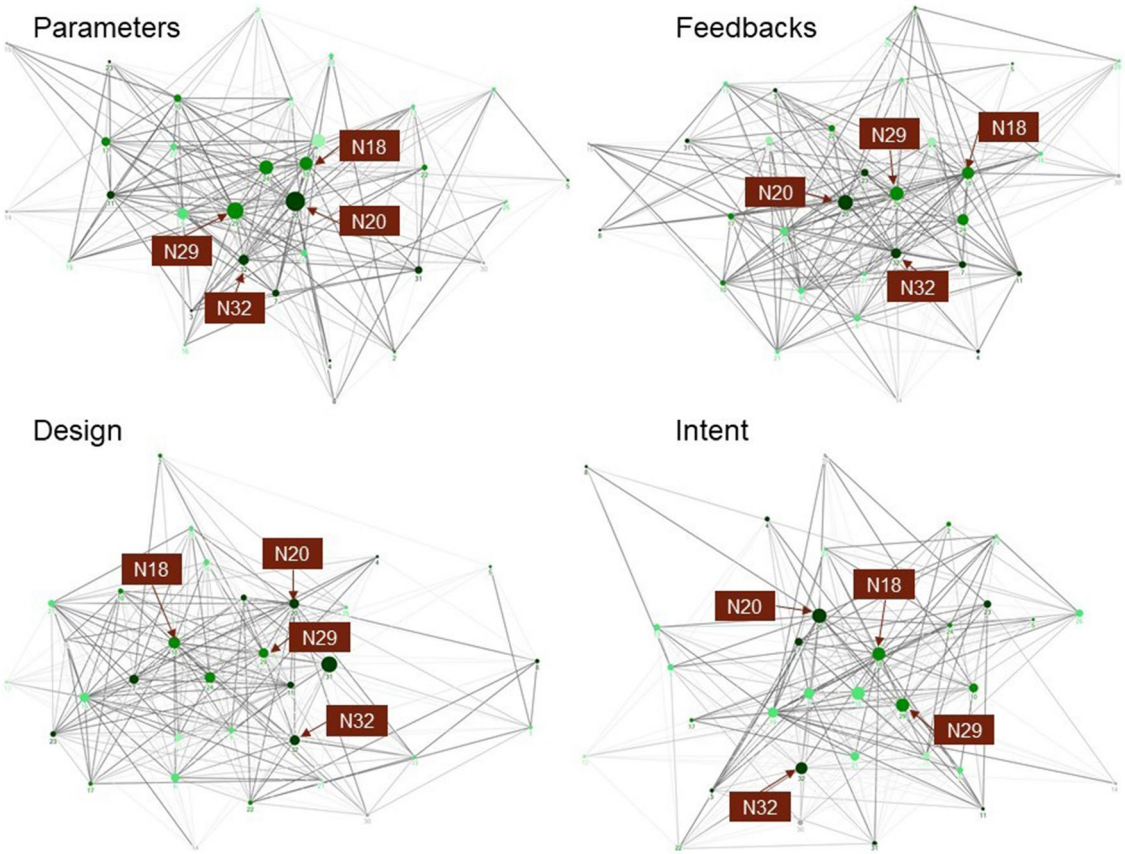

Fig. 3 Parameters, feedbacks, design, and intent network of 32 non-governmental organizations (NGO) working on sustainability in Southern Transylvania, Romania. Each node represents an NGO and the node size represents the betweenness score. The node color shows how many different groups of amplification processes are applied by the NGOs (i.e., dark green = 4, green = 3, turquoise = 2, light-green = 1, grey = 0). Ties represent relations between NGOs and the thickness of the ties shows the extent of the relation (i.e., very thick = high, thick = moderate, thin = low)

Another three NGOs had highest weighted degree scores only in network, which were N7 in design, N9 in intent, and N25 in parameters network (Table S3).

Concerning betweenness (see "Data analysis"), two NGOs were among the NGOs with the highest betweenness scores in all four networks, which were N20 and N18 (Fig. 3, Table S3). This means that N20 and N18 exerted high control over the four networks, reinforcing their key role to foster transformative change in Southern Transylvania. Three NGOs had highest betweenness scores in three networks, which were N29 in parameters, feedbacks, and intent; N24 in parameters, feedbacks, and design; and N32 in feedbacks, design and intent. Three NGOs had highest betweenness score only in one network, which were N25 in parameters, N31 in design, and N16 in intent (Fig. 3, Table S3).

Concerning eigenvector (see "Data analysis"), only N29 had highest eigenvector scores in all four networks (Table S3). Thus, N29 will potentially have future influence when intervening in the system at the level of parameters, feedbacks, design, and intent in Southern Transylvania. Four NGOs had highest eigenvector scores in three networks. N20 had high eigenvector scores in parameters, feedbacks, and intent; N24 had high eigenvector scores in parameters, feedbacks, and design; and N18 and N32 had high eigenvector scores in feedbacks, design, and intent. N9 had highest eigenvector scores in two networks, which were parameters and intent. Two NGOs had highest eigenvector scores only in one network, which were N25 in parameters and N31 in design (Table S3).

Comparison of centrality metrics between groups of amplification processes

Of the 30 NGOs that answered our survey, 25 NGOs expressed that they increased the impact of their sustainability initiatives through *amplifying within*, 20 NGOs through *amplifying out (dependent)*, 18 NGOs through *amplifying out (independent)*, and 19 NGOs through *amplifying beyond* (Table S4). Looking at how many different groups of amplification processes were applied by each NGO revealed that nine NGOs applied all four, eight NGOs applied three, ten NGOs applied two, two NGOs applied one, and only one NGO applied none (Table S4).

We found significant differences in centrality metrics between cases when NGOs applied or did not apply a group of amplification processes in the networks of parameters, feedbacks, and design (Figs. 4-6). In the following, we list

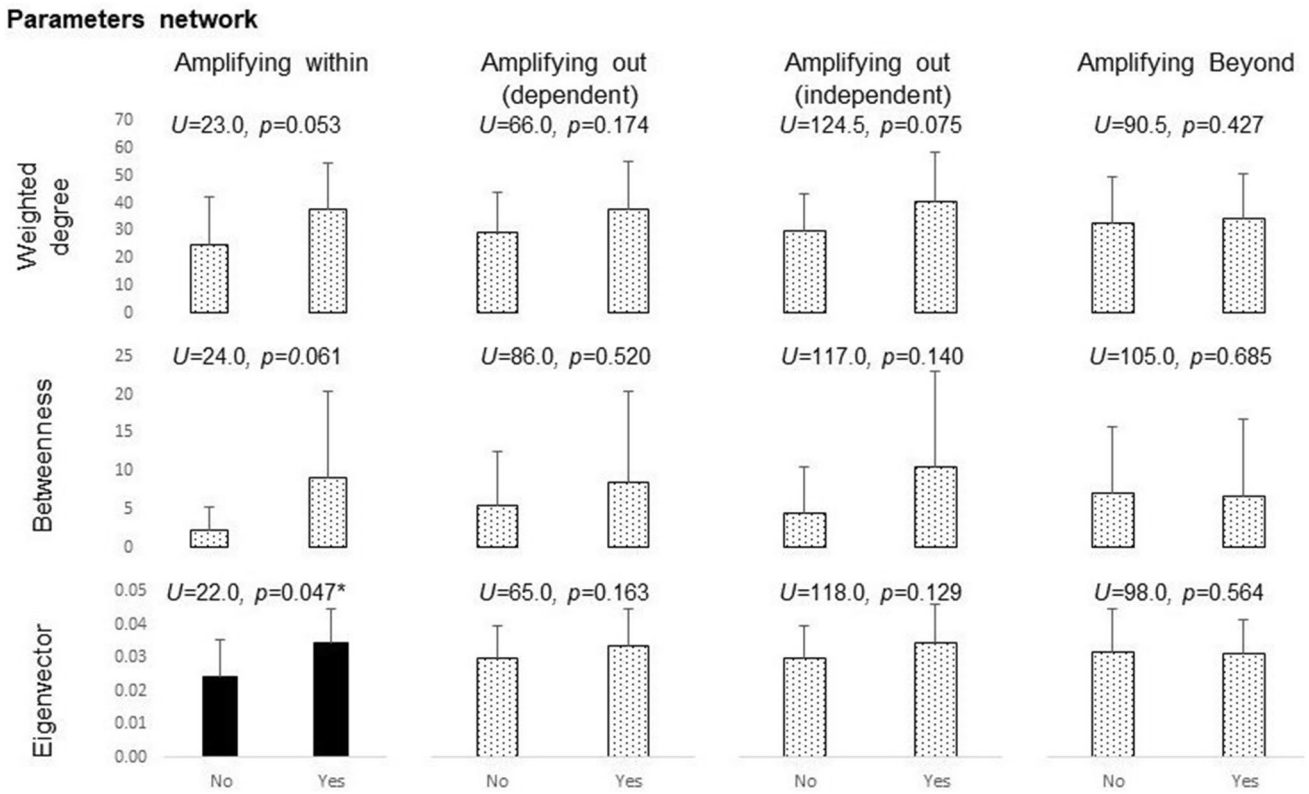

Fig. 4 Results of Mann–Whitney U test for the parameters network: each graph shows if there was a significant difference between the centrality metrics (e.g., weighted degree) of NGOs who applied a particular group of amplification processes (e.g., *amplifying within*, yes) or not (e.g., *amplifying within*, no). Bars are coloured black if $p < 0.05$

the significant differences between those cases when NGOs applied or did not apply a group of amplification processes.

We found that eigenvector was higher when NGOs applied *amplifying within* than when NGOs did not apply it (parameters network: $U = 22.0$, $p = 0.047$ (Fig. 4); feedbacks network: $U = 21.0$, $p = 0.041$ (Fig. 5); design network: $U = 20.0$, $p = 0.036$ (Fig. 6)). Thus, NGOs who stabilized and sped up the impact of their sustainability initiatives (i.e., *amplifying within*) had higher eigenvector scores in the parameters, feedbacks, and design networks than NGOs that did not *amplify within*.

In the feedbacks network, we found that the weighted degree score was higher for NGOs that applied processes of *amplifying out (dependent)* and *amplifying out (independent)* than NGOs that did not (*amplifying out (dependent)*: $U = 51.0$, $p = 0.047$; *amplifying out (independent)*: $U = 133.0$, $p = 0.033$ (Fig. 5)). Thus, NGOs who expanded the impact of their initiatives to other places (i.e., *amplifying out (dependent)*), or were the inspiration to create similar, independent initiatives at other places (i.e. *amplifying out (independent)*) presented higher weighted degree scores in the feedbacks network than NGOs that did not *amplify out* at all.

In the design network, we found that the NGOs who *amplified out (independent)* had higher weighted degree and betweenness scores than NGOs that did not apply this amplification process (weighted degree: $U = 135.0$, $p = 0.027$; betweenness: $U = 139.0$, $p = 0.017$). This result means that NGOs that inspired the creation of independent similar initiatives in other places (i.e., *amplifying out (independent)*) presented higher weighted degree (i.e., interconnectedness) and betweenness scores (i.e., control in the network) in the design network than NGOs who did not *amplify out (independent)*. We also found that NGOs who *amplified within* presented higher betweenness scores than NGOs who did not apply this amplification process ($U = 21.0$; $p = 0.041$) (Fig. 6). This means that NGOs who stabilised and sped up the impact of their sustainability initiatives (i.e., *amplifying within*) presented higher betweenness scores (i.e., control over the network) in the design network than those NGOs who did not *amplify within*.

Finally, we did not find differences in the centrality metrics in the intent network among the different groups of amplification processes applied by NGOs (Fig. 7).

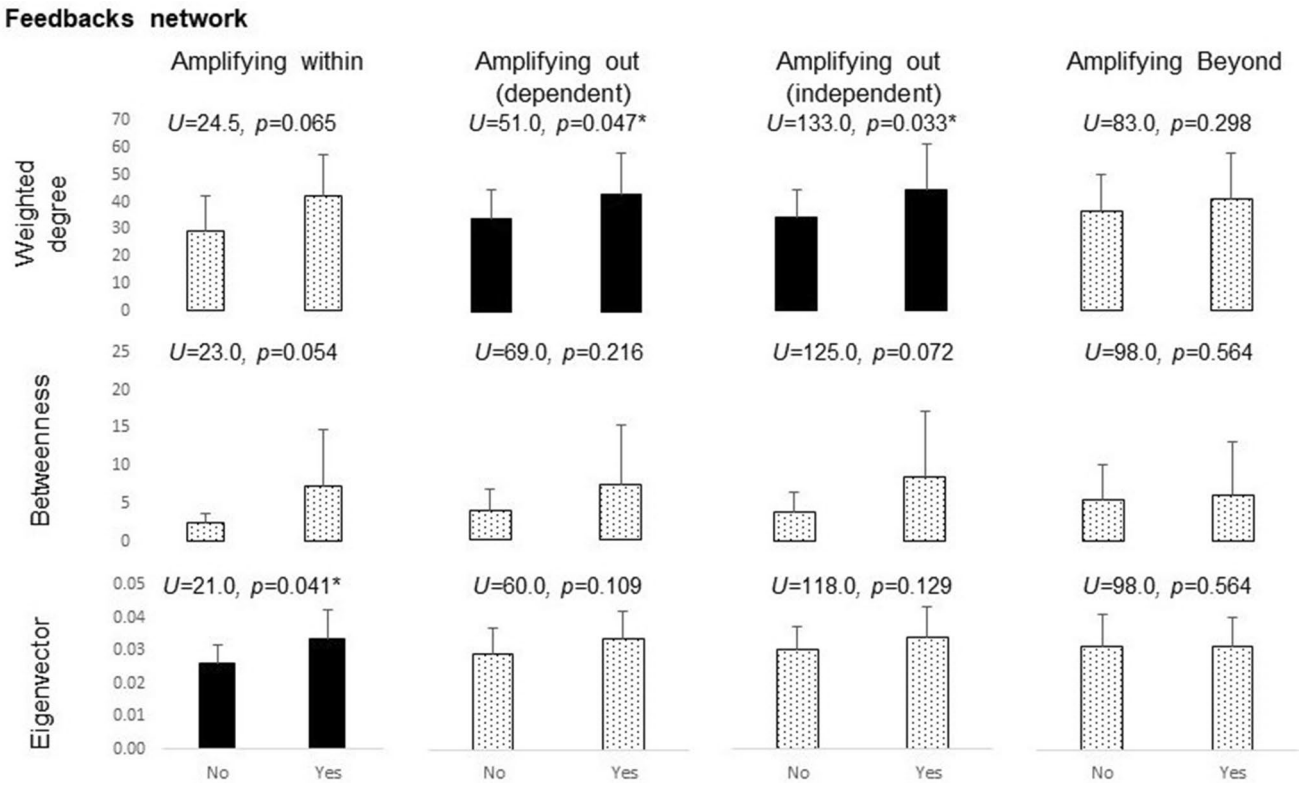

Fig. 5 Results of Mann–Whitney U test for the feedbacks network: each graph shows if there was a significant difference between the centrality metrics (e.g., weighted degree) of NGOs who applied a particular group of amplification processes (e.g., *amplifying within*, yes) or not (e.g., *amplifying within*, no). Bars are coloured black if $p < 0.05$

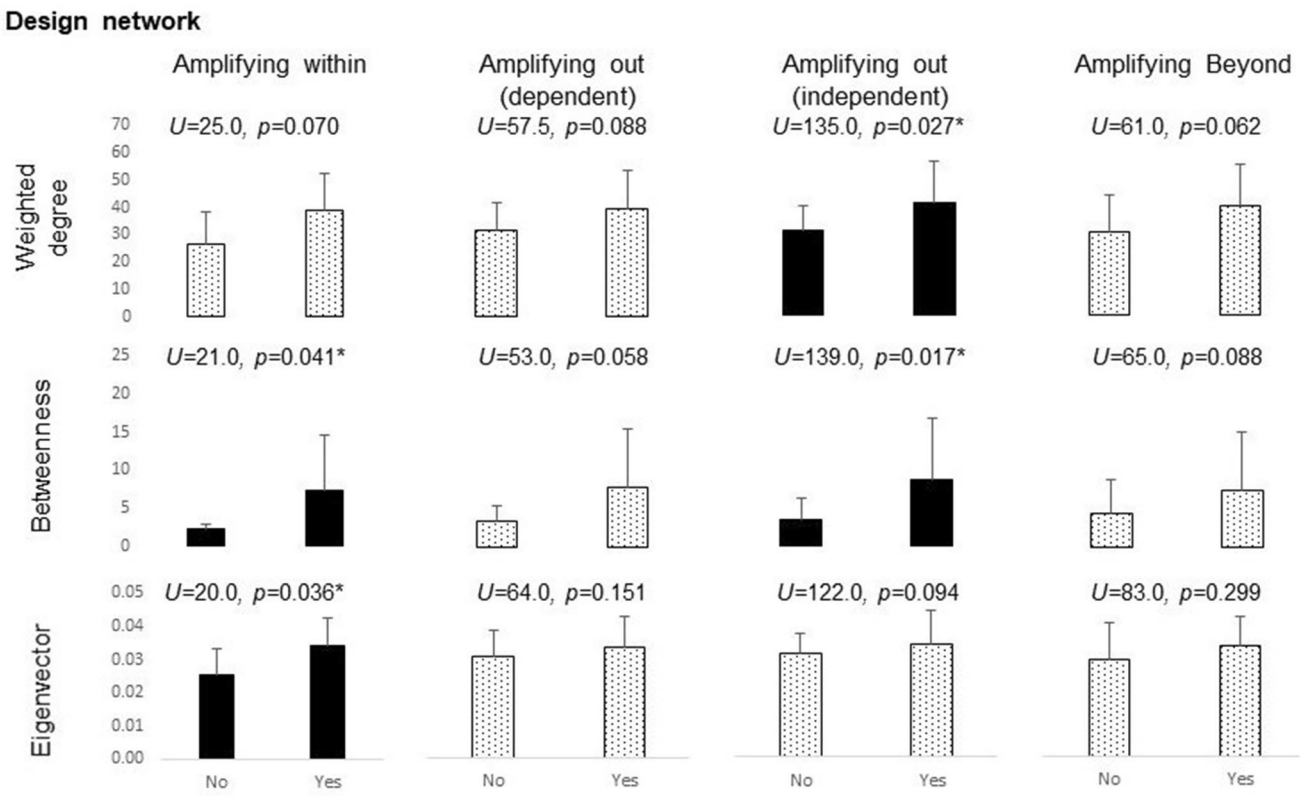

Fig. 6 Results of Mann–Whitney U test for the design network: each graph shows if there was a significant difference between the centrality metrics (e.g., weighted degree) of NGOs who applied a particular group of amplification processes (e.g., *amplifying within*, yes) or not (e.g., *amplifying within*, no). Bars are coloured black if $p < 0.05$

Discussion

We illustrated how the application of a leverage points perspective on the social networks of NGOs in Southern Transylvania can contribute to identify NGOs with higher centrality metrics in networks that intervene in different system characteristics to foster sustainability. In addition, we showed that there are significant differences in centrality metrics of NGOs that applied or not applied amplification processes. In the following sections, we discuss three tentative insights that a leverage points perspective on social networks adds to sustainability science and transformations research: (1) local actors potentially play different central roles for intervening in different system characteristics, (2) local actors that increase their impact with amplification processes are potentially also more central in networks, and (3) implications for research and practice. These insights and discussion points are specific to our case study in Southern Transylvania. However, they can contribute to further exploration of the potential of conducting social network analyses using a leverage points perspective to understand sustainability transformations.

Local actors potentially play different central roles for intervening in different system characteristics

From a leverage points perspective, local actors can intervene in systems by adjusting parameters and feedbacks (i.e., shallow system characteristics), or addressing the emerging design or intent of systems to foster sustainability (i.e., deep system characteristics) (Abson et al. 2017). Centrality metrics of local actors can be used to identify key actors for collaborations and interventions to foster sustainability, such as in the context of environmental resource governance (Prell et al. 2009). According to the centrality metrics of the NGOs from Southern Transylvania, our results indicate that there are potentially two types of local actors—in our case, NGOs—relevant for collaborations to intervene in shallow and deep system characteristics to foster sustainability (Fig. 3, Table S3). First, local actors who have high centrality metrics across networks that can intervene in both shallow and deep system characteristics. Second, local actors who have high centrality metrics only in specific networks that can address either shallow or deep system characteristics.

Regarding the first group of local actors, we found that the three NGOs N18, N20, and N29 had high scores of

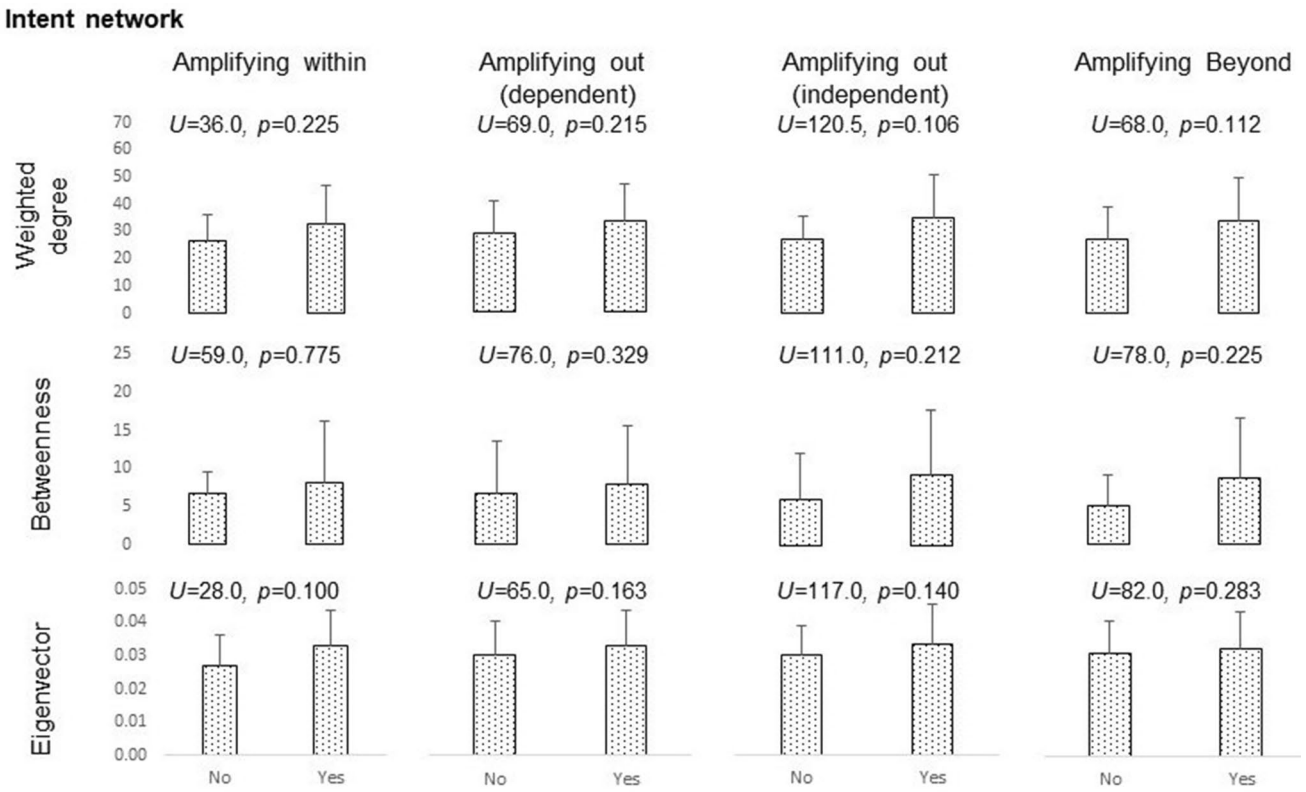

Fig. 7 Results of Mann–Whitney U test for the intent network: each graph shows if there was a significant difference between the centrality metrics (e.g., weighted degree) of NGOs who applied a particular group of amplification processes (e.g., *amplifying within*, yes) or not (e.g., *amplifying within*, no). Bars are coloured black if $p < 0.05$

centrality metrics in all four networks (i.e., at least one high centrality metric per network) and that N32 also had high centrality metrics in the feedbacks, design, and intent networks (Table S3) (Hauck et al. 2016; Abson et al. 2017). This means that the four NGOs N18, N20, N29, and N32 were highly interconnected in the networks that addressed the parameters (e.g., sharing of resources), feedbacks (e.g., exchanging information), design (e.g., working together to change policies), and intent (e.g., reconciling differences in values and worldviews) of the system Southern Transylvania (Table S3). These results confirm earlier research on sustainability in Southern Transylvania that found that the NGOs behind these four nodes are the most active NGOs that foster sustainability in the areas of Mureș, Brașov, and Sibiu (Hanspach et al. 2014; Lam et al. 2020a). The projects of N20, N29, and N32 are diverse and include establishing outdoor tourist infrastructures, conserving cultural built heritage, offering trainings to maintain traditional handicraft, supporting small-scale farmers, and conserving nature. Moreover, N18 is an umbrella organization that connects different eco-tourist activities of other NGOs in the region. All four NGOs have high scores for betweenness and/or eigenvector in the feedbacks, design, and intent networks (Fig. 3, Table S3). This means that these NGOs exert high control (i.e., betweenness) over the networks that target the feedbacks, design, and intent of the system Southern Transylvania, and have high potential to be key actors in the future (i.e., eigenvector). Although these four NGOs drive different sustainability initiatives (e.g., restoration of cultural built heritage, conservation of biodiversity), they share the vision of fostering sustainability in Southern Transylvania through their local initiatives (Lam et al. 2020a). These NGOs share their intensive local work with communities and small-scale farmers to foster well-being while conserving the unique natural and cultural heritage of Southern Transylvania.

Our study also reveals that N24 plays a central role in the parameters, feedbacks, and design networks with high scores for weighted degree, betweenness, and eigenvector (Table S3). N24 is mostly active in the regions of Mureș and Sibiu and focuses on promoting the cultural and natural heritage of these areas by, for instance, connecting various initiatives from different NGOs by celebrating seasonal food products or reactivating and reinterpreting old traditions towards new practices. Organising such activities that connect other NGOs might be the reason for N24's high centrality metrics.

Hauck et al. (2016) and Prell et al. (2009) use high centrality metrics of actors to identify key actors for collaborations and interventions, for example, in natural resource governance. The high centrality metrics of N18, N20, N24, N29, and N32, indicate that they are potentially key actors for collaborations and interventions to foster transformative change towards sustainability in shallow and deep leverage points in Southern Transylvania.

Regarding the second group of local actors, who have high centrality metrics only in specific networks, our study shows that these NGOs only play central roles (i.e., high centrality scores) in specific networks: e.g., N25 plays a central role in the parameters network, N31 in the design network, and N9 in the intent network (Table S3). This shows that some NGOs are essential to address specific system characteristics and thus are potentially key partners to intervene in specific characteristics of the system. For example, while N25 can be instrumental to share material resources and tools, N31 can be important to set up new collaborations with other organizations, and N9 can be supportive to reconcile differences in values and worldviews. Identifying the relevant partners for interventions in particular system characteristics is crucial for successful collaborations that foster sustainability transformations.

These results indicate that conducting social network analysis with a leverage points perspective to understand how local actors work together to foster sustainability in a system can shed light on the key roles that particular local actors have to intervene in specific system characteristics. Abson et al. (2017) and Dorninger et al. (2020) have said that most sustainability interventions tend to address shallower system characteristics and leverage points, which are easier to address but have limited potential for transformative change in comparison to addressing deeper system characteristics and leverage points. The application of social network analysis with a leverage points perspective can also indicate which local actors are able to mobilise actions that intervene in deeper leverage points. In addition, our study shows that some of the local actors with high centrality metrics in the networks related with deeper leverage points (i.e., design and intent) are also key actors for intervening in shallower leverage points (i.e., parameters and feedbacks). This might indicate that such local actors are essential to develop initiatives that foster change by intervening in both shallower and deeper system characteristics.

Local actors that amplify their impact are potentially also more central in networks

Literature on sustainability transformations highlights the importance of networks of local actors who apply amplification processes to increase the impact of their sustainability initiatives (Moore et al. 2015; Lam et al. 2020b). Our results show differences in the centrality metrics of NGOs that apply or not apply amplification processes (i.e., *amplifying within, out (dependent), out (independent), beyond*) in the networks of parameters, feedbacks, and design (Figs. 4, 5, 6). However, our study cannot provide insight into the level and strength of association between amplification processes and centrality metrics.

In this section, we discuss the following: (1) amplification processes and intervening in deeper system characteristics; (2) *amplifying within* and the future influence of NGOs; (3) amplification processes and the control over changing structures and institutions; and (4) *amplifying out* and the connectedness of NGOs.

First, we found a gradual increase of significant differences for the scores of centrality metrics between those NGOs that applied amplification processes and those that did not, from shallower to deeper networks (i.e., parameters to feedbacks to design). Surprisingly, we did not find any significant differences for the intent network which is probably because of the intangible nature of changing underpinning values, goals, and worldviews. In the case of Southern Transylvania, we found one significant difference for the parameters, three for the feedbacks, and four for the design network (Figs. 4, 5, 6). This gradual increase of significant differences potentially shows that the amplification of impact by NGOs in Southern Transylvania is presumably associated with successful interventions in deeper characteristics of the system (i.e., design). This could be either because NGOs that jointly intervene in the design of the system could also have more opportunities to amplify their impact, or because NGOs that amplify their impact are better able to influence deeper system characteristics. We found most significant differences for changing the design of a system, which referred to work together in the same policy processes or institutional groups, to change policies, or to set up new collaborations with other organizations (Table 1). This finding underlines the importance of amplifying impact of initiatives to change structures and institutions, which is a powerful system intervention and a recognized means to amplify impact (Abson et al. 2017; Gorissen et al. 2018).

Second, for the parameters, feedbacks, and design network, we found significant differences for the eigenvector scores between NGOs that *amplify within* and NGOs that did not (Figs. 4, 5, 6). This might mean that NGOs who try to stabilize and speed up the impact of their sustainability initiatives (i.e., *amplifying within*) will also be more relevant in the future (i.e., eigenvector) for changing the parameters (e.g., sharing material resources and tools), feedbacks (e.g., exchanging information), and design of the system (e.g., working together to change institutions and policies) in Southern Transylvania (Table 1, Table S4). This may be

because actions to extend the lifetime of initiatives and speed up impact lead to longer and faster impact of local initiatives (i.e., applying *amplifying within*), which is relevant for having more impact in the future. This finding indicates the importance of actions to stabilize and speed up the impact of NGOs' sustainability initiatives to increase their influence to foster transformative change in the future in Southern Transylvania.

Third, we found significant differences in the betweenness scores between NGOs that *amplify within* and *amplify out (independent)*, and those that did not in the design network (Fig. 6). This might signify that NGOs who stabilise and speed up the impact of their sustainability initiatives (i.e., *amplifying within*) and are the inspiration for creating new independent initiatives in other places (i.e., *amplifying out (independent)*) are more influential in changing structures and institutions in Southern Transylvania by, for example, working together with other actors to change policies (Table 1, Table S4). This insight indicates the potential importance of actions to stabilise and speed up the impact of sustainability initiatives (i.e., *amplifying within*) and of being the inspiration for other actors (i.e., *amplifying out (independent)*) to exert more control over relations that can change deeper system characteristics, such as structures and institutions in Southern Transylvania.

Fourth, we found significant differences for the weighted degree scores between NGOs that *amplify out (independent)* and those that did not in the feedbacks and design network. Moreover, we found differences in the weighted degree scores between NGOs that *amplify out (dependent)* and those that did not in the feedbacks network. This might mean that NGOs that aim to increase their impact in other places (e.g., by creating new initiatives) are also more connected with regards to exchanging information, knowledge, and informal advice. Additionally, this finding could signify that NGOs that are the inspiration for new initiatives in other places are also more connected with regards to participating in policy processes, working together with other actors to change policies, and setting up new collaborations. This potentially shows that NGOs who connect other NGOs with regards to the feedbacks and design of a system are also those who expand their impact to other places.

We conclude that these results provide tentative insights for a more differentiated understanding of why relations and networks are important for applying amplification processes to foster transformations. Our insights uncover that relations and networks are probably not important for applying amplification processes per se. Instead, they show that it potentially depends on the type of relation and network as well as the position of the local actor in the network. Based on our results from Southern Transylvania we hypothesise that NGOs that apply amplification processes are also those who have more capacity to intervene in the system characteristics of parameters, feedbacks, and design. Although we still need to explore the strength of these associations, we suggest that NGOs that apply amplification processes could be more relevant actors to collaborate with to intervene in the system of Southern Transylvania. More specifically, for intervening in deeper system characteristics, such as the social structures and institutions (i.e., design of a system), NGOs that increase their impact via *amplifying within* and *amplifying out (independent)* might be relevant partners.

Implications for research and practice

In our study, we explored the application of social network analyses of local actors with the leverage points perspective to understand sustainability transformations in Southern Transylvania. We suggest that this approach provides the following tentative contributions for sustainability science and transformations research: (1) identification of key actors that intervene in shallower and deeper leverage points; (2) empirical insights on relations and networks for amplification processes; and (3) future steps for practice and research.

First, our approach identifies key actors for intervening in specific or across system characteristics to foster transformative change towards sustainability. Recent research highlights the importance of local actors and their initiatives to foster sustainability transformations (Garrah et al. 2019). We exemplified how a leverage points perspective in a social network analysis unravels "where" (i.e., leverage points) local actors jointly intervene in a system by providing a heuristic and practical tool to structure relations according to the system characteristics that they address. In addition, we suggest that high centrality metrics can help to identify relevant key actors for collaborations and interventions to foster sustainability transformation in a similar way that has been suggested in natural resource governance (Prell et al. 2009). Our approach could also be useful in studies of environmental governance and management where the identification of key actors in fostering more sustainable governance and management systems is crucial (Hauck et al. 2016; Salpeteur et al. 2017). In addition, the suggested approach is potentially helpful for sustainability transformations research since it can support the identification of potential partners (e.g., for government, academia) for specific system interventions (e.g., in deep leverage points). It also has the potential to enable research to explore how to best support local actors in their work on specific system characteristics.

Second, our approach provides first empirical insights on the role of relations and networks for amplification processes applied by local actors to increase the impact of their sustainability initiatives. Recent research highlights the importance of relations and networks between local actors

trying to amplify their impact to foster sustainability (Moore et al. 2015; Garrah et al. 2019). Our results reveal significant differences for centrality metrics (i.e., weighted degree, betweenness, eigenvector) of NGOs in Southern Transylvania that apply or do not apply amplification processes. Our findings suggest that specific amplification processes are potentially relevant for local actors who are more connected (e.g., for exchanging information by *amplifying out (independent)*), have more control (e.g., for setting up new collaborations by *amplifying within*), or increase their future relevance (e.g., for implementing projects together by *amplifying within*) in a network.

Finally, substantial future research is necessary to further explore the potential of a leverage points perspective on social networks. For instance, it is crucial to better understand how microstructures (e.g., cliques) change across the parameters, feedbacks, design, and intent networks (Salpeteur et al. 2017). This could provide a more detailed understanding of attributes from groups of actors targeting specific system characteristics. Other research could investigate how the network structures affect the ability of actors to intervene in different system characteristics (Bodin et al. 2006). This is interesting because it could show which network structures are conducive for interventions on different system characteristics.

Conclusion

Local actors who drive sustainability initiatives can form social networks that foster transformative change towards sustainability in their context. Using a leverage points perspective when applying social network analyses has the potential to show which local actors are relevant partners for specific interventions in shallow (i.e., parameters and feedbacks) and deep (i.e., design and intent) system characteristics to foster transformative change. It can also provide insights into the role and importance of actor attributes for intervening in different system characteristics, such as the application of different amplification processes to increase the impact of their sustainability initiatives. These tentative insights on how local actors jointly intervene in different system characteristics have the potential to inform sustainability transformations research about the identification of relevant key actors for collaborations and interventions.

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4. Synthesis

This dissertation contributes to the field of sustainability transformations research. Overall, six research gaps have been identified in the literature of sustainability transformations research (Table 1, Chapters 1.2.-1.4.). This dissertation contributes to these by (1) providing an integrative typology of amplification processes that increase the impact of sustainability initiatives; (2) improving the understanding of the role of networks for amplification processes; (3) exploring the application of a leverage points perspective on social networks of local actors who foster transformative change; (4) showing the representation of indigenous and local knowledge in sustainability transformations research; (5) advancing the integration of sustainability initiatives from local actors in transformative transdisciplinary research; and (6) exploring the identification of relevant local actors for sustainability interventions in system characteristics.

4.1. Sustainability initiatives and amplification processes

4.1.1. An integrative typology of amplification processes that increase impact of sustainability initiatives

The novelty of the amplification typology

Sustainability initiatives from local actors provide alternative solution options for incumbent and unsustainable regimes that they try to alter with their impact (Loorbach et al. 2020). I propose an integrative typology of amplification processes that describe actions to increase the impact of initiatives (P1). The typology facilitates the study of amplification processes and informs transformative transdisciplinary research aiming at supporting local actors and their initiatives.

The typology facilitates the study of how initiatives increase their impact via amplification processes. It does so by integrating insights on such processes from six prominent frameworks and by dismantling the diversity of processes currently discussed. This integration is an important step for sustainability transformations research because it synthesises insights on amplification processes from frameworks that draw on different theories. Despite the high interest in the processes through which initiatives increase their impact, empirical studies that investigate these remain scarce (Moore et al. 2015, Gorissen et al. 2018). The typology provides descriptions of eight amplification processes and illustrative examples that can inform such empirical studies. Empirical studies can support the further development of theories that engage with transformations, such as advancements in resilience theory that discusses the

transformation of social-ecological systems. For example, studying how initiatives apply amplification processes can contribute to a better understanding of how initiatives prepare transformations. Pereira et al. (2018a) highlight that initiatives and their impact amplification is especially important in the beginning of transformations to prepare them. Thus, empirical studies can reveal how the increase of impact from initiatives supports the building of proto-regimes. They explore, develop, and provide potential alternative solution options for decision-makers to challenge, alter, and replace incumbent and unsustainable regimes (Geels 2002, Pereira et al. 2018a, Loorbach et al. 2020). Thus, empirical studies on amplification processes potentially provide insights on the dynamics that underlie the emergence and institutionalization of such proto-regimes.

I demonstrated how the typology can be applied in transformative transdisciplinary research with NGOs in Southern Transylvania who seek to increase the impact of their numerous sustainability initiatives to foster transformative change towards a desired vision. The study provided insights that improve our understanding of the role of networks for applying amplification processes, which I discuss more in Chapter 4.1.2. (P4).

Research that is currently in preparation also shows how the typology stimulates further research on amplification processes, which can contribute to further theory development on sustainability transformations. For example, Augenstein et al. (2020) critically reflect on the current debate on amplification processes in sustainability transformations research. They draw insights from the typology in their discussion of three key dilemmas that currently hinder research and practice concerning amplification processes, especially in transformative transdisciplinary research settings, such as in real world-laboratories or transition experiments (Schäpke et al. 2018a). The three dilemmas relate to the unclear conceptualization of impact amplification in literature, simplified understanding of amplification, and aversion of local actors towards being amplified. Augenstein et al. (2020) discuss the implications of these dilemmas for policy and transformative transdisciplinary research and propose ways to overcome the dilemmas by creating space for reflexivity, experimentation, and responsibilization at the science-policy-society interface.

The typology has stimulated various further research, which is related to the Seeds of good Anthropocenes research project and currently in preparation. The typology is used to study how local food actors try to amplify the impact of their initiatives to transform the local food system in the Stockholm city-region in Sweden (Lam et al. unpublished[4]). This study contributes insights on the concrete actions that local food actors apply to increase impact of their initiatives. The typology has also been used to study how amplification processes applied by initiatives in Africa are associated with the Sustainable Development Goals that the

[4] Unpublished work refers to studies that are still in development and are therefore not listed under references.

initiatives target (Lam and Jiménez-Aceituno unpublished). This study will show which amplification processes are used by initiatives that target different Sustainable Development Goals. The typology also informs research on the transformative potential of sustainability initiatives (Tuckey et al. unpublished) and the development of a practitioners guide on transformative potential of which amplification processes are an essential element (Moore et al. unpublished). Finally, the typology is being used by the research community of PECS to rethink how they can increase their research impact through the different amplification processes (Norström et al. unpublished).

The typology can inform transformative transdisciplinary research that aims at supporting local actors and their sustainability initiatives. During the last years, researchers are increasingly interested in engaging with local actors and their initiatives to better understand how sustainability transformations take place and can be supported (Fazey et al. 2018). Transformative research frameworks, such as transformative transdisciplinary research, provide methodological guidance on how to conduct such solution-oriented research (Wiek and Lang 2016). Such research aims at developing, testing, implementing, evaluating, and adapting evidence-supported solution options with non-academic actors that can contribute to change towards sustainability.

Research projects that apply transformative research frameworks study, for example, the conditions under which initiatives can amplify their impact to accelerate transformative change towards a low-carbon society in urban contexts (Gorissen et al. 2018, Ehnert et al. 2018), or the processes to amplify the impact of initiatives that promote a sharing economy and society in urban contexts (www.urbanup.uni-wuppertal.de). The typology can support such research by providing specific and detailed descriptions for amplification processes that local actors can apply in order to foster change in diverse contexts.

I demonstrated how the typology informed the co-design of a sustainability intervention strategy among academic (i.e., researchers) and non-academic local actors (i.e., NGOs) in the transdisciplinary case study in Southern Transylvania (P3). The typology was used as a conceptual frame for the co-designed sustainability intervention strategy. In this way, the intervention strategy specifically integrated existing and future initiatives. It supported researchers and local actors conceptually concerning increasing the impact of initiatives. In addition, the typology was used as a conceptual frame to co-produce a practitioners book that illustrates how initiatives from local actors in Southern Transylvania can increase their impact through various amplification processes (P3) (Fischer et al. 2019). This shows that the typology is potentially supportive and communicable to non-academic academic actors in transdisciplinary research settings.

4.1.2. The role of networks for amplification processes

Understanding and studying the role of networks for amplification processes

Sustainability transformations research highlights the important and enabling role of social networks from local actors for applying amplification processes (Moore et al. 2015, Gorissen et al. 2018, Loorbach et al. 2020). I contribute empirical insights to this argument and explore how this can be studied.

The results from P4 indicate the need of a more differentiated understanding of why social networks are important for applying amplification processes. Networks are not *per se* important for increasing impact of initiatives as often described in literature (Moore et al. 2015, Gorissen et al. 2018, Loorbach et al. 2020). Local actors are part of different networks, which are formed by the different types of relations between actors (e.g., networks of sharing material resources or exchanging knowledge) (Prell 2011a).

P4 provides first empirical results, which indicate that it varies due to the type of relation, if a network is important for applying a specific amplification process. This potentially means that it depends on the relation that constitute a network, whether a network is important for applying specific amplification processes or not. This calls for further research that studies which relations and networks are specifically important for which amplification processes. Such studies can potentially underpin which relations local actors should strengthen if they seek to increase the impact of their initiatives via specific amplification processes (P4). For example, my results indicate that relations targeting the feedbacks of a system are possibly more relevant for amplification processes that increase the number of initiatives (i.e., *amplifying out dependent*). In addition, future studies can improve our understanding of how local actors with their sustainability initiatives collaborate to build proto-regimes. Pereira et al. (2018a) argue that these proto-regimes can challenge or replace incumbent regimes. Studying the link between applied amplification processes and networks can therefore advance our understanding of how the impact of proto-regimes can be increased because they are formed by individual sustainability initiatives.

Studying amplification processes in social network analyses that applies a leverage points perspective constitutes a new explorative methodological contribution to sustainability transformations research (P4). I analysed the application of amplification processes as an attribute of local actors who intervene in different system characteristics due to different relations and networks (Prell 2011a, Abson et al. 2017). In addition, I tested for differences between amplification processes applied by local actors and their centrality metrics (i.e.,

weighted degree (Freeman 1978, Barrat et al. 2004, Newman 2004), betweenness (Freeman 1978, Wasserman and Faust 1994), and eigenvector (Bonacich 1972, Borgatti and Everett 1997, Prell 2011a)).

This methodological approach exemplifies how to study the importance of networks for applying amplification processes. It can inform other research that highlights and investigates the role of networks for amplification processes (Moore et al. 2015, Naber et al. 2017, Gorissen et al. 2018). Such research can lead to a better understanding of how amplification processes are linked to the individual centrality metrics of local actors. This is potentially important, for example, to understand if those local actors who have a lot of control over relations (i.e., betweenness) that target the design of a system are also those who apply specific amplification processes (e.g., *amplifying within*) as indicated by my results (P4). It can also show that local actors who apply specific amplification processes can be more connected (i.e. weighted degree) or influential in the future (i.e., eigenvector). This can also inspire future research to study how the application of amplification processes is linked to the structure of networks. Insights on this can help to understand if certain network structures support or hinder the amplification of impact.

The methodological approach can also inform research that studies which amplification processes are more or less relevant for local actors who intervene in shallow or deep system characteristics. My results suggest that specific amplification processes are more relevant for certain relations that target shallow or deep system characteristics (P4). This indicates that local actors who seek to intervene in shallow or deep system characteristics might apply specific amplification processes to increase the impact of their initiatives.

4.2. Local actors and knowledge

4.2.1. A leverage points perspective on social networks of local actors who foster transformative change

Local actors jointly intervene in different system characteristics through different relations

Sustainability transformations research highlights the important role of local actors and their networks to prepare transformations in the beginning (Moore and Westley 2011, Moore et al. 2014). Networks of local actors provide support and gather momentum for change in their system (Olsson et al. 2004, Moore et al. 2014, Pereira et al. 2018a). A leverage points perspective contributes to sort relations and networks according to the system characteristics that they address. For example, in the context of NGOs that act for sustainability in Southern

Transylvania the joint sharing of material resources constitutes an intervention in the parameters of the system. Another example are the collaborations among NGOs that aim to change policies. These relations constitute in the context of Southern Transylvania interventions in the design of the system (P4). This sorting of relations adds a theoretically informed differentiation between relations and networks that intervene in shallow or deep system characteristics. This leads to a more nuanced understanding of why networks of local actors are important for transformations. In addition, it enables the study of networks intervening in different system characteristics.

This theoretical contribution is in its infancy but contains promising potential for future research on how local actors and their networks jointly pursue interventions. For example, Moore and Westley (2011) note that different network structures are important in different phases of transformations (e.g., preparation, navigation, or consolidation phase (Olsson et al. 2006, Pereira et al. 2018a)). Different relations forming different networks that intervene in shallower and/or deeper system characteristics might also be more relevant in different phases of transformations. Future research could investigate which relations and networks are especially supportive in the preparation, navigation, or consolidation phase of transformations. Studying this might unravel which relations need to be build, supported, and strengthened in the different phases.

My results indicate two types of local actors relevant for collaborations: local actors that are central for intervening in both shallow and deep system characteristics, and local actors that are central for intervening in specific system characteristics. Local actors who are central for intervening in both shallow and deep system characteristics have high centrality metrics across networks (i.e., weighted degree, betweenness, eigenvector) (P4). These actors might be relevant partners to orchestrate and harmonize interventions, integrate and communicate understanding, and reconcile different problems between actors across the whole system (Olsson et al. 2006). This is important because transformations are highly complex and uncertain, which makes it often impossible for individual actors to achieve the desired system change (Moore et al. 2014). Such local actors have the potential to orchestrate and harmonize momentum for change emerging at different parts of the system and to build a shared identity for those desiring transformative change (Moore et al. 2014).

In contrast, local actors who are central for intervening in specific system characteristics are potentially relevant to coordinate actors who intervene at specific system characteristics. They are also relevant to communicate with other actors who try to harmonize momentum for change in the whole system (Olsson et al. 2006). Abson et al. (2017) note that interventions at shallower system characteristics might be easier, and at deeper system characteristics potentially more difficult. Understanding which local actors are central for intervening in deeper system characteristics might enhance the studying and supporting of such actors. Such actors

might apply substantially different approaches in their sustainability initiatives (e.g., changing policies versus reconciling differences in values).

Exploring applying a leverage points perspective in social network analyses

By applying a leverage points perspective in social network analyses, I explore a new methodological approach to study the role of relations and networks for intervening in systems to foster transformations. The methodological approach combines the possibilities of a social network analysis (e.g., analysis of node attributes and centrality metrics, identification of relevant actors) with the ideas of a leverage points perspective (Meadows 1999, Bodin and Prell 2011, Hauck et al. 2016, Abson et al. 2017). Combining the two is of interest for sustainability transformations research because it can provide insights on the role of individual characteristics of actors as well as their relations and network structures for intervening in specific characteristics of a system to foster transformations. This can potentially provide insights on which relations are important to strengthen among actors to support change in specific system characteristics. It can also show which individual characteristics of actors and network structure are potentially supportive for fostering change in specific system characteristics. Such insights can inform researchers studying and supporting individual actors and networks of actors who foster change towards sustainability. Despite the potential of applying a leverage points perspective in social network analyses, this methodological approach still requires testing, evaluation, and adaptations. It is an exploration and further research needs to refine it with the aim to compare results from different network analyses to draw conclusions for an advanced understanding of social networks and interventions in system characteristics.

4.2.2. Indigenous and local knowledge in sustainability transformations research

Application of ILK in research on change, transition, and transformation

Recent literature highlights the need to engage seriously with the diverse knowledge systems from local actors in sustainability transformations research, such as ILK from IPLC (Scoones et al. 2020). The results of my literature review on ILK in sustainability transformations research show that this body of literature neglects to apply ILK to study transformations (P2). Research that uses the words change, transition, and transformation and applies ILK is currently focussing on understanding what change IPLC observe and perceive in their environments (e.g., climate change in Arctic environments (Savo et al. 2016)) (P2). In addition, such research focuses on ecological change and less on social change or the interactions between the two (P2).

The results from P2 have the potential to inform future research on sustainability transformations with IPLC (Blythe et al. 2018, Scoones et al. 2020). For this, the review provides a state of the art overview of the literature that engages with IPLC in contexts of change, such as in social-ecological systems (Berkes et al. 2003), climate change (Savo et al. 2016), or biodiversity research (Hill et al. 2020). The review shows the change contexts on which such research is focusing (e.g., species change), the environments in which such research is taking place (e.g., Arctic), the applied methods (e.g., qualitative), and how such research uses the terms change, transition, and transformation (P2). These insights can help to develop research with IPLC that seeks to understand transformative change in the environments where IPLC live and how it can be navigated.

Diverse knowledge systems in sustainability transformations

The review shows that sustainability transformations research neglects to engage with IPLC and their ILK to study, understand, or navigate transformative change. These results informed two insights that underpin the call to appreciate plurality and engage with different knowledge systems from local actors in transformations research (Scoones et al. 2020).

First, appreciating plurality can potentially improve our conceptualization of sustainability transformations. The current transformations discourse is dominated by Western scientific knowledge systems and mostly based on experiences from the Global North (Scoones et al. 2020). Scoones et al. (2020) describe the three dominant Western scientific approaches to sustainability transformations and how they lead to different ways of understanding and studying transformative change (i.e., structural, systems, or enabling approaches, see Chapter 1.1.). Appreciating plurality could contribute insights from non-academic local actors on transformations. Transformations are highly political, complex, and contested due to the diversity of involved local actors and their knowledge systems (Pereira et al. 2020). Local actors have diverse interests, aspirations and interpretations of a better and desired future (Kothari et al. 2014). They have different ideas of which actions foster progress (Folbre et al. 2018, Scoones et al. 2020). This diversity of interest, aspirations, and actions seems competing and challenging but it also entails a great potential for being complementary (Luederitz et al. 2017a).

Engaging with the diverse knowledge systems from local actors could lead to the development of a plural and more differentiated understanding of transformations. Appreciating the plurality of transformation understandings can potentially lead to a better conceptualization of how transformations take place, how to navigate transformations, and what the goal of transformations is for different local actors in different places (Braun 2015, Blythe et al. 2018). This can motivate to revisit current scientific conceptualizations of transformations, such as discussed in research on social-ecological and socio-technical systems (i.e., systems

approaches, see Chapter 1.1), or research that engages with local actors to support bottom-up transformations (i.e., enabling approaches, see Chapter 1.1).

Second, appreciating plurality will potentially enhance our understanding of the diverse actions and initiatives that local actors conduct. Different understandings of transformations based on different values and worldviews lead to diverse actions and initiatives for transformative change (Luederitz et al. 2017a, Horcea-Milcu et al. 2019). Bennett et al. (2016) show in their global inventory of hundreds of sustainability initiatives the diversity of actions that local actors take to foster desired change. Examples are the promotion of alternative farming methods or the implementation of renewable energy sources (Bennett et al. 2016). Pereira et al. (2018a) show this diversity of initiatives among urban initiatives (e.g., initiatives focusing on climate smart cities or conservation ecology).

Understanding the different non-academic conceptualizations of transformations from local actors will enhance our knowledge on why local actors choose specific actions and initiatives to foster change, and how to best enable collaborations between seemingly competing local actors (Luederitz et al. 2017a). This can inspire to revisit current theories of change that discuss how sustainability initiatives prepare transformations because they can coalesce to challenge, change, or replace unsustainable regimes (Pereira et al. 2018a, Loorbach et al. 2020). For instance, by adding insights from non-academic local actors of their transformation understanding and why they think that their initiatives foster transformative change.

4.3. Transformative transdisciplinary research

4.3.1. The integration of sustainability initiatives from local actors in transformative transdisciplinary research

Highlighting the role of sustainability initiatives for transformative transdisciplinary research

Transformative research frameworks, such as transformative transdisciplinary research, describe the need to co-design sustainability intervention strategies with non-academic local actors to achieve desired futures (Wiek and Lang 2016). I propose three principles that can contribute guidance for the co-design of intervention strategies in transformative transdisciplinary research (Wiek and Lang 2016, Pereira et al. 2020) and other transformative research frameworks (e.g., Seeds of good Anthropocene scenario methodology (Pereira et al. 2018c, Sellberg et al. 2020)). The three principles highlight the role of sustainability initiatives, which need to be identified, analysed, and integrated in intervention strategies that support bottom-up, place-based transformations.

First, the principles emphasize the need to genuinely consider and engage with existing sustainability initiatives from local actors in transformative transdisciplinary research. Sustainability initiatives are important to prepare transformations, develop future scenarios, and co-design intervention strategies to achieve desired futures (Bennett et al. 2016, Pereira et al. 2018a, 2020). These initiatives are essential for intervention strategies because they collectively represent shared ideas and activities driven by diverse local actors that explore and develop alternatives to potentially unsustainable incumbent regimes that local actors seek to challenge, change or replace (Pereira et al. 2018a, Loorbach et al. 2020). The principles highlight the identification, analysis, and integration of such initiatives in transformative transdisciplinary research and other frameworks (P3). They specifically provide guidance for the stage of strategy development in transformative research frameworks (Wiek and Lang 2016). This will especially contribute to enabling approaches in sustainability transformations research, that focus on analysing, supporting, and enabling transformative change fostered by local actors from the bottom-up (Stirling 2015, Pereira et al. 2020, Scoones et al. 2020).

Second, the principles potentially lead to higher legitimacy and shared ownership for intervention strategies. Legitimacy and shared ownership are important for the implementation of intervention strategies (Wiek and Lang 2016). By integrating sustainability initiatives, intervention strategies build up, strengthen, and complement the diverse knowledge, actions, and experiences from local actors which can create legitimacy and shared ownership (Scoones et al. 2020). Depending on the local actors, in some cases this can mean the integration of ILK as it can be manifested in initiatives and experiences of IPLC (Guerrero et al. 2019). Higher legitimacy and shared ownership for intervention strategies may lead to higher success of transformative transdisciplinary research by increasing the possibility that co-designed intervention strategies become implemented and lead to the desired change.

Third, the principles operationalize the notion of leverage points in transformative transdisciplinary research. The notion of leverage points is a hitherto under-recognized heuristic and practical tool for sustainability transformations research (Fischer and Riechers 2019). In sustainability transformations research the identification and analysis of drivers and barriers for desired change have been well emphasized and studied (O'Brien 2012, Loorbach et al. 2017). In addition, the principles propose to identify with local actors leverage points in the system where interventions may trigger change across various drivers and barriers (P3). This may help to find and understand leverage points perceived by local actors, who are often the ones best understanding the dynamics of the system in which they live. Sustainability intervention strategies can integrate perceived leverage points to increase the potential for fundamental instead of incremental change (Abson et al. 2017). Research that identifies leverage points with local actors is limited. Therefore, future research could further study

leverage points that are perceived by local actors and how to work with local actors on leverage points.

4.3.2. The identification of relevant local actors for sustainability interventions in system characteristics

Relevant partners to foster transformations

Transformative transdisciplinary research highlights the importance to collaborate with relevant local actors and their sustainability initiatives to foster transformations (Wiek and Lang 2016, Pereira et al. 2020, Sellberg et al. 2020). Applying a leverage points perspective in social network analyses enables the identification of relevant science-society partners for interventions in specific or across system characteristics. By applying a leverage points perspective in social network analyses, it is possible to sort relations between local actors according to the system characteristics that they address and to analyse centrality metrics of local actors (e.g., weighted degree, betweenness, eigenvector) to elicit which actors are more central in different networks (Chapter 4.2.1.) (Bodin and Prell 2011, Hauck et al. 2016). Knowing which local actors are relevant for specific interventions enables to collaborate specifically with these local actors and improve the support of such actors as they may have different needs due to the different actions and initiatives that they apply.

However, this new approach of identifying relevant partners to foster transformative change is still in its infancy and requires further refinement, evaluation, and adaptation. Future research could study if this approach in practice really enhances the identification and selection of relevant partners. Such research could also study in past transformations of systems whether local actors with high centrality metrics in specific networks were also those who fostered change in specific system characteristics. This can provide further insights on the reliability of this approach.

4.4. Supporting local actors to foster sustainability transformations

This dissertation as a whole contributes insights to three recommendations on how transformative transdisciplinary research can support local actors fostering change towards sustainability. First, by conducting research that studies and supports local actors who increase the impact of their sustainability initiatives via amplification processes (P1, P4). Pereira et al. (2018a) discuss that sustainability initiatives play an important role for preparing transformations in their local contexts. Loorbach et al. (2020) add to this that initiatives can even have impact beyond their local contexts because their impact can diffuse to other places.

The amplification typology I propose helps researchers to study the processes that increase the impact of sustainability initiatives. Such studies potentially provide sustainability transformations research with a better understanding of the concrete actions needed for each process. In addition, it can inform future studies on the barriers and enabling factors for increasing impact. Researchers can also collaborate with initiatives who seek to have more impact. They could co-design strategies that intentionally increase the impact of initiatives. My typology can provide theoretical guidance for such strategies as I have demonstrated in the case of NGOs who seek to increase their impact in Southern Transylvania (Fischer et al. 2019).
Second, by engaging specifically with the initiatives, networks, and knowledge from local actors, who foster bottom-up, place-based transformations (P1-4). Several scholars discuss that the initiatives and knowledge of local actors and the networks they form foster bottom-up, place-based transformations because they provide alternative solution options that challenge incumbent and unsustainable regimes (Stirling 2015, Bennett et al. 2016, Pereira et al. 2018a, Scoones et al. 2020, Loorbach et al. 2020). I contribute to this discussion a better understanding of how initiatives increase their impact and how they can be integrated in transformative transdisciplinary research (P1, P3). I add a new way of conceptualizing and studying how local actors with their relations and networks intervene in systems (P4). In addition, I show with a review on ILK as an example, how knowledge from local actors is currently applied in sustainability transformations research (P2). These insights potentially advance transformative transdisciplinary research, which engages with local actors who seek to foster transformations.
Third, by identifying and collaborating with local actors that are relevant for strategic systems interventions that build on, strengthen, and complement existing initiatives (P3-4). Identifying relevant local actors to co-design intervention strategies depicts a challenge in transformative transdisciplinary research (Lang et al. 2012, Roux et al. 2017). My dissertation suggests a new methodological approach for identifying relevant local actors for collaborations that seek to intervene in specific characteristics of a system (P4). In addition, I provide guidance for co-designing sustainability intervention strategies with local actors that integrate their initiatives (P3). This potentially enhances transformative transdisciplinary research in identifying relevant partners while acknowledging and integrating their initiatives.
These three recommendations pave the way for an enhanced transformative transdisciplinary research that can potentially support local actors who with their initiatives, networks, and knowledge foster bottom-up, place-based sustainability transformations.

4.5. Limitations

Four limitations need to be raised to better understand the research of my dissertation: (1) Neglecting governance and political challenges of transformations, (2) focusing on local perspectives in a globalized world, (3) acknowledging the limits of transformative transdisciplinary research, and (4) generalizability of my results.

First, my research focused on bottom-up, place-based sustainability transformations fostered by local actors. Despite the importance of such transformations, especially in contexts where the governance structures are unreliable and unstable (e.g., corruption or weak governance structures) (Nightingale 2017), this approach neglects to pay attention to the governance and political challenges that transformations involve (Avelino and Rotmans 2009, Abson et al. 2017, Loorbach et al. 2017). Scholars have made major contributions to better understand the governance and political challenges of transformations, but it still remains under-developed in research applying enabling approaches to study transformations (Meadowcroft 2011, Patterson et al. 2017, Köhler et al. 2019, Scoones et al. 2020). However, exploring the connections between bottom-up and top-down fostered transformations may yield promising insights to support actions from both sides and to explore synergies.

Second, I highlight the role of local actors in sustainability transformations. This risks to put the burden and responsibility of transformative change only on the shoulders of those who are at the same time the most vulnerable and effected ones (Scoones et al. 2020). In addition, this approach risks falling into the localism trap. The localism trap refers to the tendency of practitioners and researchers to assume that the “local-scale” is always more desirable, preferred to larger scales, and will be more socially just (e.g., a local food system solution in comparison to a national or global solution) (Born and Purcell 2006, Mehmood et al. 2020). I do not assume that the transformations that society urgently needs should only be fostered by local actors and from the bottom-up. However, research in general and sustainability transformations research too tends to develop insights and recommendations that specifically target policy makers who then hopefully foster transformative change through top-down decisions (Pereira et al. 2018a). This maybe overestimates the ambitions and possibilities of policy makers to foster change towards sustainability. Highlighting the role of local actors will potentially lead to more transformative transdisciplinary research that co-produces knowledge, solutions, and recommendations specifically with and for local actors.

Third, current sustainability transformations research highlights the potential of transformative transdisciplinary research to have greater impact for sustainability (Pereira et al. 2020, Scoones et al. 2020, Norström et al. 2020). However, such research involves several challenges. For example, the changing role of researchers (Wittmayer and Schäpke 2014), the need to practice reflexivity (Fazey et al. 2018), the ethical considerations of researchers intervening in systems (Cockburn and Cundill 2018), the skills needed (Sellberg 2018), and

the difficulty to measure and evaluate outcomes, output, and impact (Walter et al. 2007, Luederitz et al. 2017b). In addition, a recent study by Schneider et al. (2019) reveals that there is still rather little empirical evidence that transdisciplinary research contributes to transformative change. Despite these challenges, transformative transdisciplinary research is still a promising research practice that acknowledges the potential of collaborations between academic and non-academic actors with their diverse knowledge jointly contributing to solutions for transformative change.

Fourth, the empirical insights of my dissertation need to be interpreted with limitations because they are only based on data from one transdisciplinary case study in Southern Transylvania, where I worked with NGOs. This case study was a unique and relevant case to conduct transformative transdisciplinary research for my dissertation on local actors fostering change towards sustainability with initiatives (i.e., NGOs and their initiatives) due to the circumstances that previous and ongoing research had created. However, my empirical insights should not be regarded as directly generalizable insights. Instead, they are first insights for further theory development concerning bottom-up, place-based transformations and for future studies in other places where networks of local actors foster change towards sustainability with initiatives.

4.6. Reflections on my transdisciplinary PhD journey

In this section I want to share my personal reflections on conducting a transdisciplinary PhD that are important to understand my research (van Breda et al. 2016). These experiences are potentially relevant for other (future) transdisciplinary PhDs, supervisors, transdisciplinary research projects, and funders.

First, engaging with the researchers and local actors of a transdisciplinary case study shaped the direction and sub-research questions of my research. I conducted my PhD in the research project Leverage Points for Sustainability Transformation, which had a theoretical focus on Donella Meadows idea of leverage points (Meadows 1999, Abson et al. 2017). The focus on leverage points and the previous research in the case study influenced strongly the direction of my PhD research by shaping my sub-research questions. For example, the previous research had co-developed a future vision for Southern Transylvania, named Balance Brings Beauty (Hanspach et al. 2014), which was used by the NGOs as a metaphor to explain what they want to achieve with their initiatives. During scoping meetings, local actors discussed that achieving their desired future is a matter of amplifying the impact of their initiatives. These discussions where one of the reasons why I conducted a literature review on amplification processes and developed an integrated typology (P1). I wanted to provide scientific knowledge to local actors for a real-world problem. To translate the findings of my review back to the local actors, I participated in co-writing a practitioners guide on strategies to reach Balance Bring

Beauty in which we explained in non-academic language how initiatives can increase their impact with amplification processes (Fischer et al. 2019). Another example is that NGOs in Southern Transylvania repeatedly mentioned that relations are important to reach their desired vision and that they need to better understand their networks and with who else they need to collaborate. Therefore, I conducted social network analyses in Southern Transylvania in which I applied a leverage points perspective (P4). These two examples show how my research has been developed in an interplay between my main research question and the transdisciplinary case study (Lang et al. 2012, Cockburn 2018, Sellberg 2018). This potentially deviates from other PhD research, which develop their research purely based on a scientific problem. However, this is how I conducted my transdisciplinary PhD journey and tried to increase the potential of it having societal relevance (van Breda et al. 2016, Cockburn et al. 2018).

Second, being part of an ongoing transdisciplinary case study that was led by a senior researcher provided me with a specific access and role in the case study. The senior researcher was the responsible person for the case study, held the relations to the local actors, and often served as a gatekeeper because of her previous research in Southern Transylvania (Enengel et al. 2012). She introduced me to the local actors and provided me with important context-specific knowledge to understand underlying dynamics with previous research results and personal experiences (Enengel et al. 2012, Hanspach et al. 2014). She was also important to explain to me what local actors thought and say who only spoke Romanian because I was only able to talk directly to those local actors who were able to talk in English or German to gain unfiltered insights (Temple and Young 2004). Thus, I often had to rely on her previous research and experiences when I tried to interpret what was going on in the case study. Furthermore, because the senior researcher was mainly responsible to organize and facilitate the case study, I was able to take a different role, which was mostly that of an reflective scientist and process facilitator (Wittmayer and Schäpke 2014). In the background, I observed and conducted research on questions that derived from the case study. In occasions, I facilitated workshops and presented results, such as from the social network analyses (P4). This situation gave me the opportunity to observe and reflect more, as I was less involved in relational challenges that work with local actors implicates (Harris and Lyon 2013).

Third, my personal (e.g., responsibility for my family) and project limitations (e.g., funding, case study in another country) restricted my time in the field to gain further insights of the case and to build stronger relations to the local actors. Spending time in the field and building relations and trust to the local actors is a key for successful collaborations and transdisciplinary research (Harris and Lyon 2013, van Breda et al. 2016, Sellberg 2018). However, this is not always practically possible and raises the following questions: (1) Could I have done better

transformative transdisciplinary research if I would have spent more time in the field?; and (2) What are personal and project limitations that support and limit transformative transdisciplinary research, especially in a PhD that is often limited in time and funding? I reflected on these two questions with a group of PhDs conducting transdisciplinary research in different countries and contexts (Cockburn et al. 2018). We concluded that besides the well elaborated challenges of scientific rigor and societal relevance in a transdisciplinary PhD (Jahn et al. 2012, Lang et al. 2012, van Breda et al. 2016, Cockburn 2018), self-care is a neglected challenge in this field of research (Cockburn et al. 2018, Sellberg 2018). Self-care describes the challenge of managing personal possibilities and limitations to conduct research, while being stretched between publishing scientific rigor and excellent papers, and conducting societal relevant research that fulfils expectations of local actors (Sellberg et al., unpublished).

These reflections underpin the challenges of conducting a transdisciplinary PhD (van Breda et al. 2016, Cockburn 2018, Sellberg 2018). They show (future) transdisciplinary PhDs and supervisors how such research is co-developed with non-academic actors and thus not only driven by own and scientific interests. This has implications for the funding, planning, and supervision of transdisciplinary PhDs. In addition, the reflections show to transdisciplinary research projects and funders that time and relations are important to conduct such research, which are often limited due to project and financial constraints.

4.7. Implications

This dissertation contributes insights to sustainability transformations research that focuses on the role of local actors with their initiatives, networks, and knowledge. The insights have implications for future research, the science-society interface, and the science-policy interface.

4.7.1. Future research on bottom-up sustainability transformations

The insights of my dissertation pave the way for future research concerning (1) amplification processes, (2) ILK in transformations research, and (3) transformative transdisciplinary research. First, future research could investigate empirically how sustainability initiatives individually and in networks apply amplification processes in urban and rural areas (e.g., Hamburg, Germany, or Southern Transylvania, Romania). This could provide insights on the diverse concrete actions that local actors apply to increase impact. Studying the concrete actions applied to increase impact can advance our theoretical understanding of amplification processes and the interactions between different processes (P1). It will also enhance our understanding of how networks of initiatives, for instance, in a city or on a regional level apply amplification processes.

Second, future research could investigate empirically different understandings of transformation and amplification processes from local actors, such as from IPLC. P2 showed

that the current sustainability transformations literature neglects to engage with indigenous and local understandings of transformation. However, this is crucial because IPLC with their ILK can potentially make valuable contributions to fostering and understanding transformations (Tengö et al. 2017, Scoones et al. 2020, Hill et al. 2020). Their initiatives and actions are in line with their knowledge, values, and mind-sets and maybe derive from a different way of understanding and fostering transformative change (P2). Thus, understanding what local actors think about transformation and amplification can improve our actions and conceptualization of both. In addition, this can advance top-down transformations and interventions to be locally adaptive and accepted due to the integration of local values and mind-sets.

Third, future transformative transdisciplinary research could investigate the challenges and benefits of applying the principles that provide guidance to support the integration of local actors and their initiatives in intervention strategies (P3), and of applying a leverage points perspective in social network analyses to identify relevant local actors for interventions in specific system characteristics (P4). This could support the improvement of both methodological contributions. For example, future research could unveil whether the principles need to be adopted to urban contexts because they have been derived from work with initiatives in a rural area. Urban contexts might vary with regards to geographical proximity, collaborative potential, and number, diversity, and focus of initiatives (Frantzeskaki et al. 2014, Gorissen et al. 2018). Another example of future research could try to improve the application of a leverage points perspective in social network analysis by exploring further possibilities. I have used weighted degree, betweenness, and eigenvector as centrality metrics to identify relevant local actors. However, other centrality metrics might provide further insights for identifying relevant local actors, such as closeness centrality. Closeness centrality provides insights on the independency of actors in networks to act without relying on others (Freeman 1978, Prell 2011b). In addition, future research could further explore how to best support and collaborate with actors that play relevant roles for intervening in the parameters, feedbacks, design, or intent of a system.

4.7.2. Enhancing research at the science-society interface

My dissertation provides insights for research at the science-society interface working on bottom-up, place-based sustainability transformations. First, my insights are relevant for research that conducts transdisciplinary research on transformative change, such as research from PECS. PECS research is explicitly transdisciplinary and aims to break down the barriers that impede the understanding and support of transformative change (Carpenter et al. 2012). For example, PECS research on sustainability initiatives (e.g., seeds of good Anthropocenes) can benefit from my insights on amplification processes that increase the impact of initiatives

(P1) (Bennett et al. 2016). PECS research can also benefit from my insights on the application of ILK in sustainability transformations research (P2). For example, by trying to understand indigenous and local conceptualizations of transformation while conducting research on social-ecological systems transformations with IPLC. In addition, the increasing transformative transdisciplinary research from PECS can benefit from my methodological contributions on integrating and identifying relevant local actors for collaborations (P3, P4) (Cockburn 2018, Pereira et al. 2020, Sellberg et al. 2020)

Second, my research in Southern Transylvania ended with the launch of the practitioners book on strategies to reach an alternative future which are based on my typology of amplification processes (Fischer et al. 2019). In a next step, I would like to investigate cases in which NGOs applied an amplification process, such as the replication of an initiative to another place, to understand the concrete actions that have been taken. I would also like to work with NGOs on the intentional application of different amplification processes. Both ideas for further research in Southern Transylvania, can potentially provide insights on the concrete actions and challenges that different processes entail.

Third, non-academic actors, such as local actors, can gain insights on increasing impact of their sustainability initiatives (P1), and their collaborations with other actors (P4). For example, local actors can increase impact by applying a set of different amplification processes (e.g., *replicating,* or *scaling deep*) that have different mechanisms to increase impact (e.g., higher number of initiatives, or changing values and mind-sets). Another example is that local actors can rethink their relations and collaborations with other actors concerning the different characteristics of a system that their relations address. Local actors who aim to foster transformative change can reflect on the types of relations that they are having to different actors, how strong they are, and which ones they might want to strengthen.

4.7.3. Enhancing research at the science-policy interface

My dissertation contributes insights to research at the science-policy interface concerning amplification processes and transformations. First, my typology of amplification processes could inform research on and development of policies that create protective spaces for initiatives in which they are shielded, nurtured, and empowered while they increase their impact (P1) (Leach et al. 2012, Smith and Raven 2012, Scoones et al. 2015). Shielding means to hold off risks and pressures while initiatives try to, for instance, open a new initiative in another place (Smith and Raven 2012). Nurturing means to support initiatives while they increase impact, for instance, by lowering barriers and providing subsidies (Smith and Raven 2012). Empowering means to strengthen initiatives to compete with pressures from incumbent regimes, or to create favourable environments in regimes for sustainability initiatives to increase their impact (Smith and Raven 2012).

Second, my dissertation contributes to research on transformative change at the science-policy interface, such as research from IPBES. IPBES assesses globally the state of biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long-term human well-being, and sustainable development (IPBES 2019a). In the next years, IPBES plans to analyse the factors that can leverage transformative change for biodiversity conservation while specifically highlighting the participation of IPLC in its assessments (Díaz-Reviriego et al. 2019, IPBES 2019b, Hill et al. 2020). In P2, I show the lack of engaging with indigenous and local understandings of transformation, and highlight the need to do this as a prerequisite for working with IPLC on transformative change.

5. Conclusion

This dissertation contributes theoretically and methodologically to sustainability transformations research that seeks to study and support local actors fostering change towards desired futures. Theoretically, by advancing our understanding of amplification processes that local actors apply to increase the impact of their sustainability initiatives; relations and networks from local actors that intervene in characteristics of a system (e.g., parameters); and the application of knowledge from local actors to understand transformations, such as in the case of ILK from IPLC in current sustainability transformations literature. Methodologically, by rethinking how transformative transdisciplinary research can better integrate sustainability initiatives from local actors in intervention strategies and how to identify relevant local actors for collaborations that seek to intervene in specific characteristics of a system. These contributions advance sustainability transformations research by highlighting the role of local actors with their initiatives, networks, and knowledge. Ultimately, this dissertation makes novel contributions that advance transformative transdisciplinary research, which aims to support local actors in fostering bottom-up, place-based sustainability transformations.

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7. Appendix

7.1. Paper 1 appendix

Electronic Supplementary Material

This supplementary material has not been peer reviewed.

Title: Scaling the impact of sustainability initiatives: a typology of amplification processes

Supplementary material

Table S1. Detailed overview of how the processes of different frameworks overlap and differ as well as how we grouped them under the amplification processes. We only analyzed processes that focus on increasing impact and therefore excluded cross-cutting, partnering, instrumentalising, and accumulation in this analysis. *Speeding up is based on the idea of acceleration mechanisms which processes can increase the pace of a transformation. Italics indicate not perfect matches.

Amplification processes	**Amplification frameworks and their processes**					
	Strategies for social innovation	**Seeds of good Anthropocene**	**Scale dynamics**	**Acceleration mechanisms**	**Transition management**	**Strategic niche management**
Stabilizing		***Scale up**: "[G]row to involve more people and places" (www.goodanthropocenes.net)*		**Upscaling**: Increase the number of "members, supporters or users of a single transition initiative in order to spread these new ways of [thinking, doing and organizing]." (Gorissen et al. 2018, p. 173).		**Growing**: Continuation of experiment "and more actors participate" (Naber et al. 2017, p. 344)

Speeding up				**all processes*		
Growing		**Scale up**: "[G]row to involve more people and places" (www.goodanthropocenes.net)	***Outscaling***: *"[R]eplicate and disseminate programs, products, ideas or innovative approaches in order to affect more people or to cover a larger geographical area"* (Hermans et al. 2016, p. 287).	***Upscaling***: *Increase the number of "members, supporters or users of a single transition initiative in order to spread these new ways of [thinking, doing and organizing]."* (Gorissen et al. 2018, p. 173).		**Growing**: Increase "the scale at which technologies are used" (Naber et al. 2017, p. 344)
Replicating	**Scaling out**: "Replicating or spreading programmes geographically and to greater numbers while protecting the fidelity and integrity of the innovation" (Moore et al. 2015 p. 77)	**Scale out**: Reproduce "in different places" (www.goodanthropocenes.net)	**Outscaling**: "[R]eplicate and disseminate programs, products, ideas or innovative approaches in order to affect more people or to cover a larger geographical area" (Hermans et al. 2016, p. 287).		**Broadening**: Repeat and link "an experiment in a different context" (Rotmans and Loorbach 2008, p. 27). "The result of broadening can be (…) the new or deviant culture, practices and structure get diffused (…) in a variety of contexts"	

			(van den Bosch and Rotmans 2008, p. 32).	
Transferring		***Replicating****: "[T]ake up […] new ways of [thinking, doing and organizing] of one transition initiative by another transition initiative or different actors in order to spread out these new ways."* (Gorissen et al. 2018, p. 173).	**Broadening**: Repeat and link "an experiment in a different context" (Rotmans and Loorbach 2008, p. 27). "The result of broadening can be (…) the new or deviant culture, practices and structure get (…) adopted in a variety of contexts" (van den Bosch and Rotmans 2008, p. 32)	**Replication**: Replicate means that "[t]he main concept of the experiment is replicated in other locations" (Naber et al. 2017, p. 344)
Spreading	**Scaling out**: "Disseminate principles, but with an adaptation to new contexts […] leaving it to the local community to adapt it to local conditions" (Moore	**Replicating**: "[T]ake up […] new ways of [thinking, doing and organizing] of one transition initiative by another transition initiative or different actors	**Broadening**: Repeat and link "an experiment in a different context" (Rotmans and Loorbach 2008, p. 27). "The result of broadening can be […] the new or	**Replication**: Means that "[t]he main concept of the experiment is replicated in other […] contexts" (Naber et al. 2017, p. 344)

	et al. 2015 pp. 77–78)			in order to spread out these new ways." (Gorissen et al. 2018, p. 173).	deviant culture, practices and structure fulfill a broader function." (van den Bosch and Rotmans 2008, p. 32)	
Scaling up	**Scaling up**: Impacting "higher levels of institutions through policy change" (Moore et al. 2015 p. 79)		**Upscaling**: Embed or institutionalize "an innovation and changing the 'institutional logics' of an incumbent regime" (Hermans et al. 2016, p. 287)	**Embedding**: Align "old and new ways of [thinking, doing and organizing] in order to integrate them into city-regional governance patterns." (Gorissen et al. 2018, p. 173)	**Scaling up**: "[A]pply a successful experiment at a higher scale level" (Rotmans and Loorbach 2008, p. 27)	**Transformation**: Means that "[t]he experiment shapes wider institutional change in the regime selection environment" (Naber et al. 2017, p. 344)
Scaling deep	**Scaling deep**: Spreading big cultural ideas and reframing stories to change beliefs and norms" (Moore et al. 2015, p. 77)	**Scale deep**: "[C]hange underlying values to inspire people to live in a different way" (www.goodanthropocenes.net)			**Deepening**: Learn from a transition initiative which "includes (local) shifts in ways of thinking, values and perspectives (culture), shifts in doing things, habits	

		and routines (practices)" (van den Bosch and Rotmans 2008, p. 29-30)

References:

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7.2. Paper 2 appendix

Appendix 1: Search string inserted into the database Scopus

1. Regarding transformations:
   a. TITLE-ABS-KEY (transform* OR transition* OR change*)

AND

2. Regarding indigenous and local knowledge:
   b. ("indigenous knowledge" OR "indigenous ecological knowledge" OR "indigenous environmental knowledge" OR "indigenous local knowledge" OR "local knowledge" OR "local ecological knowledge" OR "local environmental knowledge" OR "traditional knowledge" "traditional ecological knowledge" OR "traditional environmental knowledge" OR "local indigenous knowledge" OR "local traditional knowledge" OR "indigenous traditional knowledge" OR "traditional indigenous knowledge" OR "traditional local knowledge")

AND

3. Regarding document characteristics:
   a. (LIMIT-TO (DOCTYPE , "ar ")) AND (EXCLUDE (SUBJAREA , "EART ") OR EXCLUDE (SUBJAREA , " MEDI ") OR EXCLUDE (SUBJAREA , " BIOC ") OR EXCLUDE (SUBJAREA , " ENER ") OR EXCLUDE (SUBJAREA , " COMP ") OR EXCLUDE (SUBJAREA , " ENGI ") OR EXCLUDE (SUBJAREA , " NURS ") OR EXCLUDE (SUBJAREA , " PHAR ") OR EXCLUDE (SUBJAREA , " HEAL ") OR EXCLUDE (SUBJAREA , " CHEM ") OR EXCLUDE (SUBJAREA , " CENG ") OR EXCLUDE (SUBJAREA , " IMMU ") OR EXCLUDE (SUBJAREA , " MATH ") OR EXCLUDE (SUBJAREA , " NEUR ") OR EXCLUDE (SUBJAREA , " PHYS ") OR EXCLUDE (SUBJAREA , " VETE ")) AND (EXCLUDE (PUBYEAR , 2017) OR EXCLUDE (PUBYEAR , 1999) OR EXCLUDE (PUBYEAR , 1998) OR EXCLUDE (PUBYEAR , 1997) OR EXCLUDE (PUBYEAR , 1996) OR EXCLUDE (PUBYEAR , 1995) OR EXCLUDE (PUBYEAR , 1994) OR EXCLUDE (PUBYEAR , 1991) OR EXCLUDE (PUBYEAR , 1986) OR EXCLUDE (PUBYEAR , 1979))

Appendix 2: Papers included in the literature review

Author	Title	Year	Cluster
Alessa L., Kliskey A., Williams P., Barton M.	Perception of change in freshwater in remote resource-dependent Arctic communities	2008	Red
Altschuler B., Brownlee M.	Perceptions of climate change on the island of Providencia	2015	Green
Andrachuk M., Armitage D.	Understanding social-ecological change and transformation through community perceptions of system identity	2015	Blue
Apgar M.J., Allen W., Moore K., Ataria J.	Understanding adaptation and transformation through indigenous practice: The case of the Guna of Panama	2015	Blue
Aswani S., Lauer M.	Indigenous people's detection of rapid ecological change	2014	Blue
Beaudreau A.H., Levin P.S.	Advancing the use of local ecological knowledge for assessing data-poor species in coastal ecosystems	2014	Blue
Berkes F., Jolly D.	Adapting to climate change: Social-ecological resilience in a Canadian western arctic community	2002	Red
Boillat S., Berkes F.	Perception and interpretation of climate change among quechua farmers of bolivia: Indigenous knowledge as a resource for adaptive capacity	2013	Green
Boissière M., Locatelli B., Sheil D., Padmanaba M., Sadjudin E.	Local perceptions of climate variability and change in tropical forests of Papua, Indonesia	2013	Grey
Boll V.M.	Following Garkman, the frog, in north eastern Arnhem Land (Australia)	2006	Green
Brännlund I., Axelsson P.	Reindeer management during the colonization of Sami lands: A long-term perspective of vulnerability and adaptation strategies	2011	Blue
Bruegger R.A., Jigjsuren O., Fernández-Giménez M.E.	Herder observations of rangeland change in Mongolia: Indicators, causes, and application to community-based management	2014	Grey
Byg A., Salick J.	Local perspectives on a global phenomenon-Climate change in Eastern Tibetan villages	2009	Grey
Carothers C., Brown C., Moerlein K.J., Andrés López J., Andersen D.B., Retherford B.	Measuring perceptions of climate change in Northern Alaska: Pairing Ethnography with cultural consensus analysis	2014	Red
Carter B.T.G., Nielsen E.A.	Exploring ecological changes in Cook Inlet beluga whale habitat though traditional and local ecological knowledge of contributing factors for population decline	2011	Red
Chalmers N., Fabricius C.	Expert and generalist local knowledge about land-cover change on South Africa's Wild Coast: Can local ecological knowledge add value to science?	2007	Grey
Chaudhary P., Bawa K.S.	Local perceptions of climate change validated by scientific evidence in the Himalayas	2011	Grey
Chaudhary P., Rai S., Wangdi S., Mao A., Rehman N., Chettri S., Bawa K.S.	Consistency of local perceptions of climate change in the Kangchenjunga Himalaya landscape	2011	Grey
Clark D.A., Slocombe S.	Adaptive Co-Management and Grizzly Bear-Human Conflicts in Two Northern Canadian Aboriginal Communities	2011	Red
Codjoe S.N.A., Owusu G., Burkett V.	Perception, experience, and indigenous knowledge of climate change and variability: The case of Accra, a sub-Saharan African city	2014	Green
Crate S.A., Fedorov A.N.	A methodological model for exchanging local and scientific climate change knowledge in northeastern Siberia	2013	Red
de Almeida G.M.A., Ramos M.A., Araújo E.L., Baldauf C., Albuquerque U.P.	Human perceptions of landscape change: The case of a monodominant forest of Attalea speciosa Mart ex. Spreng (Northeast Brazil)	2016	Grey
Dinero S.C.	Indigenous perspectives of climate change and its effects upon subsistence activities in the Arctic: The case of the Nets'aii Gwich'in	2013	Red
Dowsley M., Wenzel G.	"The time of the most polar bears": A co-management conflict in Nunavut	2008	Red
Eisner W.R., Cuomo C.J., Hinkel K.M., Jones B.M.,	Advancing landscape change research through the Incorporation of Iñupiaq knowledge	2009	Red

Brower Sr. R.H.			
Fernández-Giménez M.E., Fillat F.	Pyrenean pastoralists'observations of environmental change: An exploratory study in los Valles Occidentales of Aragón	2012	Grey
Fernández-Llamazares Á., Díaz-Reviriego I., Guèze M., Cabeza M., Pyhälä A., Reyes-García V.	Local perceptions as a guide for the sustainable management of natural resources: Empirical evidence from a small-scale society in Bolivian Amazonia	2016	Green
Fernández-Llamazares Á., Díaz-Reviriego I., Luz A.C., Cabeza M., Pyhälä A., Reyes-García V.	Rapid ecosystem change challenges the adaptive capacity of local environmental knowledge	2015	Green
Ford J.D., Smit B., Wandel J.	Vulnerability to climate change in the Arctic: A case study from Arctic Bay, Canada	2006	Red
Frans V.F., Augé A.A.	Use of local ecological knowledge to investigate endangered baleen whale recovery in the Falkland Islands	2016	Blue
Giglio V.J., Luiz O.J., Gerhardinger L.C.	Depletion of marine megafauna and shifting baselines among artisanal fishers in eastern Brazil	2015	Blue
Gill H., Lantz T.	A community-based approach to mapping Gwich'in observations of environmental changes in the lower peel river watershed, NT	2014	Red
Golden D.M., Audet C., Smith M.A.	“Blue-ice”: framing climate change and reframing climate change adaptation from the indigenous peoples' perspective in the northern boreal forest of Ontario, Canada	2015	Red
Gómez-Baggethun E., Reyes-García V., Olsson P., Montes C.	Traditional ecological knowledge and community resilience to environmental extremes: A case study in Doñana, SW Spain	2012	Green
Hallwass G., Lopes P.F., Juras A.A., Silvano R.A.M.	Fishers' knowledge identifies environmental changes and fish abundance trends in impounded tropical rivers	2013	Blue
Hansen W.D., Brinkman T.J., Leonawicz M., Chapin III F.S., Kofinas G.P.	Changing daily wind speeds on Alaska's North Slope: Implications for rural hunting opportunities	2013	Red
Herman-Mercer N.M., Matkin E., Laituri M.J., Toohey R.C., Massey M., Elder K., Schuster P.F., Mutter E.A.	Changing times, changing stories: Generational differences in climate change perspectives from four remote indigenous communities in Subarctic Alaska	2016	Red
Homann S., Rischkowsky B., Steinbach J., Kirk M., Mathias E.	Towards endogenous livestock development: Borana pastoralists' responses to environmental and institutional changes	2008	Grey
Hopping K.A., Yangzong C., Klein J.A.	Local knowledge production, transmission, and the importance of village leaders in a network of Tibetan pastoralists coping with environmental change	2016	Green
Huntington H.P., Quakenbush L.T., Nelson M.	Effects of changing sea ice on marine mammals and subsistence hunters in northern Alaska from traditional knowledge interviews	2016	Red
Jandreau C., Berkes F.	Continuity and change within the social-ecological and political landscape of the Maasai Mara, Kenya	2016	Green
Janif S.Z., Nunn P.D., Geraghty P., Aalbersberg W., Thomas F.R., Camailakeba M.	Value of traditional oral narratives in building climate-change resilience: Insights from rural communities in Fiji	2016	Green
Kakinuma K., Ozaki T., Takatsuki S., Chuluun J.	How Pastoralists in Mongolia perceive vegetation changes caused by grazing	2008	Grey
Kassam K.-A.	Viewing change through the prism of indigenous human ecology: Findings from the afghan and Tajik pamirs	2009	Green
Kendrick A., Lyver P.O'B.	Denésǫliné (Chipewyan) knowledge of barren-ground caribou (Rangifer tarandus groenlandicus) movements	2005	Red
Kgosikoma O., Mojeremane W., Harvie B.A.	Pastoralists' perception and ecological knowledge on savanna ecosystem dynamics in semi-arid Botswana	2012	Grey

Klein J.A., Hopping K.A., Yeh E.T., Nyima Y., Boone R.B., Galvin K.A.	Unexpected climate impacts on the Tibetan Plateau: LOCAL and scientific knowledge in findings of delayed summer	2014	Green
Kokelj S.V., Lantz T.C., Solomon S., Pisaric M.F.J., Keith D., Morse P., Thienpont J.R., Smol J.P., Esagok D.	Using multiple sources of knowledge to investigate northern environmental change: Regional ecological impacts of a storm surge in the outer Mackenzie Delta, N.W.T.	2012	Red
Lauer M., Aswani S.	Indigenous knowledge and long-term ecological change: Detection, interpretation, and responses to changing ecological conditions in pacific island communities	2010	Blue
Leonard S., Parsons M., Olawsky K., Kofod F.	The role of culture and traditional knowledge in climate change adaptation: Insights from East Kimberley, Australia	2013	Green
Levine A., Sauafea-Le'Au F.	Traditional knowledge, use, and management of living marine resources in american samoa: Documenting changes over time through interviews with elder fishers	2013	Blue
Lyver P.O.B., Taputu T.M., Kutia S.T., Tahi B.	Tūhoe Tuawhenua mātauranga of kererū (Hemiphaga novaseelandiae novaseelandiae) in Te Urewera	2008	Green
Mallory M.L., Gilchrist H.G., Braune B.M., Gaston A.J.	Marine birds as indicators of arctic marine ecosystem health: Linking the Northern Ecosystem Initiative to long-term studies	2006	Red
Marin A.	Riders under storms: Contributions of nomadic herders' observations to analysing climate change in Mongolia	2010	Grey
McCarthy D.D.P., Whitelaw G.S., Anderson S., Cowan D., McGarry F., Robins A., Gardner H.L., Barbeau C.D., Charania N.A., General Z., Liedtke J., Sutherland C., Alencar P., Tsuji L.J.S.	Collaborative geomatics and the Mushkegowuk Cree First Nations: Fostering adaptive capacity for community-based sub-arctic natural resource management	2012	Red
McDowell J.Z., Hess J.J.	Accessing adaptation: Multiple stressors on livelihoods in the Bolivian highlands under a changing climate	2012	Green
McIntyre-Tamwoy S., Fuary M., Buhrich A.	Understanding climate, adapting to change: Indigenous cultural values and climate change impacts in North Queensland	2013	Green
McNamara K.E., Westoby R.	Local knowledge and climate change adaptation on erub Island, torres strait	2011	Green
Moshy V.H., Bryceson I.	Seeing Through Fishers' Lenses: Exploring Marine Ecological Changes Within Mafia Island Marine Park, Tanzania	2016	Blue
Muchagata M., Brown K.	Colonist farmers' perceptions of fertility and the frontier environment in eastern Amazonia	2000	Grey
Nichols T., Berkes F., Jolly D., Snow N.B.	Climate change and sea ice: Local observations from the Canadian western Arctic	2004	Red
Oteros-Rozas E., Ontillera-Sánchez R., Sanosa P., Gómez-Baggethun E., Reyes-García V., González J.A.	Traditional ecological knowledge among transhumant pastoralists in Mediterranean Spain	2013	Green
Oviedo A.F.P., Mitraud S., McGrath D.G., Bursztyn M.	Implementing climate variability at the community level in the Amazon floodplain	2016	Grey
Palframan A.	"In common nature": an ethnography of climate adaptation in the Lesotho Highlands	2015	Green
Paré S., Savadogo P., Tigabu M., Ouadba J.M., Odén P.C.	Consumptive values and local perception of dry forest decline in Burkina Faso, West Africa	2010	Grey
Parlee B., Manseau M.	Using traditional knowledge to adapt to ecological change: Denésǫłiné monitoring of caribou movements	2005	Red
Parlee B.L., Geertsema K., Willier A.	Social-ecological thresholds in a changing boreal landscape: Insights from cree knowledge of the Lesser Slave Lake region of Alberta, Canada	2012	Red

Reedy D., Savo V., McClatchey W.	Traditional Climatic Knowledge: Orchardists' perceptions of and adaptation to climate change in the Campania region (Southern Italy)	2014	Grey
Roba H.G., Oba G.	Integration of herder knowledge and ecological methods for land degradation assessment around sedentary settlements in a sub-humid zone in northern Kenya	2008	Grey
Rodenburg J., Both J., Heitkönig I.M.A., van Koppen C.S.A., Sinsin B., van Mele P., Kiepe P.	Land Use and Biodiversity in Unprotected Landscapes: The Case of Noncultivated Plant Use and Management by Rural Communities in Benin and Togo	2012	Grey
Shackeroff J.M., Campbell L.M., Crowder L.B.	Social-ecological guilds: Putting people into marine historical ecology	2011	Blue
Shava S., Krasny M.E., Tidball K.G., Zazu C.	Agricultural knowledge in urban and resettled communities: Applications to social-ecological resilience and environmental education	2010	Green
Taylor R.B., Morrison M.A., Shears N.T.	Establishing baselines for recovery in a marine reserve (Poor Knights Islands, New Zealand) using local ecological knowledge	2011	Blue
Turner N.J., Clifton H.	"It's so different today": Climate change and indigenous lifeways in British Columbia, Canada	2009	Green
Venkatachalam A.J., Price A.R.G., Chandrasekara S., Senaratna Sellamuttu S., Kaler J.	Changes in frigate tuna populations on the south coast of Sri Lanka: Evidence of the shifting baseline syndrome from analysis of fisher observations	2010	Blue
Vogt N., Pinedo-Vasquez M., Brondízio E.S., Rabelo F.G., Fernandes K., Almeida O., Riveiro S., Deadman P.J., Dou Y.	Local ecological knowledge and incremental adaptation to changing flood patterns in the Amazon delta	2016	Grey
Voorhees H., Sparks R., Huntington H.P., Rode K.D.	Traditional knowledge about polar bears (Ursus maritimus) in northwestern Alaska	2014	Red
Weatherhead E., Gearheard S., Barry R.G.	Changes in weather persistence: Insight from Inuit knowledge	2010	Red
Wilson N.J., Todd Walter M., Waterhouse J.	Indigenous knowledge of hydrologic change in the Yukon river basin: A case study of Ruby, Alaska	2015	Red
Wolfe B.B., Armitage D., Wesche S., Brock B.E., Sokal M.A., Clogg-Wright K.P., Mongeon C.L., Adam M.E., Hall R.I., Edwards T.W.D.	From isotopes to TK interviews: Towards interdisciplinary research in Fort Resolution and the Slave River Delta, Northwest Territories	2007	Red
Ziembicki M.R., Woinarski J.C.Z., Mackey B.	Evaluating the status of species using Indigenous knowledge: Novel evidence for major native mammal declines in northern Australia	2013	Green

Appendix 3: Coding Scheme

Category	Subcategory	Description	Variables
Paper ID			
Cluster Number			
Paper charcteristics	Author		
	Title		
	Publication Year		
	Journal		
	Citation (complete)		
	Citation/Year		
	Continent of first authors' affiliation	In which continent lies the first authors affiliation?	Africa, Asia, Europe, North America, Oceania, South America
	Country of first authors' affilitation	In which country lies the first authors affiliation?	own words, e.g. Norway, Sweden, etc., multiple entries possible and seperated with "/"
Methodological approach	Data collection	How was the data assessed?	qualitative, quantitaive, mixed, na
	Data collection: specific methods	Which method was used to collect data?	own words, e.g. interview, questionaire, observation, etc., if not clear na
	Data analysis	How was the data assessed?	qualitative, quantitative, mixed, na
	Data analysis: specific methods	Which method was used to analyse data?	own words, e.g. statistical analysis, content analysis, GIS, etc., na
Location	Continent of case study	In which continent is the observed case study located?	Africa, Asia, Europe, North America, Oceania, South America
	Country of case study	In which country is the observed case study located?	own words, e.g. Norway, Sweden, etc., multiple entries possible and seperated with "/"
	Specific location, region of case study	In which region is the case study located?	own words, e.g. Lappland, Amazonas, also cities, etc., multiple entries possible. Seperate specific location and region with "," and different locations with "/"
Stakeholder in focus	Kind of group	Which kind of group is observed or worked with in the case study?	local, indigenous, local and indigenous, na

	Name of community	Which explicit community is observed or worked with in the case study?	own words, e.g. Sami, Inuit, etc., multiple entries possible, if no community name mentioned na. Seperate different communities with "/" and put further description of cummunity in "(…)".
	Explicit stakeholder	Which explicit stakeholder group is worked with in the case study?	own words, e.g. fisher, hunter, households, community, etc., multiple entries possible
Transformation/ Transition/ Change	Use of words in the paper	Which terms are used in the paper?	transformation, transition, change; multiple entries possible. If there is a strong focus on only one of the words, put the number of mention of the other not focused words in "(…)"
	Application	In which context is the term used?	own words: e.g. social-ecological transformation, environmental change, etc.
	Category	Which category describes the context of the term 'change'?	environmental, climate, social-ecological, species
	Definition	Is there a definition of transformation/ transition/ change mentioned?	0 (no), 1 (yes)
		Which definition is mentioned?	quote of the definition, if not mentioned na
	Reference	Is the definition connected to a specific reference?	0 (no), 1 (yes)
		Which reference is used?	complete reference, multiple entries possible, if not mentioned na
ILK	Use of words in paper	Which terms are used in the paper?	indigenous, traditional, local (environmental/ ecological) knowledge, multiple entries possible
	Definition	Is there a definition of ILK mentioned?	0 (no), 1 (yes)
		Which definition is mentioned?	quote of the definition, if not mentioned na
	Reference	Is the definition connected to a specific reference?	0 (no), 1 (yes)

		Which reference is used?	complete reference, multiple entries possible, if not mentioned na
Connection of ILK and transformation/ transition/ change		How is ILK used in context of transformation/ transition/ change?	own words, e.g. interpretation of environmental change, adaptation, etc.
Scaling of ILK	Spatial scale	Is ILK used only on a local scale or on higher scales?	local, sub-national, national, supra-national, continental
	Multi-scale approach	Is there e.g. more than one case study in the paper which demonstrates a regional understanding?	0 (no), 1 (yes)
	ILK to global sustainability (Balvanera et al. 2017)	Are there insights from place-based ILK research mentioned to inform global sustainability?	0 (no), 1 (yes)
		If yes, put quote.	qoute from the text
	Scaling of an ILK-initiative (Lam et al. Unpublished)	Does the paper mention an impact of sustainability initiatives and a scaling process of the initiative?	0 (no), 1 (yes)
	Scaling process	How does the scaling process into another context look like?	stabilizing, speeding up, growing, replicating, transferring, spreading, scaling up, scaling deep

Appendix 4: Papers mentioning the terms ‘transformation’ and ‘transition’

Paper	Use of 'transformation'	Use of 'transition'
Andrachuk and Armitage (2015)	x *	x
Apgar et al. (2015)	x *	x
Aswani and Lauer (2014)	x	
Brännlund and Axelsson (2011)	x	
Bruegger et al. (2014)		x
Carter and Nielsen (2011)		x
Chalmers and Fabricius (2007)	x	x
Clark and Slocombe (2011)	x	
Codjoe et al. (2014)		x
Crate and Fedorov (2013)	x	
de Almeida et al. (2016)	x	
Dowsley and Wenzel (2008)	x	
Fernández-Llamazares et al. (2015)	x	
Ford et al. (2006)	x	x
Golden et al. (2015)	x	
Gómez-Baggethun et al. (2012)		x
Hallwass et al. (2013)	x	
Hansen et al. (2013)		x
Herman-Mercer et al. (2016)	x	x
Homann et al. (2008)		x
Jandreau and Berkes (2016)	x *	x
Kassam (2009)	x *	
Kendrick and Lyver (2005)	x	
Klein et al. (2014)		x
Kokelj et al. (2012)		x
Leonard et al. (2013)		x
Nichols et al. (2004)		x
Oviedo et al. (2016)		x
Shava et al. (2010)		x
Turner and Clifton (2009)		x
Vogt et al. (2016)		x
Ziembicki et al. (2013)		x

Papers marked with * use the term ‘transformation’ in the sense of a social-ecological transformation. All 81 papers contain the term ‘change’, therefore only the papers containing the terms ‘transformation’ and/or ‘transition’ are listed here.

Appendix 5: List of most important indicator words for each research cluster

Research in arctic environments (red)	**Research in terrestrial environments (green)**	**Research in coastal environments (blue)**	**Research in grass- and rangelands (grey)**
aboriginal	adaptation	anecdotal	agriculture
accessible	adaptive	anecdotes	agroforestry
anchorage	adults	anthropogenic	alternate
arctic	animal	applicable	arid
art	anthropology	aquatic	burning
bay	authorities	archipelago	cattle
boating	belief	artisanal	crop
changed	beliefs	biology	cultivated
chipewyan	capacity	biomass	cultivation
cold	century	boat	degraded
complex	conversation	boats	desertification
cree	culturally	coast	desirable
elder	culture	coastal	droughts
eskimo	customary	cognitive	ethnic
experienced	desire	collapse	exotic
frozen	disaster	coral	farming
geophysical	dynamic	corals	fertility
harvesting	eating	crisis	forest
hunt	economy	degradation	forested
hunted	education	endangered	forests
hunter	educational	expertise	grass
hunters	experiences	fisher	grasses
hunting	fire	fisheries	grassland
ice	flowers	fishermen	grasslands
inland	foods	fishers	grazing
inuit	generation	fishery	herd
inupiat	globalization	fishing	herder
inuvialuit	god	gulf	household
lake	government	habitats	households
lakes	governments	integrating	integrated
mammals	histories	islands	livelihood
meat	huanca	lagoon	livestock
melts	integration	lek	mitigation
moss	islander	marine	mountain
nunavut	language	memory	participatory
oil	languages	nearshore	pastoral
participants	leader	oceanic	perception
permafrost	male	opinions	places
polar	medicine	overfishing	plantations
regionally	men	pacific	planted
regions	mountainous	periods	planting
relationship	oral	perspective	poverty
renewable	parents	practical	precipitation
scales	participant	predator	rainy
snow	participate	predatory	ranching
snowmobile	pastoralism	protected	rangeland
subarctic	plateau	recreational	rangelands
territories	policies	reef	relation
timing	political	reefs	savanna
tribal	power	seas	shrub
tundra	properties	shifting	shrubs
wildlife	rain	territorial	smallholder
	rainforests	tourism	soil
	restore	transformability	timber
	rock	tropical	transhumance
	sacred	villages	tree
	school	waters	vegetation
	seed		weeds
	societies		
	spiritual		
	story		
	technology		
	traditionally		
	traditions		
	tropics		
	urban		
	valley		
	valued		
	women		
	young		
	younger		

Appendix 6: Differing characteristics of the individual research clusters

Characteristics \ Cluster		Research in arctic environments (26 papers, red)	Research in terrestrial environments (22 papers, green)	Research in coastal environments (14 papers, blue)	Research in grass- and rangeland environments (19 papers, grey)
Continental distribution	Authors' affiliation	North America (26)	North America (9), Oceania (7), Europe (6), Africa (2)	North America (5), Europe (3), South America (3), Africa (2), Asia (1), Oceania (1)	Europe (8), North America (6), South America (3), Africa (3), Asia (1)
	Case studies	North America (25), Asia (1)	Oceania (7), South America (5), Africa (4), Asia (3), Europe (2), North America (2)	North America (4), Oceania (3), Asia (2), South America (2), Europe (2), Africa (1)	Asia (7), Africa (6), South America (4), Europe (2)
Stakeholder		indigenous communities (23), local groups (3)	indigenous communities (12), local groups (10)	local groups (12), indigenous communities (2)	local groups (18), indigenous communities (1)
Key research aspect		observation and perception of climatic and environmetal changes in arctic regions	perception of climate changes and adaptive capacity of communities, inclusion of societal and cultural aspects	environmental changes in aquatic ecosystems, endangered fish and plant species, management strategies	environmental changes of grass- and rangelands and following consequences for farming and herding

The numbers in brackets indicate the frequency of occurrence of the viewed characteristics of the individual research cluster. Note that one author can have more than one institutional affiliation and one paper can observe multiple case studies in different countries and continents.

7.3. Paper 3 appendix

Ambio

Electronic Supplementary Material

This supplementary material has not been peer reviewed

Title: **Three principles for co-designing sustainability intervention strategies: Experiences from Southern Transylvania**

David P. M. Lam, Andra I. Horcea-Milcu, Joern Fischer, Daniela Peukert, Daniel J. Lang

Appendix S1: Vision description of "Balance Brings Beauty"

The narrative description of key features of Balance Brings Beauty (Hanspach et al. 2014):

Demand for environmentally friendly practices was already high in Western Europe, when in 2020, France narrowly avoided a major nuclear accident. This event precipitated rapid political changes throughout the European Union (EU). Social justice and ecological sustainability were adopted as guiding principles underpinning all EU regulations. Unlike its predecessor, the latest reform of the Common Agricultural Policy brought about fundamental changes, and is considered worldwide as a milestone towards sustainable development. Subsidies are now strongly focused on organic farming, available only to associations of farmers who can demonstrate a holistic, landscape-scale vision for sustainable resource use.

Romania's education system improved substantially over the past few decades, enabling many locals in southern Transylvania to access the new EU subsidies for sustainable farming. Farms continue to be relatively small, but almost all farmers are now part of agricultural associations and practice modern organic farming, growing a variety of crops.

The forestry sector has also changed. Demand for wood products is high, but the majority of Romania's forestry sector is based on sustainable, low-intensity harvesting. Moreover, forest regrowth rates have increased substantially. While few forested areas remain untouched, Romania's forest estate is managed according to the best available science.

Farmland and forest biodiversity initially declined when land use was upgraded to modern organic practices, but the losses were relatively minor. Water from the fountains is just as clean as it was decades ago, and continues to be favoured as the cheapest source of drinking water in many villages.

A vibrant rural tourism industry has developed in the most scenic villages. Guesthouses are common, as are cafes and traditional festivals. Local people are proud that their cultural and natural heritage is attracting tourists from all over Europe.

Few people in the region are rich in monetary terms, but hardly anybody is suffering from poverty. People coped well with the recent drought, and are largely immune to the fluctuations in agricultural commodity prices that recently shook many farmers in Western Europe. Ethnic divides have all but disappeared, partly aided by common visits by foreigners and increasing openness towards different cultures. A healthy service industry is developing in addition to the most important income sectors, namely agriculture, forestry and tourism. While many young locals leave the region for a while, many of them come back because they are attracted by the lifestyle and scenic beauty in their home region.

7.4. Paper 4 appendix

Electronic Supplementary Materials
This supplementary material has not been peer reviewed.

Title: A leverage points perspective on social networks to understand sustainability transformations: evidence from Southern Transylvania

Table S1: Anonymous descriptions for each non-governmental organization (NGO).

Descriptions of non-governmental organizations
County association established at the initiative of over 20 rural municipalities concerned with the sustainable development of the county. The aim is to promote the nature, traditions and the landscape in its entirety of this historical county. The specific focus of this association's activities lies in developing intercommunity relationships and promoting local tourism. The association is seeking to attract funding in order to support the rural practices that local tourism is dependent upon.
National association with numerous projects in Transylvania. The mission of the association is to establish a connection between ecotourism and nature conservation by establishing partnerships between the private and the public sector. The association is also creating mechanisms for the certification of local ecotourism initiatives.
National association dedicated to peasant farmers mutual support. The association advocates for their rights and better economic conditions. It ensures their access to pasture land and local seeds for socially and ecologically sustainable land management. The association is also contributing the visibility of rural lifestyles and communities and advocates for more aware relationships between producers and consumers.
Local association with an educational mission towards sustainability targeting especially young people. It organises activities that teach young people about the ecology of the local landscape. The association is also engaged in the management of protected areas.
Local association involved in socio-economic and cultural activities with a view towards sustainable development. The association is on a mission to relaunch the local economy and revive the local cultural heritage. It does so by highlighting and stimulating local initiatives based on community, socio-cultural and sustainability values.
County association aiming to develop local tourism taking into account the principles of sustainable tourism. It bridges between the public and private sector in setting the strategic directions for the development of the county tourism. It encourages the engagement of communities and their sense of responsibility for the continuity of the cultural heritage.
Association active at a micro-regional level that aims to elaborate a sustainable development strategy with a special view to the particular ecological and cultural character of the micro-region. Exemplary initiatives of the association are establishing support associations for milk producers and managing the natural park milk collection points.
NGO with the mission of increasing awareness of the heritage appertaining to a few small cities in Southern Transylvania. To this end it organises cultural events, supports educational projects for children and organizes biking tours. It actively collaborates with schools and universities from Romania and abroad.
NGO established to conserve the built heritage of the Saxon villages. The NGO provides technical knowledge, educational activities and materials for preserving the local identity of the built heritage. It is also preoccupied with the quality of life of those inhabiting the rural traditional houses.
The association is on a mission to develop local communities by reconnecting them to their landscape, especially through education towards rediscovering the region's foods and traditional food production. The association organises alternative tourism events and encourages local entrepreneurship. Values guiding its vision are sustainability and creativity.
The main focus of the association are the strategic law suits on environment protection issues, heritage protection, and academic integrity (e.g. anti-plagiarism). For example, they organize court campaigns against companies that cut wood to set up power plants, as well as law suits against abusive wood harvesting processes. Their profile also includes support for ethnic minorities' rights in Romania.
The vision, mission and values of this environmental NGO centre around raising the awareness of people regarding nature's values. Their practice of nature conservation includes protecting endangered species, enforcing laws while influencing policies regarding nature. They are also actively trying to popularise the notion of ecosystem services and to map regional ecosystem services in order to influence local to national decision-making mechanisms.
Local association dedicated to conserving the cultural identity of rural life in Transylvania. It engages in building local information points about the history and traditions of Transylvanian villages for those interested in cultural and rural tourism and for supporting the local communities to better express their identity.
National foundation that advocates for the preservation and restoration of the architectural heritage of Romania. It is engaged in networks that respect traditional craftsmanship and appropriate construction techniques. It provides support for the re-use of historic buildings, teaching people to appreciate their value.
Association active at county level towards the sustainable development of communities living in one of Transylvania's counties. In elaborating the local development strategy it tried to bring together local actors from all these communities. In

order to inform, advise and offer funding to local stakeholders the association is carrying out regular fieldwork.

Institution that deals with the preservation and practice of one of the religions in Transylvania. To do so, it also invests in the maintenance of its built heritage and in educational activities for local communities. It has numerous international partnerships with numerous organisations that share similar orientations.

Initiative for the development of ecotourism infrastructure and facilities through local networking and relying entirely on the cooperation among local actors. It emerged during consultations with local actors regarding the development of a tourism strategy for a protected area in Southern Transylvania. It promotes Southern Transylvania as a region that shares a common cultural, aesthetic and economic background.

Association of organisations active in the field of heritage conservation and community development. It provides resources and expertise for its members, while carrying out common projects and sharing best practices. It aims to facilitate interventions at legislative level concerning culture and environment.

Foundation dedicated to the rural development and capacity-building of the farming landscapes of Transylvania. In its practice of conservation of biodiversity, the foundation tries to integrate social and economic benefits for the traditional farming communities. For example, it encourages the acquisition of small units for processing community grown fruits and vegetables.

Foundation with the goal of maintaining the cultural and religious heritage of Transylvania. To do so, it performs a large number of activities that go beyond the fields of construction and preservation of the religious landmarks, particularly regarding local communities.

National foundation providing capacity building for the conservation of protected areas through integrated methods and tools. It trains and offers comprehensive mentorship to local, national and international actors in order to improve the performance of critical natural resources management.

Regional foundation for the integrated development of cultural heritage in the rural and urban environment. Among its activities there are the rehabilitation of historical buildings in the context of urban and rural development with a focus on tourism and sustainable development.

Local association delivering the local development strategy with foci on agriculture, forestry, environment and folklore. It also supports women living in the villages to produce and sell added-value products and fosters the ethnical diversity.

Local association that distributes funding and other supporting materials to assist the development of local farming and entrepreneurship. It promotes the material, immaterial and natural heritage of the micro-region by organising community and town events.

Association at micro-regional level fighting rural depopulation, aiming at rural ethnical integration and supporting local farming. It also deals with managing Natura 2000 sites protecting natural resources that are found on its territory.

Local association established as a public-private partnership aiming at rural development. It holds informative sessions for potential local entrepreneurs, organizes events for their promotion and advises them in applying for funding.

Local association that aims to develop a development strategy capitalising on the social and natural resources and relying on public consultations. It organizes local cultural events to promote traditions, small producers and community entrepreneurship. It partners with similar associations from Europe.

Foundation dedicated to the conservation of cultural and built heritage. It is involved in revitalizing traditional handicrafts and developing local communities through entrepreneurship. It encourages the creation of farming association at village level in order to secure communal pasture land for small scale farmers and therefore improve the rural quality of life holistically.

National forestry NGO with regional offices. It aims to support the development of forestry in Romania paying attention to the economy and the environment. It is open to the integration of experts from disciplines outside forestry. It is interested in adjusting current policies to the challenges of climate change.

Educational centre for sustainable development for school children and their families using experimental and explorative learning. It mainly addresses the urban and rural communities from the neighbouring counties. It also aims to capitalize on the local heritage and traditions related to a life in harmony with nature.

Regional programme of an international environmental NGO. Its regional office deals with protecting the wildlife of Transylvania by engaging in protected areas and biodiversity management. It develops programmes dedicated to sustainability transitions or to education especially targeting young people.

Project initiative to conduct an inventory of ancient trees of Romania in order to recognise their multiple social-ecological and cultural values. The mapping, registering and conserving of old trees is done with the help of citizens. The data is collected and made available on an online platform with the aim to reconnect people to ancient trees and influence the legislation on protecting ancient trees. A transdisciplinary international steering committee takes strategic decisions. To date, more than 5000 trees have been registered.

Table S2: Applying the leverage points perspective to relational questions in the context of Southern Transylvania, Romania (Q= Question).

System characteristic (Abson et al. 2017)	**Survey questions:** "Please consider the overall relationship of your organization with each of the organizations listed below, as it has unfolded over the past 5 years and in relation to your work on sustainable development in Southern Transylvania."	**Explanation how local actors through different relations change leverage points in their work that fosters sustainability**
Parameters: Mechanistic characteristics typically targeted by policy makers	- Q12: To what extent have you shared material resources and tools with the following organizations (e.g. office space and equipment, cars, event spaces and venues, facilitation materials)?	Jointly sharing material resources and tools changes with what local actors work and corresponds with changing the parameters of a system (Meadows 2008). Reasonably, local actors care about their resources to be able to work. However, increasing or decreasing resources does not directly lead to solving a problem, such as in Meadows' example where more spending on police (i.e. resources) does not solve the problem of crime (Meadows 2008). Adjusting resources that local actors work with matches adjusting the faucets of a system (Meadows 2008).
	- Q11: To what extent have you developed project applications and applied for funding or sponsorships together?	Jointly applying for funding or sponsorship together potentially increases the capacity or size of the resource buffers of local actors and stabilizes their work. This corresponds with the idea of stabilizing buffers as a leverage point (Meadows 2008).
	- Q10: To what extent have you implemented projects together (e.g. organizing workshops, creating development strategies or plans)?	Jointly implementing projects together can influence the structure and flows of the work of local actors in two ways. First, projects can be regarded as subcomponents or subsystems within a system. Jointly designing them can lead to building a good structure for collaboration. Second, designing projects together can support the strategic development and implementation of diverse projects that as a whole constitute a structure of projects within a system. These projects together influence the larger system. This corresponds with Meadows idea of system structures, such as a plumbing structure or road system of a country (Meadows 2008).
Feedbacks: Interactions between elements within a system of interest that drive internal dynamics	- Q9: To what extent have you exchanged information (e.g. by email, phone, or in person)?	Exchanging work-related information between local actors is crucial to stay informed and react in time. Exchanging information can reduce the delay between notification on that information and reaction for local actors. This corresponds with Meadows' idea of changing delays such as in the example of reducing information and money-transfer delays in financial markets (Meadows 2008).
	- Q8: To what extent have you acquired new knowledge (learned useful things) from interactions and information exchanges with the following organizations?	Acquiring new knowledge from other organizations is useful for responding to new or changing situations within the work of local actors and it leads to balancing feedback loops of local actors fostering sustainability. Such balancing feedback loops function as self-correcting response mechanisms (Meadows 2008).
	- Q7: To what extent have you exchanged informal advice (i.e. asked for opinion) in order to make decisions?	Exchanging informal advice depicts a positive feedback loop in the work of local actors fostering sustainability (Meadows 2008). The more local actors exchange informal advice, the better becomes their relation and the more they change informal advice. Of course, there are many other positive feedback loops (Meadows 2008), we chose the giving advice relation as an example because it is an important relation between local actors working towards a similar goal as it builds on friendship and trust (Prell et al. 2009, Borgatti et al. 2013).

Design: Social structures and institutions that manage feedbacks and parameters	- Q6: To what extent have you met each other as participants in the same policy processes (e.g. public consultations) or institutional groups (e.g. industry boards, steering committees, associations)?	Meeting each other in the same policy processes or institutional groups can be regarded as being part of the same information flows and receiving the same information for the work of local actors.
	- Q5: To what extent have you actively worked together to change policies (e.g. through collaborative lobbying, coalitions, or joint petitions, and legislative proposals)?	Working together to change policies corresponds with Meadows' (2008) idea of changing the rules of the system. Working together on policy changes can, for instance, lead directly to desired change (e.g. example environmental conservation) or improve the conditions for the work and initiatives of local actors.
	- Q4: To what extent have you engaged together in setting up new collaborations with other organizations or actors (e.g. state actors, businesses, research institutions, communities and associations)?	Engaging together in setting up new collaborations with other organizations or actors corresponds with Meadows' idea of self-organization (Meadows 2008). Self-organization means to create new structures and behaviours (Meadows 2008). The raw material for self-organizations to foster sustainability are, for example, initiatives from local actors.
Intent: Underpinning values, goals, and worldviews of actors that shape the emergent direction to which a system is oriented	- Q3: To what extent have you pursued similar strategies in your work?	Pursuing similar strategies in work to foster sustainability may lead to foster the same goal of or within a system. It can also support to change higher systems goals (Meadows 2008).
	- Q2: To what extent have you jointly reflected on your mission and goals?	Jointly reflecting on mission and goals can align the paradigms of local actors that drive their work. Such a reflection can foster common paradigms for the system and believes on how to transform the system (Meadows 2008).
	- Q1: To what extent have you jointly engaged in activities that help you reconcile differences in values and worldviews?	Jointly reconciling differences in values and worldviews can enable to reflect one's own values and worldviews and understand values and worldviews by others (e.g. other local actors) in order to ultimately transcend paradigms. Transcending paradigms means to understand that no paradigm is true and there is no certainty in any worldview (Meadows 2008).

Table S3: List of non-governmental organizations (NGO) and their centrality metrics per system characteristics network. Bold numbers indicate the five highest scores per centrality metric. NGOs 14 and 15 did not respond to the online survey.

NGO	Parameters network			Feedbacks network			Design network			Intent network		
	Weighted degree	Eigenvector	Betweenness	Weighted degree	Eigenvector	Betweenness	Weighted degree	Eigenvector	Betweenness	Weighted degree	Eigenvector	Betweenness
1	19	0.019599	1.830592	29	0.024085	2.540498	20	0.0174	2.202778	24	0.019625	5.294188
2	19	0.015304	0.74329	28	0.0186	1.348796	16	0.014496	2.20754	20	0.02073	2.853979
3	30	0.030087	0.642929	36	0.030306	2.456804	35	0.030535	4.674217	28	0.028634	2.266454
4	17	0.021398	0.642136	22	0.02494	1.857753	21	0.024097	1.205495	16	0.018981	3.328728
5	10	0.012659	0.707576	12	0.015442	0.090909	8	0.008571	1.203968	15	0.020003	1.240812
6	42	0.039061	5.026754	45	0.03902	5.591081	43	0.039787	9.447522	32	0.035642	5.090758
7	44	0.038764	6.001621	48	0.036367	6.543371	**54**	0.040731	11.27756	43	0.042733	7.994478
8	15	0.014615	0.619048	20	0.016075	0.619913	19	0.016679	2.563889	10	0.007151	1.236111
9	51	**0.04518**	13.58838	53	0.039057	5.646337	45	0.038756	4.175239	**50**	**0.044991**	13.84884
10	51	0.040069	6.612515	48	0.034447	4.034388	44	0.035395	3.321375	40	0.040236	10.42692
11	51	0.039533	7.301296	48	0.034475	3.487635	43	0.037636	6.109521	30	0.032156	1.665476
12	19	0.024009	1.876623	35	0.03281	7.122544	18	0.028869	1.410033	11	0.01882	1.877381
13	30	0.027039	1.998413	35	0.028039	2.952739	30	0.025266	1.781944	22	0.026823	5.45976
14	14	0.023861	0.148352	17	0.023265	0	11	0.017593	0	10	0.016348	0.0625
15	16	0.016356	0	21	0.015954	0.25	21	0.018656	0.058824	15	0.016069	0
16	22	0.025016	1.358009	33	0.026016	2.589658	36	0.036168	4.498086	39	0.044405	**21.67437**
17	47	0.038972	9.033475	48	0.035379	4.953832	35	0.033586	2.560964	24	0.029613	2.249741
18	**55**	0.043698	**19.55784**	**71**	**0.044792**	**18.9301**	**68**	**0.044416**	**17.22205**	**68**	**0.048541**	**21.59296**
19	28	0.029391	0.521079	**63**	0.038063	8.062091	**61**	0.038385	11.48343	**61**	0.043062	13.56005
20	**72**	**0.050207**	**43.30591**	**74**	**0.046274**	**28.40431**	**63**	0.040738	**12.54217**	**60**	**0.044598**	**26.75857**
21	30	0.033542	1.47697	38	0.032218	2.433619	26	0.026145	0.453907	34	0.040351	9.918276
22	29	0.029929	3.748521	37	0.030739	5.238983	33	0.026439	2.889953	21	0.027249	2.818763
23	27	0.031585	0.698002	45	0.038182	7.326304	42	0.036295	4.366588	40	0.036576	7.327731
24	**56**	**0.046745**	**22.357**	**54**	**0.043932**	**16.1082**	**49**	**0.042515**	**14.34904**	34	0.035166	3.037053
25	**54**	**0.047085**	**20.91822**	42	0.041026	9.11857	39	0.039172	6.976389	37	0.039913	5.919034

26	12	0.013436	0.291667	20	0.024425	1.186952	19	0.022679	1.855531	25	0.021542	7.519188
27	34	0.033044	5.196848	41	0.031687	2.421354	44	0.037541	5.848864	28	0.027828	1.000631
28	19	0.024507	2.650866	19	0.018119	1.248821	29	0.025574	2.567637	28	0.023321	1.830891
29	**68**	**0.048366**	**32.58481**	**66**	**0.045436**	**24.23602**	48	**0.040958**	12.17326	**47**	**0.046415**	**22.91666**
30	17	0.023441	0.689394	20	0.022146	2.131202	24	0.02635	1.797731	18	0.026802	3.695382
31	33	0.031565	6.874639	28	0.025564	2.850719	49	**0.046455**	**32.78277**	22	0.030587	3.217172
32	49	0.041941	11.99723	54	**0.043122**	**13.2165**	47	**0.042115**	**12.99174**	42	**0.045087**	**18.31714**

Table S4: List of non-governmental organizations (NGO) and the groups of amplification processes they apply to increase the impact of their initiatives. NGOs 14 and 15 did not respond to the online survey. For the groups amplifying within, out (dependent), out (independent), and beyond a “0” means not applied and a “1” means applied.

NGO	Amplifying within	Amplifying out (dependent)	Amplifying out (independent)	Amplifying beyond	Sum
1	0	0	1	1	2
2	1	1	1	0	3
3	1	1	1	1	4
4	1	1	1	1	4
5	1	1	1	0	3
6	1	1	0	0	2
7	1	1	1	1	4
8	1	1	1	1	4
9	1	0	1	0	2
10	0	1	1	1	3
11	1	1	1	1	4
12	1	0	0	0	1
13	1	0	0	1	2
14					
15					
16	1	0	0	1	2
17	1	1	0	1	3
18	1	0	1	1	3
19	0	1	0	1	2
20	1	1	1	1	4
21	1	1	0	0	2
22	1	1	1	0	3
23	1	1	1	1	4
24	1	1	1	0	3
25	1	0	0	0	1
26	0	1	0	1	2
27	1	0	0	1	2
28	1	0	0	1	2
29	1	1	1	0	3
30	0	0	0	0	0
31	1	1	1	1	4
32	1	1	1	1	4