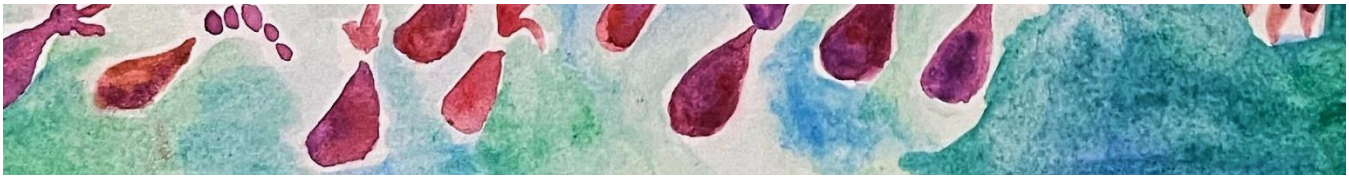
Enhancing the transformative potential of sustainability innovations: Insights from two European Biosphere Reserves

Caroline Hélène DABARD



Enhancing the transformative potential of sustainability innovations: Insights from two European Biosphere Reserves

Academic dissertation

Presented to the Faculty of Sustainability

Of Leuphana University Lüneburg

For the award of the degree

Doctor of Political Science (Dr. rer. pol.)

submitted by

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Submitted on January 15th, 2024

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Front cover: Sustainability innovations in a wave of transformation - or ananas and aubergines[1]

[1] All artwork was created by the author

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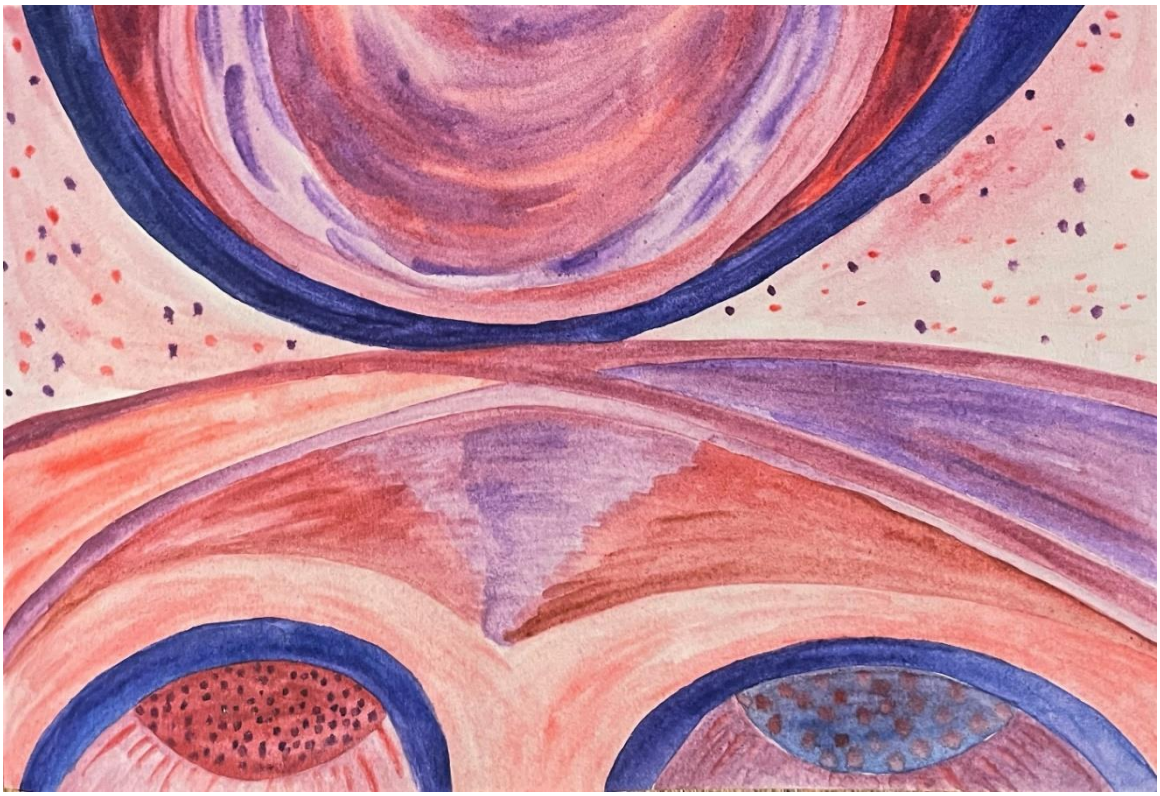

Thinking about life while watching Almeriense sunset

Acknowledgments

There were many times in the last four years when I felt lost – lost in concepts, lost on the way to an interview, lost in contradicting thoughts and fuzzy results. During those times, I sometimes felt lonely and helpless. Again and again, though, I found motivation, purpose, guidance, and joy thanks to the many people and groups who supported me during this Ph.D. journey. Finally, I am happy that the time has come to express my gratitude.

Carsten, you were the first to embark with me on this journey and support my idea in the summer of 2019 to write a Ph.D. proposal. I wrote of transformative research, participation, urban-rural linkages, systems thinking, and reconnecting Biosphere Reserves with their surroundings. You helped me design a topic I could carry for several years with much open-mindedness and guidance. Thank you for patiently letting me grow and make my way at my own rhythm. Thank you for your openness, respect, and honesty, and for always reminding me to take it slow when I got jittery and felt the time pressure. I always remember that "now is a good moment" - something you never fail to say, especially in times of doubts.

Berta, you joined us on this journey notwithstanding your personal challenges, and I am so grateful you did. When I first met you in person at Leuphana and summarized my many ideas for field research, you asked me, "But where is your heart?" I thought that was the most challenging question you asked and something I keep wondering about. I greatly appreciate your creativity and enthusiasm – no matter how confused or doubtful I feel at hearing new ideas on combining conceptual approaches. I feel inspired by your caring leadership and your critical reflections on academia and life.

I also found guidance and motivation in the many groups I was lucky to encounter on the way. At the HNEE, Leuphana, Almería, I was always glad to know I could find friendly ears

to listen to my struggles - and many people willing to take coffee breaks and have a good laugh with me.

Special thanks to the starting BRI Ph.D group - Charlotte, Jenny, Fabio, Martin, Caroline, and Laura - for creating a safe place to share doubts and fears, especially at the beginning of the journey and in times of COVID. I have enjoyed our meetings, lunches, political discussions, oat milk comparisons, garden barbecues, writing retreats, and random talks so much. Charlotte and Fabio, I feel so grateful for our long journey together in learning how to organise ourselves and others with our literature review paper.

The BRI community evolved over the years. Thanks to Jenny Hammerich, Uli Gräbener, Pierre Ibisch, Vera Luthardt, Henrik von Wehrden, Ana Filipa Ferreira, and Jarne Jargow for building up the BRI, keeping up the cooperation with Leuphana and making my own Ph.D. possible.

Special thanks to Henrik. I am very grateful for your kindness, hospitality and willingness to support me on quite various topics, from research to mindfulness. Thank you for taking so much time for support and long discussions – I admit I am as often confused as inspired by your philosophical tips, musical references, and wise advice.

I am thrilled to see how your *rising* team, Carsten, will evolve and feel thankful to Gino, Mónica and Stefan for taking me in very early on. Special thanks to Mónica for the machete, and for helping me improve the skeleton of this thesis with so much wise advice. I love your creativity and enthusiasm – I always feel unexpectedly inspired by my RE3 journey between Eberswalde and Berlin when I meet you on the platform. Slapalicious thanks to Gino for being an amazing friend, more importantly than for being an inspiring and motivating colleague.

At Leuphana, I was blessed with other groups where I found inspiration and motivation. Thank you to Berta and WebSES for taking me in as part of the group and making it possible to join online – I have particularly enjoyed meeting you all on team retreats and short Leuphana stays, Roman, Paty, Jasmine, John, Milena, Lukas, Konrad, Miguel. Special thanks to Roman for our lovely writing retreat in Almería, in particular for the healthy coffee routine and hiking talks ;) Being part of SESI was a great opportunity. I have learnt so much through the seminars and enjoyed witnessing how SESI grew and feeling the good vibes all the way to Berlin.

Thanks to the ProViae mentoring programme of Leuphana, I have had the opportunity to reflect on my motivations and goals and meet many amazing people. Thank you, Annemie and Beate, for running this great programme. I have learnt so much from the workshops, and particularly from the support group, my lovely IceBearg, with Charlotte, Kirsten, Paty and Maria. I forgot where the name came from but I know it has a smart explanation. It was always a great pleasure to discuss challenges and solutions with you, and an excellent feeling to know that I could share my struggles and would be delivered practical, philosophical and political tips. I am thankful for your open ears and hearts - and for the mix of fierce kindness and critical feminism.

I had the chance to have an official mentor, Lisen Schultz, through this mentoring programme. I have learnt so much through our talks. I am amazed at how much we could share in just a few sessions. Thank you so much, Lisen, for taking this time and embarking on this mentoring journey with me. I appreciate your openness, your reflecting questions -

right to the point - your enthusiasm and motivating insights. I felt energized and creative after each discussion with you.

Very recently, I was hosted by the most passionate and welcoming team :) Many thanks to SociECOS: Antonio, Enrica, Juanmi, Dani, Maria, Cristina, Sean. I had a fantastic stay in Almería, thanks to you. I feel so grateful for your kindness and all this time you spent with me - warmheartedly discussing research, landscapes, cultural food and personal identity, tasting cheese and wine, and laughing so much while sharing so much absurdity. When I struggled with the last bits and pieces of this thesis, I felt I could always find an open heart to listen to me and offer some support and kindness. Thank you so much for that. Special thanks to Enrica, a real sunshine, for going through this thesis as bedtime reading and encouraging me at the very end of this journey. I have loved our random talks and wine evenings together ;)

Thank you, Maraja, for joining this journey and agreeing to review this thesis with spontaneity inspite of uncertain formalities!

This whole research would not have been possible without the commitment and willingness of so many practitioners and innovation actors to share their time and knowledge with me. I am still amazed at how much I have learnt from those 100+ interviews, how clearly I remember so many of them, and how much the interviews made me grow. Furthermore, I had amazing support from two Master students to collect data with me in Schorfheide-Chorin Biosphere Reserve: Laila Heising and Irina Kirsanova. Jelke Meyer has provided beautiful and insightful icons to illustrate my results.

I am grateful for the funding for field research and conferences from the BRI, DAAD, Erasmus+ and the Leuphana Graduate Fond. Thanks to Odile Loison and the team of the Station d'Écologie Forestière for hosting me during my field research in Fontainebleau-Gâtinais Biosphere Reserve.

I am very grateful to Olivier & Mary-Frances de Bellescize & (grown) kids for their hospitality, their kindness, and their loving home during the field research in Fontainebleau-Gâtinais Biosphere Reserve - as well as to Fanny & Jean-Baptiste Dabard-Labilloy & (small) kids for taking me up on weekends. You made me feel connected and loved during this challenging time when I felt lonely and stressed.

Life would not be the same without my friends, family and partner. Thank you for making life beautiful, surprising, and joyful.

List of papers

The following list includes the three papers that contribute to this cumulative thesis. They are referred to as Chapters/ Papers in this list and in figures or, in the text body, as Chapters. An additional paper is included in Appendix 5.

Chapter 2/ Paper 1

Dabard, C.H.; Mann, C. Sustainability innovations: a proposal for an analytical framework and its empirical application in the Schorfheide-Chorin Biosphere Reserve. Sustainability Science 18, 1085–1098 (2023). https://doi.org/10.1007/s11625-022-01241-9

Chapter 3/ Paper 2

Dabard, C.H.; Mann, C.; Martín-López, B. (in press). An archetype analysis of sustainability innovations in Biosphere Reserves: insights for assessing transformative potential. Environmental Science and Policy

Chapter 4/ Paper 3

Dabard, C.H.; Mann, C.; Martín-López, B. A social network analysis of sustainability innovations: values, rules and knowledge to enhance transformative potential (To be submitted at Ambio)

Additional paper (see Appendix 5)

Dabard, C.H.; Gohr, C.; Weiss, F.; von Wehrden, H.; Neumann, F.; Hordasevych, S.; Arieta, B.; Hammerich, J.; Meier, C.; Jargow, J.; Luthardt, V.; Ibisch, P.L.; Ferreira, A.F. Biosphere Reserves as model regions for transdisciplinarity? A literature review (under review at Sustainability Science)

List of abbreviations

SCBR Schorfheide-Chorin Biosphere Reserve

FGBR Fontainebleau-Gâtinais Biosphere Reserve

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Summary

Global wicked problems call for sustainability innovations and transformations to challenge problematic systems. In this context, there have been increasing expectations that sustainability innovations induce positive and transformative outcomes. Despite a growing transformation research field, however, there is still a need to assess the actual outcomes of sustainability innovations in terms of their transformative potential. Furthermore, although much progress focussed on supportive conditions for innovations, there are only limited insights on the supportive conditions that foster sustainability innovations of strong transformative potential, as opposed to incremental innovations. This thesis aims to address these gaps, in particular, to characterise the transformative potential of sustainability innovations and to identify the supportive conditions that may enhance transformative potential. The thesis thereby examines multiple cases of local sustainability innovations in Schorfheide-Chorin and Fontainebleau-Gâtinais Biosphere Reserves, in Germany and France. Biosphere Reserves, being model regions for sustainable development designed by UNESCO, offer practical and insightful study sites on local sustainability innovations. Insights are presented in three papers, which form the Chapters of the thesis.

First, an analytical framework proposes to characterise sustainability innovations through four dimensions: context, actors, processes and outcomes. The framework identifies 31 variables that detail each dimension and enable a cross-case comparison of various sustainability innovations. With a focus on eliciting sustainability outcomes, this Chapter proposes to analyse novelty types, sustainability impacts and amplifying strategies to capture concrete outcomes. Furthermore, the Chapter highlights supportive conditions shared by two case studies of sustainability innovations in Schorfheide-Chorin Biosphere Reserve. Local sustainability are thus relevant for societal transformations and even often comprise multiple, entangled and co-evolving novelties.

Second, sustainability innovations archetypes are identified in each Biosphere Reserve based on empirical data about over a hundred sustainability innovations across the two areas. Archetypes are identified based on outcomes, including novelty type, sustainability impacts, amplifying strategies and novelty scale. Following, transformative potential is interpreted as the capacity of sustainability innovations to produce shallow or deep impacts in a leverage points perspective, and to amplify those impacts through amplifying strategies. Sustainability innovation archetypes can be characterised along a transformative continuum, where incremental innovations produce shallow outcomes and lack amplifying strategies – while transformative innovations produce impacts both shallow and deep, and implement diverse strategies to amplify out and beyond. Empirical evidence shows that few sustainability innovations display a strong transformative potential. The case studies also exemplify how various sustainability innovations could identify joint purposes and synergies, and how Biosphere Reserves may play a bridging role in this regard.

Third, the supportive conditions that are connected to different sustainability innovation archetypes are elicited through the decision-making context framework, which articulates that constellations of values, knowledge and governance arrangements underlie different transformative actions. The values that motivate innovation actors and the modes of knowledge production are characterised based on survey data. The governance arrangements that underlie different archetypes are analysed through social network analyses. In particular, governance arrangements are interpreted based on networks being diverse or homogenous, cooperative or hierarchical, and influential or peripheral. Most transformative

archetypes are linked to decision-making contexts made of plural values, collaborative knowledge co-creation and networks that are diverse, cooperative and influential. Incremental sustainability innovations are linked to instrumental values, informative knowledge production and networks that are homogenous, hierarchical and peripheral. This Chapter also highlights reformist and idealist sustainability innovations, which have mixed transformative potential. Idealist innovations focus on value shifts but lack concrete and measurable outcomes, which limits their transformative potential. Here again, the results highlight the bridging potential of Biosphere Reserves in sustainability innovations networks.

Following, the thesis proposes recommendations for innovation actors to enhance this potential, notably by identifying how to diversify sustainability outcomes and design amplifying strategies to spread impacts beyond the innovations' scopes of action. In addition, reflecting on how to twist supportive conditions related to actors and processes could enhance transformative potential, notably by articulating various values and motivations for their actions, designing more collaborative processes, and strengthening and diversifying their networks. Biosphere Reserves may also enhance their role as bridging organisations for local sustainability innovations, notably by articulating regional values and goals, thereby ensuring the integration of various types of knowledge, strengthening local networks, information flows and collaborative processes. This, in turn, may support innovation actors in navigating their context.

Finally, the thesis proposes that future research should examine interactions and coevolution of actors, processes and transformative outcomes in sustainability innovations, and elicit the different ways to mobilise values to study and enhance innovations. Furthermore, normative aspects, such as diverging perspectives on desirable outcomes, conflicts and contestations, largely remain to be explored. This could be achieved with a more substantial research focus on radical innovations, activists and social movements. Finally, the thesis acknowledges the contributions of many local sustainability innovations, which participate in multiple ways to promote greater societal transformations towards diverse desirable futures.

Zusammenfassung

Globale Probleme verlangen nach Nachhaltigkeitsinnovationen und -transformationen, um problematische Systeme in Frage zu stellen. In diesem Zusammenhang sind die Erwartungen gestiegen, dass Nachhaltigkeitsinnovationen positive und transformative Ergebnisse hervorbringen. Trotz eines wachsenden Forschungsfeldes besteht jedoch immer noch Bedarf, die tatsächlichen Ergebnisse von Nachhaltigkeitsinnovationen im Hinblick auf ihr transformatives Potenzial zu bewerten. Darüber hinaus gibt es nur begrenzte Erkenntnisse über die Bedingungen, die Nachhaltigkeitsinnovationen mit starkem Transformationspotenzial im Gegensatz zu inkrementellen Innovationen begünstigen. Die vorliegende Arbeit zielt darauf ab, diese Lücken zu schließen, insbesondere um das transformative Potenzial von Nachhaltigkeitsinnovationen zu charakterisieren und die unterstützenden Bedingungen zu identifizieren, die das transformative Potenzial erhöhen können. In dieser Arbeit werden zahlreichen lokalen Nachhaltigkeitsinnovationen in den Biosphärenreservaten Schorfheide-Chorin und Fontainebleau-Gâtinais in Deutschland und Frankreich untersucht. Biosphärenreservate, die von der UNESCO als Modellregionen für nachhaltige Entwicklung konzipiert wurden, bieten praktische und aufschlussreiche Studienorte für lokale Nachhaltigkeitsinnovationen. Die Erkenntnisse werden in drei *Papers* vorgestellt, die die Kapitel der Dissertation bilden.

Zuerst wird ein analytischer Rahmen vorgeschlagen, um Nachhaltigkeitsinnovationen durch vier Dimensionen zu charakterisieren: Kontext, Akteur*innen, Prozesse und Ergebnisse. Der Rahmen identifiziert 31 Variablen, die jede Dimension detailliert beschreiben und einen fallübergreifenden Vergleich verschiedener Nachhaltigkeitsinnovationen ermöglichen. Mit dem Schwerpunkt auf der Erzielung von Nachhaltigkeitsergebnissen werden in diesem Kapitel Neuheitstypen, Nachhaltigkeitsauswirkungen und Verstärkungsstrategien analysiert, um konkrete Ergebnisse zu erfassen. Darüber hinaus werden in diesem Kapitel unterstützende Bedingungen für zwei Fallstudien von Nachhaltigkeitsinnovationen im Biosphärenreservat Schorfheide-Chorin aufgezeigt. Lokale Nachhaltigkeitsinnovationen sind demnach relevant für gesellschaftliche Transformationen und umfassen sogar oft mehrere, miteinander verflochtene und sich gemeinsam entwickelnde Innovationen.

Zweitens werden in jedem Biosphärenreservat Archetypen von Nachhaltigkeitsinnovationen identifiziert, die auf empirischen Daten über mehr als hundert Nachhaltigkeitsinnovationen in den beiden Gebieten basieren. Die Archetypen werden anhand der Ergebnisse identifiziert, einschließlich der Art der Innovation, der Auswirkungen auf die Nachhaltigkeit, der Verstärkungsstrategien und des Umfangs der Innovation. Anschließend wird das transformative Potenzial als die Fähigkeit von Nachhaltigkeitsinnovationen interpretiert, oberflächliche oder tiefgreifende Auswirkungen in einer *Leverage Points* perspektive zu erzeugen und diese Auswirkungen durch verstärkende Strategien zu verstärken. Die Archetypen von Nachhaltigkeitsinnovationen können entlang eines transformativen Kontinuums charakterisiert werden, wobei inkrementelle Innovationen oberflächliche Ergebnisse hervorbringen und keine Verstärkungsstrategien haben, während transformative Innovationen sowohl oberflächliche als auch tiefgreifende Wirkungen hervorbringen und verschiedene Verstärkungsstrategien einsetzen. Empirische Belege zeigen, dass nur wenige Nachhaltigkeitsinnovationen ein starkes transformatives Potenzial aufweisen. Die Fallstudien veranschaulichen auch, wie verschiedene Nachhaltigkeitsinnovationen

gemeinsame Ziele und Synergien identifizieren könnten und wie Biosphärenreservate in dieser Hinsicht eine Brückenfunktion übernehmen können.

Drittens werden die unterstützenden Bedingungen, die mit den verschiedenen Archetypen von Nachhaltigkeitsinnovationen verbunden sind, durch den *Decision-making Context Framework* eruiert, der deutlich macht, dass verschiedenen transformativen Maßnahmen Konstellationen von Werten, Wissen und *Governance Arrangements* zugrunde liegen. Die Werte, die die Innovationsakteur*innen motivieren, und die Formen der Wissensproduktion werden anhand von Umfragedaten charakterisiert. Die *Governance Arrangements*, die den verschiedenen Archetypen zugrunde liegen, werden durch Analysen sozialer Netzwerke analysiert. Insbesondere werden die *Governance Arrangements* auf der Grundlage von vielfältigen oder homogenen, kooperativen oder hierarchischen und einflussreichen oder peripheren Netzwerken interpretiert. Die meisten transformativen Archetypen werden mit Entscheidungskontexten in Verbindung gebracht, die aus pluralen Werten, kollaborativer Wissensschaffung und Netzwerken bestehen, die vielfältig, kooperativ und einflussreich sind. Inkrementelle Nachhaltigkeitsinnovationen sind mit instrumentellen Werten, informativer Wissensproduktion und Netzwerken verbunden, die homogen, hierarchisch und peripher sind. In diesem Kapitel werden auch reformistische und idealistische Nachhaltigkeitsinnovationen hervorgehoben, die ein gemischtes transformatives Potenzial haben. Idealistische Innovationen konzentrieren sich auf Werteverschiebungen, haben aber keine konkreten und messbaren Ergebnisse, was ihr transformatives Potenzial begrenzt. Auch hier unterstreichen die Ergebnisse das Brückenpotenzial von Biosphärenreservaten in Netzwerken für Nachhaltigkeitsinnovationen.

Im Folgenden werden Empfehlungen für Innovationsakteur*innen ausgesprochen, um dieses Potenzial zu erhöhen, insbesondere durch die Identifizierung von Möglichkeiten zur Diversifizierung von Nachhaltigkeitsergebnissen und die Entwicklung von Verstärkungsstrategien über den Aktionsradius der Innovation hinaus. Auch das Nachdenken darüber, wie unterstützende Bedingungen in Bezug auf Akteur*innen und Prozesse verändert werden können, könnte das transformative Potenzial erhöhen, insbesondere durch die Artikulation verschiedener Werte und Motivationen für ihr Handeln, die Gestaltung kooperativerer Prozesse und die Stärkung und Diversifizierung ihrer Netzwerke. Biosphärenreservate können auch ihre Rolle als Brückenorganisationen für lokale Nachhaltigkeitsinnovationen ausbauen, insbesondere durch die Artikulation regionaler Werte und Ziele, wodurch die Integration verschiedener Arten von Wissen, die Stärkung lokaler Netzwerke, Informationsflüsse und kollaborativer Prozesse gewährleistet wird. Dies wiederum kann die Innovationsakteur*innen dabei unterstützen, sich in ihrem Umfeld zurechtzufinden.

Preface

This thesis is conceived as a cumulative thesis. Chapter 1 is the framework Chapter of the thesis and presents the research background, aims, approach, results and contributions. As such, Chapter 1 synthesises and concludes from insights presented in details in the following Chapters. Chapters 2, 3 and 4 were prepared as stand-alone articles for peer-review. Chapter 2 is published, Chapter 3 is in press and Chapter 4 will be submitted shortly after this thesis is submitted. The formatting of Chapter 2 differs, as it reproduces the final, published version of the manuscript.

Chapter 2 proposes a framework that articulates four relevant dimensions for analysis of sustainability innovations: context, actors, processes and outcomes. Chapter 3 builds on this framework, in particular on outcomes to define transformative potential, thereby adopting a leverage points perspective. Chapter 4 builds on insights from Chapter 3 about transformative potential and articulates supportive conditions along the decision-making context framework. Additionally, Appendix 5 presents a further manuscript, which was submitted to peer-review. This manuscript provides additional insights about Biosphere Reserves research.

Chapter 1

Enhancing the transformative potential of sustainability innovations: Insights from two European Biosphere Reserves - A synthesis

A fractals perspective

Chapter 1
Enhancing the transformative potential of sustainability innovations: Insights from two European Biosphere Reserves - A synthesis -

1. Introduction

1.1. Sustainability transformations

Against the need to address social inequalities, poverty, climate change and biodiversity depletion - among other current global challenges - many grassroots movements, innovations, initiatives or activist uprisings have shown that sustainability transformations are possible and necessary. Such innovations aim for transformative change in the problematic systems they target, i.e., for "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). In global policy frameworks, the need for transformations is also increasingly acknowledged (e.g. UN General Assembly 2015). In political and research discourses, terms like sustainability innovations and transformations are thus increasingly used. Yet, scholars have argued that there is a risk of mainstreaming those terms, of emptying them of their radical implications (Feola et al. 2021) and turning them into meaningless buzzwords or "blah blah blah" (Bentz et al. 2022). To address sustainability transformations and their actual outcomes, there is a need to understand their specificities better, how they might challenge problematic systems, and how to support them. For these purposes, the field of sustainability transformations and transitions research has largely expanded in the last decades. Different approaches converge in the notion that **sustainability transformations** refers to structural, systemic changes in complex systems through non-linear and multi-actor processes (Feola 2015; Patterson et al. 2017; Fisher et al. 2022).

In this field, **sustainability transitions** research examines innovation pathways, thereby adopting a systemic and governance perspective on niche innovations and incumbent regimes, or socio-technical systems (Geels 2002; Loorbach 2010; Wittmayer et al. 2018). Sustainability transitions refer to systemic shifts in specific sectors, or sub-systems (e.g. energy and mobility transitions) that encompass co-evolving changes in technologies, institutions, and economic and social structures (Loorbach et al. 2017). Transitions research has often adopted a sectoral and reformist approach to systems change through management and governance (Stirling 2015).

In contrast, **sustainability transformations** carry a more radical, large-scale, social-ecological undertone (Patterson et al. 2017; Hölscher et al. 2018). Sustainability transformations are radical and dynamic change processes that co-evolve and thereby redefine, transgress and even transcend structures, values and practices in the personal, practical and political spheres (O'Brien and Sygna 2013; Vogel and O'Brien 2022). Transformations have notably emerged from social-ecological and resilience approaches to change as an emerging property of complex systems (Westley et al. 2011; Moore et al. 2012b; Olsson et al. 2014). Transformations literature builds on the assumption that reformist transitions will not suffice to address global societal challenges. Instead, radical alternatives to shift problematic systems are required, with a broad understanding of social-ecological-technical systems (McPhearson et al. 2021; Fisher et al. 2022), thereby paying close attention

to social issues related to justice, equity and wellbeing (Temper et al. 2018; Bennett et al. 2019; Pereira et al. 2020). Yet, the concept of transformations is still a broad and rather theoretical concept, which would benefit from more empirical evidence (Feola 2015; Fisher et al. 2022). In this regard, recent empirical studies have rather focused on local, place-based sustainability innovations.

1.2. A fractals perspective on local sustainability innovations

Indeed, studying local, place-based sustainability innovations is a practical solution to conducting empirical studies on complex transformation processes. Following, recent studies explored concrete and local change processes, including grassroots innovations (Seyfang and Smith 2007; Feola and Nunes 2014), place-based sustainability initiatives (Brondizio et al. 2021; Lam et al. 2021), nature-based solutions (Palomo et al. 2021; Dubo et al. 2023), social innovations (Avelino et al. 2019; Wittmayer et al. 2022), Seeds of Good Anthropocene (Bennett et al. 2016; Tuckey et al. 2023), or radical alternatives (Temper et al. 2018; Kothari 2020). I propose the concept of **sustainability innovations** as an umbrella term for local, place-based change processes that seek to support greater societal transformations. In particular, I define sustainability innovations as processes that aim to develop new means to define and meet social needs and desires, thereby supporting positive and transformative outcomes in terms of social-ecological integrity and equity, in specific socio-technical-ecological contexts (Dabard and Mann 2022, Chapter 2). Note that sustainability innovations are not necessarily unique and novel, but are often readaptation, contextualisation or combinations of practices and ideas that differ and challenge mainstream practices and ideas (Wittmayer et al. 2022).

A **fractals perspective** has been proposed to emphasize how local, place-based initiatives and innovations can participate in greater societal transformations (O'Brien et al. 2023). Fractals are self-similar patterns that repeat and replicate in different places and at various scales. Hence, sustainability innovations can be considered as fractals - or as self-similar patterns of transformation processes - that repeat with variations across scales and spaces. Studying local sustainability innovations as fractals can, therefore, inform us about the workings of greater societal transformations.

Adopting a fractals perspective, I argue that sustainability innovations are practical and insightful case studies that provide clear case boundaries and relevant insights for societal transformation processes. In particular, the thesis aims to explore 1) the transformative potential of sustainability innovations and 2) the supportive conditions that may enhance this transformative potential. For these purposes, the thesis examines manifold sustainability innovations in two European Biosphere Reserves: Schorfheide-Chorin Biosphere Reserve (SCBR) in Germany and Fontainebleau-Gâtinais Biosphere Reserve (FGBR) in France. Biosphere Reserves are model regions designated by UNESCO for sustainable development, conservation and research (UNESCO 2017), and therefore insightful study areas dedicated to experimentations, learning and sustainability transformations (Schultz and Lundholm 2011; Westley et al. 2011; Barraclough et al. 2023).

1.3. The transformative potential of sustainability innovations

Scholars have emphasised the need to expand on the transformative potential of sustainability innovations, i.e. on their actual outcomes and capacity to radically shift problematic social-ecological-technical systems (Avelino and Wittmayer 2019; Feola et al. 2021; McPhearson et al. 2021). The mainstreaming of sustainability innovations and

transformations as buzzwords enhances the risk of taking positive outcomes for granted (Blythe et al. 2018). In that regard, reviews have shown limited empirical evidence on transformative or disruptive outcomes (Salomaa and Juhola 2020; Kivimaa et al. 2021). Hence, to better pinpoint the most transformative sustainability innovations, there is a need for empirical evidence on the transformative potential of different sustainability innovations, for methodological approaches to assess this potential and for more precise conceptualisations (Figure 1).

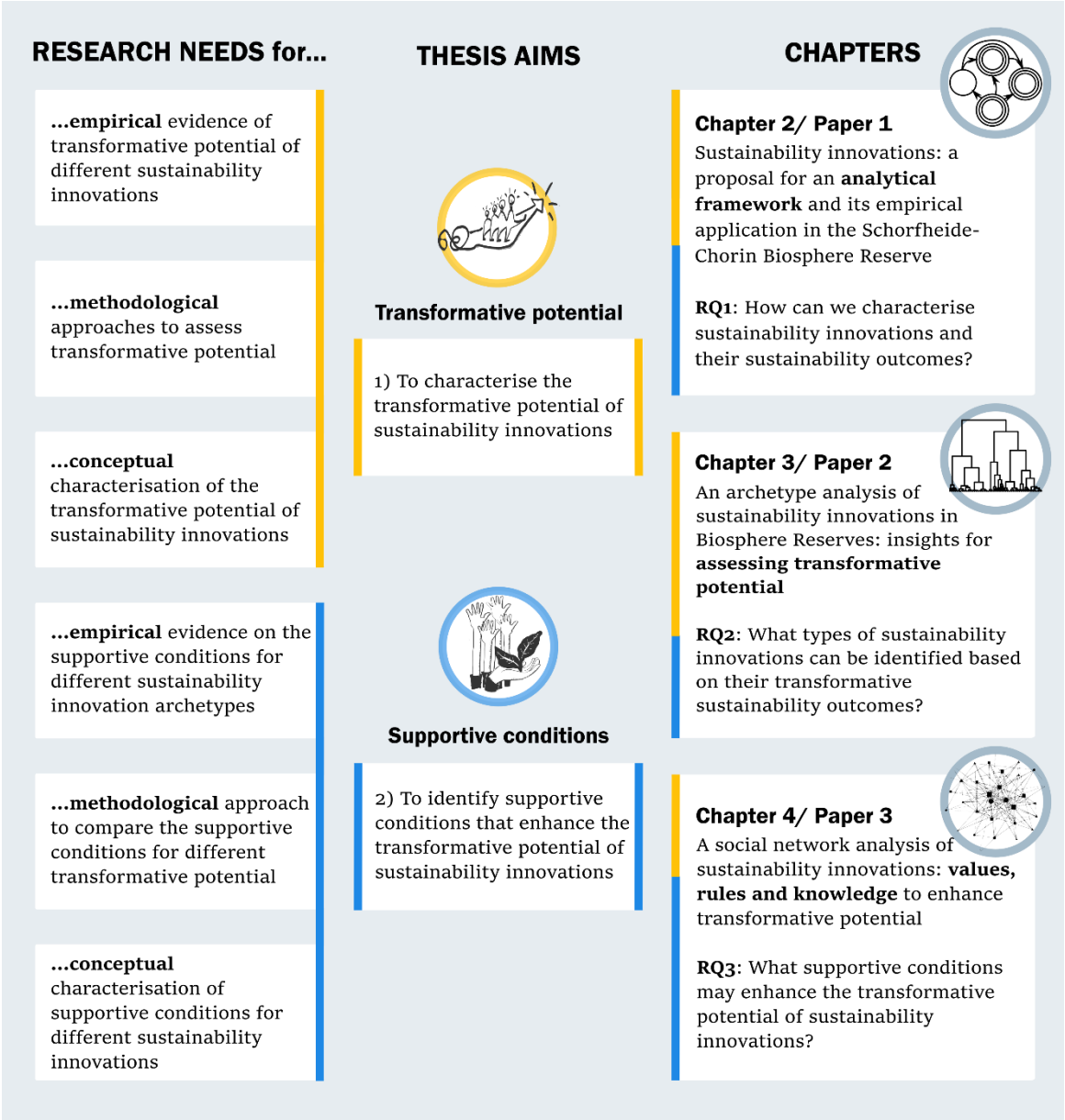


Figure 1. Research needs, thesis aims and overview of the Chapters/ Papers. The icons and colour-coding that represent transformative potential (yellow) and supportive conditions (blue) or illustrate each Chapter/Paper are used throughout the thesis. Colour-coding of right-side boxes roughly indicates the focus of the Chapters on either. understanding of transformative potential (yellow) or supportive conditions (blue).

Recent empirical studies advanced the assessment of transformative potential. For instance, Palomo et al. (2021) and Dubo et al. (2023) compared the characteristics of transformative adaption of multiple nature-based solutions in the Alps. Furthermore, sustainability impacts

have been categorised as incremental, reformist or transformative within a set of adaptation actions from a global network of cities committed to addressing climate change (Heikkinen et al. 2019) and of urban nature-based solutions (Goodwin et al. 2023). In addition, a recent framework to assess transformative capacity (Wolfram 2016) was used to study local actions for urban sustainability (Castan Broto et al 2019). Notwithstanding, most literature to date either focuses on few cases, or often assess transformative potential through processes rather than actual outcomes (Tuckey et al. 2023).

Thus, with the goal to assess the transformative potential of sustainability innovations based on their outcomes, I propose to define **transformative potential** as the capacity of sustainability innovations to impact problematic social-ecological-technical systems, induce positive changes in terms of social-ecological integrity and equity, and enhance impacts beyond their own scope of actions (Dabard et al. in press, Chapter 3). To assess the transformative potential of sustainability innovations, I propose to articulate 1) the leveraging capacity of sustainability impacts and novelty types and 2) the amplifying strategies implemented to enhance impacts beyond innovations' own scopes of action.

First, the **leverage points** framework distinguishes sustainability interventions in terms of their capacity to leverage shallow or deep changes in the systems they target (Meadows 1999; Meadows 2012; Abson et al. 2017). According to this framework, interventions at shallow levels, e.g. at parameters level through adjustments in taxes or subsidies, are rather easy to implement but have limited impacts. On the contrary, interventions at deep levels, e.g. at intent level through shifts in values and mindsets, are more difficult to achieve but can have radical, transformative impacts (Abson et al. 2017). This framework proved useful, for example to study the capacity of local actors and initiatives to foster sustainability transformations (Lam et al. 2021), or the transformative potential of conservation actions (Arponen and Salomaa 2023). In this thesis, I used a leverage points perspective to interpret 1) sustainability impacts, categorised along dimensions proposed by Gibson (2006) and Luederitz et al. (2017), and 2) novelty types. In this regard, innovations can have various **sustainability impacts**, for instance enhancing social-ecological integrity, livelihood opportunities, or equity. **Novelty types** include new products, services, organisations, as well as behavioral and value shifts (Gamito and Madureira 2019). The leverage points are a useful concept for examining the transformative potential of systems interventions (Riechers et al. 2022) and thus distinguishing shallow (incremental) from deep (transformative) impacts.

Second, a generic typology was recently proposed to capture the capacity of sustainability transformations to scale and amplify their impacts beyond initiatives' own scopes of action (Lam et al. 2020). Indeed, sustainability innovations – specifically local ones - ought to enhance their impacts beyond their own scope of action, to support broader societal change (Lam et al. 2020; O'Brien et al. 2023). **Amplification processes** include amplifying within (stabilizing, growing or speeding up an initiative within its own scope of action), amplifying out (transferring or duplicating an initiative in another context) and amplifying beyond (scaling up or scaling deep, i.e. changing mindsets and values) (Lam et al. 2020). This amplification typology is useful, because it can help distinguish sustainability innovations according to the strategies they implement to enhance their impacts, thereby giving an insight into their transformative potential beyond their own scope (Tuckey et al. 2023).

1.4. Supportive conditions for transformative sustainability innovations

While there has been little empirical research on assessing the transformative potential of diverse sustainability innovations, more insights were gained on the supportive conditions for sustainability innovations. Approaches to supportive conditions can be distinguished through analyses at either a macro or micro level (Köhler et al. 2019). At a **macro level**, recent frameworks have focussed on the structural aspects that may enable sustainability innovations. For example, the Multi-Level Perspective on transitions analyses socio-technical systems dynamics and e.g. windows or opportunities for niche innovations to emerge and spread (Geels 2002; Geels and Schot 2007). A geographic perspective on sustainability transitions examines sustainability transitions' scales, spatiality and context-specificities (Binz et al. 2020) and the supportive policy instruments for regional innovation systems (Coenen et al. 2017).

While such approaches at a macro level are useful to understand and shape supportive conditions for sustainability innovations, another branch of the literature focuses on a **micro level** of analysis, i.e. "zooming in" the case studies to understand, notably, collaborative processes, actors constellations and agency (Köhler et al. 2019). For example, transition management literature explored how co-creation **processes** of learning, experimenting and reflecting can support transformative change (Kemp et al. 2007; Wittmayer et al. 2018). Scholars have also investigated different characteristics of **actors** networks, in particular actor roles and agency (Westley et al. 2013; Wittmayer et al. 2017; Mitincu et al. 2023), or diverse types of actors and organisations (Asheim and Coenen 2005; Fischer and Newig 2016).

Despite a growing interest in transformative sustainability innovations, there is still a need for empirical evidence about the supportive conditions that may enhance transformative potential, as opposed to conditions that may foster incremental innovations (Figure 1). To address this gap, this thesis adopts a micro level perspective and focuses on supporting conditions encompassing processes and actors. The thesis thereby discusses macro-level aspects, such as contextual conditions, to a lesser extent.

This thesis notably builds on a recent framework that articulates supportive conditions of transformative adaptation as **decision-making contexts** - or specific constellations of values, rules and knowledge (Gorddard et al. 2016; Colloff et al. 2017). The decision-making context framework highlights that specific constellations of 1) value systems, 2) governance arrangements, and 3) knowledge, shape actions for e.g. transformative adaptation (Colloff et al. 2017; Lavorel et al. 2019), different forms of ecosystem management (Topp et al. 2022), or transformative nature-based solutions (Dubo et al. 2023). First, **values** refer to the goals, purposes and worldviews that guide people's decisions (Verplanken et al. 2009; Colloff et al. 2017). Value systems can be defined as how people relate to and value nature - categorised as intrinsic, instrumental or relational values (Himes et al. 2023; Pascual et al. 2023). Intrinsic values refer to valuing nature as inherently worthy, regardless of human use – for example, acknowledging animals' right to exist regardless of human benefits. On the contrary, instrumental values refer to valuing nature as a means to satisfy people's needs or desires - for example, valuing animals as a source of food. Finally, relational values refer to the importance of relationships with nature and to other people, as mediated by nature – for example, valuing the cultural meaning of relationships with animals (Pascual et al. 2023). Second, rules refer to institutions and **governance arrangements** that shape actors' behavior and choices (Gorddard et al. 2016). For instance, different legislations, market arrangements,

conservation agreements and informal rules were shown to foster different forms of ecosystem management (Topp et al. 2022). Third, different types of **knowledge** were shown to shape decisions, for example, technical, experiential or scientific knowledge (Gorddard et al. 2016). In particular, the decision-making framework was used to study supportive conditions for transformative nature-based solutions (Dubo et al. 2023).

1.5. Aims, research questions and thesis structure

In the field of sustainability transformation research, I could identify several research needs (Figure 1). First, a better understanding of **transformative potential** is needed. Empirically, there is a need to identify the transformative outcomes of different sustainability innovations. For this purpose, there is a need for methodological approaches to assess and compare the transformative potential of multiple sustainability innovations. This, in turn, will enable a more thorough conceptualisation of transformative potential. In addition, we need to understand the **supportive conditions** for transformative sustainability innovations. In this regard, there is a need for empirical evidence of specific supportive conditions for transformative vs. incremental sustainability innovations. For this purpose, methodological approaches are needed to assess supportive conditions and compare them across innovations of varying transformative potential. This will enable a better conceptualisation of supportive conditions for incremental or transformative sustainability innovations.

Therefore, the thesis aims to characterise 1) the transformative potential of sustainability innovations and 2) the supportive conditions that may enhance this transformative potential (Figure 1). Each Chapter contributes insights to the two thesis aims, which are summarised in section 3. Specifically, Chapters 2, 3, and 4 provide insights into three research questions, as follows.

1) How can we characterise sustainability innovations and their sustainability outcomes? **(RQ1)** With this question, I aim to contribute to a better understanding of sustainability innovations and their outcomes - by proposing a literature-based framework that articulates four dimensions and 31 variables for cross-sectoral, comparative analysis, as illustrated by two in-depths case studies (Chapter 2).
2) What types of sustainability innovations can be identified based on their transformative sustainability outcomes? **(RQ2)** With this question, I aim to pinpoint different archetypes of sustainability innovations and highlight varying transformative potential - by applying an archetype analysis on a large number of cases and comparing their sustainability outcomes (Chapter 3).
3) What supportive conditions, based on constellations of values, knowledge production and governance arrangements, may enhance the transformative potential of sustainability innovations? **(RQ3)** With this question, I aim to unravel how different constellations of values, modes of knowledge production and governance arrangements lead to varying transformative potential (Chapter 4).

The thesis is structured as follows. Chapter 1 corresponds to the framework chapter of a cumulative thesis and synthesises the empirical, methodological and conceptual insights provided by the following Chapters/ Papers. Chapter 1 presents the background and thesis aims (section 1), the research approach (section 2), the main contributions of each Chapter (section 3), the main learnings, challenges and implications (section 4) and conclusions (section 5). Chapters 2, 3 and 4 were conceived as stand-alone scientific papers for peer-review publication (see Appendix A.1 for publication status).

2. Research approach

2.1. Case study areas

Biosphere Reserves as study areas for sustainability transformations

The research took place in two European Biosphere Reserves, namely Schorfheide-Chorin Biosphere Reserve (SCBR) in Germany and Fontainebleau-Gâtinais Biosphere Reserve (FGBR) in France. Biosphere Reserves are areas designated by UNESCO as model regions for sustainable development, with the core missions to support 1) nature conservation, 2) human development, and 3) research, monitoring, learning and capacity-building (UNESCO 1996, 2017). In fact, Biosphere Reserves worldwide have been considered as compelling places to experiment and learn about sustainability transformations in a place-based manner (Schultz and Lundholm 2011; Westley et al. 2011; Barraclough et al. 2023). Research conducted in Biosphere Reserves has therefore increasingly examined potential interventions for sustainability transformations (Dabard et al. forthcoming, Appendix A.5). Notably, Biosphere Reserves have given way to studies on sustainability transitions and rural grassroots innovations (Kratzer 2018a; Kratzer and Ammering 2019; Kratzer et al. 2022). Studying sustainability innovations in a place-based manner - for instance within specific Biosphere Reserves - is relevant, because initiatives and innovations develop place-based solutions and develop networks locally that create cross-sectoral clusters of innovations, which influence each other (Brondizio et al. 2021; Londres et al. 2023). In this thesis, I studied multiple sustainability innovations, some of which were directed or supported by the respective Biosphere Reserves administrations, although many were developed by other actors.

Schorfheide-Chorin Biosphere Reserve

Schorfheide-Chorin Biosphere (SCBR) is located approximatively 70km north of Germany's capital city, Berlin (Figure 2). In one of the the least populated and economically thriving areas of Germany, the region is undergoing strong socio-economic changes (Stoll-Kleeman et al. 2013) - with increasing urbanisation in the southern parts of the Reserve, which have become attractive for neo-rurals and businesses. Urbanisation increases land pressure, land prices and visitor flows. The Biosphere Reserve was created top-down in the early 1990's after Germany's reunification. Since then, major land uses have been (organic) agricultural, forestry, and tourism. In this context, the Biosphere Reserve administration has developed various projects with a strong focus on nature conservation and forestry, large-scale organic agriculture, eco-tourism, and education for sustainable development (UNESCO 2021b). The administration has regional regulatory competencies and, as such, is part of multiple governance processes, notably related to nature conservation, rural development, agricultural and forestry land uses, energy, mobility, and urban planning. SCBR administration is therefore embedded in large regional networks, including other public organisations and administrative levels (e.g. *Landkreise*, or counties), forestry departments, the regional planning authority, local towns, research and academic institutions, business networks, tourism organisations and local associations. Many projects directed or supported by SCBR administration were collaborative projects, conducted in partnerships with some of these regional actors, and with national and international partners (as evidenced by qualitative insights during data collection).

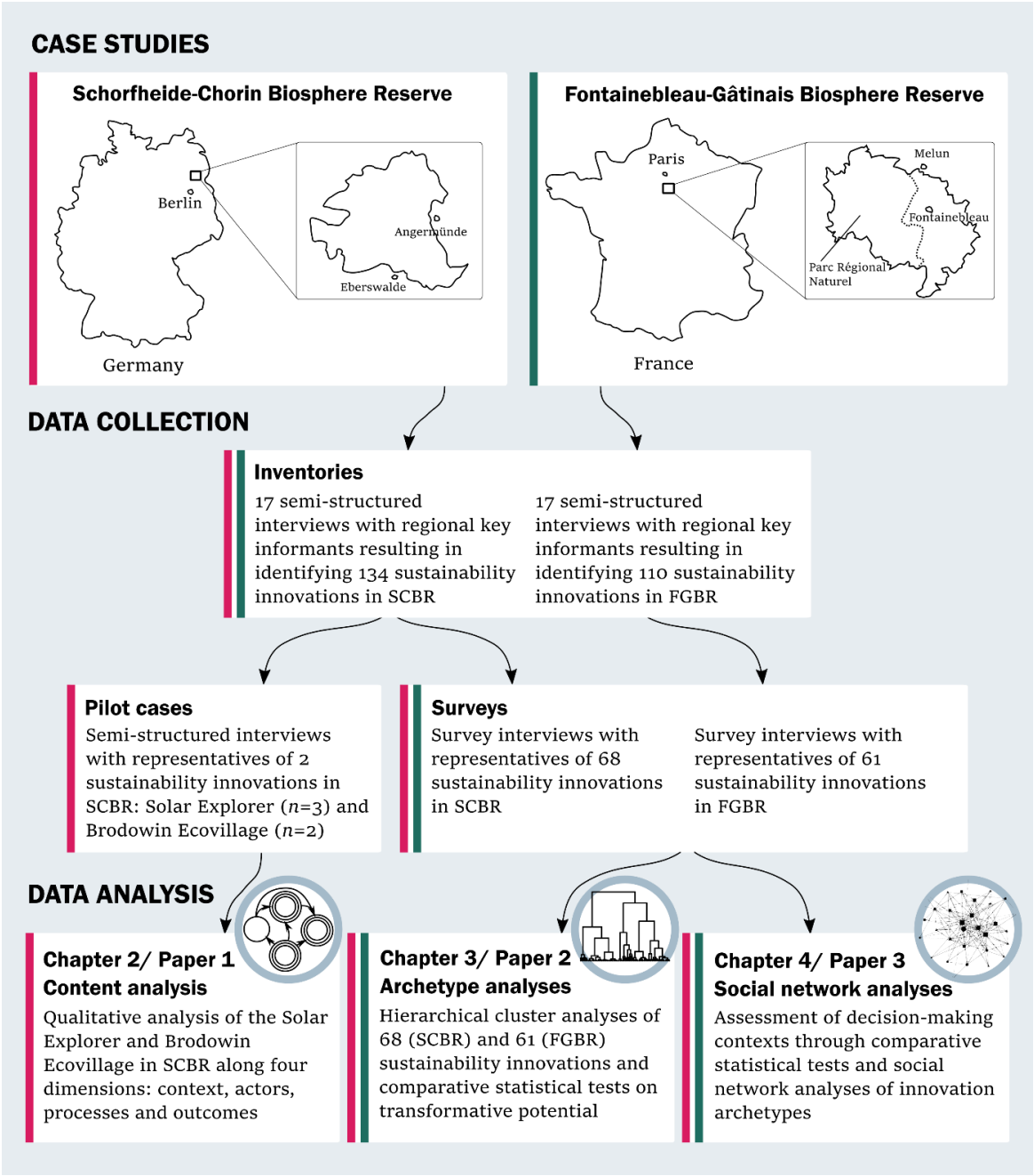


Figure 2. Thesis methodology: case study areas, data collection and analysis per Chapter/ Paper. SCBR: Schorfheide-Chorin Biosphere Reserve (red), FGBR: Fontainebleau-Gâtinais Biosphere Reserve (green). The colour code indicates that the Pilot cases and Chapter 2 were built on data from SCBR only - while the Inventories, Surveys and Chapter 3 and 4 took place and were built on data from both areas.

Fontainebleau-Gâtinais Biosphere Reserve

Fontainebleau-Gâtinais Biosphere (FGBR) is located approximatively 60km south of France's capital city, Paris (Figure 2). FGBR was created in a top-down manner by the national government in 1998. Major economic sectors and land uses are tourism, forestry and agriculture (Mathevet and Cibien 2020). In a similar situation as SCBR, the Reserve is undergoing strong urbanisation processes in its northeastern areas. Even more, since the COVID-19 pandemic, the northern part of the Reserve, which one can easily reach from Paris, has become attractive for neo-rurals and businesses (as evidenced by qualitative insights

during data collection). In the northeastern part of the Reserve, land pressure and visitor flows to the tourist attractions around Fontainebleau, have increased. On the contrary, the southwestern area is dominated by agrarian landscapes, a declining demography and a lower socio-economic background. This latter part of the Reserve is also a Regional Nature Park (*Parc Régional Naturel du Gâtinais Français*) (Figure 2). In the French context, Regional Nature Parks have similar missions as Biosphere Reserves, i.e., nature conservation and rural development. FGBR administration is specific in that it was given the form of an NGO, whose board members are the two local counties (*déparements*), the region (*Région Île-de-France*), the Regional Nature Park, the national forest office, two universities, local NGOs and local city halls (UNESCO 2021a). However, FGBR administration benefits from limited regulatory and decision-making power in the area, as well as limited financial security and human resources (as evidenced by qualitative insights during data collection). This has limited the ability of the administration team to carry out projects. Nonetheless, recent actions and projects aimed to support eco-tourism, education for sustainable development and awareness raising transitions. In comparison, the Regional Nature Park, with stronger regional decision-making power and more extensive financial and human resources, had developed many projects for rural development, notably with a focus on agro-ecology, tourism, and mobility.

2.2. Data collection

The data collection was conducted in the two case study Biosphere Reserves in three phases, as follows (Figure 2). First, an inventory was made of sustainability innovations in the case study areas. Semi-structured interviews were conducted with regional key informants to identify sustainability innovations. The interviewees were asked: 1) to share their understanding of sustainability innovations; 2) to list all projects and initiatives they knew of or were part of, that could qualify as sustainability innovations; and 3) to share the names of other relevant actors in the area, who could help in identifying further sustainability innovations as regional key informants (for the full questionnaire, see Appendix A3.A.). Key informants were people with solid knowledge of the area. The inventory started with interviewing representatives of each Biosphere Reserve administration as regional key informants. In a snowball approach, the people who were mentioned as potential key informants were contacted and asked for an interview. In each area, 17 regional key informants were interviewed. The interviews took place for 60 minutes on average, face-to-face or online, depending on the health policy regulations regarding the COVID pandemic and, later on, the interviewees' preferences. The interviews were recorded once consent was obtained, translated and analysed for content on regional sustainability innovations. Data saturation was reached once the sustainability innovations – and potential regional key informants - listed by the last interviewees repeated what had already been identified. The inventory phase identified 134 and 110 sustainability innovations in SCBR and FGBR, respectively. The inventory laid the ground for the following two phases, i.e. for selecting cases for the pilot study (used in Chapter 2) and for the survey of 129 sustainability innovations (used in Chapters 3 and 4). The inventory phase occurred in spring 2021 and spring 2022 in SCBR and in summer 2021 in FGBR (Figures 3 and 4).

Second, a pilot study was conducted on two cases in SCBR to better understand the characteristics of sustainability innovations and test the analytical framework developed in Chapter 2. For this purpose, two sustainability innovations were selected in SCBR, which were stabilized, well-established, and well-known projects with differing purposes. The first case, the Solar Explorer, was a technological and service innovation: a solar-powered catamaran developed for showcasing, research, and educational purposes. The second case,

Brodowin Ecovillage, was a social innovation, i.e. large-scale organic farm, which a network of various actors created following the re-privatisation of farmland after the fall of the German Democratic Republic. Three representatives were contacted for interviews to collect expert knowledge, for each case. The representatives had different functions and were employed by various organisations, to gather different perspectives on each case. Three interviews were conducted about the Solar Explorer and two about Brodowin Ecovillage. The semi-structured interviews were organized to gain a general understanding of each case and the context, actors, processes, and outcomes. The interviews were conducted online due to health policy restrictions. They lasted between 40 and 100 minutes, were recorded after obtaining consent and transcribed for qualitative content analysis. The pilot study was used for empirical analysis in Chapter 2.

Third, to identify different types of sustainability innovations based on their transformative outcomes and to unravel the underlying governance arrangements through social network analysis, I conducted a survey to collect data from a large number of cases. I contacted 215 sustainability innovations for a survey in person or via Zoom (131 innovations in SCBR and 84 innovations in FGBR). I completed 68 survey questionnaires in SCBR in the summer of 2022 and 61 questionnaires in the autumn of 2021 in FGBR (Figures 3 and 4). I led most survey interviews, with the exception of 32 interviews in SCBR conducted by two master students. The survey questionnaire aimed to gain 1) an overview of the sustainability innovations, actors, processes and outcomes and 2) of regional networks. For the full survey, see Appendix A.3.A. The archetype analysis (Chapter 3) built on the first part of the survey. The social network analysis (Chapter 4) built on the second part of the survey. In the network section of the survey, interviewees were given a list of relevant organisations and were asked to mark those with which they had a connection. The listed relevant organisations were those that were involved in all 134 and 110 sustainability innovations, as well as a few public organisations and regional NGOs deemed relevant by the regional key informants.

2.3. Data analysis

Following the data collection, I carried out three analysis packages in three papers, each corresponding to one of the three research questions (Figure 2). First, to characterise sustainability innovations and their sustainability outcomes (RQ1), I conducted a qualitative content analysis of the two pilot cases in SCBR. I sought to identify and compare the supportive and hindering conditions that led to different outcomes. The analysis was carried out using MaxQDA and was based on an analytical framework that highlighted four dimensions: context, actors, processes, and outcomes. The dimensions were detailed in 31 accompanying variables. This analysis is presented in Chapter 2.

Second, to identify archetypes of transformative outcomes in sustainability innovations (RQ2), I carried out a hierarchical cluster analysis, based on four outcomes variables: 1) the novelty type(s) encapsulated in each sustainability innovation (e.g. product innovation, social innovation, value shifts); 2) the sustainability impacts resulting from each case (e.g. enhanced social-ecological integrity, resource use efficiency, equity); 3) the amplifying strategies implemented to scale impacts (i.e. scaling within, beyond and deep); and 4) the scale at which the innovation was considered novel (i.e. local, regional, national). In each case study area, I conducted a multiple component analysis, followed by a hierarchical cluster analysis, to identify archetypes. Further comparative statistical tests characterised the archetypes in terms of actor and processes variables. Chapter 3 presents this archetype analysis.

Third, to elicit the decision-making contexts - in particular, the governance arrangements underlying different sustainability innovations (RQ3), I conducted social network analyses of innovations in both Biosphere Reserves. Decision-making contexts refer to systems of 1) values, 2) modes of knowledge production, and 3) rules, or governance arrangements (Gorddard et al. 2016). For this purpose, I built on the survey data and archetype analysis to articulate for each archetype: 1) the specific values (i.e. intrinsic, instrumental and/or relational (Himes et al. 2023; Pascual et al. 2023)); and 2) knowledge coproduction mode (i.e. informative, consultative or cooperative). I used social network analyses to elicit 3) the governance arrangements underlying different archetypes. I created 12 networks in total. In each of the two Biosphere Reserves, I created one full network including all innovation actors and five archetype networks, including only those actors involved in each respective archetype. I then applied statistical tests to compare centrality metrics, which display the importance and influence of each actor in a network. Following, I could interpret the governance arrangements underlying different archetypes as 1) collaborative or hierarchical, 2) diverse or homogenous and 3) influential or peripheral. Chapter 4 presents the social network analysis and comparison of decision-making contexts per archetype.

2.4. Researcher's positionality

In the following, I would like to position the thesis and myself as a Ph.D. researcher within the field of transformation research. Scholars have claimed the importance of transdisciplinary approaches to enable sustainability innovations and gain in-depth insights through long-term engagement with practice (Wittmayer and Schäpke 2014; Chambers et al. 2022). However, it was beyond the scope of this doctoral research to engage in transdisciplinary processes. Therefore, this thesis adopted a descriptive-analytical approach (Feola 2015) to understand innovations from an external and static perspective, building on punctual data collection rather than long-term transdisciplinary research.

Scholars have also discussed normative aspects within sustainability innovation research, notably the prescriptive orientation of approaches that seek to enable innovations that are considered desirable and positive (Feola 2015; Scoones et al. 2020). Although this thesis is primarily descriptive-analytical and built on knowledge from regional informants to identify sustainability innovations, I acknowledge that I was motivated by the hope to find and support positive sustainability innovations – which necessarily induced a situational, personal interpretation of what I considered positive and sustainable.

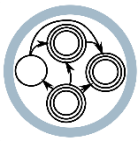
Finally, sustainability science is currently undergoing lively debates about positionality and systemic inequalities in the academic system (Temper et al. 2018; Staffa et al. 2022; Sultana 2023). Hence, this section must foster a critical lens to my position as a researcher. I acknowledge that as a multilingual, able-bodied, White woman socialized in Western Europe in an almost wholly White academic system, I have benefited from opportunities and access to resources that came from a position of relative privilege. For example, the extensive data collection conducted in two Biosphere Reserves was feasible due to access to funding opportunities from organisations of the European Union and the German academic system. In addition, being able-bodied, White and multilingual, I could move around two rural Biosphere Reserves relatively easily and safely with public transportation and bike. Finally, I must acknowledge that the findings from this thesis are strongly anchored in scientific traditions and literature produced in the Global North. Their replicability and relevance in other contexts must therefore be questioned.

Figure 3. Data collection in SCBR. 1) VERN (seed bank); 2) die Braut: Dorfbrauerei (organic brewery); 3) Finizio composting toilet system; 4) Wildblume (organic shop); 5) biking to interviews close to Angermünde; 6) fish ponds on the way to interviews. All photos in Figure 3 and 4 were taken by the author after consent of the interviewees (except for landscape pictures). In SCBR, I did many interviews online or went to the sites via public transportation for day trips. I stayed in Angermünde and travelled by bike & train for a week to finish the data collection in summer 2022.

Figure 4. Data collection in FGBR. 1) Fontainebleau forest; 2) Le Bio Paysan (organic cooperative); 3) the author on the way to Larchant for interviews; 4) Grinn (community permaculture garden); 5) Parc Naturel Régional du Gâtinais Francais: headquarters; 6) Station d'Écologie Forestière (SEF) de Fontainebleau. I stayed three months in FGBR in autumn 2021. I was able to work at the SEF (6) for desk tasks. I used public transportation and e-biked almost 1000 km to collect data in a climate-friendly manner – well, I do not have a driving licence.

3. Results and contributions

In the following sub-sections, I describe the main results and contributions of this doctoral thesis by summarising the contributions of the three scientific papers that are presented as Chapters 2, 3 and 4.



3.1. Sustainability innovations: a proposal for an analytical framework and its empirical application in the Schorfheide-Chorin Biosphere Reserve (Chapter 2/ Paper 1)

To characterise sustainability innovations, their sustainability outcomes and supportive conditions (RQ1), I aimed 1) to develop a generic analytical framework that would encompass the supportive conditions and transformative outcomes of various sustainability innovations; and 2) to test this framework on two cases as a pilot study. Building on literature about social-ecological systems (Ostrom 2007, 2009), sustainability innovations and transitions (e.g. Asheim and Coenen 2005; Hekkert et al. 2007; Geels 2011; Wittmayer et al. 2018) and sustainability assessments (Gibson 2006; Luederitz et al. 2017), I proposed to examine sustainability innovations through four dimensions: context, actors, processes and outcomes. I detailed these dimensions in a second analytical tier that included 31 variables.

Table 1. Overview of Chapter 2: research question, methodological approach and main contributions.

Chapter 2/ Paper 1. Sustainability innovations: a proposal for an analytical framework and its empirical application in the Schorfheide-Chorin Biosphere Reserve		
Research question	Methodological approach	Main results and contributions
How can we characterise sustainability innovations and their sustainability outcomes? (RQ1)	Qualitative content analysis of 2 sustainability innovations, based on semi-structured interview data, according to analytical framework: context, actors, processes and outcomes	1) Sustainability innovations can be analysed and compared through four dimensions: context, actors, process and outcomes 2) Sustainability impacts, novelty types, amplifying strategies and novelty scale can support the assessment of sustainability innovation outcomes 3) Supportive conditions for sustainability innovations include resource availability, diversity of actors, trusting and committed networks, envisioning, experimenting and navigating the regional context 4) Local sustainability innovations can participate in transformative change 5) Sustainability innovations comprise multiple, entangled and co-evolving novelties based on self-reinforcing innovative processes

The first case study, the Solar Explorer, was a solar-powered catamaran used as a place for research and educational activities about sustainability and ecology. As a technological and service innovation, the outcomes of Solar Explorer mainly comprised social-ecological stewardship, i.e., knowledge sharing and awareness-raising, through educational and research services and experimentation for solar mobility. The Solar Explorer team implemented amplifying strategies to spread their knowledge out, i.e. to help replicate similar experiments and share learnings. The second case, Brodowin Ecovillage, was a social innovation that encapsulated many novelties. The Ecovillage was created after German reunification. Instead of re-privatising agricultural land in small parcels (after collectivisation during the German Democratic Republic), local inhabitants and farmers and an external investor decided to create a large-scale, biodynamic farm in one private business. This original decision to preserve local jobs and promote organic farming gave way to multiple innovative activities. As a result, the Ecovillage induced a variety of outcomes, for instance, enhancing social-ecological integrity through biodynamic farming and biodiversity protection, strengthening livelihood opportunities through securing jobs, or enhancing natural resource use efficiency and resource maintenance through waste reduction in processing and low-carbon delivery. The Ecovillage team implemented strategies to amplify

their impacts beyond their own scope, for instance, through knowledge transfer activities in cooperation with SCBR administration. It seemed that Brodowin Ecovillage had stronger transformative outcomes than the Solar Explorer, in that it fostered a wider array of outcomes and reported strong amplifying strategies through transfer activities locally and nationally.

Both cases highlighted the importance of trust, commitment in diverse actor networks, the importance of pursuing diverse goals, such as social, economic and ecological aspects. While time for learning and reflection was limited, both cases emphasized the importance of coproduction processes, particularly for envisioning and experimenting, and the importance of navigating their own regional context. Both cases encapsulated bundles of interdependent novelties, which reinforced each other and co-evolved. The cases emphasised that transformative change can be found in discreet, local, small-scale innovations.

3.2. An archetype analysis of sustainability innovations in Biosphere Reserves: insights for assessing transformative potential (Chapter 3/ Paper 2)

To identify archetypes of sustainability innovations based on their transformative outcomes (RQ2), I conducted two hierarchical cluster analyses of the 68 and 61 surveyed innovations in SCBR and FGBR, respectively. To better understand the conditions supportive of sustainability innovations, I then characterised the actors and processes underlying different archetypes through statistical analysis (Table 2).

Table 2. Overview of Chapter 3: research question, methodological approach and main contributions.

Chapter 3/ Paper 2. An archetype analysis of sustainability innovations in Biosphere Reserves: insights for assessing transformative potential		
Research question	Methodological approach	Main results and contributions
What types of sustainability innovations can be identified based on their transformative sustainability outcomes? (RQ2)	Archetype analysis of sustainability innovations in SCBR (68) and in FGBR (61) through hierarchical cluster analyses and comparative statistical tests, based on survey data	1) Identification of 6 archetypes: Participative Transformation Governance, New Sectors for Social-ecological Transformation, Social & Sustainable Entrepreneurs, Social Innovations, Service Innovations and Technological Efficiency Innovations 2) Transformative potential can be assessed through a leverage points perspective and amplifying strategies 3) Identification of a transformative continuum, from shallow innovations, targeting shallow leverage points and lacking amplifying strategies; to transformative innovations, targeting both shallow and deep leverages and with various amplifying strategies 4) Overlaps and common interests across archetypes offer synergies for network-building, diversifying and leveraging impacts and amplifying strategies 5) Biosphere Reserves can play a bridging role in using synergies between different archetypes

This study resulted in the identification of six archetypes (Box 1). Their transformative potential was interpreted through 1) a leverage points perspective (Meadows 1999; Abson et al. 2017)and 2) an impact amplification typology (Lam et al. 2020). First, I interpreted the sustainability impacts and novelty types each archetype induced as shallow or deep leverage points. For example, new products and resource use efficiency measures were considered shallow leverage points, while new social organisations, value shifts or enhanced social-ecological integrity were considered deep leverage points. Second, I interpreted the archetypes to have a more or less transformative potential according to the amplifying strategies put in place. For example, strategies to amplify within, i.e. to accelerate and stabilise the own project, were considered more limited than strategies to amplify beyond

their own scope (e.g. through transfer activities) or to amplify deep and up (e.g. shifting values and structures).

As a result, I identified the following archetypes, four of which were common archetypes in both Biosphere Reserves (Box 1). In both Biosphere Reserves, I identified New Sectors for Social-ecological Transformation, Social and Sustainable Entrepreneurs and Social Innovations, which had mixed transformative potential. I also identified Service Innovations, which had a limited transformative potential in both areas. Technological Efficiency Innovations were found only in FGBR and had very limited transformative potential. In SCBR only, I identified Participative Transformation Governance, with strong transformative potential.

Box 1. Sustainability innovations archetypes

Four archetypes are represented in both Schorfheide-Chorin Biosphere Reserve (SCBR) and Fontainebleau-Gâtinais Biosphere Reserve (FGBR). Number (*n*) of sustainability innovations per archetype in the respective Biosphere Reserves.

Participative Transformation Governance

This archetype comprises new projects at regional scale in which local communities or relevant actors are able to participate in planning activities or networks for sustainability.
Example: development of a mobility concept, including public and private actors, NGOs and inhabitants.
(*n*=6 in SCBR)

New Sectors for Social-ecological Transformation

This archetype comprises new sectors, value-chains, products and behaviours. Innovations target change at landscape level with a social-ecological perspective on land and resource use.
Example: new sector around regional, organic, medicinal and kitchen herbs production and processing.
(*n*=11 in SCBR; *n*=17 in FGBR)

Social & Sustainable Entrepreneurs

This archetype comprises new local, organic, sustainable businesses, cooperatives or producers, who are committed to sustainability values, nature, decent work environments and personal well-being.
Example: cooperative recycling depot with work reinsertion programme.
(*n*=11 in SCBR; *n*=16 in FGBR)

Social Innovations

This archetype comprises community-based initiatives and associations, often focussed on strengthening local communities or committed to local environmental actions and political change.
Example: cooperative, itinerant and community-based cultural café.
(*n*=23 in SCBR; *n*=13 in FGBR)

Service Innovations

This archetype comprises projects targeting public transportation, local business networks or regional education programmes in a effort to propose local climate-friendly and fair access to resources and services.
Example: experimentation on free public transportationat town level.
(*n*=17 in SCBR; *n*=11 in FGBR)

Technological Efficiency Innovations

This archetype comprises the use or installation of technological tools to increase resource use efficiency or productivity in a sustainable way.
Example: installation of a small gas plant on a family farm to use agricultural waste and diversify income sources.
(*n*=4 in FGBR)

Box 1. Sustainability innovation archetypes. Numbers in brackets indicate the number of innovations that were categorised within each archetype in both case study Biosphere Reserves. SCBR: SchorfheideChorin Biosphere Reserve; FGBR: Fontainebleau-Gâtinais Biosphere Reserve. (Replication from Chapter 4.)

Following, I suggested that these different archetypes show a transformative continuum, from least transformative innovations (e.g. Technological Efficiency Innovations), focussed on shallow leverage points and incremental change, to most transformative innovations (e.g. Participative Transformation Governance), which work on both shallow and deep leverage points and enhance their impacts beyond their own project scope through various amplifying

strategies. Finally, the overlaps between archetypes suggested that there could be synergies in their actions and that building networks could help enhance their impacts. Building on shared interests and resources could help enhance transformative potential through joint actions – this could be a bridging role for Biosphere Reserves.

3.3. A social network analysis of sustainability innovations: values, rules and knowledge to enhance transformative potential (Chapter 4/ Paper 3)

To identify supportive conditions for transformative sustainability innovations (RQ3), I assessed the decision-making contexts of sustainability innovation archetypes in SCBR and FGBR. Decision-making contexts refer to constellations of 1) values, 2) modes of knowledge production and 3) governance arrangements (Gorddard et al. 2016; Colloff et al. 2017). Building on the archetypes identified in both Biosphere Reserves (Chapter 3), I compared the decision-making contexts underlying each archetype by comparing values and modes of knowledge production, based on survey data. Governance arrangements were elicited through social network analysis (Table 3).

Table 3. Overview of Chapter 4: research question, methodological approach and main contributions.

Chapter 4/ Paper 3. A social network analysis of sustainability innovations: values, rules and knowledge to enhance transformative potential		
Research question	Methodological approach	Main results and contributions
What decision-making contexts, or underlying value systems, coproduction modes and governance arrangements are most conducive of transformative change? (RQ3)	Analysis of decision-making context of sustainability innovation archetypes through comparative statistical tests and social network analyses, based on survey data	1) Transformative sustainability innovations are connected to plural values, knowledge coproduction, and diverse, collaborative, influential networks 2) Incremental innovations are connected to instrumental values, informative knowledge production and homogenous, hierarchical, peripheral networks 3) Identification of incremental, reformist, idealistic and transformative sustainability innovations based on their transformative potential and decision-making context 4) Actions at shallow leverage points are insufficient, but necessary to operationalise transformative sustainability innovations 5) When collaborating with diverse networks, Biosphere Reserves and other regional public organisations, can support or act as bridging organisations for transformative innovations

By comparing the values, knowledge production modes and governance arrangements of each archetype in SCBR and FGBR, I found that most transformative sustainability innovations (i.e. Participative Transformation Governance) were connected to plural values, collaborative knowledge co-production, and diverse, cooperative, influential networks. On the other end of the transformative continuum (Chapter 3), incremental sustainability innovations (e.g. Service Innovations) were characterised by instrumental values, informative knowledge production and hierarchical governance networks of peripheral influence. Besides incremental and transformative sustainability innovations, I highlighted reformist and idealist sustainability innovations. For instance, reformist sustainability innovations (e.g. New Sectors for Social-ecological Transformation) had a mixed transformative potential and built on instrumental and relational values, consultative knowledge production and networks of limited influence. I pinpointed idealistic sustainability innovations, e.g. Social and Sustainable Entrepreneurs and Social Innovations. Such innovations had a mixed transformative potential, with actions targeting deep leverage points, e.g. behavioral and value shifts – yet lacked concrete, operational goals and outcomes. Such idealist sustainability innovations built on relational values, cooperative knowledge co-production and collaborative, albeit specialised and somewhat influential networks. Following this, I argued that shallow innovation is not sufficient - but necessary - as a means to operationalise

transformative change and provide milestones and opportunities for learning and network-building.

Finally, Biosphere Reserves sometimes acted as bridging organisations and were quite influential in the regional networks. However, in networks led mostly by public actors, sustainability innovations had a limited transformative potential, as in reformist innovations such as New Sectors for Social-ecological Transformation.

4. Discussion

In sustainability innovation and transformation research, the thesis identified the needs for empirical, methodological and conceptual insights on 1) the transformative potential of sustainability innovations (Figure 5) and 2) the supportive conditions that may enhance this transformative potential (Figure 6). In the following, I discuss the empirical, methodological and conceptual contributions to these two aspects of sustainability innovations, followed by a discussion of methodological challenges, implications for Biosphere Reserves and innovation actors, and avenues for future research.

4.1. The transformative potential of sustainability innovations

Few sustainability innovations are transformative – empirical contributions

In spite of a growing acknowledgment that sustainability innovations are needed to address various global challenges and transform problematic systems, few empirical studies have examined in how far sustainability innovations are actually transformative. With this doctoral thesis, I have provided empirical evidence about the transformative potential of various sustainability innovations in a cross-sectoral manner, notably showing that only few innovations displayed a strong transformative potential (Figure 5).

In a first step, **Chapter 2** compared two sustainability innovations and highlighted broader sustainability impacts and amplifying strategies for Brodowin Ecovillage than the Solar Explorer. In **Chapter 3**, I examined many cases and proposed a transformative continuum from shallow, incremental innovations to deep, transformative sustainability innovations. Only few sustainability innovations were transformative, in that they addressed shallow and deep leverage points and implemented various strategies to amplify their impacts beyond their own scope of action. For example, the most transformative archetype in SCBR, Participative Transformation Governance, comprised few innovations (n=6; 9%, Box 1). On the shallow end of the continuum, many sustainability innovations had limited transformative potential, as they mostly addressed shallow leverage points and lacked amplifying strategies. For instance, Service Innovations (n=17; 25% in SCBR; n=*11*; 18% in FGBR, Box 1) usually focussed on creating new markets, services and products, thereby addressing shallow leverage points (Chapter 3). **Chapter 4** further underlined this transformative continuum and distinguished incremental, reformist, idealist and transformative sustainability innovations. These results are in line with recent empirical studies, which detected little evidence of transformative potential in local urban sustainability initiatives globally (Castán Broto et al. 2019), in nature-based solutions in the Alps (Dubo et al. 2023) or in urban nature-based solutions globally (Goodwin et al. 2023).

These results question the growing assumption that sustainability innovations create solutions and challenge problematic systems (Feola et al. 2021). Instead, in many cases, sustainability innovations might provide short-term or superficial solutions to specific issues. For instance, a Service Innovation in FGBR provided students with the opportunity to

follow their courses online, from a delocalised campus. While students with limited financial means thus had a solution to study without moving to expensive cities, the project did not address the root causes of the issue, notably the increasing financial precarity among students. Nonetheless, the multiple incremental, reformist and idealist innovations might participate in creating alternative niches, where more transformative innovations could develop over time (Geels and Schot 2007). In fact, there is still a need for empirical evidence about the potential of such sustainability innovations to evolve into radical, transformative innovations.

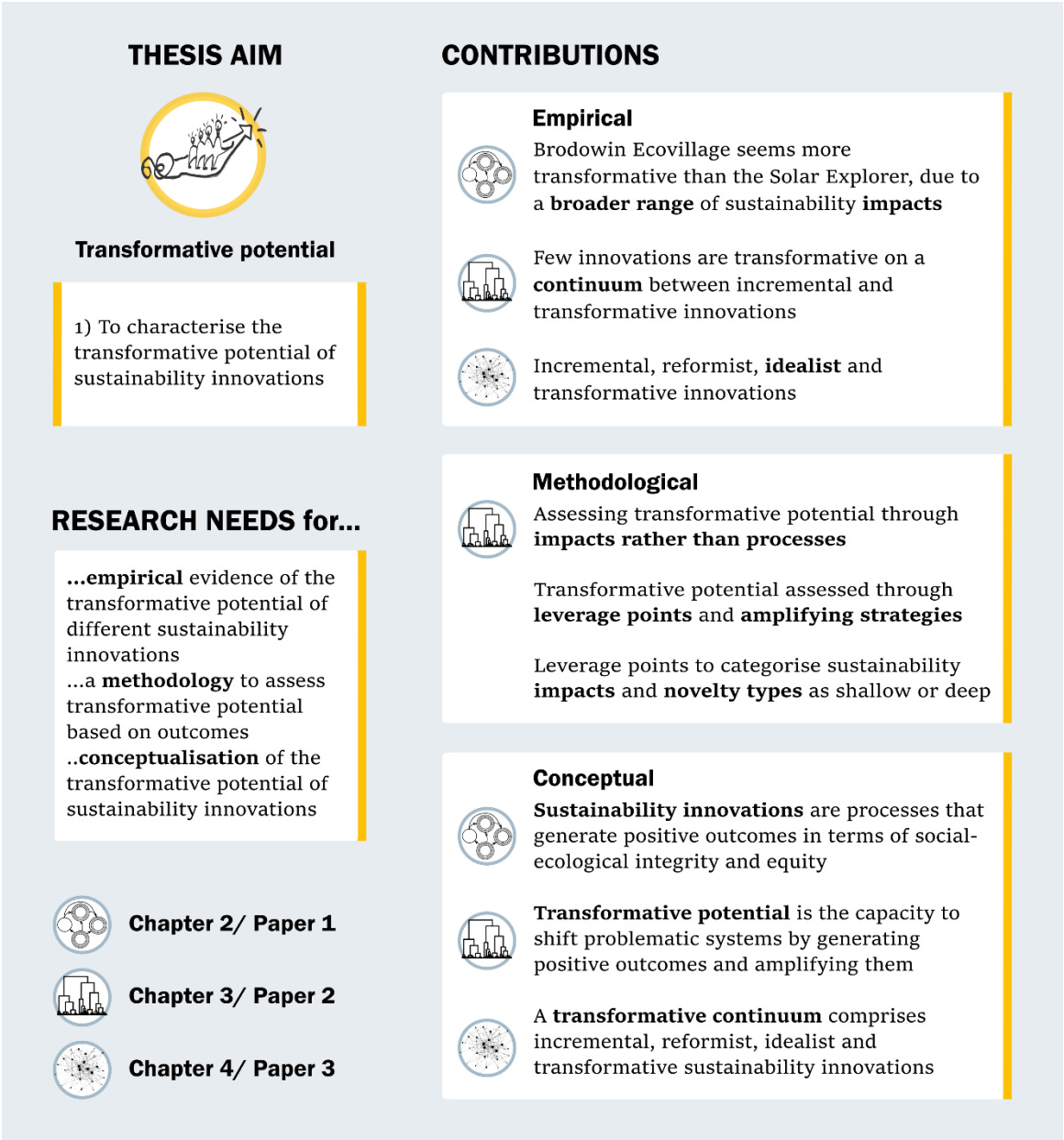


Figure 5. Thesis contributions to characterising the transformative potential of sustainability innovations. Icons indicate from which Chapter/ Paper the contributions are derived.

Leverage points and amplifying strategies to assess transformative potential – methodological contributions

Assessing transformative potential through amplifying strategies and a leverage points perspective on novelty types and sustainability impacts proved a practical approach to apply to a large number and a variety of sustainability innovations in a cross-sectoral manner (Figure 5).

First, I compared the transformative potential of sustainability innovations with a leverage points perspective to interpret data on novelty types and sustainability impacts as shallow or deep (**Chapters 3 and 4**). For instance, new products and resource use efficiency were considered shallow leverage points, while value shifts and enhanced social-ecological integrity were considered deep leverage points. Following, I could distinguish incremental from transformative sustainability innovations (Riechers et al. 2022), arguing that innovations focussed on shallow leverages were incremental and innovations focussed on shallow and deep leverages were more transformative.

Note that, in **Chapter 2**, I proposed to examine outcomes through novelty types, amplifying strategies and sustainability impacts. In particular, I compared two innovations in terms of sustainability outcomes (e.g. enhanced social-ecological integrity or livelihood opportunities) and novelty types (e.g. new products, new organisations or value shifts). This proved practical for interpreting the outcomes of sustainability innovations. Yet, it also proved challenging to assert which case was more transformative, without weighing the transformative potential through shallow or deep leverage points. The leverage points perspective was therefore valuable to compare innovations on a continuum of transformative potential.

To complement the leverage points perspective, I compared the transformative potential of sustainability innovations through amplifying strategies, which aim to enhance impacts beyond the innovations' own scopes of actions (Lam et al. 2020; Lam et al. 2021; Tuckey et al. 2023) (**Chapter 3**). Assessing amplifying strategies was relevant because some innovations addressed shallow and deep leverage points - but lacked amplifying strategies, such as New Sectors for Social-ecological Transformations. This archetype often created new products and regional value-chains (shallow leverage points) and thereby enhanced social-ecological integrity and supported structural shifts in regional agri-food systems (deep leverage points). However, this lack of amplifying strategies limited transformative potential.

This approach addresses the need to critically examine the transformative potential of sustainability innovations (Blythe et al. 2018; Fisher et al. 2022) and advances the ability of scholars to assess transformative potential through outcomes, rather than through processual aspects (Wolfram 2016; Tuckey et al. 2023). As such, this approach enables pinpointing and supporting innovations that may have the greatest capacity to solve current global challenges and propose desirable futures (Pereira et al. 2021).

Articulating sustainability innovations and their transformative potential – conceptual contributions

To advance knowledge on sustainability innovations and their transformative potential, this thesis provided the following conceptual contributions (Figure 5).

I proposed a definition of sustainability innovations as multi-scalar, multi-actor processes that develop new pathways to define and meet human needs and generate positive outcomes

in terms of social–ecological integrity and equity — in a specific and complex social–ecological-technical context (**Chapter 2**). In a fractal perspective on transformation, sustainability innovations can be understood as self-similar patterns that spread and repeat in different contexts and scales (O'Brien et al. 2023). In fact, I have shown that sustainability innovations are often bundles of intertwined and interdependent processes and novelties that reinforce each other and are co-evolving (Chapter 2). In that regard, a fractals perspective can help in analysing how sustainability innovations amplify and scale – but also how sustainability innovations are themselves sums of fractals that repeat and build on each other.

Furthermore, I conceptualised the transformative potential of sustainability innovations based on their outcomes (**Chapter 3**). I proposed that the transformative potential of sustainability innovations is their capacity to shift social-ecological-technical problematic systems by generating both shallow and deep, positive outcomes in terms of social-ecological integrity and equity, and by amplifying these outcomes beyond their scope of action. Transformative potential appeared strongest when sustainability innovations generate both shallow (or incremental) and deep (or radical) changes, and when they enhance these changes beyond their own scope of action through amplifying strategies.

Finally, I proposed a transformative continuum that comprises incremental, reformist, idealist and transformative sustainability innovations (**Chapters 3 and 4**). I suggested expanding the distinction of incremental, reformist, and transformative sustainability innovations used, e.g., for urban adaptation and mitigation actions (Heikkinen et al. 2019) and urban nature-based solutions (Goodwin et al. 2023). Idealist sustainability innovations focussed on deep leverage points such as behavioral and value shifts, often at the individual level, while building on relational and intrinsic values and cooperative decision-making – but these innovations lacked concrete, operationalisable goals and outcomes at shallow level (**Chapter 4**). For instance, Social Innovations often sought to shift individual values and behaviors through e.g. education for sustainable development and awareness-raising actions, but rarely reported concrete, measurable outcomes. Hence, while much attention has been given to deep leverage points as necessary for radical, systemic transformations (Abson et al. 2017), I proposed that transformative sustainability innovations holistically require shallow and deep impacts. Following, shallow leverages are insufficient, but necessary for radical transformations, as a means to operationalise transformative sustainability innovations (Chapter 4).

4.2. Supportive conditions for transformative sustainability innovations

Despite the numerous contributions that sought to identify supportive conditions for sustainability innovations (Salomaa and Juhola 2020; Kivimaa et al. 2021), without articulating the transformative potential of different sustainability innovations, such contributions might overlook the conditions that specifically support incremental rather than transformative sustainability innovations.

Plural values, collaboration and diverse networks may support transformative sustainability innovations – empirical contributions

This thesis provided empirical evidence about supportive conditions related to specific actors and processes, and about supportive constellations of values, knowledge production and networks for transformative sustainability innovations (Figure 6).

First, Chapters 2 and 3 addressed supportive conditions by distinguishing characteristics related actors and processes. **Chapter 2** compared two cases in SCBR and provided empirical evidence about actor characteristics that have been described as conducive for change, such as diversity in actor networks (Asheim and Coenen 2005; Wittmayer et al. 2017), availability of resources (Hekkert et al. 2007; Moore et al. 2012a) and the capacity of actors to navigate their contexts (Brondizio et al. 2021). Further empirical evidence was given on the importance of processes, such as experimenting and learning (Westley et al. 2013), building partnerships, networking and cooperating (Wittmayer et al. 2018; Tuckey et al. 2023). In fact, Brodowin Ecovillage, with a seemingly stronger transformative potential than the Solar Explorer, relied more explicitly on cooperative processes, experimentation, and learning processes. However, with a limited methodological procedure to compare the transformative potential of the two cases with a leverage points perspective (see section 4.1), these findings only partly elicit the specific conditions that support most transformative sustainability innovations rather than incremental ones.

To differentiate conditions that explicitly underlie incremental vs. transformative innovations, **Chapter 3** identified archetypes of different transformative potential among multiple cases in SCBR and FGBR. This enabled the comparison of conditions in terms of actors and processes along varying transformative potential. Notably, the distribution of intrinsic, relational and instrumental values differed per archetype, as well as the number of people involved, the actor types and their main sector of activity. Processes that differed most according to archetypes were modes of decision-making and fields of action. These insights were complemented through the analysis of decision-making contexts (Chapter 4).

In particular, **Chapter 4** applied the decision-making context framework to compare the conditions underlying different archetypes. Resulting, most transformative sustainability innovations, such as Participative Transformation Governance (SCBR), built on constellations of 1) plural values (i.e. innovations motivated equally by intrinsic, instrumental and relational values), 2) collaborative decision-making and knowledge co-production and 3) diverse, cooperative and influential networks. On the contrary, incremental innovations such as Service Innovations in SCBR and FGBR built on constellations of 1) instrumental values, 2) informative, or hierarchical, mode of decision-making and knowledge production and 3) homogenous, hierarchical and peripheral networks. These findings were in line with recent insights that transformative nature-based solutions (Dubo et al. 2023) and place-based, collaborative and just conservation (Carmenta et al. 2023) are supported by constellations of plural values, collaborative and integrative knowledge co-production and collaborative governance arrangements.

Comparing supportive conditions across sustainability innovation archetypes – methodological contributions

For a more precise understanding of the supportive conditions that enhance the transformative potential of sustainability innovations, it is necessary to decouple the analyses of outcomes and conditions (Wittmayer et al. 2022; Tuckey et al. 2023). The thesis thus compard the transformative potential of sustainability innovation archetypes, based on outcomes variables, with their respective supportive conditions, based on actors and processes variables (Figure 6).

Chapter 2 proposed an analytical framework that comprised an extensive variable set for case study analyses and distinguished outcomes from conditions - the latter were considered under three dimensions: contexts, actors and processes. The variable set proved helpful in

the in-depth qualitative analysis of two comparative cases, as it enabled the decoupled analysis of transformative potential (outcomes) and supportive conditions (context, actors, and processes). The framework could be adapted for large *n* analysis and variables related to outcomes, actors and processes were picked up in Chapters 3 and 4 to analyse multiple cases.

Figure 6. Thesis contributions to identifying the supportive conditions that may enhance the transformative potential of sustainability innovations. Icons indicate from which Chapter/ Paper the contributions are derived.

To compare multiple cases, **Chapter 3** adopted an archetype approach. Archetypes were built on variables that related to outcomes, i.e. impacts, novelty types, amplifying and scale. I then compared supportive conditions across sustainability innovation archetypes, through few variables related to actors (type, sector, resources, values, number) and processes (actions, learning, decision-making, cooperation, stage). With comparative statistics, I could interpret supportive conditions to enhance transformative potential. For example, informative (i.e. hierarchical) decision-making and instrumental values were connected to archetypes of

limited transformative potential, such as Service Innovations and Technological Efficiency Innovations.

The analysis of values and knowledge production launched in Chapter 3 was complemented by a social network analysis, which elicited the governance arrangements underlying different sustainability innovation archetypes, following the decision-making context framework (**Chapter 4**). Governance arrangements were elicited through networks that were 1) homogenous or diverse, 2) hierarchical or cooperative, and 3) influential or peripheral, based on centrality metrics of different archetypes and actor types in different networks. This approach could therefore compare conditions that shaped incremental, reformist, idealist and transformative sustainability innovations. Resulting, combining the decision-making context framework with an archetype analysis of transformative potential appeared a sound methodological approach to decouple outcomes from supportive conditions.

The supportive conditions for transformative sustainability innovations – conceptual contributions

The thesis underlined two complementary approaches to capture the supportive conditions that may enhance transformative potential: first with a focus on characteristics of actors and processes, second with a focus on constellations of values, knowledge production and networks (Figure 6).

It has been argued that conceptual plurality within transformation research helps to understand such complex processes as sustainability transformations through various perspectives (Feola 2015). In this thesis, I first focussed on actors and processes and detailed these two aspects in multiple variables. Second, I focussed on three aspects, namely values, modes of knowledge production and governance arrangements within innovation networks. These two approaches overlap. For instance, values were elicited in Chapter 3 within the actor dimension, while modes of knowledge production and decision-making were elicited within the process dimension. Eliciting governance arrangements through network analysis bridged the dimensions of actors and processes. For instance, the network analysis highlighted diversity vs. homogeneity (actors), but also cooperative vs. hierarhical networks (processes). The thesis thereby exemplified how conceptual plurality can lead to fruitful empirical research and complementary approaches to learn from complex processes (Feola 2015).

Chapter 2 advanced the understanding of supportive conditions by providing an analytical framework that articulated 31 variables in four dimensions. The framework thereby decoupled supportive conditions from outcomes. Although Chapter 2 outlined contextual conditions, this thesis generally adopted a micro-perspective on sustainability innovations (Köhler et al. 2019) and produced insights on supportive conditions with a focus on internal dimensions, i.e. actors and processes (Chapters 3 and 4). Further research should elicit how contextual conditions interplay with actors and internal processes to shape sustainability innovations. **Chapter 3** built on this framework, yet focussed solely on actors and processes as supportive conditions. Chapters 2 and 3 thus gained insights from multiple variables and built on a comprehensive approach to which conditions could be relevant for transformative sustainability innovations. Yet the analyses could not articulate the specific conditions that were supportive for most transformative innovations in particular.

On the contrary, **Chapter 4** simplified the variable set with a focus on three aspects, which gave clearer insights into the supportive conditions related to different transformative potential. The decision-making context framework proved a suitable conceptual approach to

elicit the supportive conditions underlying archetypes of varying transformative potential. In line with recent insights, this thesis proposed that plural values, diverse networks and collaborative processes are most conducive to transformative sustainability innovations (Dubo et al. 2023; Tuckey et al. 2023) and that integrative knowledge co-production, building on various types of knowledge, is likely to foster transformative innovation as well (Lavorel et al. 2019; Topp et al. 2022).

4.3. Implications for Biosphere Reserves and innovation actors

Implications for Biosphere Reserves

This thesis emphasised the capacity of Biosphere Reserves to host multiple, diverse sustainability innovations, although Biosphere Reserves are still often considered as places dedicated mostly to nature conservation rather than social-ecological transformations (Dabard et al. forthcoming, Appendix A5; Kratzer 2018b). In fact, many sustainability innovations were launched or supported by the Biosphere Reserves administrations in SCBR and FGBR. (Chapters 2 and 4) The decision-making context framework can help identify potential strategies for Biosphere Reserves to strengthen their role as bridging organisations for sustainability transformations and placed-based transformative conservation (Carmenta et al. 2023).

As plural values may foster transformative sustainability innovations (Chapter 4), Biosphere Reserves could strengthen the articulation and communication of values and goals for sustainability transformations in their regions. For instance, values and goals could be instrumental (e.g. related to rural development), relational (e.g. related to cultural heritage and community-building) and intrinsic (e.g. related to nature conservation).

In addition, Biosphere Reserves could ensure the information flows and integration of various types of knowledge, such as local, technical, experiential, scientific and tacit knowledge (Lavorel et al. 2019), and strengthen knowledge coproduction with diverse actors. Furthermore, Biosphere Reserves can support local sustainability innovations to navigate their contexts (Chapter 2), because they are clearly defined areas dedicated to specific missions, usually following place-based visions articulated for their regional development.

Finally, Biosphere Reserves could foster diverse, collaborative and influential networks that may, in turn, enhance transformative innovations (Chapter 4). Indeed, Biosphere Reserves have the potential to act as bridging organisations and foster connections between various actors across scales and sectors of activity (Olsson et al. 2007; Plummer et al. 2017).

Implications for actors in sustainability innovations

Insights from this thesis may inform innovation actors who aim to enhance the transformative potential of their sustainability innovations, by diversifying impacts and amplifying strategies; reshaping supportive conditions related to actors and processes; or specifically reshaping values, knowledge production and networks.

First, leverage points and amplifying strategies may support innovation actors to develop strategies to enhance the transformative potential of their innovations. For instance, idealist innovations with mixed transformative potential (e.g. Social and Sustainable Entrepreneurs or Social Innovations) could reflect on the concrete outcomes of their activities and identify shallow leverage points, or practical, short-term measures and actions with limited systemic impacts. Such practical and shallow actions could provide milestones and opportunities for

learning and network-building. Reformist sustainability innovations with mixed potential, such as New Sectors for Social-ecological Transformation, could reflect on the amplifying strategies put in place to share their experience and scale – and design strategies to transfer, duplicate or scale up their activities.

Second, reflecting about supportive conditions in terms of context, actors and processes; or in terms of values, knowledge production and networks could help innovation actors to identify strategies to foster transformative potential. Innovation actors could identify what potentially hinders their activities in 1) contextual conditions, 2) involved actors, their characteristics and their resources or 3) the further processes that may be needed to enhance outcomes. For instance, the Solar Explorer was limited in its outcomes, notably due to a lack of time and opportunities for learning, experimenting, reflecting and envisioning, but also due to the social context and regional transportation infrastructure (Chapter 2).

Third, following the decision-making framework, sustainability innovations could aim to identify how to articulate plural values, foster collaboration in knowledge production and decision-making, and diversify and strengthen networks (Chapter 4). For instance, sustainability innovations with limited transformative potential, such as Service Innovations, could aim to shift or include plural values - for example, by building partnerships with diverse actors who may bring in new ideas and goals. Reformist sustainability innovations, such as New Sectors for Social-ecological Transformation, which built on hierarchical networks dominated by regional public actors in FGBR, could develop more participative and collaborative methods. Finally, innovations with mixed transformative potential, e.g. Social and Sustainable Entrepreneurs in SCBR, could strengthen their networks, which were relatively homogenous, notably by connecting with diverse and influential actors.

4.4. Methodological challenges

The thesis built on an extensive data collection in two European Biosphere Reserves, first with interviews with regional key informants to identify sustainability innovations, then with survey interviews about over 100 innovations. This enabled an insightful, cross-sectoral analysis of multiple cases. Yet, a few challenges resulted from this approach throughout the whole thesis. Note that specific limitations are presented in each Chapter.

First, the thesis faced a common dilemma in sustainability innovations studies, i.e. the tension between adopting a systemic perspective versus exploring internal aspects (Köhler et al. 2019). With the aim to learn from multiple cases, the thesis adopted a micro-perspective and focussed mostly on internal aspects of sustainability innovations, notably actors, networks and processes. Supportive conditions here did not include contextual and systemic aspects except in the in-depth analysis of two cases (Chapter 2).

Second, a trade-off in collecting data from multiple cases was the need to limit the data collection to one interview about each specific sustainability innovation. Therefore, I gained only limited insights about the long-term evolution of each case and potentially disputable aspects. Although validating and discussing results with innovation actors after analysis would likely foster further insights – this was not feasible within the timeframe of the thesis. Since intensive follow-up activities were not available, I chose to share results through flyers sent via email. One flyer was sent to interviewees after finishing the data collection in each Biosphere Reserve, and another is in planning to share the final thesis results (Appendix A.2).

Third, I distinguished shallow and deep leverage points, rather than the twelve leverage points proposed by Meadows (1999) or the four system characteristics identified by Abson et al. (2017). This was a pragmatic solution to differentiate sustainability innovation archetypes, as the data was primarily categorised as novelty types and sustainability impacts. In fact, categorising innovations through their novelty types and sustainability impacts proved a practical intermediate step between the level of empirical data and the conceptual framework of leverage points.

Finally, the thesis faces the common challenge to gain generalisable insights from specific cases (Köhler et al. 2019). The similarities between sustainability innovations in SCBR and in FGBR suggest that the results could be relevant in other areas as well. Still, further empirical evidence would be needed to validate results in other contexts. In this regard, a fractals perspective may help us delineate the relevance of place-based results (O'Brien et al. 2023). Considering sustainability innovations as self-similar patterns that repeat throughout scales and places, we can learn from sustainability innovations as processes that may be repeated, replicated or re-adapted in various contexts - and as fractals, or pieces of greater societal transformation processes.

4.5. Avenues for sustainability innovation research

To better understand how actors and processes shape the transformative potential of sustainability innovations in the long term, future empirical research should examine the interactions and co-evolution of different aspects of sustainability innovations. First, the interactions between processes and outcomes could be elicited because it is likely that the processes that shape transformative innovations are themselves innovative and creative (Tuckey et al. 2023). For instance, the transformative potential of social innovations has been defined as their capacity to challenge and alter problematic systems (Avelino and Wittmayer 2019), particularly through processes of doing, thinking and organising in novel ways (Wittmayer et al. 2022).

Second, to better understand the role of values in sustainability innovations, future research could articulate the interactions of different values-related aspects in sustainability transformations (Horcea-Milcu 2022; Horcea-Milcu et al. 2023). In particular, further research could explore the interactions between 1) values as motivations for actors to pursue sustainability innovations and a potentially supportive condition, 2) values shifts as outcomes of sustainability innovations, and 3) values shifts as amplifying strategies that shape transformative potential. In this regard, distinguishing values at the individual, community and societal levels might help in better delineating how values can be mobilised for sustainability innovations (Horcea-Milcu et al. 2023).

Furthermore, there remains a need to address normative aspects in sustainability innovations research. For instance, future research should address more explicitly unexpected consequences, contestations, trade-offs and power tensions in sustainability innovations (Madsen et al. 2022; Rutting et al. 2022). This would be necessary for a better understanding of transformative potential, because different people might consider outcomes as positive or negative, notably because transformative innovations necessarily imply change, tensions, discomfort and even resistance (Temper et al. 2018; Rutting et al. 2022). In fact, critical perspectives invite us to wonder 1) whether innovation is needed and desirable at all, 2) whether sustainability innovations should scale and thereby risk mainstreaming and 3) which problematic systems require transforming, or dismantling

(Augenstein et al. 2020; Feola et al. 2021). In this regard, critical intersectional perspectives have been proposed to address power issues and normative assumptions in transformation research (Temper et al. 2018; Arora and Stirling 2023).

Finally, a challenge for future research would be to engage closely with radical sustainability innovations on the ground, notably with radical activists and social movements (Temper et al. 2018; Kothari 2020) – notably to learn from their perspectives on conditions that may enhance their transformative potential. In addition, acknowledging that many initiatives fail in their attempts at radical change but still foster learning, networking and capacity-building (Brondizio et al. 2021), future research could expand on cases of failure and capitulation. Such research would likely foster deep insights into the workings and implications of radical transformations, notably of processes that aim to challenge power structures and support resistance to and dismantling of problematic systems (Temper et al. 2018; Feola et al. 2021)

5. Conclusion

This thesis contributed to the growing field of sustainability innovations and transformations studies, which seek to understand how to unleash the potential of local, place-based sustainability innovations to participate in societal transformations towards desirable, sustainable and just futures. Key findings articulated that the transformative potential of various sustainability innovations can be assessed through a leverage points perspective on their outcomes, complemented by an analysis of amplifying strategies that aim to enhance impacts. This thesis provided evidence that most sustainability innovations have limited transformative potential. Supportive conditions can be captured through a focus on actors or processes; or a complementary focus on values, knowledge and governance arrangements. Evidence showed that plural values, collaborative processes and diverse, influential networks can enhance transformative potential. Following, implications for Biosphere Reserves management and innovation actors invited them to reflect on potential strategies to diversify their impacts, design amplifying strategies, articulate diverse values, foster collaborative processes and strengthen their networks. In turn, future research should strive to examine the plural perspectives of various actors, notably of marginalised voices, to focus on the most transformative, radical innovations and to acknowledge conflicts, discomfort and trade-offs, to explore the contributions of various sustainability innovations to great societal transformations. Yet, it appears necessary to recognize that the burden of transforming and dismantling problematic systems cannot be shouldered solely by local sustainability innovations. Nonetheless, at this point, it is time to celebrate the contributions of the many sustainability innovations in Schorfheide-Chorin and Fontainebleau-Gâtinais, which have shown how diverse initiatives can emerge in and navigate the context of Biosphere Reserves, support each other in broad and collaborative networks, and pave multiple pathways to positive and plural futures.

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Chapter 2

Sustainability innovations: a proposal for an analytical framework and its empirical application in the Schorfheide-Chorin Biosphere Reserve

Framing, framework, framed

Sustainability Science
https://doi.org/10.1007/s11625-022-01241-9

ORIGINAL ARTICLE

Sustainability innovations: a proposal for an analytical framework and its empirical application in the Schorfheide-Chorin Biosphere Reserve

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Received: 24 March 2022 / Accepted: 19 September 2022
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Abstract
Sustainability innovations influence societal transformations through the development of new products, processes, organizations, behaviors or values. Although various research approaches have tackled technological innovations in the last few decades, the specificities and enabling conditions of individual sustainability innovations remain rather unknown. We therefore propose an analytical framework, built on learning from the social–ecological systems and transitions literature. The sustainability innovation framework features four dimensions: context, actors, process and outcomes, which are detailed in 31 variables. We use the sustainability innovation framework to analyze two case studies selected in the Schorfheide-Chorin Biosphere Reserve, Germany. The first refers to technological and organizational innovation in mobility, while the second relates to social and organizational innovation in agriculture. As a result, we highlight commonalities and differences in enabling conditions and variables between the two cases, which underpin the influence of trust, commitment, resource availability, experimenting, learning, advocating, and cooperating for innovation development. The cases further demonstrate that sustainability innovations develop as bundles of interdependent, entangled novelties, due to their disruptive character. Their specificity thereby resides in positive outcomes in terms of social–ecological integrity and equity. This study therefore contributes to transitions studies via a detailed characterization of sustainability innovations and of their outcomes, as well as through a generic synthesis of variables into an analytical framework that is applicable to a large and diverse range of individual sustainability innovations. Further empirical studies should test these findings in other contexts, to pinpoint generic innovation development patterns and to develop a typology of sustainability innovation archetypes.

Keywords Innovation · Sustainability transitions · Innovation systems · Social–ecological systems · Rural innovation · Biosphere reserve

Introduction

The buzzwords "eco-innovations," "green innovations" or "sustainability-oriented innovations" have garnered much attention in research and policy in the last few decades, as they seem to be crucial milestones for societal change (Kratzer 2019; O'Brien and Sygna 2013). Yet, what really is sustainable in the processes at stake and their outcomes currently remains somewhat vague. In recent business-driven understandings of sustainability innovations (Adams et al. 2016; OECD/Eurostat 2018; Varadarajan 2017), there is neither a holistic understanding of sustainability nor much consideration for other types of innovations besides product, process, organizational and marketing innovations (Gamito and Madureira 2019).

In the last few decades, as global changes have placed pressure on the role and potential of innovations for sustainable change, the sustainability transitions research field has addressed innovations as multi-scalar processes within complex systems (Rakas and Hain 2019), thereby adopting a systemic and plural understanding of innovation. A guiding

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Published online: 17 November 2022

assumption has been that solving environmental issues requires not only changes in technology, but also holistic changes in systems comprised of actors, institutions and technology (Loorbach et al. 2017). A prominent framework in this regard is the multi-level perspective (MLP), which unravels innovation journeys within multi-scalar socio-technical systems (Geels 2002). In addition, the MLP provides an analytical framing for multi-dimensional change processes, by addressing dynamic actor–institution interactions and including issues of agency, normativity, change and stability phases, contextual path dependencies, barriers and windows of opportunity (Geels 2002; Geels and Schot 2007). Another framework, developed in parallel to the MLP, is the technological innovation systems (TIS) approach (Hekkert et al. 2007). Similarly, TIS acknowledges the systemic interactions between actors, networks and institutions in the context of socio-technical systems and focusses on radical cross-sectoral innovations, thereby emphasizing markets, actors and network interactions (Markard and Truffer 2008). With a prescriptive—rather than analytical—purpose, the transition management approach (TM) is a practice-oriented framework that guides innovation processes and navigates transitions in the making (Loorbach 2007; Wittmayer et al. 2018). A novel approach is the geography of sustainability transitions (GeoST) (Coenen et al. 2012), which largely builds on learnings from the MLP and the TIS approaches and also adopts a systemic approach to change. However, rather than focusing on technology, GeoST calls for a space-sensitive analysis of focal innovations, thereby paying close attention to spatial patterns and geographical influencing factors across local and global scales (Binz et al. 2020).

While transitions scholars understand sustainability innovations in terms of socio-technical system changes, an identified blind spot is the meanings and implications attributed to the term *sustainability* (Schlaile et al. 2017). What makes transitions and innovations *sustainable* remains often implicit, and positive impacts are usually taken for granted rather than thoroughly studied (Baker and Mehmood 2015; Feola 2020; O'Brien and Sygna 2013; Salomaa and Juhola 2020).

Through this article, we contribute to the definition of sustainability innovations and to the conceptualization of an analytical framework for a better understanding of their working conditions. We thereby focus on single innovations—rather than on systemic changes at niche and regime levels, to highlight relevant influences on their development and sustainability outcomes, in a context-specific way. We specifically address the following research questions: (1) What are the characteristics of sustainability innovations? (2) Which factors influence sustainability innovations? and (3) What are the specific outcomes of sustainability innovations? To answer these questions, we unravel the specificities of sustainability innovations and underlying social–ecological and multi-level interactions.

This article is structured as follows. In "Analyzing sustainability innovations", we define sustainability innovations as multi-scalar and multi-actor processes that develop novel ways to define and meet social needs in a specific context. We then present the theoretical foundations for our analytical framework. The framework features four dimensions of sustainability innovations, namely context, actors, process and outcomes, as well as 31 potential influencing factors and characteristics of sustainability innovations to be assessed in focal case studies. This section builds on learnings not only from the sustainability transitions literature and innovations studies, but also on social–ecological systems research (McGinnis and Ostrom 2014; Ostrom 2007) and sustainability assessments (Gibson 2006). "Methods" displays our case study methods on two sustainability innovations from Schorfheide-Chorin Biosphere Reserve (Germany), to test the analytical framework and gain a better understanding of influences and outcomes. "Results" presents the following results. We discuss our insights and the potential and limitations of our research in "Discussion" and conclude in "Conclusion".

Analyzing sustainability innovations

In this section, we first present a capacious definition of sustainability innovations, followed by an analytical framework for the detailed study of focal sustainability innovations.

Defining sustainability innovations

When seeking to comprehend sustainability innovations, transition and innovation studies offer a conceptual understanding of *innovative* aspects such as innovation types and development processes, whereas the sustainability assessment literature elaborates on what distinguishes *sustainability* innovations from what we may call *conventional* examples, i.e., innovations that have no intention and no concrete impact in terms of sustainability. Most innovation studies build on Schumpeter's (1934) seminal conceptualisation, which demonstrated that innovations, in opposition to inventions, refer to novelties applied and diffused, including product, process and organizational novelties, both radical and incremental. Business-driven understandings of innovation focus on product, process, organizational and marketing—or, in a new categorisation on product and business process innovations (OECD/Eurostat 2018). In addition, recent innovation studies have shed light on a more capacious understanding of innovations, including social, behavioral, technological or rural innovations (Gamito and Madureira 2019). In a comprehensive understanding, innovations respond to

specific social needs and desires, or even (re-)define needs and desires (Baker and Mehmood 2015). Fagerberg (2009) underlined the systemic aspects of innovation, which are embedded in and shaped by the specific environment or context in which they develop. In these complex systems, innovations develop as multi-scalar processes that unfold across various socio-technical (sub-)systems (Geels 2019), and in what follows they encompass collective processes of inventing, experimenting, developing, supporting and spreading, all of which therefore involve a multiplicity of actors.

Sustainability innovations have the same characteristics as those described above, but, as the name suggests, they particularly encapsulate sustainability outcomes. The guiding assumption is that sustainability is a comprehensive and holistic concept used to describe the preservation and strengthening of social-ecological systems in the long term, via multiple reinforcing steps (Gibson 2006). More specifically, sustainability refers to social–ecological systems capacity to maintain and restore human wellbeing, social equity and environmental integrity (Leach et al. 2010). Against this backdrop, sustainability innovations do not simply mitigate negative impacts, but rather should induce net positive outcomes. Still, sustainability also concerns processes and means rather than only targets and results (Meadows 1998), in which case precaution and justice principles must be addressed. Henceforth, sustainability remains a normative concept, for which concrete understandings and applications are context-dependent and shaped by place-specific environmental, political, social and cultural conditions (Gibson 2006; Leach et al. 2010). Sustainability innovations therefore produce positive outcomes in terms of social–ecological integrity and equity in specific contexts.

In this study, we propose the following definition: sustainability innovations are multi-scalar, multi-actor processes that develop new ways to define and meet social needs and induce positive outcomes in terms of social–ecological integrity and equity—in a specific and complex social–ecological context. This definition casts light on four prominent aspects that constitute the basis of our analytical framework: actors, processes, outcomes and context.

Developing a sustainability innovation framework

The central objective of this study is the conceptualisation of an analytical framework for sustainability innovation, which we call sustainability innovation framework in the following. This framework aims to provide a comprehensive and generic set of relevant variables that potentially induce influence on innovation development and outcomes, to enable the analysis and cross-case comparison of focal, individual sustainability innovations, in a context-sensitive manner. The sustainability innovation framework thereby conceptualizes an innovation systems by distinguishing various system dimensions and potential influencing variables. Relevant dimensions and variables, as well as their interactions, were identified deductively with help of a literature research. Conceptually, we built on prominent systemic approaches in the fields of social–ecological systems (McGinnis and Ostrom 2014; Ostrom 2009), sustainability assessments (Gibson 2006; Luederitz et al. 2017) and innovation and transitions studies, including the MLP (Geels 2002, 2011, 2019), transition management (Frantzeskaki et al. 2012; Loorbach 2007; Wittmayer et al. 2018), TIS (Cooke 2010; Bergek and Mehmood 2015; Hekkert et al. 2007) and GeoST (Binz et al. 2020; Coenen and Morgan 2020). This literature research resulted in the identification of four system dimensions (actors, process, outcomes and context) and 31 variables that potentially influence sustainability innovation development. Related concepts were synthesized to reach a comprehensive and yet clear set of variables. The resulting framework was evaluated, applied to two case studies and adjusted in an iterative manner over a year. The following sections display the concepts and literature bodies on which the framework specifically draws.

Four dimensions for analysis: context, actors, process and outcomes

The sustainability innovation framework comprises an initial analytical tier of four prominent dimensions, namely context, actors, process and outcomes, which are inspired by the social–ecological systems (SES) framework (McGinnis and Ostrom 2014; Ostrom 2007, 2009). The SES framework provides analytical guidance in assessing variables that influence the performance of institutional arrangements for the use of natural common goods in focal social–ecological systems. Furthermore, it details resource systems, resource units, governance systems, actors, interactions and outcomes, while related ecosystems, as well as social, economic and political settings, are considered as an influencing contexts for specific social–ecological systems (McGinnis and Ostrom 2014).

In accordance with the SES framework, albeit with a particular focus on collective processes of innovation rather than natural resource use, the sustainability innovation framework thus acknowledges the central role of *actors* in the development of sustainability innovations. Actors in this context refer to stakeholders and organizations who invent, cooperate, support, use, adopt or even hinder a focal innovation *process*. In line with the SES framework, *processes* are conceptualized as actions and interactions within the actor group and with other system dimensions. Following these interactions, *outcomes* are the results of innovation processes in a given *context*. In contrast with the SES approach, which focuses on biophysical and governance systems (Ostrom 2009), we adopt herein a more generic approach to the

settings in which innovative actors interact and experiment. As proposed by the innovation systems approach (Markard et al. 2015) and GeoST (Binz and Truffer 2017), innovations are shaped by their local and global contexts. Different aspects will appear relevant in different cases, so we refer to general settings as *context* and include a large range of potentially relevant aspects, such as political, social, technological, economic and biophysical settings, as detailed in the next section. Note that, in line with the SES framework, the sustainability innovation framework seeks to guide case analysts in unraveling relevant factors and characteristics in given situations (Ostrom 2007). We acknowledge systemic multi-level influences—but focus on context-specific individual innovations rather than broader regime or system change processes (Geels 2019).

Context

The context dimension of the analytical framework refers to all external influences and conditions that shape, support or hinder sustainability innovations. Specific contextual conditions may constitute direct barriers or opportunities for innovation, such as regional lock-ins, due to existing industrial infrastructure (Geels and Schot 2007), or new policy programs and funding opportunities (Shove and Walker 2007). The context also sets a baseline against which processes may be considered novel and sustainable (Gibson 2006). For instance, while a product or behavior can be innovative in a given place at a certain time, the same product or behavior might as well go unseen in another context (Fagerberg 2009). Similarly, some form of novelty may bring about sustainability improvements in a given context, while it may be a setback in another. Various systems analysis approaches focus on particular context conditions. The SES framework, for instance, emphasizes biophysical conditions (McGinnis and Ostrom 2014), while the MLP focuses on socio-technological system conditions (Geels 2011). TIS recognizes the influence of governance and institutions on the development of technologies, albeit it falls short of biophysical, cultural and social aspects (Asheim and Coenen 2005). GeoST calls for a more comprehensive understanding of the place-specific conditions of innovations (Coenen et al. 2012). This approach addresses space and place in a relational manner, including histories, cultures, actors, materials and their interactions (Binz et al. 2020). The sustainability innovation framework thereby acknowledges that the framing of relevant scales, influencing variables and the bounding of focal sustainability innovations in their relevant context, as part of complex social-ecological systems, may vary depending on research objectives, personal interpretations and normative assumptions (Leach et al. 2010). To encompass the variety of potential influences on sustainability innovation development, we propose a set of generic context variables, which might play out very differently across cases and need to be defined and carefully reflected upon while framing the case analysis: ecological (C1), political (C2), economic and financial (C3), social and cultural (C4), technological and infrastructural (C5) and other contextual variables (C6).

Actors

The actor dimension of the sustainability innovation framework encompasses all relevant stakeholders and organizations that innovate, support, cooperate in, use, adopt or even hinder a specific sustainability innovation. The social-ecological systems framework provides a starting point for detailing this dimension, by highlighting the influence of the number of actors, their characteristics, their norms, values and trust in terms of collective decision-making (McGinnis and Ostrom 2014). Furthermore, looking at innovations rather than at the use of natural common goods, the innovation systems approach acknowledges the prominent role of organizations, such as firms, research and administration, and insists on distinguishing actors types, e.g., private, public and individuals (Asheim and Coenen 2005). As proposed by Westley et al. (2013) and Asheim and Coenen (2005), actors' resources, knowledge and roles, including inventors, supporters and advocates, have been identified as potentially relevant variables for case study analyses. In what follows, the actor dimension features seven variables that guide the analysis of involved people and organizations by type (A1), role (A2), resources and competences (A3), interests and values (A4), trust and commitment (A5), number (A6) and other characteristics (A7).

Process

The process dimension of the sustainability innovation framework refers to what actors do and how they do it. Within the field of sustainability transitions, the transition management approach has thoroughly explored change processes by accompanying transition processes in the making of and learning from practice, for instance in cities (Frantzeskaki et al. 2020) or in the energy sector (Kemp et al. 2007). Wittmayer et al. (2018) distinguish the major phases and activities of transition processes, including building teams and partnerships, problem analysis and framing, envisioning and setting goals, acting and experimenting and reflecting. Furthermore, the social-ecological framework highlights the shaping effects of conflicts in decision-making, such as in natural resource use and conflicting interests among stakeholders (McGinnis and Ostrom 2014). The technical innovation systems approach further underlines the need for lobbying and gravitating toward other organisations' higher governance levels, as in the case of novel technologies, such as biofuels or renewable energies, which require regulatory

adjustments and social and political support (Bergek et al. 2015). Consequently, we synthesize these learnings and sustainability innovation processes into eight variables: envisioning and goal-setting (P1), action and experiments (P2), learning and sharing knowledge (P3), decision-making (P4), building networks and partnerships (P5), conflicts (P6), advocating, marketing and lobbying (P7) and other potential processes (P8).

Outcomes

The fourth dimension of the sustainability innovation framework refers to outcomes, which encompasses innovation types, as well as its development stages and sustainability-related results. Outcomes include the type of novelty at stake, for example social, institutional, behavioral and organizational innovations (Gamito and Madureira 2019). In this dimension, we also refer to development stages such as amplification and spreading processes and results (Lam et al. 2020). Besides innovation type and the development stages, the outcome dimension is much less explored in innovations and transition studies. Whereas some authors highlight processual aspects, such as responsibility, participation, learning and systemic and long-term thinking (Schlaile et al. 2017; Wittmayer et al. 2018), no comprehensive analytical set is provided by any of the analysis frameworks at hand.

The sustainability innovation framework thus builds on learnings from the sustainability assessment literature to expand on outcomes. The guiding assumption is that sustainability is a comprehensive, holistic and normative concept employed to describe the protection and strengthening of social–ecological systems in the long term. Social–ecological integrity requires multiple reinforcing steps, which maintain conditions for human wellbeing as being interdependent with biophysical systems and life support functions (Gibson 2006). We now follow the proposed list of sustainability features provided by Gibson (2006) and Luederitz et al. (2017), and we use them as potential outcomes of sustainability innovations. Innovations may cause structural changes in physical and social structures (Luederitz et al. 2017), while resource maintenance and efficient use ensure the long-term viability of social–ecological systems (Gibson 2006). In addition, livelihood sufficiency and opportunity allow individuals and communities to strengthen their quality of life and wellbeing (Luederitz et al. 2017), and intra- and intergenerational equity guarantee equal opportunities and decent life conditions (Luederitz et al. 2017). Social–ecological stewardship and democratic governance strengthen individuals and communities in their commitment and ability to promote sustainability and democratic decision-making (Avelino et al. 2020; Luederitz et al. 2017). Precaution and adaptation account for risks and unforeseen changes, and they improve the ability to prevent or react to them (Gibson 2006). As a result, the outcomes dimension features ten variables: innovation type (O1), amplifying and spreading (O2), structural changes (O3), social–ecological integrity (O4), livelihood sufficiency and opportunity (O5), intra- and intergenerational equity (O6), resource maintenance and efficiency (O7), social–ecological stewardship and democratic governance (O8), precaution and adaptation (O9) and other potential outcomes (O10).

In summary, the sustainability innovation framework consists of four system dimensions—context, actors, outcomes and processes—and a set of 31 potentially influencing variables related to these dimensions (Fig. 1). The framework depicts major influences and interactions, which unfold across these system dimensions and scales (Binz and Truffer 2017; Coenen et al. 2012; Hielscher et al. 2022). Acknowledging the multi-scalar character of sustainability innovation, the analytical framework particularly considers actors' interactions, spanning from local to global scales and contexts, with a focal starting point on individual sustainability innovations (Köhler et al. 2021).

Methods

To test the applicability and accuracy of the sustainability innovation framework for analytical purposes, two sustainability innovations were selected as case studies in Schorfheide-Chorin Biosphere Reserve (Germany), a peri-urban to rural region located to the northeast of Berlin. As biosphere reserves, nominated by UNESCO, aim to function as model regions for sustainable development, they provide compelling study sites for sustainability innovation. Our cases were the Solar Explorer, a solar-powered catamaran developed for research and education purposes, and Brodowin Ecovillage, a large-scale, organic farm stemming from a former collectivist land cooperative.

Case selection

The two cases were selected during a regional inventory of sustainability innovations at the Schorfheide-Chorin Biosphere Reserve. In the first phase of the inventory, five semi-structured expert interviews were conducted with regional informants about sustainability innovations and prominent projects in the region. Interviewees were representatives of local administrations, the biosphere reserve, a local association and a university (Table 1). From the inventory, two cases were selected. A first criterion was to select well-known, real-world, stabilized innovations in the region, which were mentioned by several of our regional informants. A second criterion was to select cases that differed in terms of goals, sectors and innovation type, thus allowing the framework to be applied to varying contexts for

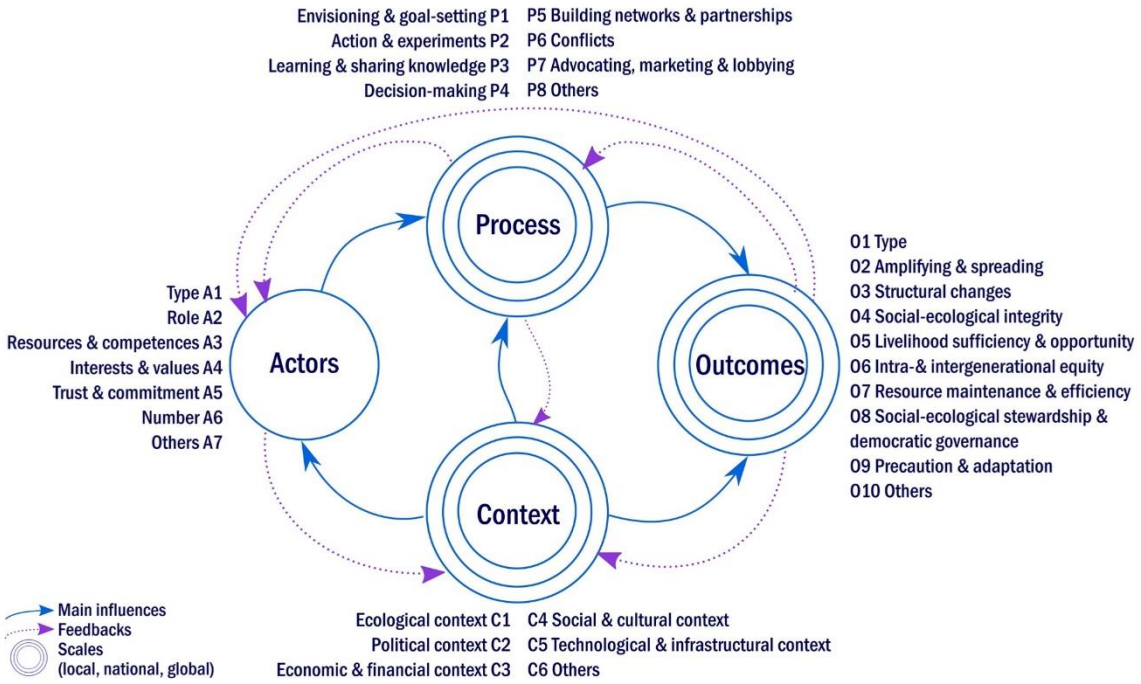

Fig. 1 Sustainability innovation framework. Dimensions, variables and interactions

Table 1 List of interviews

ID	Organization	Function	Topic	Length	Date
SCi1	Schorfheide-Chorin Biosphere Reserve	Employee	Regional SI inventory	01:00	03/03/2021
SCi2	Schorfheide-Chorin Biosphere Reserve	Employee	Regional SI inventory	01:00	15/03/2021
SCi3	University for Sustainable Development Eberswalde	Scientific staff member	Regional SI inventory	00:20	23/03/2021
SCi4	Regional Planning Department	Employee	Regional SI inventory	00:40	24/03/2021
SCi5	Schorfheide-Chorin Biosphere Reserve	Employee	Regional SI inventory and Solar Explorer	01:10	09/04/2021
SCÖB1	Ökodorf Brodowin GmbH	Employee	Brodowin Ecovillage	01:10	20/04/2021
SCSE1	Kulturlandschaft Uckermark e.V	Executive director	Solar Explorer	01:10	20/04/2021
SCÖB2	Ökodorf Brodowin e.V	Board member	Brodowin Ecovillage	01:40	04/05/2021
SCSE2	Kulturlandschaft Uckermark e.V	Former employee	Solar Explorer	00:50	05/05/2021

cross-case comparison. The first case is the Solar Explorer, a sun-powered catamaran developed in 2011 for educational purposes by a wide range of public and private actors. The second case is Brodowin Ecovillage, a social innovation, which started with the creation of a large-scale biodynamic farm after German reunification and later developed through multiple incremental changes. Both initiatives were pioneers at a time when solar power and biodynamic farming were very much in their infancy.

Qualitative expert interviews and data analysis

Qualitative data were collected on each sustainability innovation through online semi-structured expert interviews. Following a request for an interview sent to three prominent actors per case, five agreed while one person involved in the Brodowin Ecovillage declined. Contacted stakeholders were employees, a board member of a local association and a representative of the biosphere reserve, each of whom had in-depth knowledge of their respective

cases. The interviewees had different functions and positions, and each was employed by a different organization (private firm, NGO, public administration), which ensured a variety of opinions and perspectives on each case. The analytical framework was used to structure the interview guide along the four sustainability innovation dimensions: context, actors, process and outcomes. Variables were transposed into questions along the four mentioned dimensions. Additionally, questions were included about the perceived influence of the vicinity of the capital city and of the biosphere reserve, to elaborate on potential specific influences. Interviews lasted about one hour on average. The audio recordings were transcribed and then coded with MaxQDA for qualitative content analysis (Mayring 2007), using the sustainability innovation framework dimension and variables for categorisation. Consequently, we identified relevant variables and drew a comparison of influences and characteristics across the two cases.

Results

The Solar Explorer: a technological and service innovation

The Solar Explorer is an 18-m-long research and educational solar-powered catamaran, which has been based on the Werbellinsee in Schorfheide-Chorin Biosphere Reserve since 2011. In 2006, the original idea was developed by a network of diverse actors: a boat constructor, the biosphere reserve administration, a local association, the German society for solar energy, a nearby university and other supporters had the boat built in 2011. Since then, the Solar Explorer has been dedicated primarily to education for sustainability, and equipped with high-tech research equipment for ecological research, thereby becoming a well-established technological and product innovation. What factors have influenced the development and the outcomes of the Solar Explorer? What are its outcomes? The analysis of the interview material casts light on the following variables, as described in the following paragraphs.

Context

The development of the Solar Explorer happened in a context of growing awareness (C4) of global changes (C1), at a time when solar technology was on a very small scale globally (C5). Locally, the biosphere reserve and the clear-water lake ecosystem (C1) inspired the actors to commit to sustainability. The attractive location for tourism and outdoor recreation, aligned with the will of schools to support education for sustainability (C4), represented a good opportunity to reach out to visitors. Funding opportunities by public (C2) and private donors at regional and national levels (C3) enabled the project's implementation. However, the regional mobility infrastructure (C5) prevented access to the Solar Explorer by public transportation—and thus participation by some schools. Furthermore, the Covid-19 pandemic (C4) put a stop to all educational programs in 2020.

Actors

A few regional visionaries and leaders developed the project by reaching out to resource and knowledge brokers and to implementers (A2). Their diverse interests (e.g., solar technology, education for sustainability, rural development) (A4) gave way to the multiple facets of the sustainability innovation. The availability of professional competences (e.g., solar technology, education) and soft skills (e.g., networking, facilitating) was considered a crucial resource (A3). Understanding of local structures and mentalities was mentioned also as a requirement for successful implementation (A3). Funding was constantly searched for and made the innovation and its stabilization possible (A3). Strong commitment by many actors (A5) prevented failure, due, for instance, to a lack of funding.

Process

Throughout the whole process, a crucial activity involved advocating for the project to find support for funding at the local and national levels, to inform schools about the program and to search for potential partners for the development of new projects (P7). Additionally, actors focused on implementation (i.e., boat construction and maintenance, educational program) (P2). Nevertheless, the continuous search for funding required a great deal of energy and therefore strongly limited monitoring (P3) and the development of new ideas (P1). The Solar Explorer was thereby ever more focused on education for sustainability rather than on ecological research, and the research equipment has been less used than envisioned.

Outcomes

Against this backdrop, the Solar Explorer became a technological product innovation at a global level and a service innovation for education for sustainability in the region (O1). This resulted in sustainability outcomes, as it fostered local resource maintenance and efficient use through solar technology for mobility (O7), thereby becoming a flagship project for the biosphere reserve administration and an inspiring demonstration project for solar technology. The Solar Explorer also participated in ecological stewardship (O8) through showcasing solar technology and through awareness-raising and knowledge transfer at the local to global

levels, with a strong focus on local school children. The project also fostered actor empowerment and capacity-building. Indeed, the Solar Explorer gave way to further experimental projects in the field of regional sustainable mobility, with the commitment of many of the involved actors (O2). For instance, following projects in the biosphere reserve targeted e-bike mobility and public transportation networks. Finally, the Solar Explorer participated in strengthening regional intergenerational equity by promoting high-quality educational programs in a low-density rural region in which such offerings are rare (O6). Indeed, several of our interviewees underlined the difficulty for such a rural area to provide out-of-school educational activities in comparison to well-connected and well-financed schools in urban areas.

Brodowin Ecovillage: a social, multi-faceted innovation

The Brodowin Ecovillage is a regionally well-known sustainability innovation in the agricultural sector. It is a private large-scale biodynamic farm developed in the early 1990s on former collectivist cooperative land (in German *Landwirtschaftliche Produktionsgenossenschaft*). After the regime change, agricultural land around the village could have been redistributed to its former owners, but about 80 local farmers took the decision to continue with a collective scheme via a private company, with the goal to preserve jobs and to transition to biodynamic farming. The name "Ecovillage" was adopted, as almost all former landowners and villagers committed to the decision. This initial social innovation gave way to multiple other novelties. Most importantly, the Brodowin Ecovillage implemented nature protection measures. Further incremental innovations in processing, commercialisation and low-carbon delivery were also developed, and so the scheme was thus considered an organizational and a social innovation, which grew as a result of further product, marketing and process innovations. What factors influenced the emergence, the development and the outcomes of Brodowin Ecovillage?

Context

The original catalyst for the creation of the Ecovillage was the national political transition in 1989 and the early 90s (C2). The transition raised local questions relating to the reprivatisation of land. Although sustainability and organic agriculture were niche concepts at that time at a global level (C4), the simultaneous creation of the biosphere reserve (C2) inspired involved actors to opt for organic farming. The growing demand for and acceptance of organic agriculture (C4) in the ensuing decades supported the stabilization of the farm. Furthermore, its proximity to Berlin offered regional market opportunities (C3), while the low-density rural region (C4) has allowed surface expansion in later stages. Very recently, the COVID-19 pandemic (C4) saw an increase in demand for organic products and therefore economically benefitted the Ecovillage.

Actors

The original discussion about a potential redistribution of agricultural land involved former employees of the collectivist cooperatives and other village actors. After the creation of the private farm to oversee the project, other actors committed to the idea, such as the local Ecovillage association (in German Ökodorf Brodowin e.V.), regional and national private partners (e.g., neighboring farms and donors) and the biosphere reserve administration (A1). This actor constellation crystallized around multiple interests (A4), such as ensuring local jobs and economic viability, promoting sustainable land use and nature protection and enhancing quality of life. Actors played different roles in terms of leadership, facilitating, implementing and resource- and knowledge-brokering (A2). The availability of funding (A3), provided by the directors, enabled the stability and development of the farm throughout difficult times. The interview partners considered trust, strong commitment (A5) and competent personnel (A3) as critical success factors. Professional expertise, not only in agriculture, but also in ecology and nature conservation, as well as soft skills like facilitation and networking (A3) also enabled the success of the project.

Process

The interviewees shed light on challenges and crises as catalysts for innovation throughout the whole process, e.g., political transition. Hence, a pattern of envisioning solutions and setting goals (P1), doing experiments (P2) and learning from them (P3) was repeatedly reported by our interviewees. An example was the development of processed products, which first started as a limited activity but soon expanded to make use of leftovers and surpluses, which then led to more recipes and more products. Experiments were made possible by open decision-making processes (P4), such as the initial decision to work collectively or the common yearly design of nature protection measures together with the local association.

Outcomes

Over the last few decades, the variety of activities has ensured economic stability (O9) and led to multiple outcomes, including the original social innovation and follow-up product and process innovations (O1). Locally, the farm grew in area and net benefits and extended its panel of products to processed food, dairy and meat, vegetables

and fruits in weekly subscription. Incremental innovations were made in products and processing (O2), and structural changes were made to the local landscape, which turned from conventional large-scale agriculture to organic farming with protected patches of land for biodiversity (O3). In turn, this enhanced social–ecological integrity through the preservation of habitats for fauna and flora while creating attractive landscapes for locals and visitors—and thus enhancing human quality of life (O4). Resource maintenance and efficient use were strengthened through the processing of leftovers from the vegetable, fruit and meat production, the use of solar energy on site and CO_2 emission reductions in delivery through partnerships with bike delivery services in Berlin (O7). The high employment rate on the organic farm fostered local livelihood sufficiency (O5), albeit the spread and growth of the farm also fostered land concentration and the dependency of smaller farms on their large-scale neighbor, for instance for dairy processing. To some, the Ecovillage came to resemble an agricultural monopoly. Nonetheless, as it attracted tourists, new business opportunities were created for local housing and gastronomy entrepreneurs (O5). Yet increasing tourist flows from Berlin toward what became an eco-tourism attraction—coupled with underdeveloped public transportation infrastructure—increased pressure on the local population and environment, due to high numbers of private cars in the village and surrounding areas. Finally, social–ecological stewardship (O8) was strengthened through knowledge production and capacity-building within the actor constellation, leading to amplification and spreading at the regional and national levels (O2). Indeed, the implementation of nature protection measures was institutionalized on the farm and later applied in follow-up agroecology projects in the region and beyond, led partly by the same actors (O2).

Cross-case comparison

Through multiple actors and processes, and with various sustainability outcomes, both cases epitomized the proposed definition of sustainability innovations. Nonetheless, the cases displayed clear differences in the variables and conditions that influence the emergence, development and outcomes of each sustainability innovation.

As for commonalities, both cases emphasized the importance of a trusting, committed actor network that would support the sustainability innovation through complementary roles and competences, as well as with secure funding (A1, A2, A3, A4 and A5). Actor diversity fostered diverse goal-setting, including social, ecological and economic aspects. As for processes, envisioning, experimenting, learning, advocating and building partnerships were most influential in both cases (P1, P2, P3, P4 and P7). Nonetheless, little time could be dedicated to learning and envisioning by the Solar Explorer team, which was considered a limiting factor for development. Both innovations benefited from windows of opportunity to develop; for example, changes in land tenure systems enabled the creation of the Ecovillage. Both innovations co-evolved with their contexts (C1, C2, C3 and C4), such as organic farming with a nearby urban market. With regards to outcomes, the cases displayed different results, but both produced a panel of multiple outcomes. For example, the Solar Explorer aimed to strengthen not only social–ecological stewardship, but also livelihood opportunities and equity. Figure 2 highlights the common set of influencing factors, in particular in the actor and process dimensions, which were mentioned by interviewees in each case. The outcome dimension showed more diversity between the two cases.

Besides commonalities, it was also possible to detect differences between the two cases by applying the analytical framework. Overall, the Solar Explorer and Brodowin Ecovillage differed in terms of secure funding, and consequently in their capacity to achieve certain goals, and therefore in their outcomes. As for the Ecovillage, the commitment of diverse actors fostered the integration of economic viability with sustainable measures and local livelihood opportunities. These diverse goals resulted in various outcomes, including structural changes, improvements to social–ecological integrity, job preservation and precautionary measures. Secure funding thereby proved crucial. Conversely, the Solar Explorer project lacked secure and permanent funding, and so the team focused on building partnerships and advocating. This, in turn, limited time for learning and envisioning, finally resulting in less diverse projects and outcomes. As a result, the Solar Explorer resulted most prominently in awareness-raising and social–ecological stewardship.

Discussion

In this article, we set out to provide a specific and wide-ranging characterization of sustainability innovation and to develop an analytical framework, which we tested in two case studies. In the following, we discuss the framework's analytical capacity and insights gained from its application on two case studies, our contributions to transitions and innovations studies and the methodological limitations of this study.

Specific characteristics of sustainability innovations

The case studies demonstrated that the proposed analytical framework is applicable, generic and comprehensive and that it applies well to multiple types of sustainability innovations at stake. The framework enabled us to study the influencing factors, characteristics and outcomes of two

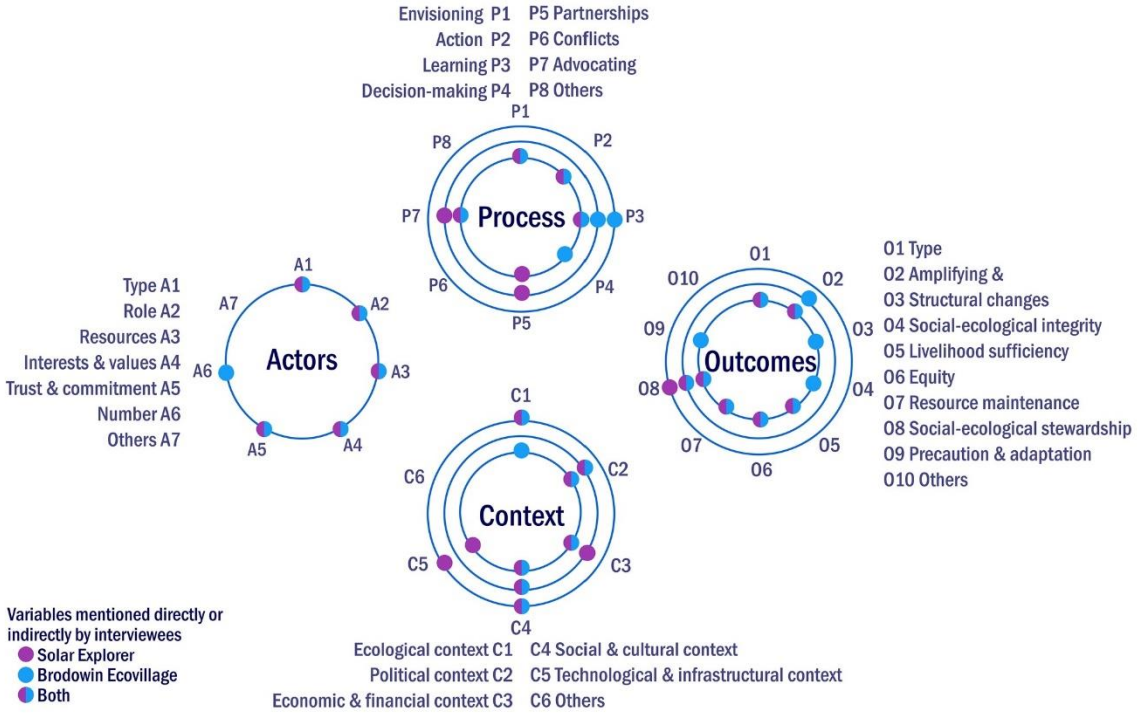

Fig. 2 Solar Explorer and Brodowin Ecovillage: relevant analytical variables

cases of sustainability innovations in a comparative manner, thereby allowing us to interpret the cases material in terms of commonalities and differences.

The cross-case comparison provided empirical confirmation of a key set of actor- and process-related conditions, which turned out to be crucial for innovation development. In accordance with transitions and innovations studies, resource availability (Hekkert et al. 2007), various competences and roles (Wittmayer et al. 2017), trust and commitment, building partnerships and advocating (Wittmayer et al. 2018), envisioning, experimenting and learning (Asheim and Coenen 2005) all proved crucial in fostering or—when missing—limiting our focal innovations. Moreover, actors' capacity to understand and navigate their contexts, i.e., to use opportunities, co-create enabling conditions and overcome barriers, appeared to have a great impact on success and sustainability outcomes. For example, the close vicinity of Berlin, the capital city, created opportunities and challenges alike for both the Solar Explorer and the Ecovillage. Further studies are needed to understand sustainability innovation dynamics in differently urbanized areas, for instance in peri-urban biosphere reserves (Harris et al. 2019). Our cases also suggested a strong influence of the biosphere reserve on innovative activities; yet, as shown by Kratzer (2018), we expect that our cases were exceptional in that regard and that most regional innovations are less impacted by the local biosphere reserve.

Furthermore, both cases illustrated that sustainability innovations develop as bundles of interdependent, entangled novelties (Avelino et al. 2019). For example, the Ecovillage started with social and organizational innovation, followed by various, successive product, process and market novelties to adapt to evolving markets and opportunities. These innovation entanglements relate to cluster effects, although the latter are more often reported at the regional level and across many organizations (Asheim and Coenen 2005; Fagerberg 2009). Built capacities and learnings often open up the way for further innovations at the regional or organizational level (Luederitz et al. 2017). More specifically, though, sustainability innovations, being disruptive in current deteriorating social–ecological systems, require changes in their own context, for instance in values, habits and institutions (Engels et al. 2019). Consequently, it is not surprising that they encapsulate multiple novelties, or innovation types, to fully unfold (Wittmayer et al. 2020, 2022). With regard to the specificity of sustainability innovations in contrast to other innovation types, this study therefore showed that it resides in outcomes rather than in another particular type of novelty. For example, the Solar Explorer comprised technological and organizational novelties, but it

was most specific in dedicating these novelties to social–ecological stewardship and educational programs for local, rural schoolchildren. In that sense, sustainability innovations differ from product, process or organizational innovations, which are substantially characterized by their novelty type, rather than by outcomes.

Prospectively, our study pledged for additional studies of what we may call "discreet" innovations. These are less eye-catching—but no less insightful—innovations than, say, socio-technical changes in mobility or energy systems or other prominent global technological innovations (Avelino et al. 2019; Feola 2020; Nicolosi et al. 2018; Wittmayer et al. 2022; Köhler et al. 2019). Sustainability innovations can be part of a trend of similar projects rather than global pioneers (Nicolosi et al. 2018). For instance, the Ecovillage, with its large-scale organic farming scheme, was not unique but nevertheless proved innovative in its regional and even national context through the creation of new social, cooperative arrangements and through a combination of employment, biodiversity conservation and organic farming. Many such discreet innovations ought to exert adaptive capacities and be innovative in their local contexts (Fagerberg 2009). The participation of such discreet, local innovation to niche development (Geels 2011) remains to be explored and promises compelling insights into space-sensitivity and context-dependency of societal, systemic change processes (Gamito and Madureira 2019).

A generic, systems-based framework

The analytical framework was built on conceptual insights from transition studies, the SES framework and sustainability assessments. Using these frameworks as the conceptual foundation for analysis proved insightful, as they cover important dimensions, such as governance systems, biophysical, socio-technical systems, and address different levels of analysis, from small-scale, individual social–ecological arrangements or innovations to broader scale, systemic change processes.

The study demonstrated that the sustainability innovation framework is generic and covers a comprehensive range of variables. In comparison, other frameworks tend to address particular dimensions. The SES framework focuses on social–ecological systems, thereby highlighting governance systems (McGinnis and Ostrom 2014). The MLP and TIS target technological innovations and therefore concentrate on socio-technical arrangements across broader, multi-scalar change processes (Bergek et al. 2015; Geels 2011). In contrast, the proposed sustainability innovation framework included a large number of fined-grained variables, potentially relevant for focal, individual sustainability innovations. Such a generic and fined-grained approach proved useful, because sustainability innovations, as demonstrated above, may encompass various types of small-scale innovations, including technological, behavioral, process novelties, etc (Hielscher et al. 2022). Moreover, as sustainability innovations are normatively loaded, their understanding may vary across contexts, which therefore requires a broad analytical approach with regard to outcomes (Ramos-Mejía et al. 2018). In this exploratory study, we thus tested a large range of variables, to better understand the multi-facetted concept of sustainability innovation.

Furthermore, the framework expounded on the sustainability outcomes dimension, which has received little attention so far in the transitions and innovation literature (Feola 2020; Truffer et al. 2022). For instance, the Ecovillage resulted in various beneficial outcomes, from structural landscape changes to livelihood sufficiency, although some contentious monopolistic structures were criticized as well. The critical evaluation of some interviewees underlined that understandings of sustainability—and consequently sustainability innovations—may vary subjectively and across contexts. This underpins the need for thorough analyses of innovations' outcomes. In this regard, further elaboration should take into consideration approaches other than the ample research—and underlying understandings of sustainability innovations—from the Global North, which we have largely used in our research (Nesari et al. 2022; Preuß et al. 2021; Ramos-Mejía et al. 2018).

Methodological limitations

Our study faced methodological limitations typical of social empirical qualitative research. In general, it posited that our interviewees' perceptions of past and current events would provide comprehensive information; however, they did not mention all of the potential variables. Although it is possible that some variables indeed had no relevance, a lack of information could also mean that characteristics or influences were not perceived or reported by our interviewees, or that the variables had been overseen during the analysis. For instance, influential factors might have been omitted or under-evaluated, e.g., if they were taken for granted or related to long-past events. Although interviewees were carefully chosen, so as to provide in-depth knowledge through a diversity of perspectives on each case, their positions as employees or active supporters in the cases might only cast a certain—positive—light on the projects.

Sustainability, similar to the concept of innovation, is a normative, value-driven concept and can be interpreted in various ways across different contexts (Meadows 1998; Schlaile et al. 2017). In our empirical study, we thus built on our interviewees' knowledge and judgment to identify, first, local sustainability innovations and, second, their positive—or negative—outcomes. Note that sustainability innovations may have destructive consequences, even

though they challenge unjust and destructive systems (Avelino 2021; Fougère and Meriläinen 2021). For example, the large-scale concentration of agricultural land has arguably reinforced monopolistic land ownership and thus affected intra-generational equity.

While the case study material provided ample information about the relative importance of specific factors, the framework in itself does not yet provide an explanatory pattern in sustainability innovation development and outcomes. Rather, the framework provides a comprehensive set of potentially relevant variables as guidelines for the case analysis and interpretation. It was therefore only possible to assess the relative influence of the mentioned variables through interview material analysis, although a detailed weighting scheme applied during a discourse analysis on larger n data could provide insights about the most influential variables in a cross-case comparison scheme. Thereafter, we could neither provide insights about the mechanisms through which the mentioned variables exerted influence over focal innovations nor assess in how far perceived influence may relate to causal relationships. As argued by Coenen et al. (2012), historic or geographic interpretations of innovation journeys do not unravel causality links. More generally, the framework does not provide a blueprint for identifying what necessarily supports or hinders sustainability innovation.

Conclusion

The analytical framework synthesized influencing variables and the characteristics of single sustainability innovations into four analytical dimensions: context, actors, process and outcomes. The specificity of sustainability innovations resides in their positive outcomes, in terms of social-ecological integrity and equity, so the outcomes dimension therefore detailed relevant variables for analysis. Furthermore, our empirical cases demonstrated that the framework is comprehensive, generic and applicable to a wide range of novelty types, rather than merely technological innovations. As a result of our case studies, we were able to identify preliminary patterns and a set of key common factors. Nonetheless, further empirical research is required on various sustainability innovations and in different settings, to identify innovation patterns across contexts. In this regard, the sustainability innovation framework provides the opportunity to develop a typology and build up a comparative scheme about sustainability innovation archetypes, development patterns, contextual influences and potential barriers. Such learnings will in turn inform innovation governance, by underpinning the design of enabling contexts. The need thus remains to thoroughly examine the outcomes of innovations at stake, and to go beyond mere declarations of intentions, to support truly transformative sustainability innovations.

Acknowledgements We are most grateful for all interviewees from the Schorfheide-Chorin Biosphere Reserve, the Solar Explorer and the Brodowin Ecovillage for their expertise and their willingness to share their time and knowledge. We also thank Henrik van Wehrden, participants of the 14th Conference of the European Society for Ecological Economics and two anonymous reviewers for their constructive comments and suggestions.

Author contributions CHD: conception and design, data collection and analysis, article draft and revision. CM: substantial contributions to conception and design, article revision, thesis supervision. Both authors read and approved the final manuscript.

Funding Open Access funding enabled and organized by Projekt DEAL. This work was supported by the Biosphere Reserves Institute and the Innovation and Career Centre "ProBio-LaB" by the Ministry of Science, Research and Culture of the federal state of Brandenburg, Germany.

Data and code availability Not applicable.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

Ethics statement All interviewees gave their informed consent before participating in the study.

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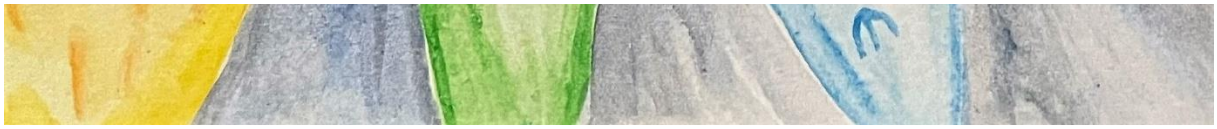
Chapter 3

An archetype analysis of sustainability innovations in Biosphere Reserves: insights for assessing transformative potential



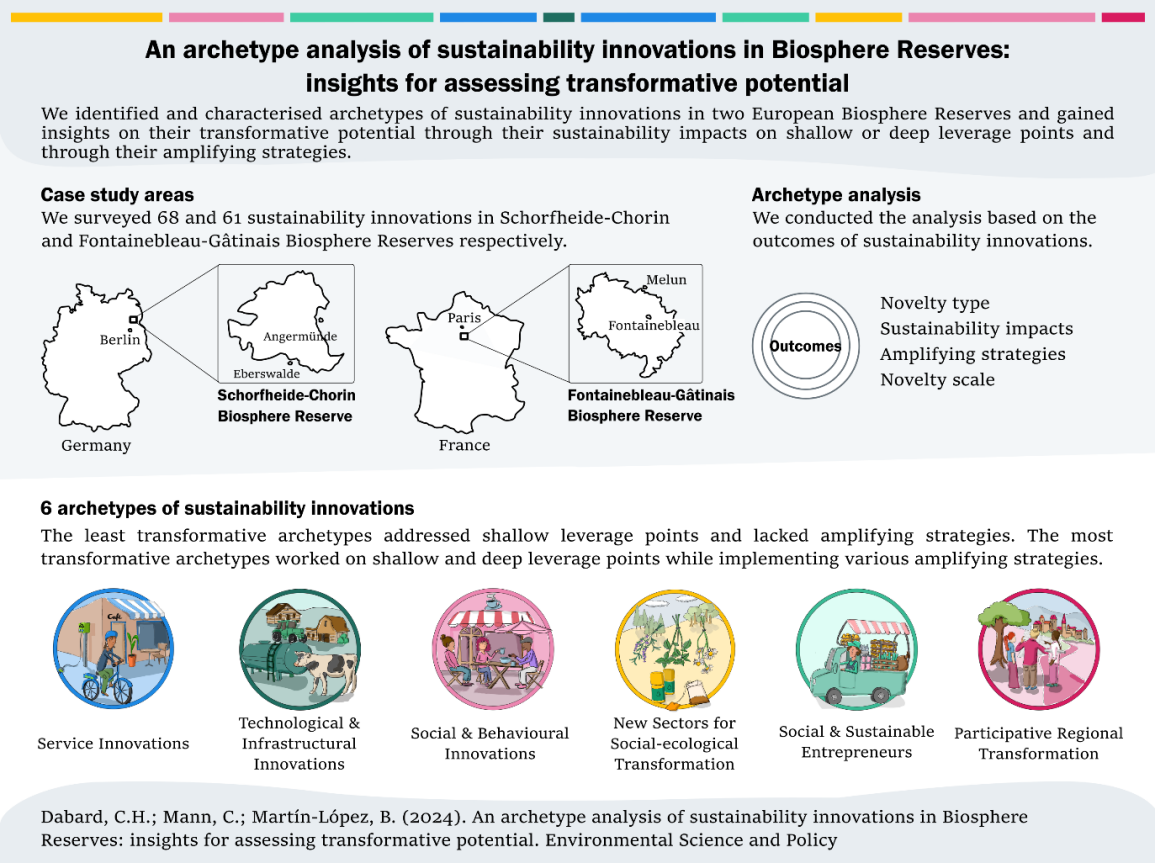
The double cluster analysis

Chapter 3
An archetype analysis of sustainability innovations in Biosphere Reserves: insights for assessing transformative potential

This chapter is in press as a peer-reviewed article in Environmental Science and Policy.

Dabard, C.H.; Mann, C.; Martín-López, B. (in press) An archetype analysis of sustainability innovations in Biosphere Reserves: insights for assessing transformative potential. Environmental Science and Policy

Graphical abstract



Abstract

Sustainability transformations are considered to provide pathways to solve current wicked problems, although empirical approaches are still limited in order to assess their actual transformative potential. In this study, we analyse a diverse set of 129 sustainability innovations in two Biosphere Reserves in Germany and France (Schorfheide-Chorin and Fontainebleau-Gâtinais), based on an analytical framework that characterises and groups innovations through actors, processes and outcomes. With a hierarchical cluster analysis conducted on innovation outcomes, we identify six archetypes: Participative Transformation Governance, New Sectors for Social-ecological Transformations, Social and Sustainable Entrepreneurs, Social Innovations, Service Innovations and Technological Efficiency Innovations. The most transformative archetype, Participative Transformation Governance, targets both shallow and deep leverage points, while implementing diverse amplifying strategies to enhance impacts. The least transformative archetypes, e.g. Service Innovations,

target shallow leverage points and lack amplifying strategies. Our archetype approach thus proves suitable for capturing a diverse range of sustainability innovations and characterising their transformative impacts. Synergies between archetypes could be identified and further research should elaborate on the bridging role of Biosphere Reserves to best use synergies and enhance transformative processes.

1 Introduction

Growing societal and political expectations emphasise transformative innovations as necessary responses to address wicked sustainability problems (O'Brien and Sygna 2013; Leach et al. 2015). In line with these expectations, various frameworks and approaches have been recently developed to understand how sustainability transformations emerge and develop and in how far they contribute to system changes. For example, they have examined stages and levels of change processes in specific socio-technical systems, through a multi-scalar approach (Geels 2019), and socio-institutional approaches have focused on governance and agency to steer positive change in specific economic sectors, such as health and energy (Loorbach et al. 2017). Against the backdrop of theory-driven concepts of large-scale transformation, some authors have focused on bottom-up approaches, building on local initiatives to design scenarios for positive futures (Bennett et al. 2016; Pereira et al. 2021), nature-based solutions (Palomo et al. 2021), knowledge co-production processes for transformation (Chambers et al. 2021; Chambers et al. 2022) and grassroots and social innovations (Seyfang and Smith 2007; Smith and Stirling 2018; Wittmayer et al. 2022). Whilst these various notions may vary in terms of scale and scope, most relate to radical structural system changes in complex social-ecological-technical systems, which take the form of non-linear, non-teleological processes over which dedicated human action has only limited influence (Feola 2015; Hölscher et al. 2018; Fisher et al. 2022). In particular, this study focusses on diverse local innovative initiatives to shed light on their transformative potential. Thus we frame these initiatives as sustainability innovations, which we understand as multi-actor, multi-scalar processes that develop new means to define and meet social needs and desires in specific contexts, thereby resulting in positive outcomes in terms of social-ecological integrity and equity (Dabard and Mann 2022).

While expectations on the disruptive capacity of innovations grow, two aspects of sustainability transformations result in ongoing lively scientific discussions: (1) their transformative potential or how to assess their outcomes, and (2) their diversity or how to navigate the plurality of innovations, their processes and actors involved.

So far, only few empirical studies examine the actual transformative potential of sustainability innovations and initiatives (Luederitz et al. 2017; Salomaa and Juhola 2020; Wittmayer et al. 2022; Tuckey et al. 2023). Therefore, there is no standard procedure to assess transformative outcomes. Innovations have long been categorised as incumbent or radical (Freeman and Soete 1997; Luederitz et al. 2017; Lam et al. 2020), but without actually assessing transformative potential, transformation concepts bear the risk of being instrumentalized to justify business-as-usual (Olsson et al. 2014; Blythe et al. 2018; Feola et al. 2021). In this study, we consider the transformative potential of sustainability innovation as their capacity to produce positive impacts in terms of social-ecological integrity and equity, and in particular to foster radical changes within the social-ecological-technical systems they are embedded in. We approach transformative outcomes by examining the leverage points addressed by sustainability innovations and the extent of their amplifying - or scaling - strategies. First, to address leverage points, we build on sustainability impacts,

as categorised by Luederitz et al. (2017) and the innovation types, e.g. social innovations or product innovations. A leverage points perspective assesses the capacity of innovations to radically change the systems they are embedded in (Meadows 1999). Following, we distinguish shallow innovations that often just mildly rearrange the way a system functions - and deep, or radical innovations, that seek to transform the rules, underlying values and worldviews within systems (Abson et al. 2017; Riechers et al. 2022). Second, to capture the scaling potential of sustainability innovations, we build on different amplifying strategies, as proposed by Lam et al. (2020), who distinguish scaling within (growing, accelerating), scaling out (e.g. transferring, duplicating) and scaling beyond (scaling up by impacting larger governance levels and changing values).

While there is a growing understanding that sustainability transformations encompass a multitude of processes, an increasing body of literature aims to capture a diversity of sustainability transformations through empirical, large *n* studies (Bennett et al. 2016; Chambers et al. 2021; Wittmayer et al. 2022). Bennett et al. (2016), for instance, highlighted the plural nature of sustainability initiatives globally. Wittmayer et al. (2022) proposed a typology of social innovations in energy, looking at social interactions in doing, thinking and organising social innovations. Recently, special light has been cast on local, rural or grassroots initiatives – as a relevant scale for problem-solving and context-sensitive studies (Seyfang and Smith 2007; Palomo et al. 2021; Pereira et al. 2021). However, typologies often focus on specific sectors of activity, such as energy (Wittmayer et al. 2022); specific topics or fields of actions, such as bottom-up initiatives for energy, agriculture or wellbeing (Pereira et al. 2021); or specific types of innovations, such as nature-based solutions (Palomo et al. 2021) or such as social innovations (Wittmayer et al. 2022). Hence, there is a need to provide typologies beyond sectors and targeted topics in which innovations emerge, and rather to explore whether archetypes of transformative outcomes can be found across sectors, thereby highlighting common grounds of diverse innovations and actors engaged for sustainable change.

With the aim to capture the transformative potential of a diversity of sustainability innovations, this study examines more than a hundred of sustainability innovations identified in two European Biosphere Reserves: Schorfheide-Chorin Biosphere Reserve (Germany) and Fontainebleau-Gâtinais (France). We use an archetype analytical approach to empirically characterise sustainability innovations and to identify patterns among multiple innovation cases across contexts. This offers an intermediate level of abstraction to capture diversity while avoiding overgeneralisation (Oberlack et al. 2019). We specifically aim to: (1) to identify archetypes of sustainability innovations based on their transformative *outcomes* and (2) to understand their diversity based on the *actors* and *processes* underpinning these archetypes. Finally, we discuss implications for the management of Biosphere Reserves to lever sustainability transformations.

2 Materials and methods

2.1 Case study Biosphere Reserves: Fontainebleau-Gâtinais (FGBR) and Schorfheide-Chorin (SCBR)

Data was collected in two European Biosphere Reserves, namely Schorfheide-Chorin Biosphere Reserve (SCBR) in north-eastern Germany and Fontainebleau-Gâtinais Biosphere Reserve (FGBR) in northern France (Figure 1). Biosphere Reserves are learning places for sustainable development, designated by UNESCO (Schultz and Lundholm 2011b). They aim to reinforce (1) the conservation of biodiversity and cultural diversity, (2) economic sustainable development and (3) logistic support for research, monitoring, education and training

(UNESCO 2018), and hence to reconcile nature conservation and sustainable development. As model regions for conservation and development, Biosphere Reserves thus are bound to support sustainability transformations and innovations – even, Biosphere Reserves can be considered as sustainability transformations per se as they aim to foster livelihood, conservation and learning (Stoll-Kleemann and Welp 2008; Reed 2016; Kratzer et al. 2022). Biosphere Reserves are thus a compelling and practical entry point in transformation studies in peri-urban areas. We focus here on sustainability innovations that are either directly launched or supported by Biosphere Reserves, but also on many cases that are developed by other actors, in the context of Biosphere Reserves that can be supportive for sustainability innovations.

Figure 1. Study methodology. The three boxes display (1) the case study maps and the number of sustainability innovations identified and surveyed in each Biosphere Reserve, (2) the analytical framework adapted from Dabard and Mann (2022) and (3) the dimensions and variables used for the archetype analysis.

Schorfheide-Chorin Biosphere Reserve. SCBR, located approximatively 70km north of Berlin, was created in 1990 in a top-down manner during the political transition to German reunification. SCBR is characterised by forests, farmland, grasslands, lakes and 75 settlements strewn across 129,161 ha and home to 35,000 inhabitants (UNESCO 2021b; UNESCO Biosphärenreservat Schorfheide-Chorin 2023). Major land uses are (organic) agriculture, forestry and tourism. SCBR is located in one of the least populated and least economically thriving regions in Germany (Stoll-Kleeman et al. 2013). Nonetheless, the region is experiencing strong socio-economic changes. Its proximity to the capital city makes the southern parts of the reserve ever more attractive for households and businesses (Beetz et al. 2005), thereby increasing land pressure, land prices and visitor flows. Against this backdrop, the Biosphere Reserve's administration has developed a variety of projects with a focus on nature conservation, organic agriculture, sustainable tourism and education for sustainable development (UNESCO Biosphärenreservat Schorfheide-Chorin 2023). Their projects were often conducted in close cooperation with a dense network of regional organisations, such as the forestry department, research and academic institutions, business networks, tourism organisations and local associations.

Fontainebleau-Gâtinais Biosphere Reserve. FGBR was nominated in 1998 in a top-down manner by the national government (Borsdorf et al. 2014), and it is located approximatively 70km south of Paris (Figure 1). The region is dominated by deciduous forests, farmland and 130 villages and towns, accounting for 290,000 inhabitants living in an area of 150,544 ha as of 2022 (UNESCO 2021a; Centre d'Écotourisme de Franchard 2022). Major land uses are tourism, forestry and agriculture (Mathevet and Cibien 2020). Whilst those areas of FGBR closer to the capital city have a growing demography, wealthier socio-economic levels and increasing land pressure and visitor flows, the southern-western areas are agrarian landscapes with a declining demography and lower socio-economic levels. With little means and human resources, the managing association has focused its activities mainly on educational, awareness-raising and communication projects (Centre d'Écotourisme de Franchard 2022). The western, mostly agrarian part of the Reserve, is also a Regional Nature Park (*Parc Régional Naturel du Gâtinais Français*), with similar missions to those of UNESCO Biosphere Reserves. The Regional Nature Park, with more resources than the Biosphere Reserve, conducted multiple projects for regional development and sustainable land use (Mathevet and Cibien 2020), by building partnerships with various regional and local organisations.

2.2 Analytical framework

The study builds on an analytical framework proposing four dimensions to examine sustainability innovations (Dabard et al., 2022) (Figure 1). First, the social-ecological-technical context in which innovations unfold influences what people may need or desire, while creating opportunities or barriers for transformations (Schot and Geels 2008; Ostrom 2009; Fisher et al. 2022). Second, actors, i.e. the relevant people and organisations involved in sustainability innovations, bring various resources, characteristics and values, which shape their actions (Asheim et al., 2005; Westley et al., 2013; Bennett et al., 2016). Third, actors go through multiple processes of planning, collaborating, experimenting or learning, which therefore result in specific outcomes (Loorbach, 2007; Wittmayer et al., 2017). Fourth, the outcomes of sustainability innovations, as was mentioned above, can be examined through their impacts (Gibson, 2006; Luederitz et al., 2017), amplifying strategies (Lam et al., 2020) and scale (Binz et al., 2017).

2.3 Data collection

This study is based on a mixed-methods design. To identify sustainability innovations in both Biosphere Reserves, we first conducted semi-structured interviews with regional key informants (n=18 in SCBR; n=17 in FGBR). The interviews took place in spring 2021 and 2022 in SCBR and in summer 2021 in FGBR. We selected the interviewees through a snowball approach, starting with the Biosphere Reserve administration and asking our interviewees to suggest further informants. The interviews provided a set of 134 sustainability innovations in SCBR and 110 in FGBR. For the list of interviewees (Tables A.1 and A.2) and the interview guidelines, see Appendix A.

As we set out to characterise a large number of diverse sustainability innovations, we chose to focus on single, small-scale cases, i.e., single innovations or innovative initiatives, rather than on more complex and multi-level processes, such as sectoral transitions. This procedure allowed us to analyse the diversity and transformative potential of many cases by reducing the complexity of each case. We took the set of 244 sustainability innovations as mentioned by regional informants as a practical starting point to pinpoint relevant initiatives contributing to sustainability in the area. Note that the cases considered here were not necessarily novel or unique at large scale - but often constituted a re-contextualisation, re-adaptation of similar ideas and practices in their own local or regional context. Furthermore, our cases often encapsulated various types of novel practices and ideas (e.g. new organisations engaged to produce novel products and foster new behaviours). Hence, the analysis scope per case was of the sustainability innovation as a bundle of novelties, or as the overarching sustainability innovation initiative, rather than the many novelties it may produce.

To collect in-depth information, we contacted a representative of 215 sustainability innovations (n=131 in SCBR, n=84 in FGBR) by telephone or email, or we approached them personally on site. Based on these exchanges, we completed 68 questionnaires in SCBR and 61 questionnaires in FGBR, either face-to-face or online, depending on the respondents' availability (Figure 1). The survey was conducted in summer 2022 in SCBR and in autumn 2021 in FGBR. The questionnaire was organised into six sections: (1) overview of the project in terms of goals, values and development stage; (2) actors' characteristics in terms of sector, partner organisations, resources, number of people involved and time spent for learning; (3) innovative impacts in novelty scale, novelty types, amplifying strategies and sustainability aspects; (4) relationship with the Biosphere Reserve administration; (5) local networks and (6) sociological questions. The results presented herein draw on data from sections (1), (2) and (3). For the list of interviewed sustainability innovations (Tables A.3 and A.4) and for the full questionnaire, see Appendix A.

2.4 Data analysis

We operationalised the framework developed by Dabard and Mann (2022) to characterise a large number of sustainability innovations along the dimensions of actors, processes and outcomes. We thereby chose to focus on single, small-scale cases, that is single innovations or innovative initiatives, rather than on more complex, large-scale processes, such as sectoral transitions. Furthermore, we concentrated our study to a reduced set of variables that could be collected within a survey questionnaire, excluding the many contextual factors that would require lengthier interviews. This procedure allowed us to analyse the transformative potential of many cases by reducing the complexity of each case (Jiménez-Aceituno et al. 2020; Pereira et al. 2021).

The sustainability innovation framework highlights the relevance of the actors involved and the processes underpinning the resulting outcomes (Figure 1, Table 1). The questionnaire allowed us to gather information on five variables representing the actors dimension: (1) actor type as public, private or civil society organisations, (2) professional sector activity of the lead organisation, (3) availability of resources, (4) values underpinning the innovation as explained by the respondents and (5) number of people involved. Five variables represented the process dimension: (1) fields of actions and experiments, (2) time spent on learning, sharing knowledge and reflective processes, (3) modes for decision-making and collaborative deliberation (4) scale of cooperation with external partners, and (5) development stage of the innovation. Table 1 describes the variables, underlying rationale and main references supporting their selection and the exemplary question of the survey. For further details on the elaboration of this framework, please refer to Dabard and Mann (2022).

Table 1. Description of the outcomes, actors and process variables used in the study, including supporting references and questionnaire questions.

Variable	Description	Survey questions
Actors	Actors, i.e. people, networks and organisations that are involved in innovations, shape collaborative processes differently depending on their agendas, roles, values, resources and characteristics (Asheim and Coenen 2005; Ostrom 2009; Wittmayer et al. 2017).	
1. Type	Actors typically carry out different agendas depending on their type, (i.e. public, private or civil society organisation), while a diversity of actor types and roles is often emphasised as enhancing innovation (Asheim and Coenen 2005; Wittmayer et al. 2022).	Q1, Q8
2. Sector	The sector of activity is indicative of actors' potential goals or fields of actions and further characterises different type of actors (Asheim and Coenen 2005). Sector refers here to the main field of activity of the lead actors (e.g. agriculture, tourism, public administration) based on categories from OECD (2022), adding few specific categories, e.g. nature conservation (see e.g. Table B1).	Q6
3. Resources	The availability of relevant resources is crucial for innovation processes and experimentation and is approached here in terms of having enough/ not enough financial, material, human, environmental resources and expertise, skills, competence (Westley et al. 2013; Baker and Mehmood 2015).	Q7
4. Values	Actors' values influence their behaviours and willingness to collaborate and innovate (Ostrom 2009). We focus on values involving the importance and meaning given to nature and sustainability by innovation actors, categorised as intrinsic, relational or instrumental values (Chan et al. 2016; Pascual et al. 2023). Relational values include those meaningful relations between people and nature, as well as between people mediated by nature As several values can co-exist in an innovation, we coded them as expressing/not expressing (1) intrinsic, (2) relational and (3) instrumental values. Previous research applied the same approach to research the potential for transformation of nature-based solutions (Palomo et al. 2021).	Q2, Q3
5. Number	The number of persons actively involved in sustainability innovations may influence their capacity to innovate by bringing in various, complementing agendas, ideas, resources and networks (Ostrom 2009; Bennett et al. 2016).	Q9
Processes	Sustainability innovations entangle multiple co-evolving processes (Geels 2011). What actors do and how they do it defines the innovation processes and shapes their potential outcomes (Frantzeskaki et al. 2012; Wittmayer et al. 2017).	
1. Actions	Actors usually target several, specific issues, fields or topics of actions, experiments, events and activities - which in turn influence the potential outcomes of innovations (Bennett et al. 2016). Here, actions are inductively categorised as e.g. ESD & awareness-raising, nature connectedness, tourism, arts, decent work, equity, Youth, etc.	Q1, Q2, Q3, Q6, Q14, Q16
2. Learning	Innovations build on learning, reflecting, and knowledge-sharing activities, which are often carried out in an iterative manner throughout innovation processes and which may reinforce the radical turn of innovation initiatives (Loorbach 2007; Wittmayer et al. 2017). Learning is categorised in this study as spending enough time & often enough/ not enough time & not often enough for these activities.	Q11
3. Decision-making	The governance processes underpinning decision-making and deliberation within actor networks and the forms they may take influence other collaborative processes and thus the resulting outcomes (Ostrom 2009). Here, we consider the usual decision-making	Q10

	mode within the innovation team, including lead actors and partners, categorised as informative, consultative or cooperative mode of decision-making (Stringer et al. 2006).	
4. Cooperation	Networks and collaborative arrangements are deemed crucial for innovations, as they may enhance access to resources and knowledge (Bergek et al. 2015). Cooperation refers here to partnerships, participation in networks, events or lobby activities at regional, national, or international scale.	Q22
5. Stage	Innovations typically go through development phases, categorised here as beginning, stabilising, disseminating (Moore et al. 2014; Geels 2019).	Q4, Q5
Outcomes	Resulting from the processes in which various actors were involved, outcomes of sustainability innovations comprise their outputs and (in)direct impacts (Luederitz et al. 2017; Tuckey et al. 2023).	
1. Type	The type of novelties induced by the sustainability innovations (e.g. new organisation, behaviour, market, service, values, technology, sector, value-chain and/ or product (Gamito and Madureira 2019)) is an indicator of the potential leveraging capacity of innovations, i.e. of their shallow or deep impacts in social-ecological-technical systems (Meadows 1999; Abson et al. 2017).	Q13
2. Amplifying	Strategies of scaling sustainability impacts within and beyond the own scope of innovations may enhance their impacts and foster broader-scale change. They are categorised here as scaling within (growing, stabilising), scaling out (transferring, duplicating), and scaling deep (changing values, mindsets, structures) (Lam et al. 2020).	Q15
3. Impacts	Sustainability impacts resulting from innovations give an indicator of the shallow, i.e. superficial or deep, radical consequences of implementing such innovations (Abson et al. 2017). Impacts are categorised here - based on categories developed for assessing the sustainability of e.g. transitions experiments - as enhancing and improving structural physical changes, structural social changes, social-ecological integrity, livelihood sufficiency & opportunity, intra- & intergenerational equity, resource maintenance & efficient use, social-ecological stewardship & democratic governance, precaution & adaptation (Gibson 2006; Luederitz et al. 2017).	Q3, Q16
4. Scale	The scale at which the project is considered innovative, i.e. as a local, regional, national or international pioneer gives an indicator of the disruptive potential and of the scalability of the innovations, although radical changes can happen without being unique (Binz and Truffer 2017; Feola 2020). Note that beyond the creation of something completely new, a novelty can be the adaptation, combination, reinvention or restoration of things, practices or ideas (Wittmayer et al. 2022).	Q12

To identify archetypes of innovation projects based on their transformative *outcomes*, we selected four variables from the questionnaire: (1) the novelty *type* resulting from the innovation process, (2) the scaling or *amplifying* strategies employed to enhance the impacts of the innovation, (3) sustainability *impacts* resulting from the focal innovation, and (4) the *scale* at which the innovation constituted a novelty (Table 1). Using these variables in each BR, we conducted a multiple correspondence analysis (MCA), an ordination test used for categorical data, which allowed the identification of relationships between different *outcomes* variables. Five components explained 71.1% of accumulated variance in SCBR (Table B.1) and six components explained 69.1% of variance in FGBR (Table B.2). For the MCA axes and their scores, see Appendix B. Following the MCAs, we performed hierarchical cluster analyses (HCAs) with those five and six MCA components in SCBR and FGBR respectively. We used the Ward's linkage method and the Euclidean distance as clustering technique (Ward, 1963). The resulting clusters were interpreted as innovation archetypes and were subsequently characterised through *outcomes* delivered. For this, we carried out an analysis of variance (ANOVA) followed by the post hoc Bonferroni comparison test by which we compared the MCA components among the different clusters for each Biosphere Reserve (Figure 1). Finally, to understand which *actors* and *processes* underpin the innovation archetypes, we carried out Chi-squared contingency table tests for all categorical variables (Table 1) and Kruskal-Wallis tests for the *number* of people (Figure 1).

All analyses were performed using the XLSTAT statistical and data analysis solution 2022 (Addinsoft, Paris, France).

3 Results

Schorfheide-Chorin Biosphere Reserve (SCBR). The most common archetype in SCBR was Social Innovations, which made up 34% of sustainability innovations, albeit with a very local transformative potential. Indeed, projects in this archetype targeted rather deep leverage points, e.g. through the creation of new organisations or new services and through strengthening value shifts. Yet, they did not report amplifying strategies to scale out or beyond (Table 2, Table B.5). Social Innovations involved many people (22 persons in average), mostly from civil society organisations and actors from education and nature conservation. Social Innovations reported strong relational values and focussed their *actions* on community-building, arts, recreation and local youth. An example innovation was the creation of a local village association to prevent the destruction of old commons-based orchards in the area through collective action, which later took up various projects towards community-building and preserving the local environment.

Another well-spread archetype in SCBR was Service Innovations (25% of all projects in SCBR). Service Innovations acted on shallow leverage points, for instance by building on new products and services, aiming to a more efficient use of resources through physical infrastructural change. There was no clear evidence of amplifying strategies put in place to enhance outcomes. Service Innovations were mostly represented in two *sectors* of activity, namely public administration, and agriculture and livestock. A specificity of this archetype relies in the underlying instrumental *values* and in a rather hierarchical, or informational decision-making. Many *actions* targeted enhancing economic viability and sustainable mobility. An example was the creation of an e-bike-friendly network of places, restaurants and shops, where e-bike tourists could load their bikes and e.g. discover local producers.

Social and Sustainable Entrepreneurs (16%) focused on both shallow and deep leverage points, for instance creating new services and products and promoting new *values* (Table 2). However, there was no evidence of strong amplifying strategies to scale impacts in most innovations. Social and Sustainable Entrepreneurs were particularly present in tourism, arts and recreation, where they addressed a broad range of issues related to wellbeing and lifestyle, nature connectedness and consumerism. Entrepreneurs reported strong relational *values*, but this archetype involved significantly few people (in average 5 persons per case). An exemplary initiative was the creation of a small, traditional and organic brewery by a female neo-rural, who built this business as a mean to enhance her own well-being and that of her family by moving to a village, to provide for herself with close-by work and to use local products to brew beer that she could sell mostly in the region.

New Sectors for Social-ecological Transformation (16%) addressed both shallow and deep leverage points, for instance developing new value-chains or sectors, technologies and products, combined with changes in behaviour. New Sectors particularly sought to enhance social-ecological system integrity, by e.g. promoting biodiversity-friendly agricultural practices. Interviewees of this archetype often reported applying *amplifying* strategies to scale deep (Table 2). In terms of actors, New Sectors were notably led by public organisations, which coordinated a large number of people (21 persons per project in average). Aiming for rural regional development, public actors often built partnerships with research organisations. An example is an experimental project by a large consortium made of a start-up, communal services, research organisations and local farmers, that sought to collect and transform human manure from compost toilets as a fertilizer for agricultural use.

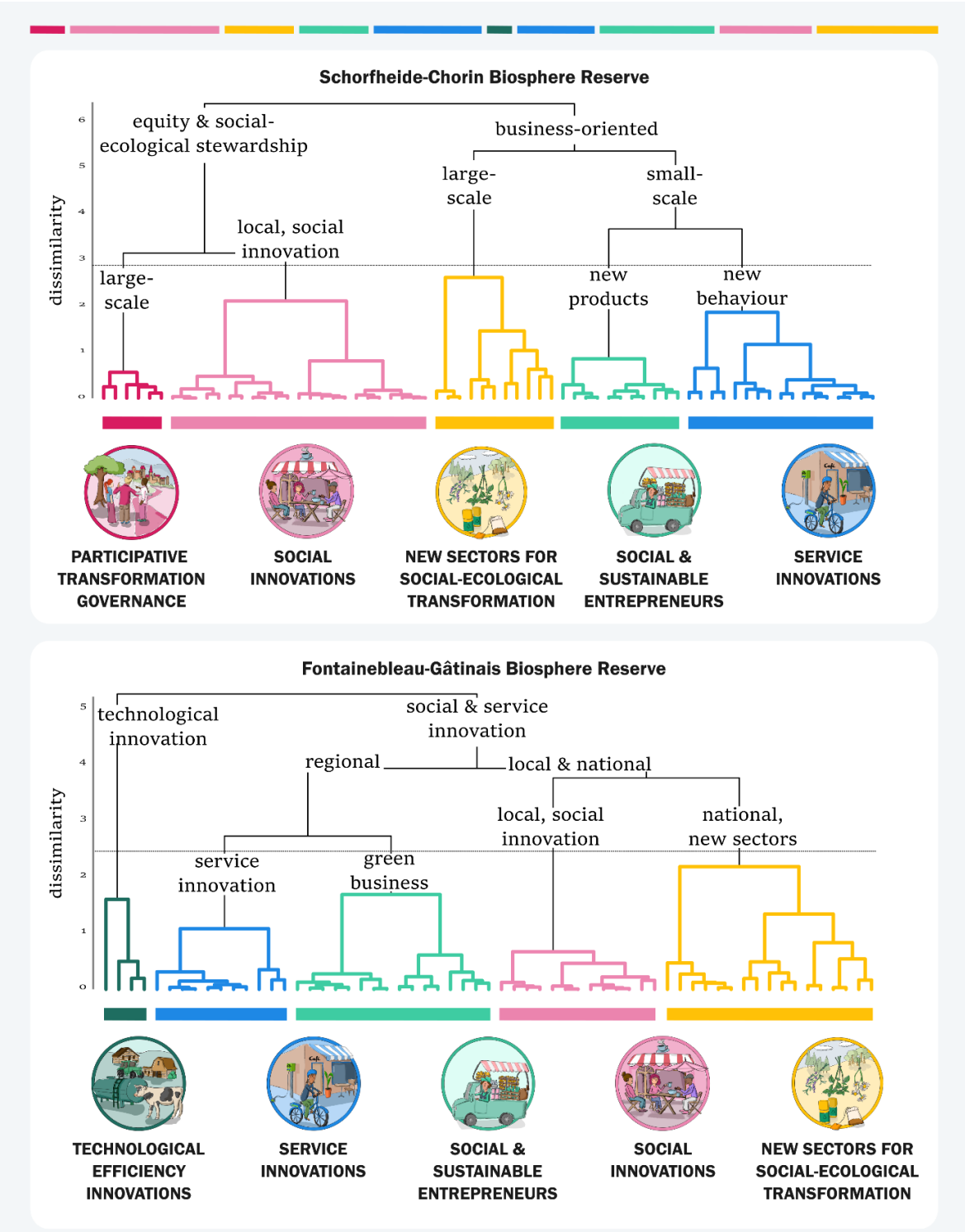


Figure 2. Hierarchical cluster analysis (HCA) of sustainability innovations in Schorfheide-Chorin and Fontainebleau-Gâtinais Biosphere Reserves. The dendograms represent the different clusters (shown by different colourings and icons) of sustainability innovations according to the similarity between the innovations, based on their novelty *type*, sustainability *impacts*, *amplifying* strategies and *scale*. The HCAs revealed that four clusters were very similar in both Biosphere Reserves. These common archetypes share the same names, icons and colours. The colouring is based on a colour-blind-friendly palette from: https://davidmathlogic.com.

Finally, the least represented archetype was Participative Transformation Governance (9%), which focussed on shallow and deep leverage points, in particular by enhancing social-ecological stewardship and democratic governance, value shifts, as well as precaution and adaptation principles. These projects aimed to increase their transformative potential through *amplifying* strategies to scale out (duplicate, transfer) their actions, but also to scale deep, i.e. change values and relevant structures (Table 2). Such projects were mostly led by organisations from civil society and research, who worked on issues related to governance (Table B.5). An example is the collaborative development of a public transportation and mobility concept for the Biosphere Reserve and its region, involving a variety of regional organisations with the goal to propose well-functioning and climate-friendly mobility services for inhabitants and tourists.

Table 2. Relevant characteristics of archetypes in terms of *outcomes*, *actors* and *processes* in SCBR. The table compiles the most relevant characteristics of each archetype, i.e. those for which statistical differences, where found between archetypes (*p < 0.1; **p < 0.05; ***p < 0.01) or those characteristics that were present for at least 50% of innovations within the archetype.

Variables	Social Innovations (*n*=23; 34%)	Service Innovations (*n*=17; 25%)	Social & Sustainable Entrepreneurs (*n*=11; 16%)	New Sectors for Social-ecological Transformation (*n*=11; 16%)	Participative Transformation Governance (*n*=6; 9%)
Outcomes					
Type	New organisation (70%***) & service (78%)	New market (76%***), service (53%) & product (24%*)	New values (73%) & service (64%)	New sector (91%***), behaviour (64%***), technology (55%***) & product (27%*)	New values (100%***), service (50%) & organisation (67%)
Amplifying	-	-	-	Scaling deep (55%)	Scaling out (83%***) & deep (83%*)
Impacts	Structural social change (91%*)	Resource maintenance and efficient use (82%***) & structural physical change (71%**)	Structural social change (64%)	Structural social (82%) and physical (55%) change, social-ecological integrity (45%*), resource maintenance & efficient use (64%), precaution & adaptation (36%*)	Social-ecological stewardship & democratic governance (83%***), precaution & adaptation (67%***), structural social change (83%)
Scale	National (52%**)	Regional (88%***)	Local (100%***)	International (55%***)	National (50%)
Actors					
Type	Civil society (57%**) & public (57%)	Private (82%) & public (53%)	Private (82%)	Public (91%***) & private (73%)	Public (50%) & private (50%)
Sector	Nature conservation (26%*) & education (13%*)	Public administration (35%**) & agriculture (12%*)	Tourism (45%*)	-	Civil society (50%*) & science (33%*)
Values	Relational (87%**)	Instrumental (71%*) & relational (53%)	Relational (100%**)	Instrumental (64%)	Relational (67%) & intrinsic (50%)

Number (*mean*)	22**	12	5**	21**	17
Process					
Actions	Community-building (43%*), arts and recreation (39%***) & Youth (22%**)	Economic viability (53%*) & mobility (35%*)	Wellbeing & lifestyle (45%***), decent work (27%*), consumption modes (27%**) & nature connectedness (27%*)	Rural regional development (55%*), research (45%**) & waste (18%*)	Governance (50%***), rural regional development (50%), ESD and awareness-raising (50%) & climate change (33%**)
Decision-making	-	Information (29%**)	-	-	Cooperation (83%)
Cooperation	Regional (78%)	Regional (71%)	-	-	Regional (83%), national (83%*) & international (50%)

Fontainebleau-Gâtinais Biosphere Reserve. The most common archetype in FGBR was New Sectors for Social-ecological Transformation, representing 28% of all innovations. These projects targeted both shallow and deep leverage points, typically focussing on enhancing social-ecological integrity, e.g. through sustainable land use, and thereby encapsulating new value-chains or sectors, organisations and products (Table 3). However, they rarely applied amplifying strategies to enhance their impacts beyond their own scope of action. This archetype was usually led by public organisations with *actions* in relation to rural regional development and research, based on consultations with regional partners (Table 3, Table B.6). An example launched by the Regional Nature Park was the collaborative, multi-actor development of a regional, organic production of medicinal and culinary herbs and their local processing – in order to create high-income opportunities for local cereal farmers, to strengthen biodiversity and to promote the region through high-value products.

In FGBR, Social and Sustainable Entrepreneurs (26%) worked on both shallow and deep leverage points, e.g. by aiming to enhance intra- or intergenerational equity, developing new services and promoting *values* shifts. In that regard, many Entrepreneurs applied scaling deep strategies, i.e. seeking to change values and structures. Private organisations and businesses in the *sectors* of trade, tourism, arts and recreation made most of the archetype. The entrepreneurs built on strong relational *values* to launch projects in relation to a broad range of topics, including community-building, wellbeing and lifestyle, equity and social justice, decent work and alternative consumption modes. An example is a newly created association, working on a collaborative project with local towns and communal services to open a recycling and upcycling depot, featuring a collective café and cultural activities, while proposing a work reinsertion programme.

Social Innovations (21%) focussed on deep leverage points, by aiming to shift *behaviour* and *values*, notably by providing new livelihood opportunities, such as e.g. access to educational or cultural activities. However, they rarely reported about scaling strategies. This archetype relied mostly on civil society organisations and initiatives dedicated to community-building, alternative consumption modes, arts and recreation (Table 3, Table B.6). An example is the creation of a cooperative and ambulant café by the habitants of a small village, who wanted a collective space to meet and plan cultural or educational events.

Service Innovations (18%) also had limited transformative potential in FGBR. Indeed, this archetype focussed on shallow leverage points and did not often apply amplifying strategies. Service Innovations were largely led by public administration, who reported about

instrumental *values* and an informative decision-making. An example is the delocalised, online campus created for local students, who had too limited financial means to move to Paris or surroundings and therefore could profit from a delocalised campus to pursue online studies.

Finally, Technological Efficiency Innovations (7%) was a thinly populated archetype specific to FGBR. Projects focused on shallow leverages, notably by introducing technology to foster efficiency in natural resource use in agro-food systems, working on waste, energy, economic viability and agro-ecology (Table 3). These innovations rarely reported amplifying strategies. An example was the installation of a small gas plant on a family farm, to make use of agricultural waste and animal manure and provide the farm with diversified income sources.

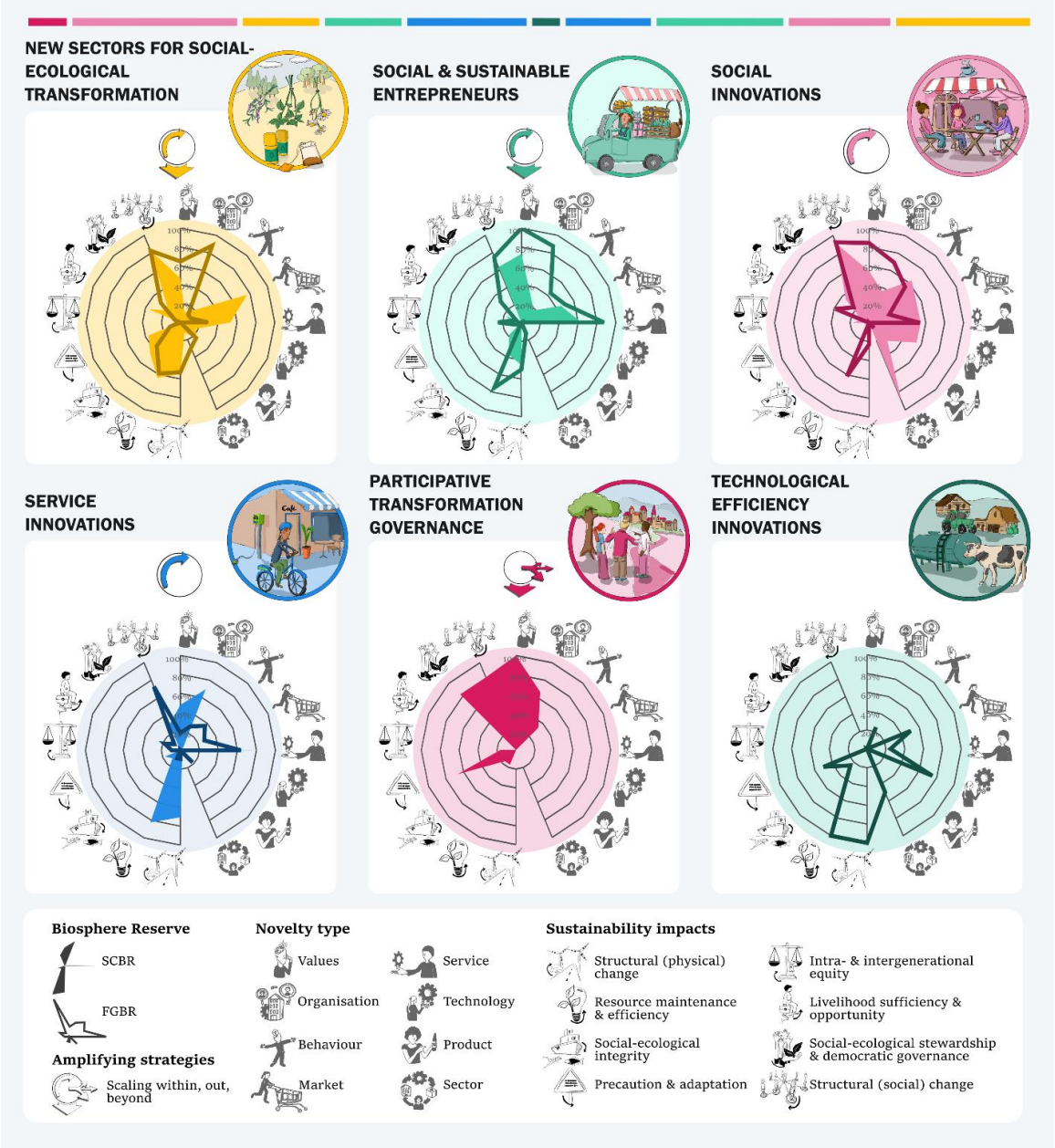


Figure 3. Characteristics of sustainability innovations archetypes. Spider diagrams plot the percentage of innovations along the novelty *types* and sustainability *impacts*. The areas circumscribed by the percentages are filled with colours (SCBR) or outlined (FGBR) and are more or less similar depending on the archetypes. The archetypes boxes show the *amplifying* strategies with icons on top of each archetype box.

Table 3. Relevant characteristics of archetypes in terms of *outcomes*, *actors* and *processes* in FGBR. The table compiles the most relevant characteristics of each archetype, i.e. those for which statistical differences were found between archetypes (*p < 0.1; **p < 0.05; ***p < 0.01) or those characteristics that were present for at least 50% of innovations within the archetype.

Variables	New Sectors for Social-ecological Transformation (*n*=17; 28%)	Social & Sustainable Entrepreneurs (*n*=16; 26%)	Social Innovations (*n*=13; 21%)	Service Innovations (*n*=11; 18%)	Technological Efficiency Innovations (*n*=4; 7%)
Outcomes					
Type	New organisation (88%*), values (65%), sector (29%) & product (24%*)	New values (100%***), service (88%***), organisation (88%) & market (50%*)	New values (85%), organisation (69%), behaviour (54%*) & service (54%)	New service (64%)	New technology (75%***), sector (50%) & market (50%)
Amplifying	-	Scaling deep (69%)	-	-	-
Impacts	Structural social change (82%), structural physical change (53%), social-ecological integrity (35%***) & resource maintenance & efficient use (59%)	Structural social change (75%), resource maintenance and efficient use (75%), structural physical change (50%) & equity (25%***)	Structural social change (92%), resource maintenance & efficient use (62%), livelihood sufficiency & opportunity (38%**)	Structural social change (73%)	Structural physical change (100%**), resource maintenance & efficient use (100%) & precaution & adaptation (50%**)
Scale	National (41%***)	Regional (100%***)	Local (100%***)	Regional (91%***)	Local (75%*)
Actors					
Type	Public (71%**) & private (59%)	Private (81%**)	-	Public (64%)	Private (75%)
Sector	-	Trade (38%***) & tourism (13%*)	Civil society (46%*)	Public administration (27%*)	Agriculture (75%***)
Values	Relational (94%) & instrumental (82%)	Relational (100%*) & instrumental (56%)	Relational (85%) & instrumental (85%)	Instrumental (45%*)	Instrumental (100%)
Number (mean)	10	7	10	8	4
Process					
Actions	Rural regional development (53%***) & research (29%**)	Community-building (56%*), economic viability (44%), equity (38%**), decent work (38%**), consumption modes (38%*), well-being (38%*), & local food systems (50%)	Community-building (62%**), consumption modes (46%**) & arts and recreation (46%*)	ESD & awareness-raising (55%)	Waste (75%**), agro-ecology (75%*), economic viability (75%*), energy (50%**) & local food systems (75%)
Decision-making	Consultation (47%*)	-	Cooperation (62%)	Information (45%**)	Cooperation (50%)
Cooperation	Regional (59%*) & national (59%)	-	-	Regional (55%) & national (55%)	Regional (55%) & national (55%)

4 Discussion

4.1 Assessing transformative potential through leverage points and amplifying strategies

Two aspects appeared most informative to assess the transformative potential of sustainability innovations: (1) leverage points, or the capacity of sustainability innovations to change systems they are embedded in through deep or shallow leverages, which we approached by analysing the types of novelties and impacts, and (2) amplifying strategies, as a mean for sustainability innovations to enhance their impacts beyond their own scope and in the future. Note that the use of *scale* within our archetype analysis proved only partly informative. We acknowledged that sustainability innovations identified in SCBR and FGBR were not necessarily novel or unique globally - rather they were very often a re-contextualisation or adaptation of ideas and already existing practices. However, local re-adaptation of ideas and practices did not prove less transformative. For instance, the collaborative recycling depot in FGBR was categorised as local, although similar initiatives exist elsewhere. Nonetheless, this project carried a radical and holistic approach to co-creative waste management. Hence, the *scale* at which innovations can be considered novel or unique conveyed limited explanatory power on the transformative potential of sustainability innovations. Rather, further conceptualisation would be needed, for instance to understand how the scope of action (i.e. whether initiatives act at local, regional, national or international level) may enhance transformative potential, in particular in relation with amplifying strategies and scaling through networks.

Hence, these results suggest what we call a transformative continuum. The least transformative end of this continuum was largely populated with e.g. Service Innovations, with sustainability innovations targeting shallow leverage points and lacking amplifying strategies. In both Biosphere Reserves, Service Innovations relied on rather hierarchical, or informative governance and built on rather instrumental values. For example, the delocalised campus created in FGBR enabled students to study online as a mean to avoid commuting, but did not address in a more systematic way the issue of financial precarity and the inability to move out of the family home to study. At the most transformative end of the continuum, only few sustainability innovations within the archetype Participative Transformation Governance applied holistic approaches with both shallow and deep leverage points, and amplifying strategies to scale out and beyond. For example, a Transition Town initiative in SCBR created a network of local projects and initiatives engaged for sustainability, thereby acting to replicate successful practices (scaling out) and to strengthen shifts in values and behaviours towards more sustainable ways of life (scaling deep). We could locate many cases in-between the shallow and holistic ends of this transformative continuum. Here, sustainability innovations usually targeted both shallow and deep leverage points but failed to apply amplifying strategies to enhance their impacts beyond the scope of their own projects. For example, Social and Sustainable Entrepreneurs seemed a promising bundle of local projects working on both shallow and deep leverage points, for instance by promoting organic products and local food systems, but also by using their business activities to promote value shifts, i.e. aiming to scale deep. For instance, the cooperative recycling depot and cultural café in FGBR aimed to improve resource use through up- and recycling, but also to spread alternative mindsets in approaching waste management in a co-creative and inclusive manner. Nonetheless, Social and Sustainable Entrepreneurs were limited in their transformative potential by the fact that they were often relying on small teams, which might explain the lack of amplifying strategies to scale beyond, or transfer and duplicate activities beyond their own scope of action.

4.2. Methodological limitations

The large number of studied cases, together with their diversity within in each Biosphere Reserve and their similarities in the comparison across Biosphere Reserves, enabled us to provide a comprehensive overview of the diversity of sustainability innovations and thus provided a sound basis for our archetype analysis (Eisenack et al. 2019). We acknowledge that cases within each archetype can vary and that e.g. Social Innovations and Service Innovations have a rather different profile in SCBR and in FGBR (Figure 3). Yet, we identified them as similar through the HCA based on all four aspects of outcomes (novelty type, amplifying strategies, sustainability impacts and scale) and used our expert knowledge about the sustainability innovations to characterise the archetypes as such (Eisenack et al. 2019).

To ensure comparability and learnings from large empirical data, archetype analyses compare many cases based on a limited number of variables - and thereby cannot gain an in-depth understanding of contextual conditions, external or diverging actors' perspectives and potential negative consequences in all cases (Eisenack et al. 2019; Köhler et al. 2019; Oberlack et al. 2019). Following, large *n* studies of transformations often ensure cross-case learnings by collecting data from a rather internal perspective, i.e., from *actors* or project representatives, and consider contextual conditions to a small extent (Bennett et al. 2016; Jiménez-Aceituno et al. 2020; Chambers et al. 2021; Palomo et al. 2021).

Like other large *n* studies, we used information collected from representatives of the identified innovations, which implied a number of limitations. First, we acknowledge our limited access to diverging perspectives from other actor groups, which would be necessary to better understand the plurality of perspectives on what constitutes a desirable innovation and what unexpected consequences might be (Blythe et al. 2018; Avelino et al. 2019; Bennett et al. 2019). In that regard, we aimed to provide a capacious framework to empirically assess the transformative potential of sustainability innovations by building on leverage points and amplifying strategies. While this procedure enabled us to pinpoint promising archetypes, researchers long abandoned the hope for panaceas and increasingly acknowledge that radical transformations question and transcend existing values, mindsets and goals (Ostrom 2009; Vogel and O'Brien 2022). Therefore, further research is needed to understand the plurality of values and worldviews that underlie transformations (McPhearson et al. 2016; van der Hel 2018; Feola 2020; Chambers et al. 2022). Such a strategy would enable a better understanding of both the incentives to engage in transformations.

Furthermore, while our variable set was designed to capture the most salient characteristics of a large number of innovations through survey interviews, other relevant aspects would require specific attention in further research, e.g. through further in-depth interviews to better understand the influence of the context and the role of Biosphere Reserves. We acknowledge that our variable set and analyses did not allow to examine how variables might co-evolve and interact through the innovation processes. For instance, actors' values might emerge, change and shift throughout deliberation and collaboration processes in an innovation, which in turn might play a role in setting new goals and implementing new actions (Verplanken et al. 2009; Horcea-Milcu et al. 2019). Therefore, a more reflexive practice is needed in transformation research when selecting variables, including reflection on the assumptions behind their assessment and the meaning of potential interactions throughout the life of the innovation (Bennett et al. 2016; McPhearson et al. 2016). Moreover, further investigation could assess to what extent self-reported impacts and outcomes were fully realised. For instance, the survey did not always clearly elicit whether radical value

shifts indeed took place or whether awareness-raising activities merely sought to foster value shifts.

Finally, whilst the four shared archetypes and the large number of cases we analysed suggest a likely replicability of results in other peri-urban areas in Europe (Eisenack et al. 2019), our results are place-sensitive and further empirical research would need to test these results in other contexts.

4.3 Archetype overlaps: implications for strengthening the transformative potential in Biosphere Reserves

The sets of five archetypes in each Biosphere Reserve displayed some overlaps, for instance in the outcomes of different archetypes. Arguably, the overlaps offered opportunities for collaboration and synergies across archetypes. For example, New Sectors, Social and Sustainable Entrepreneurs and Social Innovations all displayed a focus on new organisations, value shifts and sustainable resource use. These overlaps, which are a rather common result in archetype analyses (Eisenack et al. 2019), suggest that actors engaged in the different archetypes share common visions and interests. Following, a promising synergy could be to strengthen New Sectors for Social-ecological Transformations by building on the work and expertise of Social and Sustainable Entrepreneurs. While the Entrepreneurs show strong interest to conserve nature by itself (intrinsic values) and to enhance relationships (relational values), yet their initiatives typically lack human resources. By engaging with initiatives from the archetype New Sectors, local Entrepreneurs could build on broad networks and gain in momentum and willpower.

In this regard, Biosphere Reserves could play the role of bridging organisations by building networks and ensuring learning across different archetypes (Schultz et al. 2011; Schultz and Lundholm 2011a). For instance, the Regional Nature Park within FGBR coordinated various initiatives within New Sectors for Social-ecological Transformation. In a rather top-down manner, the Park thereby acted as project lead or knowledge broker, building partnerships with a variety of local and regional organisations, including Social and Sustainable Entrepreneurs. In contrast, sustainability innovations in SCBR were often able to build on long-established, collaborative networks among major regional organisations, such as the Biosphere Reserve, local and regional public administrations, research organisations and business networks (Dabard and Mann 2022). A prominent result of regional networks was the archetype Participative Transformation Governance, which was identified only in SCBR, in which collaborative arrangements between multiple and diverse regional actors played a crucial role. Hence, Biosphere Reserves may act as facilitators in regional sustainability innovations, but how this role can be reinforced would require more investigation.

5 Conclusion

We proposed a comprehensive approach to assess transformative outcomes with a generic set of variables, applicable in various sectors of activities. We thereby emphasised the need for a differentiated understanding of transformative potential, taking into account both the leveraging capacity of innovations, but also the amplifying strategies put in place. Following, we could differentiate archetypes of sustainability innovations in terms of their transformative outcomes.

Most archetypes had a limited transformative potential, notably due the lack of amplifying strategies to enhance impacts beyond their own scope of actions. Many innovations, such as Service Innovations or Technological Efficiency Innovations even seemed mere incremental

improvements in socio-technical systems that they did not radically challenge. And yet many other initiatives, such as Social and Sustainable Entrepreneurs, Social Innovations or New Sectors for Social-ecological Transformation had a strong wish for radical innovation and addressed both shallow and deep leverage points in a holistic manner. However, these archetypes often lacked resources to diversify impacts or to enhance them through amplifying strategies. In this regard, a differentiated approach to assess transformative potential was useful to pinpoint the potential fields of action or amplifying strategies that could help innovations enact their transformative potential.

It is nonetheless relevant to acknowledge the diversity of archetypes within a transformative continuum, from least to most transformative, as plural pathways towards sustainable futures in a context-sensitive manner, where plural pathways are required to solve wicked problems in a way that meets the expectations and wishes of a diversity of people. In this regard, further empirical studies are needed to unravel diverging expectations and assumptions about transformations of different actor groups. Indeed, while disruptive transformations aim to challenge existing power relations and destabilise old social-ecological-technical systems – in the process, new systems and path dependencies emerge. Hence, it is crucial to pinpoint trade-offs, diverging interests as well as shared responsibilities for change, because policy and societal actors are increasingly seeking to enable more just, context-sensitive and impactful transformations. Scientific actors should thereby also critically reflect about their own roles, underlying assumptions and preferences regarding sustainability transformations, for they are also embedded in systems of power relations.

Finally, this study highlighted many initiatives that unfolded within two European Biosphere Reserves. While the Biosphere Reserves sometimes launched sustainability innovations themselves, they also sometimes acted as bridging organisations or knowledge brokers in developing synergies between innovations. The typology we developed can inform Biosphere Reserve governance in deciding which innovations to support and how. At the very least, our archetype analysis highlighted some of the many initiatives, associations, social innovations and various projects that emerged with or without influence from the Biosphere Reserves, and that should be celebrated as seeds of transformations towards positive futures.

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Chapter 4

A social network analysis of sustainability innovations: values, rules and knowledge to enhance transformative potential

Social nodes

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A social network analysis of sustainability innovations: values, rules and knowledge to enhance transformative potential

This manuscript will be submitted for peer-review to Ambio.

Dabard, C.H.; Mann, C.; Martín-López, B. A social network analysis of sustainability innovations: values, rules and knowledge to enhance transformative potential

Abstract

To understand how sustainability innovations can support in solving global wicked problems, there is a need to assess their transformative potential and the conditions that support transformative innovation. In this study, we build on an archetype analysis of sustainability innovations based on their transformative potential to assess their respective decision-making contexts, or constellations of underlying values, knowledge production and governance arrangements. Specifically, we use social network analyses to characterise different governance arrangements. We find that plural values and influential, collaborative networks are linked to most transformative sustainability innovations, while instrumental values and hierarchical networks are linked to incremental innovations. We highlight incremental, reformist, idealist and transformative sustainability innovations and build on a leverage points perspective to propose that incremental, shallow innovations are necessary to operationalise transformative change. We suggest that future research should explore the co-evolution of decision-making contexts and transformative potential, to better understand how to enhance transformative innovations.

1 Introduction

Sustainability transformations are increasingly being acknowledged as necessary steps to ensure humanity's future. However, such buzzwords like sustainability, innovation and transformations have been used as empty words and described as "blah blah blah" (Bentz et al. 2022), as they too often describe incremental change and reinforcing existing problematic systems rather than challenging the status quo. Against this backdrop, there is a growing call in sustainability science to explore the characteristics of radical transformations, as opposed to incremental change (Temper et al. 2018; Feola et al. 2021)

Sustainability transformations encompass a variety of multi-scalar and multi-actor change processes that seek to radically challenge problematic systems, and to foster justice and equity, as much as social-ecological integrity (Hölscher et al. 2018; Bentz et al. 2022). However, only recently did scholars address the need to distinguish radical transformative change from incremental reforms (Blythe et al. 2018; Feola et al. 2021; Rutting et al. 2022). In fact, it has been shown that only few empirical studies address disruptive impacts in transformations research and that there has been no standard procedure to assess transformative outcomes (Castán Broto et al. 2019; Kivimaa et al. 2021). For example, Jiménez-Aceituno et al. (2020) proposed to categorise initiatives according to the Sustainable Development Goals they target, while Palomo et al. (2021) and Dubo et al. (2023) categorised nature-based solutions according to characteristic of transformative adaptation. Goodwin et al. (2023) classified nature-based solutions as incremental, reformist or transformative based on their structural impacts on problematic systems. Tuckey et al. (2023) grouped sustainability projects as potentially transformative or not depending on their amplifying

strategies and scale. To capture both the impacts of sustainability innovations and their amplifying strategies, we propose to empirically assess the transformative potential of sustainability innovations by combining a leverage points perspective (Abson et al. 2017) with a typology of amplification processes (Dabard et al. forthcoming; Lam et al. 2020).

Following the lack of empirical evidence on transformative capacity and outcomes of sustainability innovations, there is also a need to better understand what conditions are most conducive and supportive of transformative change. A recent analytical framework to appraise the conditions, or decision-making contexts, for transformative adaptation in a comprehensive manner is the value-rules-knowledge framework (Gorddard et al. 2016; Colloff et al. 2017). Decision-making contexts are defined as systems of specific values, rules and knowledge that shape, for example, transformative adaptation (Gorddard et al. 2016; Colloff et al. 2017; Lavorel et al. 2019), ecosystem management (Topp et al. 2022), or transformative nature-based solutions (Dubo et al. 2023). Values refer to how people's judgements regarding the importance of nature are justified in specific contexts, such as the transformative potential of innovations, (Pascual et al. 2023). Rules refer to formal and informal institutions, as well as the governance arrangements that underlay transformative behaviour (Gorddard et al. 2016). Knowledge refers to different types of information, such as technical, scientific or experiential knowledge, that is used in transformation processes and to the processes by which it is coproduced by actors (Colloff et al. 2020).

The decision-making context framework connects these different dimensions and has thereby proved useful and comprehensive, as it encompassed recent learnings about supportive conditions for innovation, resilience and transformation. For instance, transformation and resilience studies have shown that diverse networks and the participation of multiple actors foster radical and creative processes, notably because diverse actors would bring diverse values into such processes (Biggs et al. 2012; Avelino et al. 2017). Furthermore, innovations studies showed how multi-scalar governance arrangements may enable or hinder sustainability innovations (Bergek et al. 2015; Geels 2019). Finally, learning and experimenting, or participative knowledge co-production, have been shown to be crucial to promote sustainability innovations (Wittmayer and Schäpke 2014; Chambers et al. 2022; Tuckey et al. 2023).

Thus, while some supportive conditions for sustainable change have been pointed out already - such as diversity of actors and values, participative governance and knowledge integration – it is not yet clear what decision-making context constellations are most conducive to sustainability innovations with strong transformative potential, as opposed to incremental innovation (Dubo et al. 2023; Tuckey et al. 2023). This study aims to explore the relationship between the transformative potential of different sustainability innovations and the underlying values, rules and knowledge-coproduction processes that shape different decision-making contexts. In particular, we explore whether specific decision-making contexts, articulated by different systems of values, rules and knowledge of actors, lead to a greater transformative potential of sustainability innovations.

For the purpose of this study, we examined 129 sustainability innovations in two Biosphere Reserves (Dabard et al. forthcoming). We focussed on sustainability innovations, which we define as new pathways to meet human needs and aspirations, that generate positive outcomes for social-ecological integrity and equity (Dabard and Mann 2022). We suggest that local sustainability innovations can be used as a practical entry point to study transformative change, as they offer a bounded and managerial scale for analysis in comparison to greater

societal transformation processes (Hölscher et al. 2018). Sustainability innovations can be understood as small-scale changes in practices, behaviours or ideas that may participate to greater, societal transformations. We differentiated the transformative potential of the 129 sustainability innovations through, (1) the impacts they produced according to a leverage points perspective (Meadows 1999; Abson et al. 2017) and (2) the amplifying strategies they implement to increase their impacts (Lam et al. 2020). Following, we could identify sustainability innovation archetypes with a strong or limited transformative potential, and compared them in terms of decision-making contexts, or constellations of values, governance arrangements and knowledge co-production. While the empirical analysis of values and knowledge co-production was part of Dabard et al. (forthcoming), in this study, we focus particularly on eliciting the governance arrangements underlying the different sustainability innovation archetypes through a social network analysis.

2 Material and methods

2.1 Case studies

Empirical data collection on sustainability innovations took place in two Biosphere Reserves: Schorfheide-Chorin (Germany) and Fontainebleau-Gâtinais (France). Biosphere Reserves are model regions designated by the UNESCO to showcase nature conservation, sustainable development as well as research, education and monitoring (UNESCO 2017). As such, Biosphere Reserves may arguably play the role of bridging organisations and foster learning, co-creation and transformative processes (Schultz and Lundholm 2011; Reed and Price 2020; Barraclough et al. 2021). In this regard, Biosphere Reserves are practical and compelling study sites to study sustainability innovations, as they have the capacity to foster innovative social networks and collaborative projects towards sustainable development.

Schorfheide-Chorin Biosphere Reserve is located approximatively 70 km north of Berlin and is now a well-established administrative unit with diverse projects regarding nature conservation, large-scale organic farming, tourism and education (UNESCO 2021b). Belonging to the State Office for Environment of the Brandenburg Ministry of Rural Development, Environment and Agriculture, the Biosphere Reserve administration is part of various horizontal and vertical planning and regulatory processes in several policy sectors. These cover agricultural and forestry land-uses, nature conservation, rural development, energy and urban planning. The administration is thus influenced by multi-sector and multi-level governance arrangements - and collaborates with various public and private actors and organisations such as two counties (in German *Landkreise*), the regional planning authority, local towns and city halls but also with private actors, NGOs, universities and research organisations.

Fontainebleau-Gâtinais Biosphere Reserve is located 60km south of Paris. The Biosphere Reserve administration was created as an NGO, which board is composed notably by two counties (in French *départements*), the Région Île-de-France, the National Forest Office, the Regional Nature Park Gâtinais Francais, two universities, local environmental NGOs as well as local city halls (UNESCO 2021a). Although the associative management form of this Biosphere Reserve might enable participative and polycentric governance, it has proven challenging so far, because the NGO has been dependent on other institutions. Nonetheless, the Biosphere Reserve has implemented a few projects related to tourism and education. A large part of its territory is managed by the Parc Régional Naturel du Gâtinais Francais. Regional Nature Parks have similar missions to those of Biosphere Reserves in the French

regulation (Mathevet and Cibien 2020). This Park has benefitted from large means and implemented various projects with a strong focus on rural development through agro-ecology, tourism and mobility.

2.2 Data collection

Semi-open interviews were conducted with 17 regional informants in each Biosphere Reserve to identify sustainability innovations. The interviews were followed by a survey with representatives of 68 and 61 sustainability innovations in SCBR and FGBR respectively. The survey targeted (1) the characteristics of each sustainability innovation regarding involved actors, processes and transformative potential and (2) their social networks. The first part of the survey was used to identify and characterise archetypes of sustainability innovations, in particular in terms of novelty type, sustainability impacts, amplifying strategies, values and knowledge co-production (Box 1). The second part of the survey listed relevant actors and asked the respondents to indicate those with whom they had a connection (e.g. project partnership, funding, sharing resources, informal exchanges). Relevant actors included all actors involved in sustainability innovations and those public organisations, which were deemed particularly relevant for innovation in the region by the regional informants. The survey data about relationships between actors was complemented through online searches, e.g. in cases where many official project partners were involved. In this case, the official websites were used as complementary information about lead and partner organisations.

2.3 Sustainability innovation archetypes

With the goal to relate the transformative potential of sustainability innovations with their underlying value and knowledge co-production systems, we built on an archetype analysis conducted on the 68 (SCBR) and 61 (FBGR) innovations we surveyed (Dabard et al. forthcoming). The archetype analysis used variables related to transformative outcomes of sustainability innovations, in particular to (1) their sustainability impacts and novelty types, which we characterised as shallow or deep leverage points; and (2) their amplifying, or scaling, strategies to enhance their impacts beyond their own scope of action (Table 1). First, a leverage points perspective characterises interventions according to their capacity to shift a problematic system – from shallow leverage points that are easy to implement but with limited impact (for example slightly adapting how a system functions), to deep leverage points that are difficult to operationalise but that have the capacity to shift systems (for example changing the underlying values and goals of a system) (Abson et al. 2017). Second, amplifying strategies can be identified as amplifying within (e.g. enhancing, accelerating impacts within an innovations' scope of action), amplifying out (e.g. duplicating or transferring an innovation in another context) or amplifying beyond and deep (e.g. changing the underlying values and the structure of a system) (Lam et al. 2020).

The archetype analysis resulted in identifying five archetypes in each Biosphere Reserve. We interpreted four archetypes to be common in both case study area: Social and Sustainable Entrepreneurs, Social Innovations, New Sectors for Social-Ecological Transformation, and Service Innovations. In SCBR, we furthermore identified Participative Transformation Governance projects and in FGBR, we identified Technological Efficiency Innovations (Box 1). We identified Participative Transformation Governance as the most transformative archetype as it addressed both shallow and deep leverage points, for example by developing sustainable public transportation services through a collaborative consortium of local actors and regional organisations. This archetype applied various amplifying strategies such as amplifying out and beyond, for example through transfer activities to share learnings from

completed projects to other initiatives in the country, and by supporting collaborative consortiums for regional governance. Technological Efficiency Innovations and Service Innovations proved to display a very limited transformative potential, as they addressed only shallow leverage points, such as providing services for e-bike tourism or using agricultural waste for biogas production. These archetypes lacked amplifying strategies to enhance their impacts (Dabard et al. forthcoming).

Box 1. Sustainability innovations archetypes

Four archetypes are represented in both Schorfheide-Chorin Biosphere Reserve (SCBR) and Fontainebleau-Gâtinais Biosphere Reserve (FGBR). Number (*n*) of sustainability innovations per archetype in the respective Biosphere Reserves.

Participative Transformation Governance

This archetype comprises new projects at regional scale in which local communities or relevant actors are able to participate in planning activities or networks for sustainability.
Example: development of a mobility concept, including public and private actors, NGOs and inhabitants.
(*n*=6 in SCBR)

New Sectors for Social-ecological Transformation

This archetype comprises new sectors, value-chains, products and behaviours. Innovations target change at landscape level with a social-ecological perspective on land and resource use.
Example: new sector around regional, organic, medicinal and kitchen herbs production and processing.
(*n*=11 in SCBR; *n*=17 in FGBR)

Social & Sustainable Entrepreneurs

This archetype comprises new local, organic, sustainable businesses, cooperatives or producers, who are committed to sustainability values, nature, decent work environments and personal well-being.
Example: cooperative recycling depot with work reinsertion programme.
(*n*=11 in SCBR; *n*=16 in FGBR)

Social Innovations

This archetype comprises community-based initiatives and associations, often focussed on strengthening local communities or committed to local environmental actions and political change.
Example: cooperative, itinerant and community-based cultural café.
(*n*=23 in SCBR; *n*=13 in FGBR)

Service Innovations

This archetype comprises projects targeting public transportation, local business networks or regional education programmes in a effort to propose local climate-friendly and fair access to resources and services.
Example: experimentation on free public transportationat town level.
(*n*=17 in SCBR; *n*=11 in FGBR)

Technological Efficiency Innovations

This archetype comprises the use or installation of technological tools to increase resource use efficiency or productivity in a sustainable way.
Example: installation of a small gas plant on a family farm to use agricultural waste and diversify income sources.
(*n*=4 in FGBR)

Box 1. Sustainability innovations archetypes. Numbers in brackets indicate the number of innovations that were categorised within each archetype in both case study Biosphere Reserves. SCBR: Schorfheide-Chorin Biosphere Reserve; FGBR: Fontainebleau-Gâtinais Biosphere Reserve

2.4 Values and knowledge co-production systems underpinning archetypes

We used survey data to characterise the archetypes in terms of (1) values and (2) knowledge co-production processes to assess the decision-making contexts of different sustainability innovations (Table 1). First, we elicited values by categorising statements given by interviewees in response to open questions about their activities, their goals, missions and underlying values, and about the sustainable character of their projects. Values refer to the motivations that guide the actions, behaviour and goals of individuals and groups (Schwartz et al. 2012). Alike other empirical studies, we approached values by categorising the way in which innovative actors justified the importance of nature and sustainability within their innovation, and coded the statements as expressing instrumental, intrinsic or relational

values (Chan et al. 2016; Topp et al. 2022). Instrumental values referred to the survey respondents expressing their motivation for their sustainability innovations, as based on their own benefit or the benefit of other human beings. An example are projects developing new organic products for income stabilisation, e.g. organic mushrooms production within a cereal farm. Intrinsic values referred to a motivation of survey respondents for their projects based on e.g. their belief that animals and nature should have the right to thrive, regardless of human use. An example is a conservation project that aimed to protect wildlife habitat for animal wellbeing. Finally, relational values referred to respondents mentioning that their activities were based on the motivation to enhance people's relationships to nature or to enhance people-to-people relationships through nature and sustainability actions. An example was the creation of community gardens as a mean to enhance human-nature connectedness in participants and to foster community-building.

Besides values, we also categorised the sustainability innovation archetypes according to survey responses about the most common mode of decision-making, deliberation and knowledge production within the innovation team, categorised as informative, consultative or cooperative. The survey asked the respondent to choose the most common mode of decision-making and collaborative deliberation. Informative deliberation and knowledge production referred to the project managers taking decisions and informing relevant partners and team members. Consultation referred to the project managers taking decisions after consulting relevant partners and team members. Cooperation referred to the project managers taking decisions together with relevant partners and team members. For full details about the different sustainability innovation archetypes and the archetype analysis, see Dabard et al. (forthcoming).

Table 1. Description and operationalisation of the transformative potential and of the decision-making context of sustainability innovation archetypes.

Characteristics of archetypes	Description
1. Transformative potential	The capacity of sustainability innovations to produce and scale transformative outcomes, assessed through leverage points and amplifying strategies.
Leverage points	The capacity of sustainability innovations to address shallow or deep leverage points in targeted systems, i.e. to induce incremental or radical change (Meadows 1999; Abson et al. 2017; Riechers et al. 2022). The leverage points are captured through their sustainability impacts (Gibson 2006; Luederitz et al. 2017) and their novelty types, e.g. social innovation, product innovation. These were categorised based on survey responses and attributed to either shallow or deep leverage points.
Amplifying strategies	Strategies implemented to scale activities and impacts within (growing and accelerating), out (transferring and duplicating) and beyond (changing rules, structures and values (Lam et al. 2020), based on survey responses.
2. Decision-making context	The systems of values, rules and knowledge that shape sustainability innovations (Gorddard et al. 2016; Colloff et al. 2017), captured through survey responses and social network analysis.
Values	The way in which innovative actors value relationships to nature and relationships between people mediated by nature, categorised as instrumental, intrinsic and/or relational values (Pascual et al. 2023), categorised based on open-ended questions from the survey about missions, goals, values and sustainability aspects of sustainability innovations.
Knowledge	Forms of knowledge co-production and decision-making in sustainability innovations, categorised as informative, consultative or cooperative processes, based on survey responses.
Rules	Rules-in-use and rules-in-form that underlay specific governance arrangements among sustainability innovations (Colloff et al. 2017). Governance arrangements are assessed here through social network analysis, in particular through the diversity, connectedness and influence of sustainability innovations in networks.

2.5 Social network analysis and underlying governance arrangements

To complete the analysis of the decision-making contexts underlying different sustainability innovation archetypes in terms governance arrangements, we conducted a social network analysis (Table 1). Rules are understood as the rules-in-use and rules-in-form that shape the governance arrangements of sustainability innovations (Colloff et al. 2017). Specifically, we characterised the different innovation networks as being either diverse or homogenous, collaborative or hierarchical and influential or peripheral to capture the governance arrangements underlying the different innovation archetypes.

This approach to assess governance arrangements within innovative networks is in line with recent empirical studies making use of social network analysis to understand governance models for social-ecological systems resilience and transformation (Bodin and Tengö 2012; Isaac et al. 2014; Salpeteur et al. 2017; Barraclough et al. 2022). In transformation studies, social network analyses were used for instance to better understand the diffusion of grassroots innovations (Feola and Butt 2017), the potential of local actions for urban resilience and adaptation (Therrien et al. 2019), local NGO networks and their joint actions for transformative change (Lam et al. 2021), or the implementation of nature-based solutions (Giordano et al. 2021; Mitincu et al. 2023),

To compare governance arrangements, we created 12 social networks in total. Social networks represent nodes, in our case innovation actors, and edges, or connections between them. The nodes are categorised by: 1) archetype (i.e. whether the actors were involved in several archetypes, in Participative Transformation Governance, Social & Sustainable Entrepreneurs, New Sectors for Social-ecological Transformation, Social Innovations, Service Innovations, Technological Efficiency Innovations or no archetype) and 2) actor type (i.e. whether the actors were public organisations, private organisations, NGOs, civil society organisations or research organisations). We created full networks in each Biosphere Reserve which comprised all actors (n=223 in SCBR; n=305 in FGBR). Moreover, we created five archetype networks in each Biosphere Reserve, including only actors directly involved in the corresponding sustainability innovation archetypes. These actors comprised the official project partners, funding organisations and those actors considered particularly important by the survey respondents. In all 12 networks, we computed actor centrality metrics, i.e. degree, betweenness and eigenvector. Degree centrality sums up each actor's connections and thus shows how well connected one actor is. Betweenness centrality calculates how often an actor is on the shortest path between two others and thus shows how central, or bridging, an actor is. Eigenvector centrality computes how well connected an actor is to other important actors and therefore shows how influential an actor is. Specifically, eigenvector centrality is often used to show potential future influence (Prell 2015).

To articulate the governance arrangements underlying different archetypes, we characterised the social networks of the innovation archetypes as diverse or homogenous, collaborative or hierarchical and influential or peripheral, through a series of statistical tests on centrality metrics in the full networks and in the archetype networks (Table 1). To address the diversity or homogeneity and the collaborative or hierarchical character of different archetypes, we tested for differences of the centrality metrics among actor types in each archetype network by applying Kruskall-Wallis tests. This enabled us to highlight how specific actor types were of particular importance for different archetypes, e.g. whether one actor type was dominating the network or if several actor types collaborated on similar levels. To assess the influence and connectedness of different archetypes, we tested for

differences of the centrality metrics among different archetypes in the full networks, using Kruskall-Wallis tests. Furthermore, we performed Chi-square contingency tables and Fischer's exact test to explore the level of association between the type of actor and archetypes in order to determine how bridging actors, i.e. influential actors with the potential to connect others and to ensure a flow of information and resources across archetypes, were distributed in the archetypes.

Note that the results for the archetype Technological Efficiency Innovations are not presented, for the social network underlying this archetype comprised only 11 actors and gave way to no significant results. The social network visualisation and analyses were carried out using, first, Gephi: an open source software for exploring and manipulating networks (Bastian et al 2009) and, second, NodeXL: a free and open network overview, discovery and exploration add-in for Excel (Smith et al 2010). All statistical analyses were carried out using XLStat statistical and data analysis solution 2022 (Addinsoft, Paris, France).

3 Results

In the following, the six identified archetypes, their transformative potential and decision-making contexts are presented, with a focus on governance arrangements through social network analysis.

Participative Transformation Governance. This archetype, specific to SCBR, proved most transformative. The identified initiatives targeted deep and shallow leverages and implemented strong amplifying strategies to scale out (duplicating or transferring the innovation elsewhere) and to scale beyond by changing people's values (scaling deep) and by changing policy rules (scaling up) (Table 2). For instance, one project aimed to develop climate-friendly public transportation for the region, which meant reorganising the bus timelines to accommodate local people and tourists (shallow leverage point), but also collaborating with local towns, regional and national transportation firms and tourism actors to propose a holistic mobility concept across administrative units (deep leverage points). In Participative Transformation Governance, actors usually worked in a cooperative manner and reported plural values, i.e. instrumental, relational and intrinsic values. As for the governance arrangements underlying Participative Transformation Governance, we found that the networks involved a broad diversity of actors, who organised in a cooperative manner. The actor metrics in the archetype network revealed no significant differences in centrality (Figure S1), suggesting that a diverse set of actors collaborated in a non-hierarchical manner. Furthermore, this archetype proved highly connected and influential, as was shown by the particularly high metrics of Participative Transformation Governance actors in the full SCBR network (Figure 1) and by the high number of bridging actors, which are actors engaged in several archetypes, including in Participative Transformation Governance (Table S1).

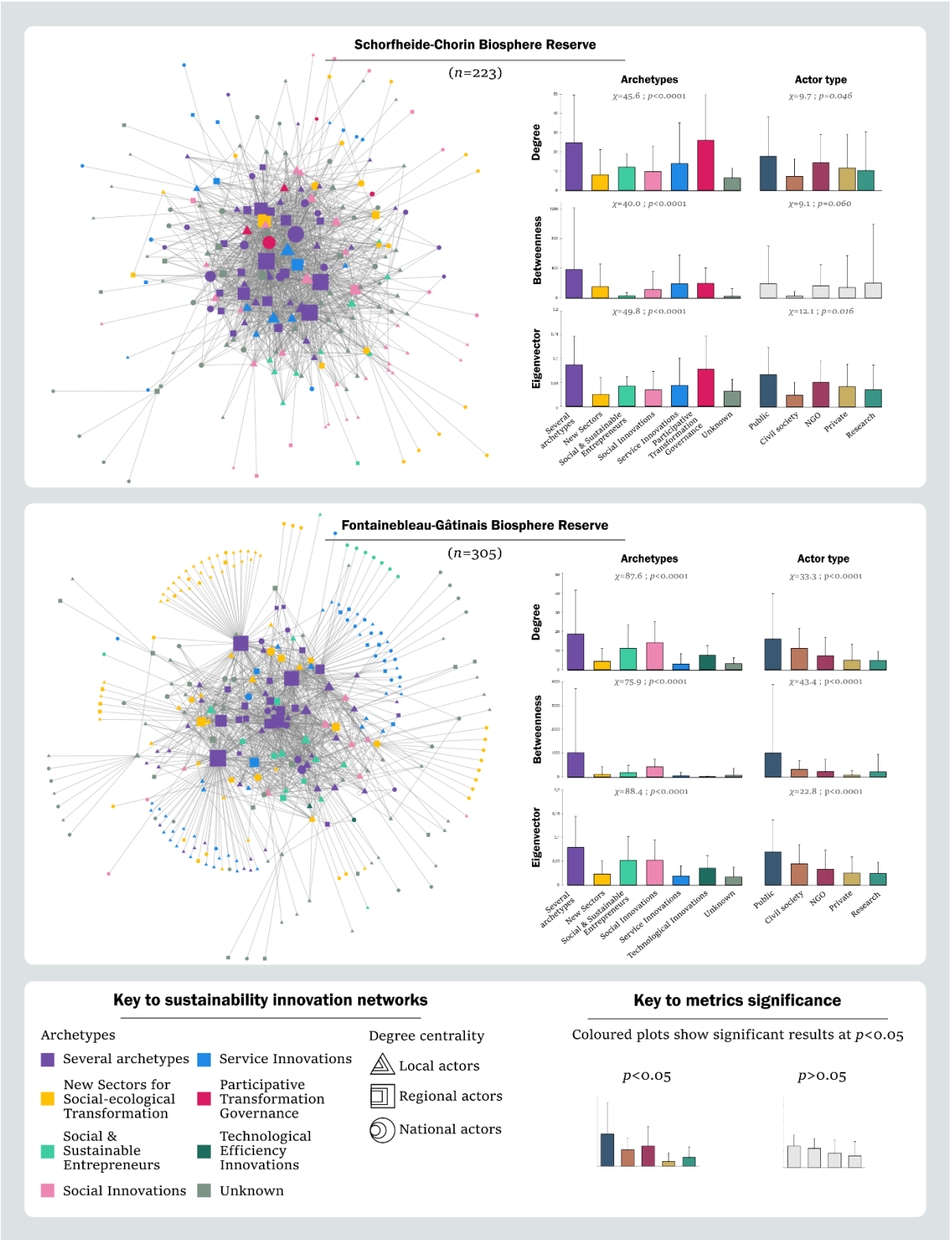

Figure 1. Social networks (left) in Schorfheide-Chorin Biosphere Reserve (top) and Fontainebleau-Gâtinais Biosphere Reserve (bottom), showing connections between all actors. Bar plots (right) show differences in centrality metrics (degree, betweenness, eigenvector) across archetypes and actor types.

New Sectors for Social-ecological Transformation. In SCBR, New Sectors revealed disparate transformative outcomes (Table 2). Many sustainability innovations in this archetype targeted shallow and deep leverages, for example developing organic products (shallow leverage point) and collaborative, regional partnerships and value-chains in the agricultural sector (deep leverage point). Yet, New Sectors had limited scaling potential, with a lack of amplifying strategies. With regards to their decision-making context, New Sectors in SCBR relied on instrumental values, for example seeing organic agriculture as a means for regional development and job creation. Respondents reported about both consultative and collaborative knowledge production. As for the governance arrangements underlying New Sectors, we found a rather diverse, collaborative, but specialised network. We did not find significant differences in centrality metrics in the archetype network, showing that all actors collaborated at a similar level (Figure S1). Likewise, we did not find a significant association between the number of actors and being involved in several archetypes (Table S1), indicating that actors in the New Sectors did not act as bridging actors. In fact, they presented low centrality metrics in the full SCBR network (Figure 1), suggesting a rather peripheral, very loosely connected archetype.

In FGBR, New Sectors for Social-ecological Transformation had a similarly disparate transformative potential, acting on both shallow and deep leverages, albeit with rare amplifying strategies (Table 2). For instance, some projects aimed to develop local and organic school canteens, which fostered consumption of seasonal vegetables (shallow leverage point). This also required the collaborative reorganisation of public catering with public organisations, local producers and caterers – with the motivation to foster healthy and local organic food - and to strengthen rural small businesses (deep leverage points). As to their decision-making context, New Sectors in FGBR built on mostly relational and instrumental values and a consultative knowledge production mode. The social networks revealed a hierarchical governance structure behind the New Sectors in FGBR, particularly influenced by public actors (Figure S1). Indeed, the archetype network showed very strong differences in centrality metrics across actor types, with public actors dominating the network with high degree, betweenness and eigenvector centrality. Furthermore, New Sectors proved to be peripheral in FGBR, as shown by the particularly low centrality in the full FGBR network (Figure 1) and the very few bridging actors that were involved in this archetype (35% of actors; Table S1). In fact, we found a positive significant association between the number of actors and being exclusively involved in the New Sectors archetype (Fischer's exact test $p = 0.005$; Table S1).

Social & Sustainable Entrepreneurs. In SCBR, Entrepreneurs had a rather limited transformative potential. Although their actions focused on deep leverage points, such as raising awareness and thereby aiming to shift values and individual behaviour towards sustainability, their amplifying strategies were limited (Table 2). For example, a local nature tour guide aimed to foster human-nature connectedness by offering workshops and walking tours through nature, thereby raising awareness about various sustainability topics. Regarding the decision-making context, Entrepreneurs had strong relational values but no specific form of knowledge production, most likely because they involved very few actors. The social network analysis revealed a small, rather loose network of dispersed and homogenous actors (Figure S3). Social and Sustainable Entrepreneurs showed no differences in centrality metrics across actor types, suggesting a collaborative network. However, this archetype was peripheral in the full SCBR network, with a particularly low betweenness centrality of Social and Sustainable Entrepreneurs (Figure 1).

In FGBR, Social and Sustainable Entrepreneurs had more transformative impact. This archetype targeted both shallow and deep leverage points. For example, several grassroots organic cooperatives supported local farmers and sold organic products (shallow leverage point) – while also trying to build alternatives to capitalist consumption by fostering community-building and regional networks (deep leverage point). Some innovations reported strategies to scale beyond, most notably through shifting values and behaviours, for example regarding consumption (Table 2). Regarding the decision-making context, respondents in this archetype reported relational values, e.g. with a focus on community-building, while the knowledge production mode remained unspecified, mostly due to very small teams in this archetype. As for the governance arrangements related to this archetype, we found a diverse, collaborative, rather influential network influence. Rather balanced centrality metrics in the archetype network revealed that diverse actors collaborated on similar level (Figure S3). In the full FGBR network, Entrepreneurs had a particularly high eigenvector centrality, suggesting that this archetype was well-connected to influential actors and could gain in influence in the future (Figure 1).

Social Innovations. In SCBR, Social Innovations had disparate outcomes, with actions targeting deep leverage points, but limited scaling strategies (Table 2). For instance, a village cultural association aimed to foster lively rural communities through culture, and offered arts-based workshops to teenagers and children, notably about human-nature relationships, thereby making caring, slow and sparing use of human resources. The decision-making context underlying Social Innovations consisted of relational values and knowledge production in a cooperative or consultative manner. Surprisingly for Social Innovations, the network analysis revealed rather hierarchical governance arrangements. Indeed, the archetype network appeared quite dominated by one research organisation, with especially high centrality metrics (Figure S4). Furthermore, this archetype appeared peripheral, very loosely connected to other innovations in the full SCBR network. Social Innovations had a very low centrality (Figure 1) and particularly few bridging actors since we found a positive association between being actor of Social Innovation and being exclusively involved in this archetype (Fischer's exact test $p = 0.017$; Table S1).

On the contrary, in FGBR, Social Innovations had a strong transformative potential, with actions targeting both shallow and deep leverage points. However, their reported amplifying strategies remained quite limited (Table 2). For instance, a local branch of a national citizen association for democracy pressured the local city hall and negotiated with election candidates to implement concrete sustainability measures at town level, for example for the city hall to purchase sustainable supplies (shallow leverage point), but also to create a local and independent long-term commission for nature protection (deep leverage point). Regarding their decision-making context, Social Innovations in FGBR relied on relational and instrumental values and they established processes of cooperative co-production of knowledge. The network analysis highlighted a rather diverse, collaborative network of high influence since Social Innovations actors had high centrality in the full FGBR network (Figure 1) and were strongly involved in the other archetypes (Fischer's exact test $p < 0.001$; Table S1). The archetype network showed no differences in betweenness centrality among different actor types, which revealed a collaborative working mode (Figure S4).

Service Innovations. In SCBR, Service Innovations had a very limited transformative potential. They targeted shallow leverage points and rarely implemented amplifying strategies (Table 2). For example, a new service was developed for e-bike tourists: a network of places to re-load their bike and a labelling action as e-bike friendly region. The decision-

making context relied on instrumental values and processes of knowledge production that are merely informative - and sometimes cooperative. The governance arrangements relied on a rather collaborative network, with diverse actors that had similar centrality metrics, suggesting cooperation at eye-level (Figure S5). In the full SCBR network, Service Innovations had average centrality metrics, and therefore average influence (Figure 1).

In FGBR, Service Innovations had a similarly low transformative potential, with actions targeting shallow leverage points and limited amplifying strategies. An example was the creation of labels for local businesses and organisations that broadly aligned with the goals of the Parc Régional Naturel or of the Biosphere Reserve. Service Innovations relied mostly on relational values and processes of knowledge production that were informative (Table 2). The network analysis revealed a hierarchical and very loosely connected network. Indeed, Service Innovations had low centrality metrics in the full FGBR network (Figure 1) and the archetype network showed that public actors were particularly influential in comparison to all other actor types (Figure S5).

Table 2. Characterisation of sustainability innovation archetypes in terms of transformative potential and decision-making context, defined by the values-rules-knowledge framework. The percentages indicate the most reported novelty types, sustainability impacts, values and knowledge production modes in the respective archetypes, based on survey data. Governance arrangements are defined according to the network analysis.

Archetype	Transformative potential	Decision-making context
Schorfheide-Chorin Biosphere Reserve		
Participative Transformation Governance (*n*=32)	**Deep leverage** Novelty type: new values (100%), organisation (67%) Impacts: social-ecological stewardship& democratic governance (83%), precaution & adaptation (67%) **Strong scaling potential** Amplifying: scaling out (83%) and beyond (83%)	**Values**: plural values (relational: 67%, intrinsic: 50%, instrumental: 33%) **Knowledge**: cooperative (83%) **Governance arrangements:** Diverse, collaborative and influential network
New Sectors for Social-ecological Transformation (*n*=60)	**Shallow & deep leverages** Novelty type: new sector (91%), behaviour (64%), technology (55%), product (27%) Impacts: social-ecological integrity (45%), precaution & adaptation (36%) **Limited scaling potential** Amplifying: scaling beyond (55%),	**Values**: instrumental (64%), intrinsic (36%) **Knowledge**: consultation (45%) **Governance arrangements:** Diverse, collaborative and peripheral network
Social & Sustainable Entrepreneurs (*n*=23)	**Deep leverage** Novelty type: new values (73%), service (64%) Impacts: N.A. **Limited scaling potential** Amplifying: N.A.	**Values**: relational (100%) **Knowledge**: NA **Governance arrangements:** Homogenous, collaborative and peripheral network
Social Innovations (*n*=89)	**Deep leverage** Novelty type: new organisation (70%) Impacts: structural social change (91%) **Limited scaling potential** Amplifying: N.A.	**Values**: relational (87%) **Knowledge**: cooperative (48%), consultative (43%) **Governance arrangements:** Diverse, hierarchical and peripheral network
Service Innovations (*n*=56)	**Shallow leverage** Novelty type: new market (70%), new product (24%) Impacts: resource maintenance and efficient use (82%), structural physical change (71%) **Limited scaling potential**	**Values**: instrumental (71%) **Knowledge**: informative (29%) **Governance arrangements:** Diverse and collaborative, average influence

	Amplifying: N.A.	
Fontainebleau-Gâtinais Biosphere Reserve		
New Sectors for Social-ecological Transformation (*n*=120)	**Shallow & deep leverages** Novelty type: new organisation (88%), sector (29%), product (24%) Impacts: social-ecological integrity (35%) **Limited scaling potential** Amplifying: N.A.	**Values**: relational (94%), instrumental (82%) **Knowledge**: consultative (47%) **Governance arrangements:** Diverse, hierarchical and peripheral network
Social & Sustainable Entrepreneurs (*n*=46)	**Shallow & deep leverages** Novelty type: new values (100%), service (88%), organisation (88%) Impacts: intra-& intergenerational equity (25%) **Deep scaling potential** Amplifying: scaling deep (69%)	**Values**: relational (100%), instrumental (56%), intrinsic (25%) **Knowledge**: NA **Governance arrangements:** Diverse, collaborative and influential network
Social Innovations (*n*=39)	**Deep leverage** Novelty type: new behaviour (54%), values (85%) Impacts: livelihood sufficiency & opportunity (38%) **Limited scaling potential** Amplifying: N.A.	**Values**: relational (85%), instrumental (85%) **Knowledge**: cooperative (62%) **Governance arrangements:** Diverse, collaborative and influential network
Service Innovations (*n*=109)	**Shallow leverage** Novelty type: new service (64%) Impacts: N.A. **Limited scaling potential** Amplifying: N.A.	**Values**: relational (85%), instrumental (45%) **Knowledge**: informative (45%) **Governance arrangements:** Diverse, hierarchical network and peripheral network

4 Discussion

4.1 Most transformative innovations build on plural, collaborative and influential social networks

The most transformative archetype, Participative Transformation Governance in SCBR, displayed a decision-making context that is characterised by plural values, cooperative knowledge co-production and a diverse and influential network. On the contrary, we found that sustainability innovations archetypes with the least transformative potential - i.e. Service Innovations in both SCBR and FGBR - built on instrumental values, process of knowledge creation that are merely informative, and hierarchical, homogenous, peripheral networks. Recent studies have shown that plural valuation and knowledge systems and collaborative decision-making support holistic, place-sensitive and just conservation (Carmenta et al. 2023) and inclusive conservation and transformative Protected Areas governance (Chaplin-Kramer et al. 2023). Yet, so far, there has been limited evidence on the relation to the transformative potential of sustainability innovations. For example, Dubo et al. (2023) showed that plural valuation and the inclusion of different knowledge systems, together with collaborative governance, underlined transformative nature-based solutions with higher capacity for transformative adaptation. By contrast, instrumental valuation, top-down regulations and formal governance were connected to nature-based solutions of low capacity for transformative adaptation (Dubo et al. 2023). It seems evident that innovations undergone by a diversity of actors with plural values are likely to pursue a variety of goals on both shallow and deep leverages – yet, the co-evolution thereof remains to be explored. While values impact the goals that actors pursue; it is also likely that actors' values would evolve throughout the innovation process, depending on the shallow and/or deep actions they carry out and on their learning processes (Pascual et al. 2023). Moreover, the transformative potential of innovations arranged by broad, well-connected and influential networks is likely

to encompass diverse amplifying strategies, although a recent study showed that networks and amplifying strategies are likely to co-evolve as well (Lam et al. 2021).

4.2 Shallow innovations are insufficient - but necessary for transformative change

Social Innovations in SCBR and Social and Sustainable Entrepreneurs in FGBR displayed mixed transformative potential, with a focus on deep leverage points, for example through awareness-raising activities aiming to shift people's worldviews and behaviours. However, these archetypes lacked actions targeting shallow leverage points and amplifying strategies to scale out, i.e. to transfer or duplicate their actions and learnings. In terms of decision-making context, Social Innovations and Entrepreneurs displayed relational values and rather collaborative networks, albeit with limited influence and outreach. We suggest that the limited transformative potential of Social Innovations (SCBR) and Social and Sustainable Entrepreneurs (FGBR) resulted from a somewhat idealist understanding of behavioural and value shifts as the main paths to radical changes. While education or awareness-raising activities are widely expected to foster individual behaviour and value shifts towards sustainability, and thus to contribute to transformative impacts at societal scale through– evidence has shown that individual behaviour and value shifts, albeit changes at deep leverage points, are not sufficient for radical system change (Balmford et al. 2021; Carmenta et al. 2023). In a similar vein, we observed that sustainability innovations, with a focus on deep leverage points such as value and behaviour shifts, which relied on very strong relational, and sometimes intrinsic, values – but lacked concrete outcomes. This result is in line with Burgos-Ayala et al. (2020), who showed that Columbian environmental management projects, which tackled only deep leverages, for example projects to re-design management based on indigenous people's values and cosmovisions, lacked concrete, necessary changes at shallower levels. Another study found that nature-based solutions building on strong relational values were connected to innovative behaviour - but remained very local, and bounded, in their capacity for transformative adaptation (Dubo et al. 2023). It has been argued that shallow interventions are insufficient for systematic, radical change (Abson et al. 2017; Riechers et al. 2021). We propose instead that shallow innovations are insufficient for transformative change - but necessary, as a way of operationalising transformative innovation by producing concrete, measurable and short-term impacts, by creating milestones for action and by providing opportunities for learning, network-building and co-creating innovation processes. However, how to foster chains of leverages, e.g. from shallow innovation paving the way for radical transformation, and how to disentangle interactions between leverages, remains to be explored (Riechers et al. 2021; Riechers et al. 2022).

4.3 Incremental, reformist, idealist and transformative sustainability innovations

Our results highlighted several types of sustainability innovations in the two Biosphere Reserves, which correspond and complement recent findings on transformative change. For instance, Heikkinen et al. (2019) and Goodwin et al. (2023) proposed that adaptation actions and nature-based solutions can be categorised as incremental, reformist and transformative. In a similar vein, we found that e.g. Service Innovations produced incremental change at shallow leverage points, for example by providing tourists with a network of e-bike friendly places. New Sectors for Social-ecological Transformation can be seen as reformist innovations, carried out by incumbent actors and aiming to shift e.g. agri-food systems in a positive manner, albeit in a rather individual, non-structural manner. Participative Transformation Governance proved most transformative among the identified archetypes.

We argue that idealist innovations, such as some Social Innovations or Social and Sustainable Entrepreneurs, are yet another type beside incremental, reformist and transformative innovation. Idealist sustainability innovations focus on individual value and behaviour change through actions on deep leverages, albeit with limited concrete operationalisation.

Our approach to assessing the decision-making context and transformative potential of various sustainability innovation archetypes may help in pinpointing possible strategies to enhance their transformative outcomes. For instance, incremental innovations such as Service Innovations could enhance impacts by diversifying their actions towards more deep leverage points and by implementing amplifying strategies. For this purpose, diversifying their networks might prove useful, as this would foster collaboration with more diverse actors, potentially bringing in new ideas and goals – but also providing opportunities for scaling strategies (Biggs et al. 2012; Kratzer and Ammering 2019; Lam et al. 2021; Mitincu et al. 2023). Reversely, idealist innovations such as Social and Sustainable Entrepreneurs or Social Innovations could enhance their transformative outcomes by designing actions targeting concrete, albeit shallow, leverage points and more concrete scaling strategies to transfer or duplicate. A possible avenue to operationalise their strong visions and relational values could be to build up or make use of existing partnerships with influential and incumbent actors, which have been shown to have the capacity to foster and broker innovations (Mitincu et al. 2023). For instance, the Social and Sustainable Entrepreneurs in FGBR had a particularly high eigenvector, showing that they were well connected to influential actors in the FGBR network. Often, these influential actors are regional public organisations, which might take up the role of brokers, or bridging organisations.

4.4 Biosphere Reserves as bridging organisations for sustainability innovations

Our comparative analysis was placed in two Biosphere Reserves, one in Germany, close to the city of Berlin, and one in France, close to Paris. We found that large scale protected areas like Biosphere Reserves or Regional Nature Parks, similar to other regional public administration units, can act in the role of being bridging organisations. In both case studies, regional public actors, in particular the Biosphere Reserve or Regional Nature Park administrations, but also communal services organisations such as those responsible for waste disposal and recycling chains, played a central role in the innovative networks. Further empirical research is needed to better understand the exact role of those organisations as pioneers or change agents in fostering sustainability innovations (e.g. as innovators, resource providers or knowledge brokers) and the quality of connections they had to the various innovation actors. Nonetheless, our results suggest that Biosphere Reserve administrations can act as network brokers and connect various actors (Mitincu et al. 2023), as they appeared central not only in the full networks, but also in many of the archetype networks. Note however, that when public actors largely dominated, e.g. in the networks underlying Service Innovations or New Sectors for Social-ecological Transformation, the resulting sustainability innovations had only limited transformative potential, resulting in incremental or reformist sustainability innovations. A recent study found a similar result, arguing that most transformative initiatives were grounded in local, place-based organisations, while initiatives controlled by external organisations had limited positive impacts (Londres et al. 2023). Hence, public actors seem to foster transformative outcomes, when they support and participate in collaborative processes with diverse actors (Mitincu et al. 2023).

4.5 Methodological limitations and future research

To complete the analysis of decision-making contexts of different archetypes - or constellations of values, knowledge and governance arrangements - the social network analysis enabled us to assess governance arrangements in terms of actor diversity, connectedness and influence. Nonetheless, the analysis faced a few limitations. First, it was beyond the scope of this study to characterise each connection between actors in more depth and to weight the quality of the relationships. In a weighted analysis, we could have rated connections as more or less strong, e.g. according to whether actors closely collaborated on specific projects or were in sporadic contact. This would for instance allow a more precise understanding of the potential role of public actors in fostering sustainability innovations, as it was not clear how closely public actors collaborated on projects or merely were in contact with multiple innovation actors. Yet, the data collection did not give way to consistent results on the type of connections that interviewees had. Note that unweighted connections remain a wide-spread approach to social network analysis, as they still give an overview of the most important connections and actors in a non-quantitative manner (Crona and Bodin 2010; Alonso Roldán et al. 2015; Kratzer and Ammering 2019).

Furthermore, it appeared that our approach to the values-rules-knowledge framework, in particular our means to assess governance arrangements in networks, and knowledge, as modes of coproduction and decision-making, was sometimes redundant and would require more details in further empirical research. For instance, collaborative and diverse networks usually reported cooperative knowledge co-production and decision-making, as in e.g. Participative Transformation Governance. In a more fine-tuned data collection, we would gain insights with details on knowledge by examining, as was done in recent studies, what type of knowledge was produced and used, such as e.g. technical, scientific or experiential knowledge (Lavorel et al. 2019; Topp et al. 2022; Dubo et al. 2023). We acknowledge that this limited our contributions to a better understanding of how values, rules and knowledge co-production co-evolve and shape sustainability innovations.

Finally, the study built on data collected through one-time survey interviews and thus did not capture the probable co-evolution of decision-making contexts with transformative outcomes. It has been shown that values, rules and knowledge co-evolve (Lavorel et al. 2019; Dubo et al. 2023), and it is likely that they would influence and be influenced by transformative processes. However, punctual survey interviews are a common and practical procedure to study and compare a large number of cases and gain an overview of transformative processes (Chambers et al. 2021; Topp et al. 2022; Dubo et al. 2023),

5 Conclusion

We compared the decision-making context of various sustainability innovation archetypes in relation we their transformative potential and distinguished radical, transformative innovations from incremental innovations. We highlighted that plural valuation of nature and collaborative governance related to strongest transformative potential, while instrumental values and hierarchical, homogenous networks implemented incremental sustainability innovations of little transformative potential. Pinpointing idealist sustainability innovations, we suggested that actions on deep leverage points are necessary for a strong transformative potential – but require more concrete, albeit shallow, actions for operationalisation. In this regard, it remains to be explored how incremental innovations could shift to radical, deeply transformative change – and in how far those innovations that

were considered transformative might have started off with shallow, incremental change. This sheds light on the need to better understand the co-evolution of transformative potential with decision-making contexts. Further empirical research would be necessary to unravel how e.g. value shifts or changes in collaborative arrangements within actor network might enhance transformative potential - and how transformative processes might lead to value shifts and changes in collaborative processes. In this regard, assessing transformative potential using a leverage points perspective, combined with an analysis of amplifying strategies, has the potential to help innovative actors and policy-makers identifying the most promising initiatives and innovations. Finally, paying attention to the underlying values, knowledge production and governance arrangements may help innovative actors and policy-makers in identifying strategies to create supportive conditions for transformative change, for example by purposefully connecting with diverse actors, reflecting on values and motivations, building on different types of knowledge and strengthening collaborative decision-making.

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Appendix

Appendix list

A.1 List of papers and author contribution statements

The appendix includes the author contribution statements and the publication status as required by the dissertation guidelines. I certify that all of the information given in this appendix is true, both individually and as a whole.

Chapter 2: Dabard, C.H.; Mann, C. Sustainability innovations: a proposal for an analytical framework and its empirical application in the Schorfheide-Chorin Biosphere Reserve. Sustainability Science 18, 1085–1098 (2023). https://doi.org/10.1007/s11625-022-01241-9

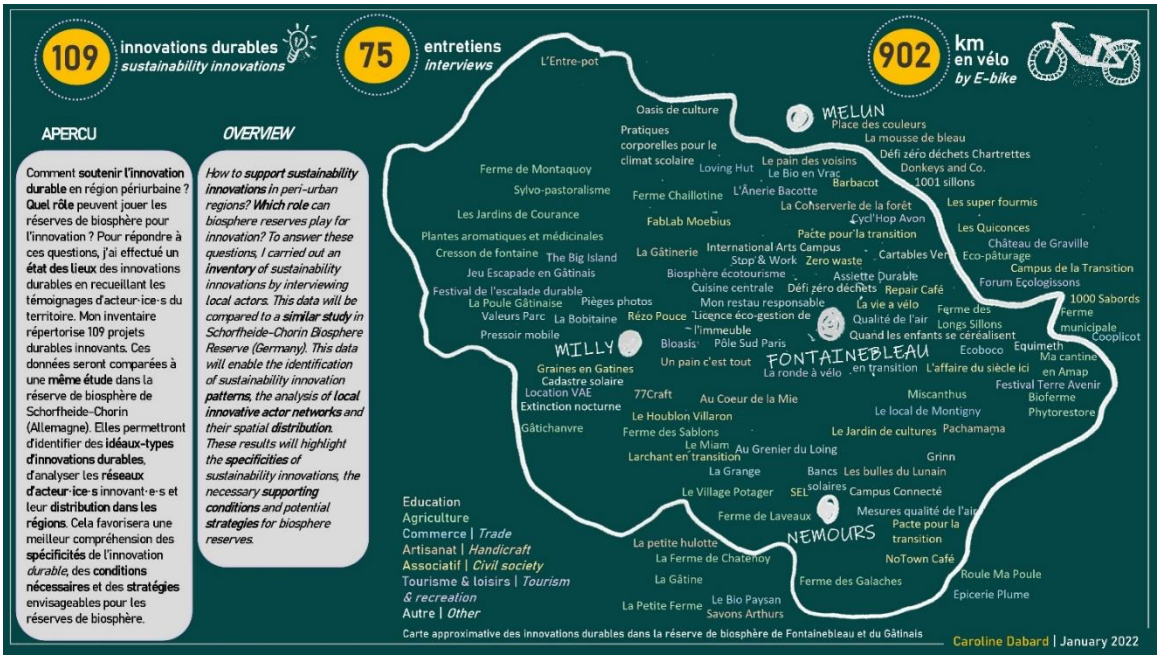
Chapter 3: Dabard, C.H.; Mann, C.; Martín-López, B. (in press). An archetype analysis of sustainability innovations in Biosphere Reserves: insights for assessing transformative potential. Environmental Science and Policy

Chapter 4: Dabard, C.H.; Mann, C.; Martín-López, B. A social network analysis of sustainability innovations: values, rules and knowledge to enhance transformative potential. (unpublished)

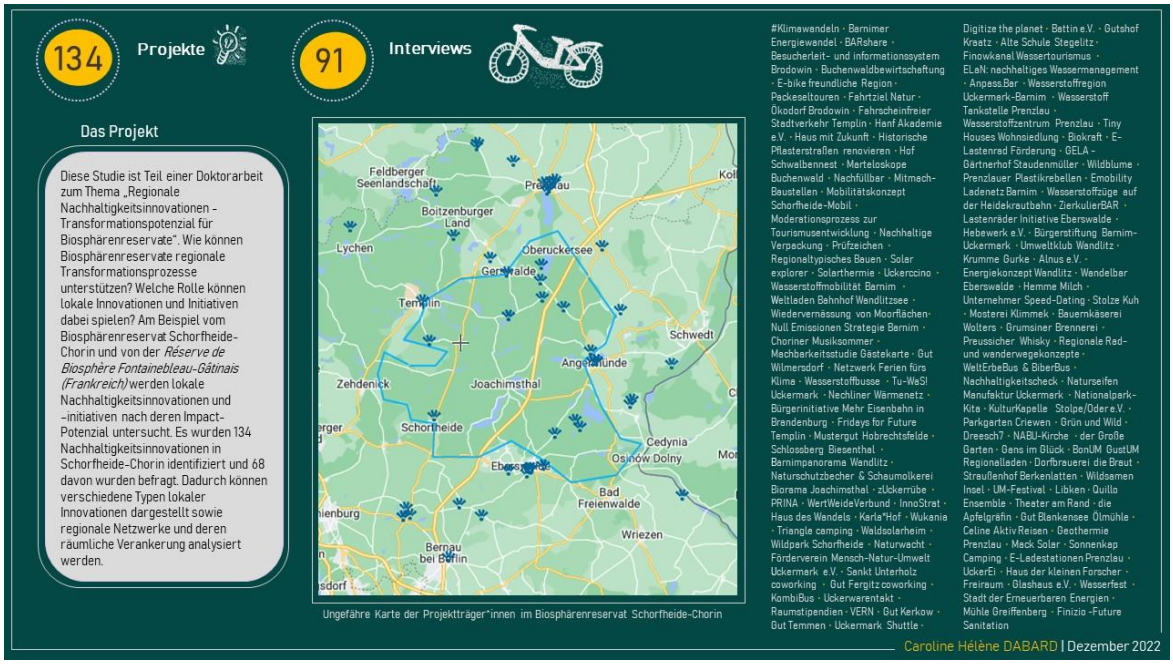
Chapter Nb.	Journal and publication status	Specific contributions	Author status and weighting factor
2	Sustainability Science, published	**Caroline Hélène DABARD:** Conceptualization, methodology, Investigation, Formal Analysis, Writing – original draft, Writing - review and editing Carsten MANN: Conceptualization, Methodology, Writing - review and editing, Supervision.	First author with predominant contribution (1.0)
3	Environmental Science and Policy, in press	**Caroline Hélène DABARD:** Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Visualization, Writing – original draft Carsten MANN: Conceptualization, Supervision, Writing – original draft, Writing - review & editing Berta MARTÍN-LÓPEZ: Conceptualization, Methodology, Formal analysis, Supervision, Writing – original draft, Writing - review & editing	First author with predominant contribution (1.0)
4	To be submitted at Ambio	**Caroline Hélène DABARD:** Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Visualization, Writing – original draft Carsten MANN: Conceptualization, Supervision, Writing – original draft, Writing - review & editing Berta MARTÍN-LÓPEZ: Conceptualization, Methodology, Supervision, Writing - review & editing	First author with predominant contribution (1.0)

A.2 Societal outreach flyers

Flyer 1: thank you note to interviewees and relevant people for data collection in FGBR – January 2022



Flyer 2: thank you note to interviewees and relevant people for data collection in SCBR – December 2022


134
Projekte
91
Interviews
Das Projekt
Diese Studie ist Teil einer Doktorarbeit zum Thema „Regionale Nachhaltigkeitsinnovationen - Transformationspotenzial für Biosphärenreservate". Wie können Biosphärenreservate regionale Transformationsprozesse unterstützen? Welche Rolle können lokale Innovationen und Initiativen dabei spielen? Am Beispiel vom Biosphärenreservat Schorfheide-Chorin und von der Réserve de Biosphère Fontainebleau-Gâtinais (Frankreich) werden lokale Nachhaltigkeitsinnovationen und -initiativen nach deren Impact-Potenzial untersucht. Es wurden 134 Nachhaltigkeitsinnovationen in Schorfheide-Chorin identifiziert und 68 davon wurden befragt. Dadurch können verschiedene Typen lokaler Innovationen dargestellt sowie regionale Netzwerke und deren räumliche Verankerung analysiert werden.
Feldberger Seenlandschaft
Boitzenburger Land
Lychen
Oberuckersee
Templin
Schwedt
Zehdenick
Joachimsthal
Schorfheide
Cedynia
Osinów Dolny
Bad Freienwalde
Wriezen
Bernau bei Berlin
Ungefähre Karte der Projektträger*innen im Biosphärenreservat Schorfheide-Chorin
#Klimawandeln · Barnimer Energiewendel · BARshare · Besucherleit- und informationssystem Brodowin · Buchenwaldbewirtschaftung · E-bike freundliche Region · Packseltouren · Fahrtziel Natur · Ökodorf Brodowin · Fahrscheinfreier Stadtverkehr Templin · Hanf Akademie e.V. · Haus mit Zukunft · Historische Pflasterstraßen renovieren · Hof Schwalbennest · Marteloskope Buchenwald · Nachfüllbar · Mitmech-Baustellen · Mobilitätskonzept Schorfheide-Mobil · Moderationsprozess zur Tourismusentwicklung · Nachhaltige Verpackung · Prüfzeichen · Regionaltypisches Bauen · Solar explorer · Solarthermie · Uckerccino · Wasserstoffmobilität Barnim · Weltladen Bahnhof Wandlitzsee · Wiedervernässung von Moorflächen-Null Emissionen Strategie Barnim · Choriner Musiksommer · Machbarkeitsstudie Gästekarte · Gut Wilmersdorf · Netzwerk Ferien fürs Klima · Wasserstoffbusse · Tu-WaSI Uckermark · Nechliner Wärmenetz · Bürgerinitiative Mehr Eisenbahn in Brandenburg · Fridays for Future Templin · Mustergut Hobrechtsfelde · Schlossberg Biesenthal · Barnimpanorama Wandlitz · Naturschutzbecher & Schaumolkerei Biorama Joachimsthal · zUckerrübe · PRINA · WertWeideVerbund · InnoStrat · Haus des Wandels · Karla*Hof · Wukania · Triangle camping · Waldsolarheim · Wildpark Schorfheide · Naturwacht · Förderverein Mensch-Natur-Umwelt Uckermark e.V. · Sankt Unterholz coworking · Gut Fergitz coworking · KombiBus · Uckerwarentakt · Raumstipendien · VERN · Gut Kerkow · Gut Temmen · Uckermark Shuttle · Digitize the planet · Bettin e.V. · Gutshof Kreatz · Alte Schule Stegelitz · Finowkanal Wassertourismus · ELaN: nachhaltiges Wassermanagement · Anpass.Bar · Wasserstoffregion Uckermark-Barnim · Wasserstoff Tankstelle Prenzlau · Wasserstoffzentrum Prenzlau · Tiny Houses Wohnsiedlung · Biokraft · E-Lastenrad Förderung · GELA - Gärtnerhof Staudenmüller · Wildblume · Prenzlauer Plastikrebellen · Emobility Ladenetz Barnim · Wasserstoffzüge auf der Heidekrautbahn · ZierkulierBAR · Lastenräder Initiative Eberswalde · Hebewerk e.V. · Bürgerstiftung Barnim-Uckermark · Umweltklub Wandlitz · Krumme Gurke · ALnus e.V. · Energiekonzept Wandlitz · Wandelbar Eberswalde · Hemme Milch · Unternehmer Speed-Dating · Stolze Kuh · Mosterei Klimmek · Bauernkäserei Wolters · Grumsiner Brennerei · Preussicher Whisky · Regionale Rad- und wanderwegekonzepte · WeltErbeBus & BiberBus · Nachhaltigkeitscheck · Naturseifen Manufaktur Uckermark · Nationalpark-Kita · KulturKapelle Stolpe/Oder e.V. · Parkgarten Criewen · Grün und Wild · Dreesch7 · NABU-Kirche - der Große Garten · Gans im Glück · BonUM. GustUM Regionalladen · Dorfbrauerei die Braut · Straußenhof Berkenlatten · Wildsamen Insel · UM-Festival · Libken · Quillo Ensemble · Theater am Rand · die Apfelgräfin · Gut Blankensee Ölmühle · Celine Aktiv Reisen · Geothermie Prenzlau · Mack Solar · Sonnenkap Camping · E-Ladestationen Prenzlau · UckerEi · Haus der kleinen Forscher · Freiraum · Glashaus e.V. · Wasserfest · Stadt der Erneuerbaren Energien · Mühle Greiffenberg · Finizio -Future Sanitation
Caroline Hélène DABARD | Dezember 2022


Zeitplan
2022 Veröffentlichung des analytischen Rahmens
2023 Analysen und Veröffentlichungen
2024 Projektende und Verteidigung der Dissertation
Publikation
Dabard, C. H. & Mann, C. (2022) Sustainability innovations. A proposal for an analytical framework and it empirical application in the Schorfheide-Chorin Biosphere Reserve. Sustain Sci. https://doi.org/10.1007/s11625-022-01241-9
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Flyer 3: preparatory notes for a flyer in March 2024

At the time of thesis submission, the flyer is not achieved. The flyer should be prepared in three versions: French, German, English. The flyer will comprise 5-7 slides covering the following points through icons, figures, photos and text:

- Acknowledgements of interviewees and relevant actors and organisations for their support to the research
- Overview of the research aims and questions
- Overview of methods and timeline
- Summary of relevant results in lay language for practice and management, including propositions for reflection questions along the lines of Section. 4.3 in Chapter 1
    - Summary of what makes transformative potential
    - Summary of supportive conditions for most transformative sustainability innovations
    - Reflection points for enhancing transformative potential along shallow vs. deep impacts; and amplifying strategies
    - Reflection points for twisting supporting conditions along actors and values, processes and decision-making, and regional governance and networks
    - Reflection points for Biosphere Reserves administrations, Regional Nature Parks and similar public actors – along their supportive capacity for sustainability innovations and their potential bridging roles
- Examples of sustainability innovations, photos of the Biosphere Reserves
- Background information:
    - Short bio – 1 to 2 sentences about the author
    - Logos, adresses and where to find more informations, links to published papers, ResearchGate, BRI, HNEE and Leuphana

A.3 Appendix Chapter 3/ Paper 2

Appendix A.3 - Table of contents

Lists of interviews

Table A.1 Interviews with regional informants in SCBR

ID	Interviewee organisation	Interview date	Interview length	Interviewee age group	Gender
SCi1	Biosphärenreservat	03/03/2021	1:00	31-50 yrs	male
SCi2	Biosphärenreservat	15/03/2021	1:00	31-50 yrs	male
SCi3	Hochschule für Nachhaltige Entwicklung Eberswalde	23/03/2021	0:20	31-50 yrs	male
SCi4	Regionale Planungsgemeinschaft Uckermark-Barnim	24/03/2021	0:40	51-70 yrs	male
SCi5	Biosphärenreservat	09/04/2021	1:10	51-70 yrs	male
SCi6	Biosphärenreservat	04/05/2021	1:40	51-70 yrs	male
SCi7	Landkreisverwaltung Uckermark	14/03/2022	1:00	51-70 yrs	female
SCi8	Naturpark Barnim	18/03/2022	0:45	51-70 yrs	male
SCi9	Hochschule für Nachhaltige Entwicklung Eberswalde	22/03/2022	1:00	31-50 yrs	male
SCi10	Innovation Campus meBest	28/03/2022	0:35	18-30 yrs	female
SCi11	WITO Barnim	28/03/2022	0:25	51-70 yrs	female
SCi12	Tourismusmarketing Uckermark	30/03/2022	0:35	31-50 yrs	female
SCi13	Hochschule für Nachhaltige Entwicklung Eberswalde	05/04/2022	0:35	51-70 yrs	male
SCi14	Landkreisverwaltung Uckermark	07/04/2022	0:45	31-50 yrs	male
SCi15	Kreiswerke Barnim	11/04/2022	0:45	31-50 yrs	male
SCi16	Tourismusverein Angermünde	12/04/2022	0:50	51-70 yrs	female
SCi17a	LAG Uckermark e.V.	12/04/2022	1:10	31-50 yrs	female
SCi17b	LAG Uckermark e.V.	12/04/2022	1:10	51-70 yrs	female
SCi18	UM Festival	05/05/2022	0:30	51-70 yrs	female
SCi19	Stadtverwaltung Prenzlau	05/05/2022	1:00	31-50 yrs	female

Table A.2 Interviews with regional informants in FGBR

ID	Interviewee organisation	Interview date	Interview length	Interviewee age group	Gender
FGi1	Université Paris-Diderot	06/04/2021	00:45	51-70 yrs	female
FGi2	Pôle Sud Paris	14/04/2021	01:00	> 70 yrs	male
FGi3	Fédération des Associations du Sud Seine-et-Marne pour la Protection de la Vallée de la Seine	30/04/2021	01:40	31-50 yrs	male
FGi4	Ecotron	04/05/2021	00:40	31-50 yrs	male
FGi5	Parc natural régional du Gâtinais Francais	12/05/2021	01:40	51-70 yrs	female
FGi6	Réserve de Biosphère	10/06/2021	01:00	31-50 yrs	female
FGi7	Leader 77 Seine et Marne Attractivité	04/08/2021	01:15	18-30 yrs	female
FGi8	Parc natural régional du Gâtinais Francais / GAL Leader Gâtinais	04/08/2021	01:15	18-30 yrs	female
FGi9	coop cité	18/08/2021	00:40	51-70 yrs	male
FGi10a	Objectif Terre 77	26/08/2021	01:00	31-50 yrs	female
FGi10b	Objectif Terre 77	26/08/2021	01:00	51-70 yrs	male
FGi11	Communauté de Communes du Pays de Nemours	30/08/2021	00:50	51-70 yrs	male
FGi12	Réserve de Biosphère	11/10/2021	00:55	31-50 yrs	male
FGi13	Commune de Thomery	11/10/2021	01:10	> 70 yrs	male
FGi14	Commune de Nemours	12/10/2021	00:40	51-70 yrs	male
FGi15	Les champs des possibles	08/10/2021	00:15	31-50 yrs	male
FGi16	Villes en Transition	08/10/2021	00:15	31-50 yrs	male
FGi17	Commune d'Avon	02/11/2021	01:10	31-50 yrs	female

Table A.3 Surveyed sustainability innovations in SCBR

ID	Sustainability innovation	Interviewee organisation	Interview date	Interviewee age group	Gender
SCSI1	#Klimawandeln	Biosphärenreservat	28/06/2022	31-50 yrs	male
SCSI3	Barshare	Kreiswerke Barnim	02/06/2022	18-30 yrs	female
SCSI4	Besucherleit- und informationssystem Brodowin	Ökodorfverein Brodowin e.V.	19/08/2022	51-70 yrs	female
SCSI5	Buchenwaldbewirtschaftung	Biosphärenreservat	19/08/2022	51-70 yrs	male
SCSI6	E-bike freundliche Region	Biosphärenreservat	28/06/2022	51-70 yrs	male
SCSI7	Packeseltouren	Packeseltouren	14/06/2022	51-70 yrs	female
SCSI8	Fahrtziel Natur	Biosphärenreservat	28/06/2022	51-70 yrs	male
SCSI10	Fahrscheinfreier Stadtverkehr Templin	Stadtverwaltung Templin	03/08/2022	31-50 yrs	male
SCSI11	Hanf Akademie e.V.	Hanffaser Uckermark e.G	29/06/2022	51-70 yrs	male
SCSI12	Haus mit Zukunft	Hochschule für Nachhaltige Entwicklung Eberswalde	29/06/2022	31-50 yrs	male
SCSI13	Historische Pflasterstraßen	Biosphärenreservat	28/06/2022	51-70 yrs	male
SCSI18	Mobilitätskonzept Schorfheide-Mobil	Interlink GmbH	21/09/2022	51-70 yrs	female
SCSI19	Moderationsprozess zur Tourismusentwicklung	Biosphärenreservat	28/06/2022	51-70 yrs	male
SCSI20	Nachhaltige Verpackung	Carbonauten	15/06/2022	18-30 yrs	male
SCSI21	Prüfzeichen	Biosphärenreservat	28/06/2022	51-70 yrs	male
SCSI22	Regionaltypisches Bauen	Biosphärenreservat	28/06/2022	51-70 yrs	male
SCSI27	Wasserstoffmobilität Barnim	Kreiswerke Barnim	02/06/2022	31-50 yrs	female
SCSI33	Choriner Musiksommer	Choriner Musiksommer e.V.	16/08/2022	51-70 yrs	male
SCSI35	Machbarkeitsstudie Gästekarte	Tourismus Marketing Brandenburg	21/07/2022	31-50 yrs	male
SCSI37	Gut Wilmersdorf	Gut Wilmersdorf	14/09/2022	31-50 yrs	male
SCSI38	Netzwerk Ferien fürs Klima	Tourismus Marketing Uckermark	29/06/2022	31-50 yrs	female
SCSI39	Wasserstoffbusse	Uckermärkische Dienstleistungsgesellschaft	27/06/2022	51-70 yrs	male
SCSI41	Nechliner Wärmenetz	Enertrag	15/09/2022	51-70 yrs	male
SCSI45	Bürgerinitiative Mehr Eisenbahn in Brandenburg	BVB / Freie Wähler	11/08/2022	51-70 yrs	other
SCSI50	Mustergut Hobrechtsfelde	Förderverein Naturpark Barnim	09/08/2022	51-70 yrs	male
SCSI56	Biorama Joachimsthal	Biorama-Projekt	01/07/2022	51-70 yrs	female
SCSI59	zUckerrübe	Hochschule für Nachhaltige Entwicklung Eberswalde	08/07/2022	31-50 yrs	male
SCSI62	WertWeideVerbund	Hochschule für Nachhaltige Entwicklung Eberswalde	14/07/2022	31-50 yrs	female
SCSI64	InnoStrat	TU Berlin	07/07/2022	31-50 yrs	female
SCSI71	Triangle Camping	Triangle Camping	05/09/2022	51-70 yrs	female
SCSI72	Waldsolarheim	Förderkreis Waldschule Eberswalde e.V.	13/07/2022	51-70 yrs	female
SCSI73	Wildpark Schorfheide	Wildpark Schorfheide	26/07/2022	31-50 yrs	female
SCSI76	Sankt Unterholz coworking	Dathe & Biel GbR	16/09/2022	51-70 yrs	male

SCSI77	Gut Fergitz Coworking	Gut Fergitz	14/09/2022	31-50 yrs	female
SCSI79	KombiBus	Uckermärkische Dienstleistungsgesellschaft	27/06/2022	51-70 yrs	male
SCSI80	Uckerwarentakt	Hochschule für Nachhaltige Entwicklung Eberswalde	27/06/2022	31-50 yrs	female
SCSI81	Raumstipendien	Stadtverwaltung Angermünde	01/07/2022	31-50 yrs	male
SCSI83	VERN	Verein zur Erhaltung und Rekultivierung von Nutzpflanzen	13/09/2022	51-70 yrs	male
SCSI86	Uckermark Shuttle	Uckermärkische Dienstleistungsgesellschaft	27/06/2022	51-70 yrs	male
SCSI87	Digitize the planet	Digitize the planet e.V.	01/06/2022	31-50 yrs	female
SCSI88	Battin e.V.	Battin e.V.	29/06/2022	51-70 yrs	female
SCSI93	Finowkanal Wassertourismus	Unser Finowkanal e.V.	26/07/2022	> 70 yrs	male
SCSI94	ELaN: nachhaltiges Wassermanagement	Hochschule für Nachhaltige Entwicklung Eberswalde	13/09/2022	51-70 yrs	female
SCSI95	Anpass.Bar	Hochschule für Nachhaltige Entwicklung Eberswalde	08/07/2022	31-50 yrs	female
SCSI96	Wasserstoffregion Uckermark-Barnim	Regionale Planungsgemeinschaft Uckermark-Barnim	19/09/2022	31-50 yrs	male
SCSI99	Tiny Houses Wohnsiedlung	Gemeinde Milmersdorf	16/09/2022	51-70 yrs	female
SCSI103	Wildblume	Wildblume - Naturkost & Bistro	29/06/2022	31-50 yrs	male
SCSI105	Emobility Ladenetz Barnim	Kreiswerke Barnim	02/06/2022	31-50 yrs	female
SCSI107	ZierkulierBAR	Fraunhofer Center for Responsible Research and Innovation	08/09/2022	31-50 yrs	female
SCSI110	Bürgerstiftung Barnim-Uckermark	Bürgerstiftung Barnim-Uckermark	13/07/2022	51-70 yrs	male
SCSI112	Krumme Gurke	Krumme Gurke	08/06/2022	31-50 yrs	female
SCSI115	Wandelbar Eberswalde	Transition Initiative WandelBar	15/06/2022	31-50 yrs	male
SCSI117	Unternehmer Speed-Dating	Tourismusverein Angermünde	18/08/2022	51-70 yrs	female
SCSI120	Bauernkäserei Wolters	Bauernkäserei Wolters	13/07/2022	> 70 yrs	male
SCSI124	WeltErbeBus & BiberBus	Tourismusverein Angermünde	22/08/2022	51-70 yrs	female
SCSI125	Nachhaltigkeitscheck	Tourismusverein Angermünde	18/08/2022	51-70 yrs	female
SCSI129	KulturKapelle Stolpe/Oder e.V.	KulturKapelle Stolpe/Oder e.V.	26/09/2022	> 70 yrs	female
SCSI131	Grün und Wild	Grün und Wild	01/07/2022	51-70 yrs	female
SCSI132	Dreesch7	Dreesch7	17/06/2022	51-70 yrs	female
SCSI133	NABU-Kirche	Aktionskreis NABU-Kirche Neu Temmen	08/07/2022	51-70 yrs	male
SCSI134	der Große Garten	Der Große Garten	12/09/2022	31-50 yrs	female
SCSI137	Dorfbrauerei die Braut	Die braut Dorfbrauerei Stegelitz GmbH	13/09/2022	31-50 yrs	female
SCSI140	UM-Festival	Freunde der Uckermark e.V.	14/09/2022	51-70 yrs	female
SCSI142	Quillo Ensemble	Quillo e.V.	19/09/2022	51-70 yrs	female
SCSI153	Haus der kleinen Forscher	Landkreis Uckermark	22/06/2022	18-30 yrs	female
SCSI154	Freiraum	Angermünder Bildungswerk e.V.	28/07/2022	51-70 yrs	male
SCSI155	Glashaus e.V.	Glashaus Prenzlau	22/06/2022	31-50 yrs	female
SCSI158	Mühle Greiffenberg	Verein zur Förderung von Landwirtschaft, Handwerk und Kultur e.V.	12/09/2022	51-70 yrs	male

Table A.4 Surveyed sustainability innovations in FGBR

ID	Sustainability innovation	Interviewee organisation	Interview date	Interviewee age group	Gender
FGSI1	Campus Connecté Pays de Nemours	Commune de Nemours	20/10/2021	31-50 yrs	female
FGSI2	La Grange	La Grange	20/10/2022	31-50 yrs	female
FGSI3	Le Bio Paysan	Le Bio Paysan	28/10/2021	31-50 yrs	male
FGSI4	La Gâtine	Gâtinorge	28/10/2021	51-70 yrs	female
FGSI5	Ferme des Sablons	Ferme des Sablons	03/11/2021	31-50 yrs	male
FGSI6	Ferme de Laveaux	Ferme de Laveau	04/11/2021	18-30 yrs	male
FGSI7	La petite hulotte	La petite hulotte	04/11/2021	31-50 yrs	female
FGSI8	Pacte pour la transition Nemours	Pacte pour la transition Nemours	05/11/2021	51-70 yrs	female
FGSI9	Au Grenier du Loing	Au Grenier du Loing	05/11/2021	31-50 yrs	female
FGSI10	Le Jardin de cultures	Le Jardin de cultures	08/11/2021	31-50 yrs	male
FGSI11	Assiette Durable	Ethic Ocean	08/11/2021	31-50 yrs	female
FGSI12	Pôle Sud Paris	Pôle Sud Paris	02/11/2021	>70 yrs	male
FGSI13	Campus de la Transition	Campus de la Transition	02/11/2021	31-50 yrs	male
FGSI14	International Arts Campus	International Arts Campus	09/11/2021	31-50 yrs	male
FGSI15	La vie a vélo	La vie à vélo Avon	09/11/2021	31-50 yrs	male
FGSI16	Ma cantine en Amap	Réseau AMAP	09/11/2021	31-50 yrs	female
FGSI17	Les super fourmis	Les super fourmis	10/11/2021	18-30 yrs	female
FGSI18	Oasis de culture	Collège Doisneau	08/11/2021	51-70 yrs	male

FGSI19	Pratiques corporelles pour amélioration du climat scolaire	Collège Doisneau	08/11/2021	51-70 yrs	male
FGSI20	Cuisine centrale	Communauté d'Agglomération du Pays de Fontainebleau	15/11/2021	31-50 yrs	female
FGSI21	Bioferme Phytorestore	Phytorestore	16/11/2021	51-70 yrs	male
FGSI22	1001 sillons	1001 sillons	16/11/2021	31-50 yrs	female
FGSI23	Repair Café Avon	Repair Café Avon	16/11/2021	31-50 yrs	male
FGSI24	Stop & Work Fontainebleau	IWG	18/11/2021	31-50 yrs	female
FGSI25	Ferme municipale	Commune de Varennes-sur-Seine	18/11/2021	51-70 yrs	male
FGSI26	Festival Terre Avenir	SMICTOM	19/11/2021	31-50 yrs	female
FGSI27	Grinn	Grinn	19/11/2021	31-50 yrs	female
FGSI28	Licence pro éco-gestion de l'immeuble	UPEC	22/11/2021	51-70 yrs	male
FGSI29	La Conserverie de la forêt	La Conserverie de la forêt	22/11/2021	31-50 yrs	female
FGSI30	Le local de Montigny	Le Local	22/11/2021	31-50 yrs	male
FGSI31	Gâtichanvre	Gâtichanvre	29/11/2021	31-50 yrs	male
FGSI32	Quand les enfants se céréalisent	Communauté d'Agglomération du Pays de Fontainebleau	29/11/2021	31-50 yrs	male
FGSI33	Extinction nocturne	Parc Naturel Régional du Gâtinais Francais	29/11/2021	31-50 yrs	male
FGSI34	L'affaire du siècle ici (77)	Collectif Affaire du siècle ici (77)	02/12/2021	>70 yrs	male
FGSI35	Le pain des voisins	Le pain des voisins	03/12/2021	31-50 yrs	female
FGSI36	Le Bio en Vrac	Le Bio en Vrac	03/12/2021	31-50 yrs	female
FGSI37	Le Barbacot	Le Barbacot	03/12/2021	31-50 yrs	female
FGSI38	Pièges photos	Parc Naturel Régional du Gâtinais Francais	06/12/2021	18-30 yrs	female
FGSI39	Graines en Gatines	Graines en Gâtines	07/12/2021	51-70 yrs	female
FGSI40	La Bobitaine	Parc Naturel Régional du Gâtinais Francais	07/12/2021	18-30 yrs	female
FGSI41	Savons Arthur	Savons Arthur	09/12/2021	18-30 yrs	female
FGSI42	Fontainebleau en transition	Commune de Fontainebleau	10/12/2021	31-50 yrs	male
FGSI43	L'Ânerie Bacotte	L'Ânerie Bacotte	13/12/2021	51-70 yrs	male
FGSI44	Rézo Pouce	Parc Naturel Régional du Gâtinais Francais	07/12/2021	18-30 yrs	male
FGSI45	Mise à disposition de VAE	Parc Naturel Régional du Gâtinais Francais	07/12/2021	18-30 yrs	male
FGSI46	Jeu Escapade en Gâtinais	Parc Naturel Régional du Gâtinais Francais	07/12/2021	18-30 yrs	male
FGSI47	Ecoboco	Ecoboco	14/12/2021	31-50 yrs	female
FGSI48	FabLab Moebius	FabLab Moebius	14/12/2021	31-50 yrs	male
FGSI49	Bloasis	Bloasis	15/12/2021	51-70 yrs	male
FGSI50	The Big Island	The Big Island	16/12/2021	31-50 yrs	female
FGSI51	Biosphère écotourisme	Réserve de biosphère	17/12/2021	31-50 yrs	female
FGSI52	La ronde à vélo	Réserve de biosphère	17/12/2021	31-50 yrs	female
FGSI53	La Petite Ferme	La Petite Ferme	17/12/2021	31-50 yrs	female
FGSI54	Le Village Potager	Le Village Potager	06/01/2022	51-70 yrs	female
FGSI55	La Poule Gâtinaise	Parc Naturel Régional du Gâtinais Francais	06/12/2021	18-30 yrs	female
FGSI56	Filière des plantes aromatiques et médicinales	ADEPAM	07/12/2021	18-30 yrs	female
FGSI57	Valeurs Parc	Parc Naturel Régional du Gâtinais Francais	07/01/2022	18-30 yrs	female
FGSI58	Cresson de fontaine	Parc Naturel Régional du Gâtinais Francais	07/01/2022	18-30 yrs	female
FGSI59	Equimeth	CVE	07/01/2022	31-50 yrs	male
FGSI60	Pressoir mobile	Parc Naturel Régional du Gâtinais Francais	07/01/2022	31-50 yrs	female
FGSI61	Loving Hut	Loving Hut	07/12/2021	31-50 yrs	male

Interview guideline for regional informants (English)

A) Introduction by interviewer

1) Thanking the interviewee. - Thank you very much for being here and taking time for this interview. I was told by [...] that you could tell me more about current projects, initiatives, innovations in the region. I would first outline my project and then get into the topic and questions.

2) Asking for consent about video recording and informing about the use of the anonymised collected data and that the interviewee can ask for the data to be deleted any time.

3) Introducing the project. – Introducing the Biosphere Reserves Institute at the HNE Eberswalde – Introducing the Ph.D. project on sustainability innovations in the context of biosphere reserves and the two case study regions. Topic: what projects, actors, networks are out there, what kind of sustainability innovations develop. Sub-topic: to what extent rural-urban linkages play a role - whether the proximity of a big city like Berlin/ Paris has an influence on regional innovation and how.

4) Introducing the interview context. - The first phase of the study in SCBR/FGBR is an inventory of regional projects/innovations through a snowball approach in which I ask different actors who are well established in and know the region well.

B) Introduction of the interviewee

Q1) What are your tasks in [organisation] and what does [the organisation] do?

C) Defining sustainability innovations and giving first examples

Q2) What do you associate with sustainability innovation? How do you understand sustainability innovation? Do you have any examples?

D) Searching for sustainability innovations developed by the interviewee's organisation

Q3) Does [your organisation] itself have projects that can be described as sustainability innovations?

E) Searching for sustainability innovations in the region, developed by other organisations

Q4) What other innovative, sustainable projects do you know of in the region? ...
- e.g. in municipal policy and regional planning
- in the energy sector
- in education
- in forestry
- in agriculture
- in services
- in products
- in tourism
- in the health sector
- in water/ waste sector

Q5) Do you know of local initiatives, citizens' initiatives for sustainable development in the region? Do you know of new networks and partnerships? New actors and players?

F) Sustainability innovations and urban-rural linkages

Q6) What do you think with regards to the topic of sustainability innovations and urban-rural relations? What do you associate with urban-rural linkages? What do you think of the influence of the city on the region and of the influence of the region on the city?

G) Further potential informants

Q7) Do you know someone who is well connected in the region and knows about sustainability? Someone I could ask if they know of initiatives and innovations?

H) Sociological questions

Q8 - How old are you?
- <18
- 18-30
- 31-50
- 51-70

- >70
- No answer

Q9 - What is your gender?
- female
- male
- non-binary/intersex
- no answer

Q10 - What is your nationality?

Q11 - What is your highest level of education?
- none
- Elementary school diploma
- Mittlere Reife/ CAP, BEP
- High school diploma
- Vocational training
- Bachelor's degree or equivalent
- Master's degree or equivalent
- Doctorate
- other
- No answer

I) Outro
Thanking the interviewee and asking whether they want to be informed about results and if so, noting their contact data.

Survey for sustainability innovations (English)

Thank you for your participation!

Through interviews with regional informants, approximately 150 sustainability innovations in and around the biosphere reserve were identified in spring 2022. This questionnaire aims to identify trends and typical characteristics among these many projects, as well as to discover regional networks. This study is part of a PhD thesis on "Transformation potential of UNESCO Biosphere Reserves - regional sustainability innovations in peri-urban areas". The survey is conducted by Caroline Dabard (research staff and PhD student at HNEE), and two master students at HNEE and research assistants at the Biosphere Reserves Institute. The questionnaire will take about 40 minutes to complete. Please try to answer all questions if possible. Your answers will be anonymized, aggregated and used for research purposes only. By answering this questionnaire, you consent to the anonymized storage of your data and its processing for research purposes. You can request the destruction of the recorded data at any time. If you have any questions, please contact: caroline.dabard@hnee.de

Section 1: Project overview
Q1 - What project or organization do you represent? *(Actor, type)**

**Note: Q1 to Q16 are used for the analyses presented in this study. (Targeted dimension, variable)*
Q2 - Please explain in a few words what the project is, how it came about, what it is all about.... *(Actor, values; Process, actions)*

Q3 - Tell us what goals, mission or values underlie the project. *(Actor, values; Process,*

actions)

Q4 - In which year did the project begin? *(Process, stage)*

Q5 - At what stage is the project currently? *(Process, stage)*

- o Conceptualisation
- o Experiments, first steps, trials
- o Growth, implementation
- o Stabilisation, Repetition
- o Dissemination, application in other contextsProjekt beendet
- o Failed
- o Other _____

Section 2: Actors' characteristics

Q6 - To which sector do you assign your activities? *(Actor, sector)*

- o Construction, housing
- o Mining
- o Education
- o Waste
- o Fishing
- o Services
- o Energy
- o Forestry
- o Health
- o Trade
- o Industry, production of manufactured goods
- o ICT
- o Agriculture, livestock production
- o Food and beverage production
- o Media
- o Mobility
- o public services and administration
- o Tourism, recreation, arts
- o Nature conservation
- o Waster
- o Science
- o Civil society
- o Other _____

Q7 - How do you rate the availability of the following resources for the project? *(Actor, resources)*

	Not enough	Enough	More than enough	Not relevant
Financial resources	❑	❑	❑	❑
Material resources (e.g. tools, offices…)	❑	❑	❑	❑
Human resources (e.g. staff, volunteers…)	❑	❑	❑	❑
Expertise, knowledge, skills	❑	❑	❑	❑
Ecological resources (e.g. land, plants…)	❑	❑	❑	❑

Q8 - Who is involved in the project? (Who are the project sponsors? Are there partner

and/or funding organizations? Who is responsible? Are there volunteers, staff?) *(Actor, type)*

Q9 - How many people are actively involved in the project? *(Actor, number)*

Q10 - What is the usual way of decision-making? *(Process, decision-making)*

- o Information: Responsible persons make decision and inform the team or the partners
- o Consultation: Responsible parties consult the team or partners before making decisions
- o Cooperation: all team members and partners participate equally in the decision-making process
- o Other _____

Q11 - How much time do actors spend sharing knowledge, learning and reflecting on experiences? (e.g. through meetings, seminars, informal discussions, site visits, ...) *(Process, learning)*

- o Enough time and often enough
- o Not enough time or not often enough
- o Too much time or too often
- o Other _____

Section 3: Innovative impacts

Q12 - At what scale is the project novel? *(Outcome, scale)*

- o Regional scale
- o National scale
- o International scale
- o The project is part of a movement of similar projects

Q13 - What is new in the project? *(Outcome, type)*

- o New service
- o New product
- o New market
- o New sector
- o New values
- o New norms
- o New behaviour
- o New technology
- o New organisation
- o Other _____

Q14 - Can you elaborate further on what exactly is new about the project? *(Outcome, type)*

Q15 - How do you build up the project? Are you currently striving more for the... *(Outcome, amplifying)*

- o Stabilization and growth of the project (e.g., in activities, members, resources)
- o Transfer or duplication of the project in other contexts
- o Changing the rules, mentalities and structures of which the project is a part
- o Other _____

Q16 - What is sustainable about the project? *(Outcome, impacts)*

Section 4: Relationship with the Biosphere Reserve admnistration

Q17 - Did you know that you are in the Schorfheide-Chorin Biosphere Reserve (or its surroundings)?

- o No
- o Yes
- o Not relevant

Q18 - If yes: the biosphere reserve administration....

- o has no influence on the project
- o hinders the project
- o finances the project
- o is a project partner
- o shares knowledge and expertise
- o shares material resources
- o shares human resources
- o is in informal exchange with you
- o Other _____

Q19 - More details on your contact with the biosphere reserve administration?

Section 5: Networks

Q22- Do you cooperate, participate in projects, networks or lobbying at a higher level?

- o No
- o Yes, at regional scale
- o Yes, at national scale
- o Yes, at international scale

Section 6: Sociological questions

Q23 - How old are you?

- o <18
- o 18-30
- o 31-50
- o 51-70
- o >70
- o No answer

Q24 - What is your gender?

- o female
- o male
- o non-binary/intersex
- o no answer

Q25 - What is your nationality?

Q26 - What is your highest level of education?

- o none
- o Elementary school diploma
- o Mittlere Reife/ CAP, BEP
- o High school diploma
- o Vocational training
- o Bachelor's degree or equivalent
- o Master's degree or equivalent
- o Doctorate
- o other

Identification of sustainability innovation archetypes

Description of Multiple Correspondance Analysis (MCA) axes and scores in SCBR

Schorfheide-Chorin Biosphere Reserve. The MCA conducted with the *outcomes* variables resulted in 5 components explaining 71.1% of the accumulated variance (Table B.1.). The first MCA component (F1, 32.6% of variance) captured differences in purpose: positive scores were associated with business innovations and negative scores associated with innovations aimed for equity and democratic governance. The second component (F2, 27.6%) represented the diversity of innovations based on type and scale, in which social-ecological innovations were captured by its positive scores and local social innovations by its negative scores. The third component (F3, 4.9%) captured differences in types of innovations, with positive scores identifying technological innovations and negative scores identifying social-ecological innovations. The fourth component (F4, 3.2%) associated positive scores with new products and social-ecological systems and negative scores with behavioural innovations enhancing livelihood opportunity and sufficiency. The fifth component (F5, 2.7%) differentiated behavioural and product innovations with, respectively, positive or negative scores.

Table B.1. Variables scores for the nine components derived from the MCA in SCBR. The percentages indicate the percentage of variance. * indicate the components that were used in the Hierarchical Cluster Analysis (HCA)

Variable/ MCA component	F1* (36.7%)	F2* (27.6%)	F3* (4.9%)	F4* (3.2%)	F5* (2.7%)	F6 (1.6%)	F7 (0.5%)	F8 (0.1%)	F9 (≥0.0%)
1. Type									
New organisation-0	0.138	-0.054	0.002	-0.015	0.011	-0.036	0.019	-0.003	0.000
New organisation-1	-0.185	0.073	-0.002	0.020	-0.015	0.048	-0.025	0.004	0.000
New behaviour-0	-0.020	-0.066	-0.012	0.024	-0.032	0.009	0.006	-0.002	0.001
New behaviour-1	0.071	0.233	0.042	-0.083	0.114	-0.031	-0.023	0.008	-0.004
New market-0	-0.151	0.018	0.026	-0.010	0.000	-0.010	0.006	-0.002	0.001
New market-1	0.276	-0.033	-0.048	0.018	0.001	0.018	-0.010	0.004	-0.003
New service-0	0.062	0.165	-0.034	0.010	-0.010	-0.001	-0.049	0.004	0.003
New service-1	-0.036	-0.096	0.019	-0.006	0.006	0.001	0.028	-0.002	-0.002
New values-0	0.060	-0.107	0.018	-0.031	-0.025	0.040	-0.012	0.000	-0.004
New values-1	-0.045	0.080	-0.014	0.023	0.019	-0.029	0.009	0.000	0.003
New technology-0	-0.059	-0.039	-0.024	-0.004	0.005	-0.005	-0.002	-0.001	-0.002
New technology-1	0.341	0.227	0.136	0.025	-0.027	0.028	0.010	0.007	0.011
New sector, value chain-0	-0.052	-0.061	-0.020	0.002	-0.020	-0.014	-0.006	-0.002	0.001
New sector, value chain-1	0.222	0.256	0.085	-0.010	0.084	0.061	0.026	0.007	-0.003
New product-0	-0.035	-0.029	0.004	-0.019	0.016	-0.006	0.005	-0.001	0.000
New product-1	0.305	0.251	-0.034	0.164	-0.136	0.054	-0.043	0.009	-0.003
2. Amplifying									
Scale within-0	-0.108	0.522	-0.043	-0.054	-0.057	-0.099	0.022	-0.009	-0.003
Scale within-1	0.014	-0.070	0.006	0.007	0.008	0.013	-0.003	0.001	0.000
Scale out-0	0.022	-0.062	-0.043	0.015	0.019	0.016	-0.003	-0.007	0.000
Scale out-1	-0.062	0.173	0.118	-0.041	-0.052	-0.045	0.008	0.019	0.001
Scale beyond-0	-0.028	-0.111	0.008	0.033	0.018	0.002	0.003	0.004	-0.006
Scale beyond-1	0.040	0.159	-0.011	-0.047	-0.026	-0.002	-0.005	-0.006	0.009
3. Impacts									
Structural (physical) changes-0	-0.148	0.014	-0.022	-0.024	0.007	0.017	0.001	-0.006	0.002
Structural (physical) changes-1	0.198	-0.019	0.030	0.032	-0.010	-0.022	-0.001	0.008	-0.002
Structural (social) changes-0	0.260	-0.079	-0.012	0.006	-0.061	-0.058	0.000	-0.001	0.000
Structural (social) changes-1	-0.116	0.035	0.005	-0.003	0.027	0.026	0.000	0.000	0.000
Social-ecological integrity-0	-0.008	-0.064	0.021	-0.014	-0.007	0.002	-0.002	-0.003	0.002
Social-ecological integrity-1	0.044	0.372	-0.120	0.079	0.038	-0.014	0.010	0.018	-0.014
Livelihood sufficiency & opportunity-0	-0.044	-0.001	-0.013	0.032	-0.028	-0.002	0.007	0.000	0.001
Livelihood sufficiency & opportunity-1	0.187	0.004	0.055	-0.136	0.117	0.009	-0.030	0.002	-0.003
Intra- & intergenerational equity-0	0.035	0.012	-0.006	0.005	0.005	-0.002	-0.002	-0.006	-0.001
Intra- & intergenerational equity-1	-0.365	-0.123	0.060	-0.047	-0.055	0.019	0.022	0.066	0.009
Resource maintenance & efficient use-0	-0.192	0.040	-0.038	0.013	0.005	0.000	0.002	0.006	-0.002
Resource maintenance & efficient use-1	0.229	-0.048	0.045	-0.016	-0.005	0.000	-0.002	-0.008	0.002
Social-ecological stewardship & democratic governance-0	0.071	-0.060	-0.006	0.009	0.002	-0.003	0.004	0.005	0.001
Social-ecological stewardship & democratic governance-1	-0.250	0.211	0.022	-0.031	-0.008	0.011	-0.015	-0.018	-0.002
Precaution & adaptation-0	-0.013	-0.072	0.026	0.007	0.011	0.006	-0.004	0.001	0.001
Precaution & adaptation-1	0.070	0.375	-0.136	-0.036	-0.055	-0.029	0.023	-0.007	-0.005

4. Scale									
Local novelty-0	0.011	0.030	0.020	-0.019	-0.026	0.020	0.005	-0.001	-0.002
Local novelty-1	-0.051	-0.138	-0.093	0.091	0.123	-0.095	-0.024	0.007	0.009
Regional novelty-1	0.053	-0.060	-0.073	-0.100	-0.049	0.020	0.002	0.005	-0.002
National novelty-0	0.045	-0.020	-0.075	-0.021	0.015	0.007	0.005	0.004	0.003
National novelty-1	-0.100	0.046	0.168	0.047	-0.033	-0.016	-0.011	-0.009	-0.006
International novelty-0	-0.020	-0.039	0.006	-0.012	-0.009	-0.015	-0.008	0.000	-0.001
International novelty-1	0.175	0.342	-0.051	0.104	0.082	0.132	0.066	-0.004	0.009

Description of MCA axes and scores in FGBR

Fontainebleau-Gâtinais Biosphere Reserve. The first six components of the MCA explained 69.1% of the accumulated variance (Table B.2). The first MCA component (F1, 42.7% of variance) captured differences in types of sustainability innovations, with positive scores associated with sectoral and technological novelties, and with negative scores associated with social and equity-oriented innovations. The second component (F2, 9.8%) associated positive scores with new sectors and social-ecological integrity and negative scores with local innovations. The third component (F3, 8.1%) associated positive scores with equity-oriented business innovations and negative scores with local, social change. The fourth component (F4, 4.4%) distinguished between positive scores associated with technological novelties and negative scores associated with social-ecological systems transformation. The fifth component (F5, 2.5%) captured the implementation of transfer activities with positive scores and a focus on building livelihood opportunities with negative scores. The sixth component (F6, 1.6%) distinguished between livelihood opportunities and precaution strategies associated with positive scores and duplicating initiatives associated with negative scores.

Table B.2. Variables scores for the ten components derived from the MCA in FGBR. The percentages indicate the percentage of variance. * indicate the components that were used in the Hierarchical Cluster Analysis (HCA)

Variable/ MCA component	F1* (42.7%)	F2* (9.8%)	F3* (8.1%)	F4* (4.4%)	F5* (2.5%)	F6* (1.6%)	F7 (0.8%)	F8 (0.1%)	F9 (0.1%)	F10 (≥0.0%)
1. Type										
New organisation-0	-0.021	-0.116	-0.009	0.109	-0.019	-0.042	-0.018	0.002	-0.001	-0.003
New organisation-1	0.009	0.052	0.004	-0.049	0.009	0.019	0.008	-0.001	0.000	0.001
New behaviour-0	0.091	0.013	0.008	-0.017	-0.026	-0.003	0.002	0.007	-0.001	0.000
New behaviour-1	-0.187	-0.026	-0.016	0.034	0.053	0.007	-0.004	-0.015	0.002	-0.001
New market-0	0.009	0.041	-0.069	0.022	0.004	-0.003	0.004	-0.005	0.002	-0.001
New market-1	-0.023	-0.097	0.164	-0.052	-0.010	0.007	-0.010	0.013	-0.005	0.002
New service-0	0.175	0.022	-0.039	-0.014	0.006	-0.011	-0.026	-0.009	-0.011	-0.001
New service-1	-0.139	-0.017	0.031	0.011	-0.004	0.009	0.021	0.007	0.009	0.000
New values-0	0.136	-0.017	-0.023	0.091	-0.041	-0.034	0.028	0.001	-0.003	0.003
New values-1	-0.071	0.009	0.012	-0.048	0.022	0.018	-0.015	0.000	0.002	-0.002
New technology-0	-0.040	0.011	-0.005	-0.012	-0.007	-0.004	-0.002	-0.001	0.000	0.000
New technology-1	0.769	-0.214	0.097	0.232	0.143	0.069	0.047	0.026	0.006	-0.005
New sector, value chain-0	-0.069	-0.029	0.007	-0.002	-0.002	-0.010	0.005	-0.002	-0.003	0.000
New sector, value chain-1	0.400	0.170	-0.039	0.012	0.014	0.056	-0.030	0.010	0.014	-0.003
New product-0	-0.032	0.003	0.005	0.002	0.012	0.005	0.015	0.002	0.003	0.000
New product-1	0.244	-0.024	-0.035	-0.014	-0.091	-0.036	-0.116	-0.013	-0.021	-0.001
2. Amplifying										
Scale within-0	0.215	-0.097	0.016	0.021	0.149	-0.050	-0.019	0.001	0.002	0.005
Scale within-1	-0.037	0.017	-0.003	-0.004	-0.026	0.009	0.003	0.000	0.000	-0.001
Scale out-0	-0.012	-0.022	0.000	-0.021	-0.019	0.019	0.007	0.002	-0.005	0.000
Scale out-1	0.051	0.088	0.000	0.084	0.076	-0.079	-0.029	-0.008	0.022	0.001
Scale beyond-0	0.072	0.015	-0.058	0.005	-0.028	-0.006	-0.004	0.004	0.004	0.000
Scale beyond-1	-0.148	-0.031	0.120	-0.011	0.058	0.012	0.007	-0.009	-0.008	-0.001
3. Impacts										
Structural (physical) changes-0	-0.133	0.014	-0.040	0.019	0.004	-0.002	-0.012	0.010	-0.002	0.001
Structural (physical) changes-1	0.192	-0.020	0.058	-0.027	-0.006	0.003	0.018	-0.014	0.002	-0.001
Structural (social) changes-0	0.227	-0.147	0.123	-0.011	-0.013	-0.041	0.006	0.009	0.002	-0.004

Structural (social) changes-1	-0.074	0.048	-0.040	0.003	0.004	0.013	-0.002	-0.003	-0.001	0.001
Social-ecological integrity-0	-0.057	-0.025	-0.004	0.007	-0.001	-0.003	-0.006	0.000	0.002	0.000
Social-ecological integrity-1	0.439	0.190	0.032	-0.055	0.009	0.021	0.043	0.000	-0.018	0.001
Livelihood sufficiency & opportunity-0	0.018	0.016	0.016	-0.008	0.018	-0.014	0.003	0.001	-0.005	0.000
Livelihood sufficiency & opportunity-1	-0.102	-0.090	-0.091	0.046	-0.105	0.082	-0.015	-0.004	0.026	-0.002
Intra- & intergenerational equity-0	0.027	-0.011	-0.014	-0.012	-0.002	-0.005	-0.001	0.003	0.001	0.001
Intra- & intergenerational equity-1	-0.304	0.124	0.161	0.137	0.019	0.058	0.014	-0.036	-0.008	-0.014
Resource maintenance & efficient use-0	-0.122	0.045	-0.069	0.049	-0.006	-0.026	0.029	0.005	-0.012	-0.001
Resource maintenance & efficient use-1	0.091	-0.033	0.051	-0.037	0.004	0.020	-0.022	-0.003	0.009	0.001
Social-ecological stewardship & democratic governance-0	0.040	-0.022	0.028	0.010	-0.027	-0.004	0.006	-0.006	0.001	0.000
Social-ecological stewardship & democratic governance-1	-0.135	0.073	-0.094	-0.034	0.091	0.013	-0.019	0.020	-0.003	0.000
Precaution & adaptation-0	-0.034	-0.009	-0.004	-0.017	-0.004	-0.011	0.003	-0.002	0.001	0.001
Precaution & adaptation-1	0.385	0.100	0.040	0.190	0.042	0.122	-0.032	0.024	-0.016	-0.012
4. Scale										
Local novelty-0	0.003	0.086	0.056	0.005	-0.011	-0.016	-0.001	0.001	0.002	0.000
Local novelty-1	-0.006	-0.189	-0.124	-0.011	0.025	0.036	0.001	-0.003	-0.005	0.000
Regional novelty-0	0.117	-0.085	-0.100	-0.039	0.019	0.006	0.015	-0.004	0.000	-0.002
Regional novelty-1	-0.106	0.077	0.091	0.035	-0.017	-0.005	-0.013	0.003	0.000	0.001
National novelty-0	-0.023	-0.012	0.010	0.022	-0.001	0.013	-0.004	-0.001	-0.002	0.002
National novelty-1	0.179	0.092	-0.077	-0.166	0.007	-0.102	0.035	0.004	0.013	-0.015
International novelty-0	-0.039	-0.008	0.000	-0.005	0.000	-0.004	-0.003	0.001	0.000	-0.001
International novelty-1	0.748	0.158	-0.004	0.087	0.006	0.072	0.052	-0.026	0.006	0.018

Table B.3. ANOVA tests to unravel differences of the MCA axes between HCA clusters in SCBR. Mean values with a, b or c display significant differences from one another based on pairwise comparison t-test with Bonferroni correction ($p < 0.01$).

MCA Axes	New Sectors for Social-ecological Transformation (*cluster 1*)	Social and Sustainable Entrepreneurs (*cluster 3*)	Social Innovations (*cluster 5*)	Service Innovations (*cluster 2*)	Participative Transformation Governance (*cluster 4*)
F1: business innovation vs. equity & stewardship	0.315^{a}	-0.027^{b}	-0.300^{c}	0.375^{a}	-0.442^{c}
F2: social-ecological systems vs. local, social innovation	0.491^{a}	-0.261^{b}	-0.131^{b}	-0.150^{b}	0.505^{a}
F3: technological vs. precaution and social-ecological integrity	0.162^{a}	-0.194^{b}	0.097^{a}	-0.097^{ab}	-0.038^{ab}
F4: new products and social-ecological integrity vs. new behaviour and livelihood sufficiency	0.063^{ab}	0.230^{a}	-0.016^{ab}	-0.106^{b}	-0.174^{b}
F5: behavioural vs. product innovation	0.200^{a}	0.296^{a}	-0.076^{b}	-0.150^{b}	-0.195^{b}

Table B.4. ANOVA tests to unravel differences of the MCA axes between HCA clusters in FGBR. Mean values with a, b or c display significant differences from one another based on pairwise comparison t-test with Bonferroni correction ($p < 0.01$)

MCA Axes	New Sectors for Social-ecological Transformation (*cluster 5*)	Social and Sustainable Entrepreneurs (*cluster 3*)	Social Innovations (*cluster 2*)	Service Innovations (*cluster 1*)	Technological Efficiency Innovations (*cluster 4*)	*F*
F1: sectoral & technological vs. social & equity-oriented innovation	0.248^{b}	-0.237^{c}	-0.154^{c}	-0.175^{c}	0.877^{a}	22.453
F2: new sectors for social-ecological integrity vs. local innovation	0.203^{a}	0.104^{a}	-0.278^{b}	0.029^{a}	-0.458^{b}	12.516
F3: social business vs. local, social change	-0.114^{bc}	0.316^{a}	-0.283^{c}	-0.006^{b}	0.158^{ab}	16.270
F4: technological vs. social-ecological change	-0.145^{b}	-0.057^{b}	-0.102^{b}	0.291^{a}	0.371^{a}	10.367
F5: transfer activities vs. building livelihood opportunities	0.025^{ab}	0.057^{ab}	-0.015^{ab}	-0.207^{b}	0.285^{a}	3.567
F6: livelihood opportunity & precaution strategies vs. duplicating initiatives	-0.107^{bc}	0.104^{ab}	0.186^{a}	-0.237^{c}	0.087^{abc}	8.380

c. Actors and processes underpinning archetypes

Table B.5. Distribution of outcomes, actors and processes variables within clusters in SCBR. Significance: *p < 0.1; **p < 0.05; ***p < 0.01.

Variables	New Sectors for Social-ecological Transformation (*cluster 1;* *n*=11; 16%)	Social and Sustainable Entrepreneurs (*cluster 3*; *n*=11; 16%)	Social Innovations (*cluster 5*; *n*=23; 34%)	Service Innovations (*cluster 2*; *n*=17; 25%)	Participative Transformation Governance (*cluster 4*; *n*=6; 9%)	Chi-squared test
Outcomes						
1. Type						
New organisation	*n*=4 ; 36%	*n*=3 ; 27%	*n*=16 ; 70%***	*n*=2 ; 12%***	*n*=4 ; 67%	χ^2=16.098***
New behaviour	*n*=7 ; 64%***	*n*=2 ; 18%	*n*=1 ; 4%**	*n*=3 ; 18%	*n*=2 ; 33%	χ^2=15.989***
New market	*n*=6 ; 55%	*n*=5 ; 45%	*n*=0 ; 0%***	*n*=13 ; 76%***	*n*=0 ; 0%*	χ^2=30.722***
New service	*n*=6 ; 55%	*n*=7 ; 64%	*n*=18 ; 78%	*n*=9 ; 53%	*n*=3 ; 50%	χ^2=3.819
New values	*n*=6 ; 55%	*n*=8 ; 73%	*n*=11 ; 48%	*n*=8 ; 47%	*n*=6 ; 100%**	χ^2=7.150
New technology	*n*=6 ; 55%***	*n*=0 ; 0%	*n*=1 ; 4%	*n*=3 ; 18%	*n*=0 ; 0%	χ^2=18.935***
New sector, value chain	*n*=10 ; 91%***	*n*=0 ; 0%	*n*=1 ; 4%**	*n*=2 ; 12%	*n*=0 ; 0%	χ^2=44.522***
New product	*n*=3 ; 27%*	*n*=0 ; 0%	*n*=0 ; 0%*	*n*=4 ; 24%*	*n*=0 ; 0%	χ^2=11.249**
2. Amplifying						
Scale within	*n*=8 ; 73%	*n*=11 ; 100%	*n*=23 ; 100%**	*n*=17 ; 100%	*n*=1 ; 17%***	χ^2=38.954***
Scale out	*n*=5 ; 45%	*n*=0 ; 0%**	*n*=5 ; 22%	*n*=3 ; 18%	*n*=5 ; 83%***	χ^2=16.909***
Scale beyond	*n*=6 ; 55%	*n*=2 ; 18%	*n*=8 ; 35%	*n*=7 ; 41%	*n*=5 ; 83%*	χ^2=8.004*
3. Impacts						
Structural (physical) changes	*n*=6 ; 55%	*n*=5 ; 45%	*n*=0 ; 0%*	*n*=12 ; 71%**	*n*=0 ; 0%**	χ^2=13.139**
Structural (social) changes	*n*=9 ; 82%	*n*=7 ; 64%	*n*=21 ; 91%***	*n*=5 ; 29%***	*n*=5 ; 83%	χ^2=19.415***
Social-ecological integrity	*n*=5 ; 45%***	*n*=2 ; 18%	*n*=0 ; 0%**	*n*=2 ; 12%	*n*=1 ; 17%	χ^2=12.499**
Livelihood sufficiency & opportunity	*n*=4 ; 36%	*n*=2 ; 18%	*n*=2 ; 9%	*n*=5 ; 29%	*n*=0 ; 0%	χ^2=6.321
Intra- & intergenerational equity	*n*=0 ; 0%	*n*=1 ; 9%	*n*=4 ; 17%	*n*=0 ; 0%	*n*=1 ; 17%	χ^2=5.268

Resource maintenance & efficient use	*n*=7 ; 64%	*n*=4 ; 36%	*n*=5 ; 22%***	*n*=14 ; 82%***	*n*=1 ; 17%	χ^2=18.382***
Social-ecological stewardship & democratic governance	*n*=2 ; 18%	*n*=0 ; 0%	*n*=8 ; 35%	*n*=0 ; 0%**	*n*=5 ; 83%***	χ^2=23.289***
Precaution & adaptation	*n*=4 ; 36%*	*n*=0 ; 0%	*n*=0 ; 0%**	*n*=3 ; 18%	*n*=4 ; 67%***	χ^2=21.175***
4. Scale						
Local novelty	*n*=0 ; 0%	*n*=11 ; 100%***	*n*=0 ; 0%***	*n*=0 ; 0%**	*n*=1 ; 17%	χ^2=62.266***
Regional novelty	*n*=1 ; 9%**	*n*=0 ; 0%***	*n*=10 ; 43%	*n*=15 ; 88%***	*n*=2 ; 33%	χ^2=28.121***
National novelty	*n*=4 ; 36%	*n*=0 ; 0%**	*n*=12 ; 52%**	*n*=2 ; 12%*	*n*=3 ; 50%	χ^2=13.893***
International novelty	*n*=6 ; 55%***	*n*=0 ; 0%	*n*=1 ; 4%	*n*=0 ; 0%	*n*=0 ; 0%	χ^2=28.108***
Actors						
1. Type						
Public organisation	*n*=10 ; 91%***	*n*=1 ; 9%***	*n*=13 ; 57%	*n*=9 ; 53%	*n*=3 ; 50%	χ^2=14.994***
Private organisation	*n*=8 ; 73%	*n*=9 ; 82%	*n*=10 ; 43%**	*n*=14 ; 82%	*n*=3 ; 50%	χ^2=9.145*
Civil society organisation	*n*=3 ; 27%	*n*=2 ; 18%	*n*=13 ; 57%**	*n*=4 ; 24%	*n*=2 ; 33%	χ^2=7.299
2. Sector						
Education	*n*=0 ; 0%	*n*=0 ; 0%	*n*=3 ; 13%**	*n*=0 ; 0%	*n*=0 ; 0%	χ^2=6.140
Energy	*n*=1 ; 9%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=0 ; 0%	χ^2=5.259
Trade	*n*=0 ; 0%	*n*=1 ; 9%	*n*=0 ; 0%	*n*=1 ; 6%	*n*=0 ; 0%	χ^2=3.185
Handicrafts, industry, goods production	*n*=1 ; 9%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=1 ; 6%	*n*=0 ; 0%	χ^2=3.185
ICT	*n*=1 ; 9%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=0 ; 0%	χ^2=5.259
Agriculture, livestock	*n*=0 ; 0%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=2 ; 12%*	*n*=0 ; 0%	χ^2=6.182
Food and beverages manufacturing	*n*=0 ; 0%	*n*=1 ; 9%	*n*=0 ; 0%	*n*=1 ; 6%	*n*=0 ; 0%	χ^2=3.185
Mobility	*n*=1 ; 9%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=1 ; 17%	χ^2=6.962
Public Administration and services	*n*=3 ; 27%	*n*=1 ; 9%	*n*=1 ; 4%*	*n*=6 ; 35%**	*n*=0 ; 0%	χ^2=9.519**
Tourism, Arts, Recreation	*n*=0 ; 0%	*n*=5 ; 45%*	*n*=7 ; 30%	*n*=3 ; 18%	*n*=0 ; 0%	χ^2=9.444*
Nature conservation	*n*=2 ; 18%	*n*=0 ; 0%	*n*=6 ; 26%*	*n*=1 ; 6%	*n*=0 ; 0%	χ^2=6.936
Science	*n*=2 ; 18%	*n*=0 ; 0%	*n*=0 ; 0%*	*n*=2 ; 12%	*n*=2 ; 33%*	χ^2=9.151*
Civil society	*n*=0 ; 0%	*n*=3 ; 27%	*n*=6 ; 26%	*n*=0 ; 0%**	*n*=3 ; 50%*	χ^2=12.150**
3. Resources						
Financial resources	*n*=6 ; 55%	*n*=5 ; 45%	*n*=10 ; 43%	*n*=6 ; 35%	*n*=4 ; 67%	χ^2=7.547
Material resources	*n*=9 ; 82%	*n*=7 ; 64%	*n*=16 ; 70%	*n*=8 ; 47%	*n*=3 ; 50%	χ^2=19.317**
Human Resources	*n*=6 ; 55%	*n*=1 ; 9%**	*n*=9 ; 39%	*n*=8 ; 47%	*n*=2 ; 33%	χ^2=13.507*
Expertise, skills	*n*=8 ; 73%	*n*=8 ; 73%	*n*=20 ; 87%	*n*=16 ; 94%	*n*=5 ; 83%	χ^2=3.494
Environmental resources	*n*=5 ; 45%	*n*=6 ; 55%	*n*=8 ; 35%	*n*=9 ; 53%	*n*=2 ; 33%	χ^2=4.294
4. Values						
Intrinsic values	*n*=4 ; 36%	*n*=3 ; 27%	*n*=5 ; 22%	*n*=5 ; 29%	*n*=3 ; 50%	χ^2=2.157
Relational values	*n*=4 ; 36%**	*n*=11 ; 100%**	*n*=20 ; 87%**	*n*=9 ; 53%	*n*=4 ; 67%	χ^2=16.352***
Instrumental values	*n*=7 ; 64%	*n*=2 ; 18%*	*n*=7 ; 30%	*n*=12 ; 71%**	*n*=2 ; 33%	χ^2=11.562**
Processes						
1. Actions						
Animal welfare	*n*=0 ; 0%	*n*=1 ; 9%	*n*=1 ; 4%	*n*=0 ; 0%	*n*=0 ; 0%	χ^2=2.647
Climate change	*n*=0 ; 0%	*n*=0 ; 0%	*n*=1 ; 4%	*n*=0 ; 0%	*n*=2 ; 33%**	χ^2=13.701***
Waste	*n*=2 ; 18%**	*n*=0 ; 0%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=0 ; 0%	χ^2=10.678**
Biodiversity	*n*=1 ; 9%	*n*=1 ; 9%	*n*=2 ; 9%	*n*=2 ; 12%	*n*=2 ; 33%	χ^2=3.049
Water	*n*=1 ; 9%	*n*=0 ; 0%	*n*=2 ; 9%	*n*=0 ; 0%	*n*=0 ; 0%	χ^2=3.141
Energy	*n*=3 ; 27%	*n*=1 ; 9%	*n*=1 ; 4%	*n*=4 ; 24%	*n*=0 ; 0%	χ^2=5.259
Mobility	*n*=3 ; 27%	*n*=0 ; 0%	*n*=2 ; 9%	*n*=6 ; 35%*	*n*=1 ; 17%	χ^2=6.962
Local food systems	*n*=0 ; 0%	*n*=2 ; 18%	*n*=3 ; 13%	*n*=4 ; 24%	*n*=0 ; 0%	χ^2=4.397
ESD & awareness raising	*n*=2 ; 18%	*n*=5 ; 45%	*n*=11 ; 48%	*n*=2 ; 12%**	*n*=3 ; 50%	χ^2=8.279*

Community-building	*n*=0 ; 0%**	*n*=5 ; 45%	*n*=10 ; 43%*	*n*=2 ; 12%	*n*=2 ; 33%	χ^2=10.995**
Wellbeing, lifestyle	*n*=0 ; 0%	*n*=5 ; 45%***	*n*=0 ; 0%*	*n*=1 ; 6%	*n*=0 ; 0%	χ^2=22.401***
Nature connectedness	*n*=0 ; 0%	*n*=3 ; 27%*	*n*=2 ; 9%	*n*=2 ; 12%	*n*=0 ; 0%	χ^2=5.488
Equity & social justice	*n*=1 ; 9%	*n*=0 ; 0%	*n*=3 ; 13%	*n*=2 ; 12%	*n*=2 ; 33%	χ^2=4.268
Decent work	*n*=1 ; 9%	*n*=3 ; 27%*	*n*=1 ; 4%	*n*=2 ; 12%	*n*=0 ; 0%	χ^2=5.060
Consumption modes	*n*=2 ; 18%	*n*=3 ; 27%**	*n*=0 ; 0%*	*n*=1 ; 6%	*n*=0 ; 0%	χ^2=8.841*
Governance	*n*=0 ; 0%	*n*=0 ; 0%	*n*=2 ; 9%	*n*=1 ; 6%	*n*=3 ; 50%***	χ^2=14.957***
Rural regional development	*n*=6 ; 55%*	*n*=0 ; 0%**	*n*=6 ; 26%	*n*=6 ; 35%	*n*=3 ; 50%	χ^2=9.231*
Economic viability	*n*=5 ; 45%	*n*=4 ; 36%	*n*=5 ; 22%	*n*=9 ; 53%*	*n*=0 ; 0%*	χ^2=8.040*
Eco-tourism	*n*=2 ; 18%	*n*=5 ; 45%	*n*=10 ; 43%	*n*=5 ; 29%	*n*=1 ; 17%	χ^2=3.762
Arts & recreation	*n*=0 ; 0%	*n*=4 ; 36%	*n*=9 ; 39%***	*n*=0 ; 0%**	*n*=0 ; 0%	χ^2=16.110***
Cultural heritage	*n*=1 ; 9%	*n*=1 ; 9%	*n*=5 ; 22%	*n*=1 ; 6%	*n*=0 ; 0%	χ^2=3.723
Agro-ecology	*n*=3 ; 27%	*n*=3 ; 27%	*n*=2 ; 9%	*n*=5 ; 29%	*n*=1 ; 17%	χ^2=3.457
Eco-construction	*n*=2 ; 18%	*n*=0 ; 0%	*n*=3 ; 13%	*n*=1 ; 6%	*n*=0 ; 0%	χ^2=3.535
Handicrafts	*n*=1 ; 9%	*n*=1 ; 9%	*n*=4 ; 17%	*n*=0 ; 0%	*n*=0 ; 0%	χ^2=4.326
Spirituality, religion	*n*=0 ; 0%	*n*=1 ; 9%	*n*=1 ; 4%	*n*=0 ; 0%	*n*=0 ; 0%	χ^2=2.647
Research	*n*=5 ; 45%**	*n*=0 ; 0%	*n*=1 ; 4%**	*n*=4 ; 24%	*n*=2 ; 33%	χ^2=12.430**
Youth	*n*=0 ; 0%	*n*=1 ; 9%	*n*=5 ; 22%**	*n*=0 ; 0%	*n*=1 ; 17%	χ^2=6.757
2. Learning						
Time spent for learning	*n*=9 ; 82%*	*n*=7 ; 64%	*n*=12 ; 52%	*n*=6 ; 35%*	*n*=4 ; 67%	χ^2=6.604
3. Decision-making						
Information	*n*=1 ; 9%	*n*=1 ; 9%	*n*=1 ; 4%	*n*=5 ; 29%**	*n*=1 ; 17%	χ^2=5.846
Consultation	*n*=5 ; 45%	*n*=3 ; 27%	*n*=10 ; 43%	*n*=4 ; 24%	*n*=0 ; 0%	χ^2=5.768
Cooperation	*n*=5 ; 45%	*n*=4 ; 36%	*n*=11 ; 48%	*n*=8 ; 47%	*n*=5 ; 83%	χ^2=3.622
4. Cooperation						
Regional cooperation	*n*=4 ; 36%**	*n*=5 ; 45%	*n*=18 ; 78%	*n*=12 ; 71%	*n*=5 ; 83%	χ^2=8.674*
National cooperation	*n*=5 ; 45%	*n*=3 ; 27%	*n*=11 ; 48%	*n*=8 ; 47%	*n*=5 ; 83%*	χ^2=4.914
International cooperation	*n*=4 ; 36%	*n*=0 ; 0%**	*n*=9 ; 39%	*n*=5 ; 29%	*n*=3 ; 50%	χ^2=6.847
5. Stage						
Beginning	*n*=1 ; 9%	*n*=1 ; 9%	*n*=3 ; 13%	*n*=1 ; 6%	*n*=0 ; 0%	χ^2=1.275
Growth	*n*=5 ; 45%	*n*=3 ; 27%	*n*=10 ; 43%	*n*=9 ; 53%	*n*=0 ; 0%*	χ^2=6.194
Stabilisation	*n*=3 ; 27%	*n*=6 ; 55%	*n*=9 ; 39%	*n*=5 ; 29%	*n*=5 ; 83%*	χ^2=7.103
Dissemination	*n*=2 ; 18%	*n*=1 ; 9%	*n*=1 ; 4%	*n*=2 ; 12%	*n*=1 ; 9%	χ^2=1.943

Table B.6. Distribution of outcomes, actors and processes variables within clusters in FGBR. Significance:*p < 0.1; **p < 0.05; ***p < 0.01

Variable	Service Innovations (*cluster 1;* *n*=11; 18%)	Social Innovations (*cluster 2;* *n*=13; 21%)	Social and Sustainable Entrepreneurs (*cluster 3;* *n*=16; 26%)	Technological Efficiency Innovations (*cluster 4;* *n*=4; 7%)	New Sectors for Social-ecological Transformation (*cluster 5*; *n*=17; 28%)	Chi-squared test
Outcomes						
New organisation	*n*=3 ; 27%***	*n*=9 ; 69%	*n*=14 ; 88%	*n*=1 ; 25%*	*n*=15 ; 88%*	χ^2=0.018***
New behaviour	*n*=4 ; 36%	*n*=7 ; 54%*	*n*=7 ; 44%	*n*=0 ; 0%	*n*=2 ; 12%**	χ^2=0.009*
New market	*n*=3 ; 27%	*n*=3 ; 23%	*n*=8 ; 50%*	*n*=2 ; 50%	*n*=2 ; 12%*	χ^2=0.007
New service	*n*=7 ; 64%	*n*=7 ; 54%	*n*=14 ; 88%***	*n*=1 ; 25%	*n*=5 ; 29%**	χ^2=0.013**
New values	*n*=2 ; 18%***	*n*=11 ; 85%	*n*=16 ; 100%***	*n*=0 ; 0%**	*n*=11 ; 65%	χ^2=0.029***
New technology	*n*=0 ; 0%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=3 ; 75%***	*n*=0 ; 0%	χ^2=0.045***
New sector, value chain	*n*=0 ; 0%	*n*=0 ; 0%	*n*=2 ; 13%	*n*=2 ; 50%	*n*=5 ; 29%*	χ^2=0.011**
New product	*n*=2 ; 18%	*n*=1 ; 8%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=4 ; 24%*	χ^2=0.006
2. Amplifying						
Scale within	*n*=11 ; 100%	*n*=13 ; 100%	*n*=15 ; 94%	*n*=1 ; 25%***	*n*=12 ; 71%*	χ^2=0.020***
Scale out	*n*=4 ; 36%	*n*=0 ; 0%*	*n*=2 ; 13%	*n*=1 ; 25%	*n*=5 ; 29%	χ^2=0.007
Scale beyond	*n*=2 ; 18%	*n*=4 ; 31%	*n*=11 ; 69%***	*n*=1 ; 25%	*n*=2 ; 12%**	χ^2=0.014***
3. Impacts						

Structural (physical) changes	*n*=1 ; 9%**	*n*=3 ; 23%	*n*=8 ; 50%	*n*=4 ; 100%**	*n*=9 ; 53%	χ^2=0.014***
Structural (social) changes	*n*=8 ; 73%	*n*=12 ; 92%	*n*=12 ; 75%	*n*=0 ; 0%***	*n*=14 ; 82%	χ^2=0.015***
Social-ecological integrity	*n*=0 ; 0%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=1 ; 25%	*n*=6 ; 35%***	χ^2=0.015***
Livelihood sufficiency & opportunity	*n*=2 ; 18%	*n*=5 ; 38%**	*n*=1 ; 6%	*n*=0 ; 0%	*n*=1 ; 6%	χ^2=0.009*
Intra- & intergenerationa l equity	*n*=1 ; 9%	*n*=0 ; 0%	*n*=4 ; 25%**	*n*=0 ; 0%	*n*=0 ; 0%	χ^2=0.009*
Resource maintenance & efficient use	*n*=1 ; 9%***	*n*=8 ; 62%	*n*=12 ; 75%	*n*=4 ; 100%	*n*=10 ; 59%	χ^2=0.016***
Social-ecological stewardship & democratic governance	*n*=1 ; 9%	*n*=3 ; 23%	*n*=5 ; 31%	*n*=0 ; 0%	*n*=5 ; 29%	χ^2=0.003
Precaution & adaptation	*n*=0 ; 0%	*n*=0 ; 0%	*n*=1 ; 6%	*n*=2 ; 50%**	*n*=2 ; 12%	χ^2=0.012**
4. Scale						
Local novelty	*n*=1 ; 9%	*n*=13 ; 100%***	*n*=0 ; 0%***	*n*=3 ; 75%*	*n*=2 ; 12%*	χ^2=0.045***
Regional novelty	*n*=10 ; 91%***	*n*=0 ; 0%***	*n*=16 ; 100%***	*n*=0 ; 0%**	*n*=6 ; 35%	χ^2=0.042***
National novelty	*n*=0 ; 0%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=7 ; 41%***	χ^2=0.020***
International novelty	*n*=0 ; 0%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=1 ; 25%	*n*=2 ; 12%	χ^2=0.007
Actors						
1. Type						
Public organisation	*n*=7 ; 64%	*n*=4 ; 31%	*n*=4 ; 25%*	*n*=1 ; 25%	*n*=12 ; 71%**	χ^2=0.010**
Private organisation	*n*=4 ; 36%	*n*=6 ; 46%	*n*=13 ; 81%**	*n*=3 ; 75%	*n*=10 ; 59%	χ^2=0.007
Civil society organisation	*n*=3 ; 27%	*n*=6 ; 46%	*n*=5 ; 31%	*n*=0 ; 0%	*n*=8 ; 47%	χ^2=0.004
2. Sector						
Education	*n*=0 ; 0%	*n*=0 ; 0%	*n*=2 ; 13%	*n*=0 ; 0%	*n*=2 ; 12%	χ^2=0.004
Energy	*n*=0 ; 0%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=1 ; 6%	χ^2=0.003
Trade	*n*=1 ; 9%	*n*=1 ; 8%	*n*=6 ; 38%***	*n*=0 ; 0%	*n*=0 ; 0%*	χ^2=0.012**
Handicrafts, industry, goods production	*n*=0 ; 0%	*n*=1 ; 8%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=1 ; 6%	χ^2=0.002
Agriculture, livestock	*n*=0 ; 0%	*n*=0 ; 0%	*n*=2 ; 13%	*n*=3 ; 75%***	*n*=3 ; 18%	χ^2=0.017***
Food and beverages manufacturing	*n*=1 ; 9%	*n*=1 ; 8%	*n*=1 ; 6%	*n*=0 ; 0%	*n*=0 ; 0%	χ^2=0.002
Public Administration and services	*n*=3 ; 27%*	*n*=1 ; 8%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=2 ; 12%	χ^2=0.006
Tourism, Arts, Recreation	*n*=0 ; 0%	*n*=0 ; 0%	*n*=2 ; 13%*	*n*=0 ; 0%	*n*=0 ; 0%	χ^2=0.006
Nature conservation	*n*=4 ; 36%	*n*=3 ; 23%	*n*=0 ; 0%**	*n*=1 ; 25%	*n*=5 ; 29%	χ^2=0.007
Civil society	*n*=2 ; 18%	*n*=6 ; 46%*	*n*=3 ; 19%	*n*=0 ; 0%	*n*=3 ; 18%	χ^2=0.006
3. Resources						
Financial resources	*n*=8 ; 73%	*n*=8 ; 62%	*n*=7 ; 44%	*n*=3 ; 75%	*n*=8 ; 47%	χ^2=0.006
Material resources	*n*=8 ; 73%	*n*=5 ; 38%	*n*=10 ; 63%	*n*=4 ; 100%	*n*=10 ; 59%	χ^2=0.019**
Human Resources	*n*=5 ; 45%	*n*=5 ; 38%	*n*=5 ; 31%	*n*=2 ; 50%	*n*=7 ; 41%	χ^2=0.005
Expertise, skills	*n*=9 ; 82%	*n*=10 ; 77%	*n*=11 ; 69%	*n*=3 ; 75%	*n*=9 ; 53%	χ^2=0.005
Environmental resources	*n*=3 ; 27%	*n*=5 ; 38%	*n*=7 ; 44%	*n*=2 ; 50%	*n*=6 ; 35%	χ^2=0.008
4. Values						
Intrinsic values	*n*=2 ; 18%	*n*=2 ; 15%	*n*=4 ; 25%	*n*=1 ; 25%	*n*=2 ; 12%	χ^2=0.001
Relational values	*n*=9 ; 82%	*n*=11 ; 85%	*n*=16 ; 100%*	*n*=1 ; 25%***	*n*=16 ; 94%	χ^2=0.017***

Instrumental values	*n*=5 ; 45%*	*n*=11 ; 85%	*n*=9 ; 56%	*n*=4 ; 100%	*n*=14 ; 82%	χ^2=0.009*
Processes						
1. Actions						
Animal welfare	*n*=0 ; 0%	*n*=1 ; 8%	*n*=1 ; 6%	*n*=0 ; 0%	*n*=1 ; 6%	χ^2=0.001
Climate change	*n*=0 ; 0%	*n*=2 ; 15%	*n*=0 ; 0%	*n*=1 ; 25%	*n*=2 ; 12%	χ^2=0.005
Waste	*n*=0 ; 0%	*n*=2 ; 15%	*n*=4 ; 25%	*n*=3 ; 75%**	*n*=2 ; 12%	χ^2=0.012**
Biodiversity	*n*=0 ; 0%	*n*=2 ; 15%	*n*=0 ; 0%	*n*=1 ; 25%	*n*=2 ; 12%	χ^2=0.005
Water	*n*=0 ; 0%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=1 ; 25%	*n*=1 ; 6%	χ^2=0.008
Energy	*n*=0 ; 0%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=2 ; 50%**	*n*=2 ; 12%	χ^2=0.003
Mobility	*n*=2 ; 18%	*n*=2 ; 15%	*n*=0 ; 0%	*n*=0 ; 0%	*n*=0 ; 0%	χ^2=0.007
Local food systems	*n*=3 ; 27%	*n*=4 ; 31%	*n*=8 ; 50%	*n*=3 ; 75%	*n*=6 ; 35%	χ^2=0.004
ESD & awareness raising	*n*=6 ; 55%	*n*=6 ; 46%	*n*=6 ; 38%	*n*=0 ; 0%	*n*=7 ; 41%	χ^2=0.004
Community-building	*n*=5 ; 45%	*n*=8 ; 62%**	*n*=9 ; 56%*	*n*=0 ; 0%	*n*=0 ; 0%***	χ^2=0.019***
Health	*n*=0 ; 0%	*n*=0 ; 0%	*n*=1 ; 6%	*n*=0 ; 0%	*n*=0 ; 0%	χ^2=0.003
Wellbeing, lifestyle	*n*=1 ; 9%	*n*=5 ; 38%	*n*=6 ; 38%*	*n*=0 ; 0%	*n*=0 ; 0%**	χ^2=0.012**
Nature connectedness	*n*=1 ; 9%	*n*=1 ; 8%	*n*=2 ; 13%	*n*=0 ; 0%	*n*=2 ; 12%	χ^2=0.001
Equity & social justice	*n*=1 ; 9%	*n*=4 ; 31%	*n*=6 ; 38%**	*n*=0 ; 0%	*n*=0 ; 0%**	χ^2=0.011**
Decent work	*n*=2 ; 18%	*n*=3 ; 23%	*n*=6 ; 38%**	*n*=0 ; 0%	*n*=0 ; 0%**	χ^2=0.009*
Consumption modes	*n*=0 ; 0%*	*n*=6 ; 46%**	*n*=6 ; 38%*	*n*=1 ; 25%	*n*=0 ; 0%**	χ^2=0.015***
Governance	*n*=0 ; 0%	*n*=3 ; 23%	*n*=1 ; 6%	*n*=0 ; 0%	*n*=4 ; 24%	χ^2=0.006
Rural regional development	*n*=4 ; 36%	*n*=1 ; 8%	*n*=0 ; 0%***	*n*=1 ; 25%	*n*=9 ; 53%***	χ^2=0.015***
Economic viability	*n*=0 ; 0%*	*n*=3 ; 23%	*n*=7 ; 44%*	*n*=3 ; 75%*	*n*=3 ; 18%	χ^2=0.012**
Eco-tourism	*n*=1 ; 9%	*n*=0 ; 0%	*n*=3 ; 19%	*n*=0 ; 0%	*n*=2 ; 12%	χ^2=0.003
Arts & recreation	*n*=5 ; 45%	*n*=6 ; 46%*	*n*=2 ; 13%	*n*=0 ; 0%	*n*=2 ; 12%	χ^2=0.010**
Cultural heritage	*n*=3 ; 27%	*n*=1 ; 8%	*n*=0 ; 0%*	*n*=1 ; 25%	*n*=4 ; 24%	χ^2=0.006
Agro-ecology	*n*=4 ; 36%	*n*=1 ; 8%*	*n*=2 ; 13%	*n*=3 ; 75%*	*n*=8 ; 47%	χ^2=0.012**
Eco-construction	*n*=0 ; 0%	*n*=1 ; 8%	*n*=2 ; 13%	*n*=1 ; 25%	*n*=3 ; 18%	χ^2=0.003
Handicrafts	*n*=0 ; 0%	*n*=2 ; 15%	*n*=1 ; 6%	*n*=0 ; 0%	*n*=1 ; 6%	χ^2=0.003
Spirituality, religion	*n*=0 ; 0%	*n*=0 ; 0%	*n*=1 ; 6%	*n*=0 ; 0%	*n*=0 ; 0%	χ^2=0.003
Research	*n*=0 ; 0%	*n*=0 ; 0%	*n*=1 ; 6%	*n*=1 ; 25%	*n*=5 ; 29%**	χ^2=0.010**
Youth	*n*=2 ; 18%	*n*=1 ; 8%	*n*=2 ; 13%	*n*=0 ; 0%	*n*=1 ; 6%	χ^2=0.002
2. Learning						
Time spent for learning	*n*=6 ; 55%	*n*=5 ; 38%	*n*=8 ; 50%	*n*=2 ; 50%	*n*=11 ; 65%	χ^2=0.006
3. Decision-making						
Information	*n*=5 ; 45%**	*n*=2 ; 15%	*n*=3 ; 19%	*n*=1 ; 25%	*n*=2 ; 12%	χ^2=0.005
Consultation	*n*=4 ; 36%	*n*=2 ; 15%	*n*=2 ; 13%	*n*=1 ; 25%	*n*=8 ; 47%*	χ^2=0.006
Cooperation	*n*=2 ; 18%	*n*=8 ; 62%	*n*=7 ; 44%	*n*=2 ; 50%	*n*=5 ; 29%	χ^2=0.006
4. Cooperation						χ^2=0.006
Regional cooperation	*n*=6 ; 55%	*n*=4 ; 31%	*n*=2 ; 13%**	*n*=2 ; 50%	*n*=10 ; 59%*	χ^2=0.009*
National cooperation	*n*=6 ; 55%	*n*=6 ; 46%	*n*=5 ; 31%	*n*=2 ; 50%	*n*=10 ; 59%	χ^2=0.003
International cooperation	*n*=5 ; 45%	*n*=3 ; 23%	*n*=2 ; 13%	*n*=1 ; 25%	*n*=7 ; 41%	χ^2=0.005
5. Stage						
Beginning	*n*=3 ; 27%	*n*=3 ; 23%	*n*=2 ; 13%	*n*=0 ; 0%	*n*=3 ; 18%	χ^2=0.002
Growth	*n*=1 ; 9%***	*n*=6 ; 46%	*n*=13 ; 81%***	*n*=1 ; 25%	*n*=7 ; 41%	χ^2=0.015***
Stabilisation	*n*=4 ; 36%	*n*=3 ; 23%	*n*=0 ; 0%**	*n*=2 ; 50%	*n*=5 ; 29%	χ^2=0.008*
Dissemination	*n*=3 ; 27%	*n*=0 ; 0%	*n*=1 ; 6%	*n*=1 ; 25%	*n*=2 ; 12%	χ^2=0.006

A.4 Appendix Chapter 4/ Paper 3

Supplementary materials – table of content

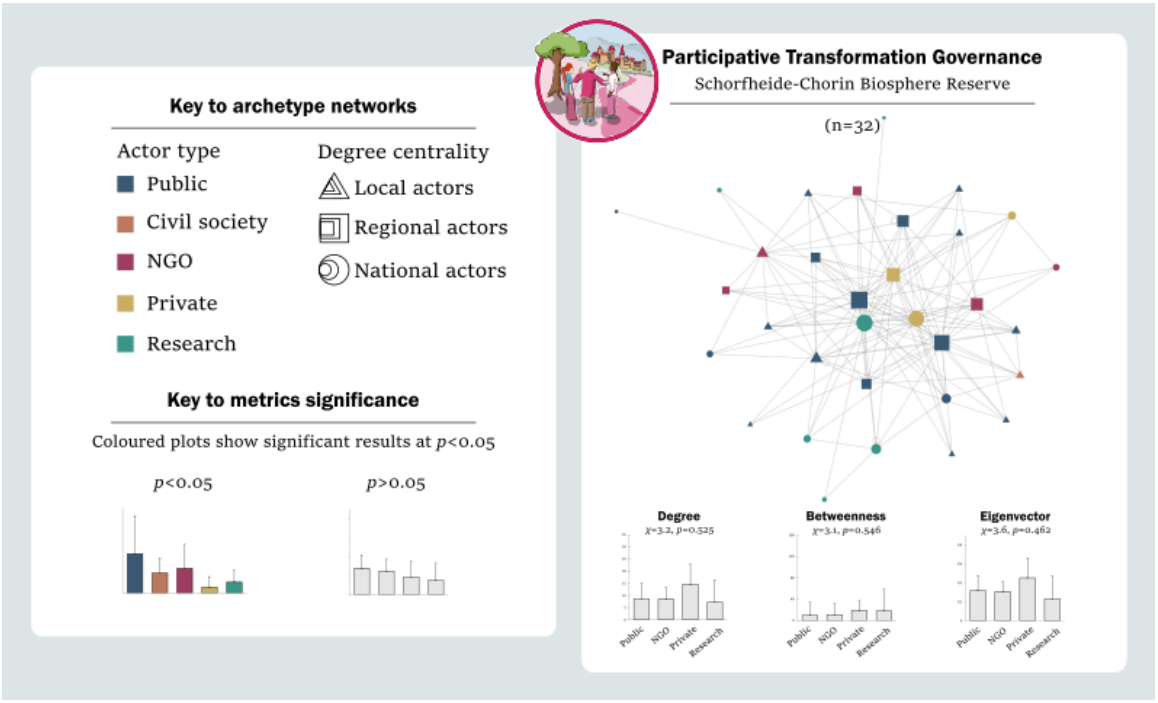
Table S1. Number of actors (percentage presented in brackets) involved only in one archetype or in several archetypes and chi-squared test per Biosphere Reserve. * denote significant positive association at 5% significance level according to Fisher's exact test.

Sustainability innovations archetypes	N actors involved only in the archetype (%)	N actors involved in several archetypes (%)	Chi-square test
Schorfheide-Chorin Biosphere Reserve			χ^2=10.071, p=0.039
Participative Transformation Governance (n=32)	7 (22%)	25 (78%)*	
New Sectors for Social-ecological Transformation (n=60)	26 (43%)	34 (57%)	
Social & Sustainable Entrepreneurs (n=23)	8 (35%)	15 (65%)	
Social Innovations (n=89)	46 (52%)*	43 (48%)	
Service Innovations (n=56)	21 (36%)	37 (64%)	
Fontainebleau-Gâtinais Biosphere Reserve			χ^2=18.926, p<0.001
New Sectors for Social-ecological Transformation (n=120)	78 (65%)*	42 (35%)	
Social & Sustainable Entrepreneurs (n=46)	23 (50%)	23 (50%)	
Social Innovations (n=39)	10 (26%)	29 (74%)*	
Service Innovations (n=109)	60 (56%)	47 (44%)	

Table S2. Network properties of full networks and archetype networks of the Schorfheide-Chorin Biosphere Reserve (SC) and Fontainebleau-Gâtinais Biosphere Reserve (FC)

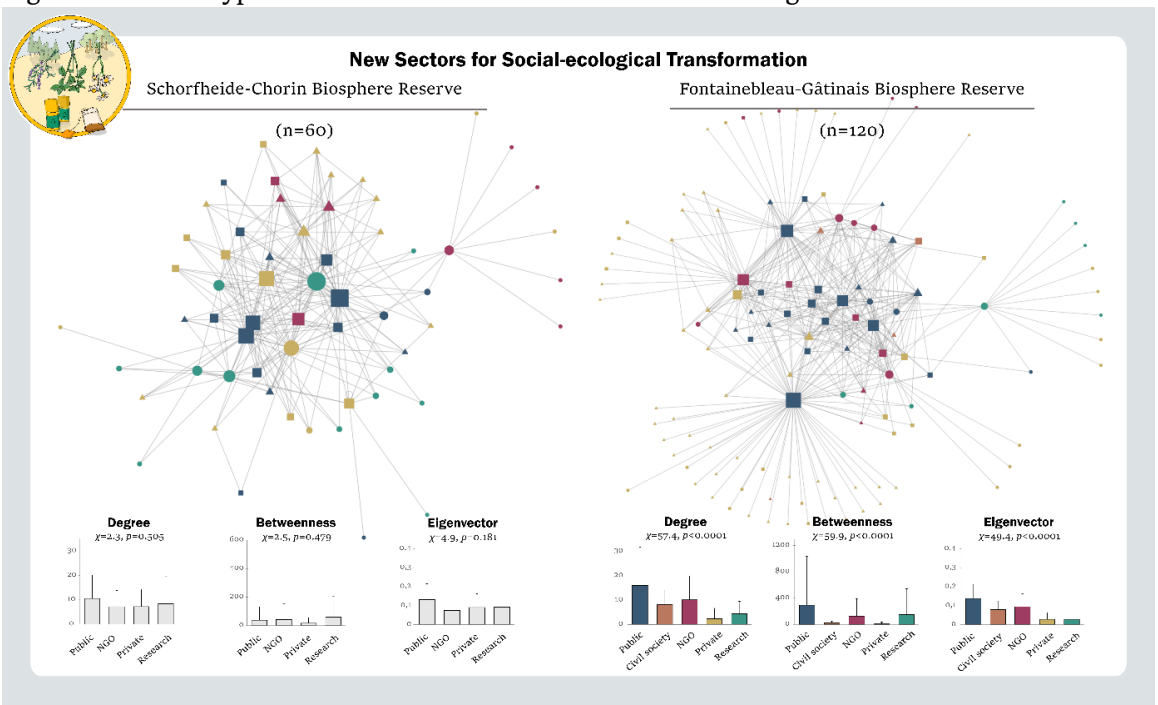
	Full network		New Sectors for Social-ecological Transformation		Social & Sustainable Entrepreneurs		Social Innovations		Service Innovations		Participative Transformation Governance	Technological Efficiency Innovations
Biosphere Reserve	SC	FG	SC	FG	SC	FG	SC	FG	SC	FG	SC	FG
Number of nodes	223	305	60	120	23	46	89	39	56	109	32	11
Graph density	0.06	0.02	0.14	0.05	0.17	0.18	0.12	0.19	0.22	0.04	0.28	0.35
Average geodesic distance	2.43	2.8	2.16	2.51	2.19	2.12	2.17	2.07	1.99	2.31	1.72	1.65

Figure S1. Archetype network of Participative Transformation Governance and bar plots showing centrality metrics (degree, betweenness, eigenvector) of different actor types. The key to archetype networks and the key to metrics significance is common to all following



figures depicting archetype networks and centrality metrics.

Figure S2. Archetype network of New Sectors for Social-ecological Transformation and bar



plots showing centrality metrics (degree, betweenness, eigenvector) of different actor types.

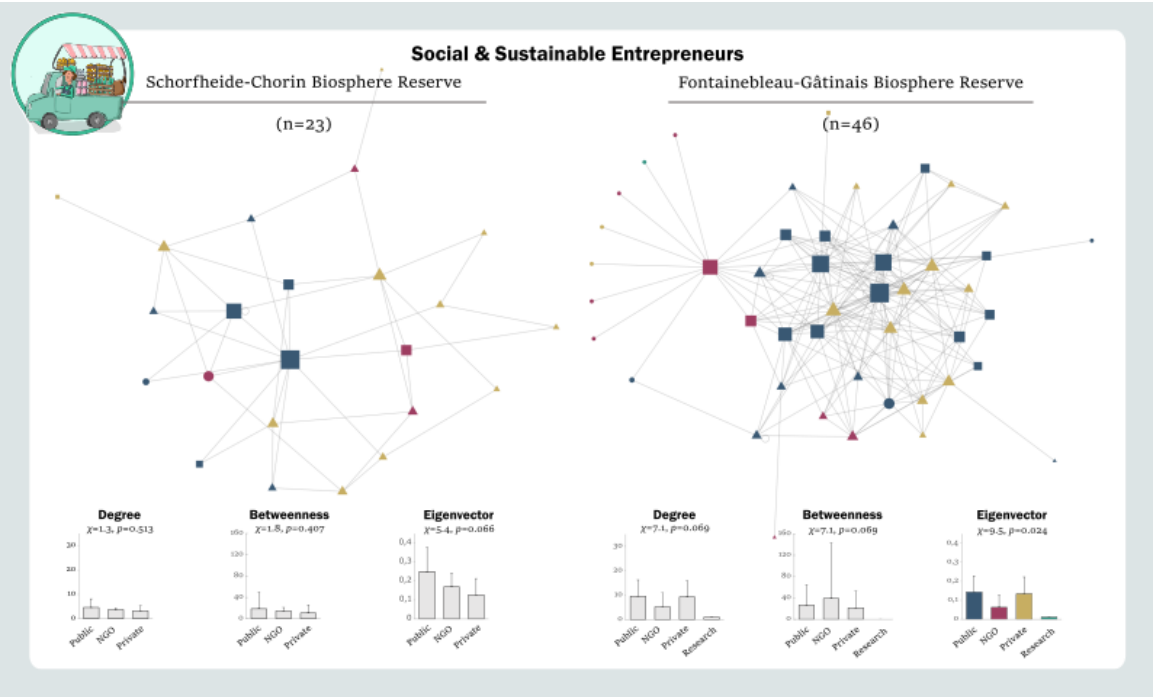


Figure S3. Archetype network of Social and Sustainable Entrepreneurs and bar plots showing centrality metrics (degree, betweenness, eigenvector) of different actor types.

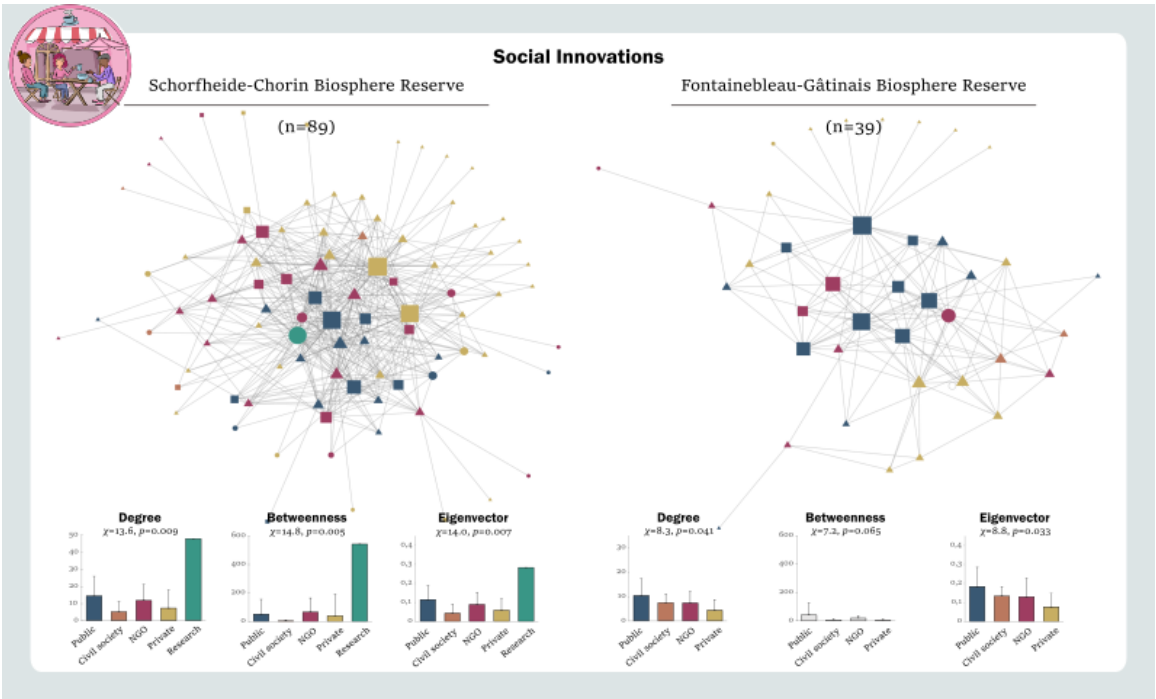


Figure S4. Archetype network of Social Innovations and bar plots showing centrality metrics (degree, betweenness, eigenvector) of different actor types.

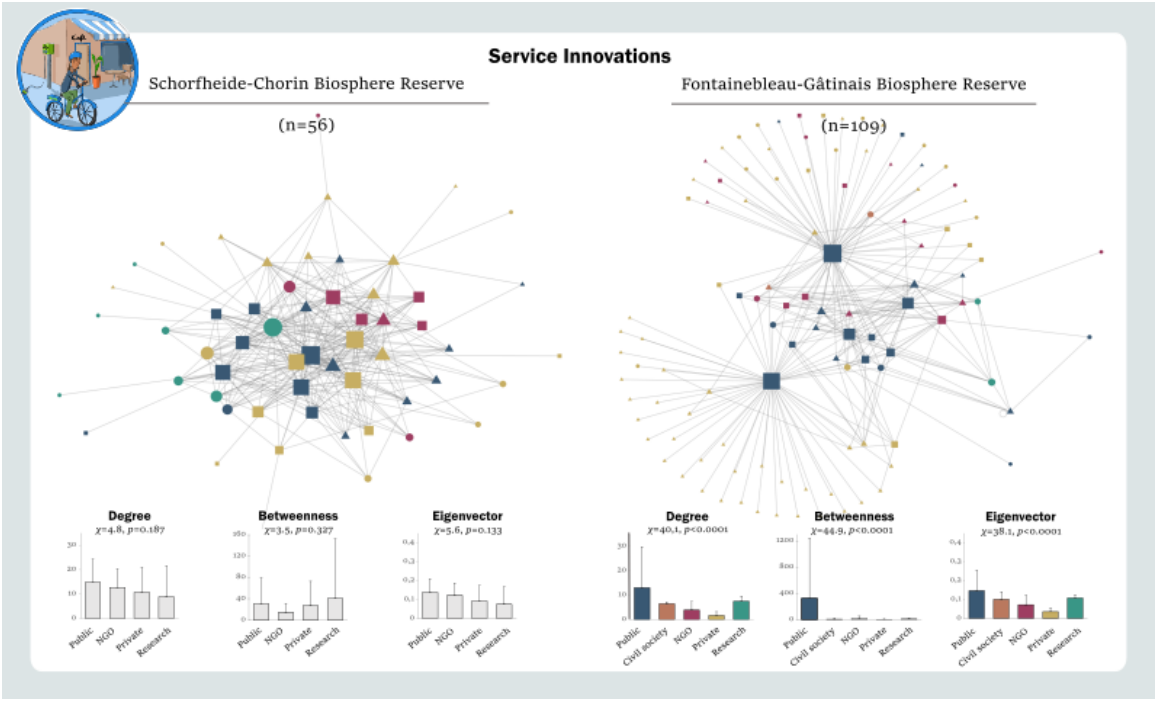


Figure S5. Archetype network of Service Innovations and bar plots showing centrality metrics (degree, betweenness, eigenvector) of different actor type

A.5. Additional paper

Biosphere Reserves as model regions for transdisciplinarity? A literature review

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This manuscript is under review at Sustainability Science.

Abstract

The UNESCO Man and the Biosphere program advocates and designates Biosphere Reserves as learning sites for sustainable development. Yet the extent to which research aligns with their core objectives - biodiversity conservation, economic development and capacity building - remains uncertain. In response, transdisciplinary research in conservation and development aims at implementing more diverse, participatory methods to improve effective management as well as governance. This study provides a systematic screening of scientific research in and on Biosphere Reserves published since 1975. Research fields in Biosphere Reserves are diverse and range from social to political to ecological investigations. We identified an emerging field of transdisciplinary science in research related to or conducted in UNESCO Biosphere Reserves, highlighting progress in author gender equality as compared to studies that did not build on a transdisciplinary mode. Most transdisciplinary studies were conducted in Mexican and Indian Biosphere Reserves. Transdisciplinary research in Biosphere Reserves calls for high-impact knowledge, addressing deep leverage points and the inclusive participation of underrepresented and discriminated groups. Thereby, Biosphere Reserves as specialized areas for sustainable development could play a vital role.

1 Introduction

Acknowledging the need for integrated approaches to mainstream sustainable development, the UNESCO Man and the Biosphere (MAB) Programme promotes Biosphere Reserves as areas dedicated both to nature conservation and sustainable human development (UNESCO 2017). Biosphere Reserves have three core missions: (1) biodiversity conservation, (2) economic development and (3) logistic support and capacity building, in particular through research (UNESCO 1996). To meet those goals, the MAB Programme emphasizes the contribution of local actors - specifically of Women, Youth, and Indigenous People - to Biosphere Reserves' effective, equitable and participatory planning (UNESCO 2017). To support logistics and capacity building, scientific research is expected to contribute to the other missions, i.e. conservation and development. However, recent reviews have shown that research on Biosphere Reserves has been largely confined to the natural sciences (Kratzer 2018; Pool-Stanvliet and Coetzer 2020). Research conducted in Biosphere Reserves merely used these study sites for a broad range of issues, but hardly focussed on the factors influencing a successful implementation of the MAB Programme (Ferreira et al. 2020; Pool-Stanvliet and Coetzer 2020). Biosphere Reserves research has seen an increasing call for more co-productive, inter- and transdisciplinary approaches to investigate pressing issues, such as effective management and participatory governance (van Cuong et al. 2017; Ferreira et al. 2020; Barraclough et al. 2023).

Transdisciplinary sustainability research is increasingly expected to promote solution-finding processes for real-world sustainability issues (Kates et al. 2001; Lang et al. 2012; Norström et al. 2020). This field emerged rather recently and encompasses a diverse array of approaches, e.g. participatory research, transformative research or knowledge co-production (Norström et al. 2020; Chambers et al. 2021). These approaches share the mission to produce knowledge in a participatory manner or mode (Pohl and Hirsch Hadorn 2008; Lang et al. 2012; Brandt et al. 2013), while inducing positive societal effects in the social-ecological systems they investigate (Pereira et al. 2020; Jahn et al. 2021; Lawrence et al. 2022). Three key features of transdisciplinary research can be highlighted: (1) a focus on real-world problems and developing solutions to wicked problems (Chambers et al. 2021; Lawrence et al. 2022), (2) the combination of different types of knowledge, including Indigenous and Local Knowledge (Bartlett et al. 2012; Brandt et al. 2013; Knapp et al. 2019; Reed et al. 2023) and (3) involvement of practitioners and relevant non-academic actors (Talwar et al. 2011; Lang et al. 2012; Jahn et al. 2021).

The current MAB strategy and its Lima Action Plan highlight the role of Biosphere Reserves in the operationalization of transdisciplinarity sustainability science, as it calls for involvement of local communities and relevant actors in Biosphere Reserves research and governance (UNESCO 2017). Scholars also have increasingly called for co-creative, participative and transdisciplinary approaches in Biosphere Reserves research (Ishwaran et al. 2008; Schultz et al. 2011; Coetzer et al. 2014; Barraclough et al. 2023). Yet, there is still a lack of evidence about the extent of transdisciplinarity in the global context of Biosphere Reserves and only few empirical studies have investigated the application and benefits of transdisciplinary research in Biosphere Reserves. Nevertheless, a body of literature has been dedicated to understanding how to improve the governance of Biosphere Reserves through adaptive co-management (Olsson et al. 2007; Schultz and Lundholm 2010; Plummer et al. 2017) and through bridging and facilitating organizations (Schultz et al. 2011; Reed and Abernathy 2018; Walk et al. 2020). Multiple studies were conducted within recent

transdisciplinary programs in Canadian Biosphere Reserves, e.g. on the practice of collective learning, participatory research, knowledge co-production (Reed et al. 2014; Reed and Abernathy 2018), the challenges of community engagement (George and Reed 2017), or the ethics of transdisciplinary research conducted with and by Indigenous People (Reed et al. 2023). Another strand of literature anchored in South African Biosphere Reserves has explored e.g. the contributions of the MAB programme for conservation and development (Stanvliet et al. 2004; Coetzer et al. 2014), inter- and transdisciplinary processes to establish Biosphere Reserves (Pool-Stanvliet et al. 2018), and collaborative learning processes (Pool-Stanvliet and Coetzer 2020). Concerning the actual outcomes of applying transdisciplinary approaches in Biosphere Reserves, empirical evidence is limited. One example is a comparative study of four co-productive projects in the area of Kristianstad Vattenrike Biosphere Reserve, in Sweden (Malmborg et al. 2022).

There is also a need to better assess the contributions of Biosphere Reserves research - and specifically of transdisciplinary research - in addressing the need for diversity and participation. The most recent MAB strategy calls to enhance the participation of a diversity of actors, namely scientists, policy-makers, local communities (including Indigenous People) and the private sector, in facilitating sustainability science in Biosphere Reserves (UNESCO 2017). This call for participation and diversity has been echoed in sustainability science, particularly in transdisciplinary research (Staffa et al. 2022; Vogel and O'Brien 2022; Caniglia and Vogel 2023). However, when it comes to the concrete involvement of local actors in research processes, a stark contrast has been identified between ideal transdisciplinarity (i.e. methodologies committed to strong collaboration and empowerment of non-academic actors) and the wide-spread application of transdisciplinary approaches, often limited to consultations with non-academic actors (Brandt et al. 2013; Zscheischler and Rogga 2015; Jahn et al. 2021). Recent studies have argued that the discrepancy between the geographic location of researchers and their study sites - where researchers from Global North study the Global South - shows an academic neocolonial pattern (Brandt et al. 2013; Ghosh 2020; Sultana 2022; Zonta et al. 2023). In Biosphere Reserves research, the limited involvement of non-academic actors has been pointed out as well (Stoll-Kleeman et al. 2010; Reed 2016; Barraclough et al. 2021). While such neocolonial mechanisms, as well as the underrepresentation of Women and minorities have been identified in scientific research (Hofstra et al. 2020; Zonta et al. 2023), there is so far little evidence about such aspects in transdisciplinary research in Biosphere Reserves.

Transdisciplinary approaches ideally address real-world challenges and explore transformative solutions (Pereira et al. 2020; Lawrence et al. 2022). While it is expected that transdisciplinary research may support the successful implementation of the MAB Programme (Reed 2016; UNESCO 2017; Ferreira et al. 2020; Barraclough et al. 2023), there is still a lack of evidence about the outcomes of transdisciplinary approaches in terms of transformative impacts. It is a widespread challenge for transdisciplinary researchers to monitor and report about concrete societal impacts and there is no standard procedure so far (Newig et al. 2019; Chambers et al. 2021; Schäfer et al. 2021). Hence, to address the transformative potential of transdisciplinary research in Biosphere Reserves, we follow recent reviews (Brandt et al. 2013; Riechers et al. 2021a; Zimmermann et al. 2023) and examine (1) the different types of knowledge (systems, target, transformation and process knowledge) produced in scientific publications, from descriptive to more transformative types (Brandt et al. 2013; Lawrence et al. 2022) and (2) the leverage points addressed, i.e.

the potential interventions, policies, innovations or practices and their more or less systemic impacts in focal situations (Meadows 1999; Meadows 2012; Abson et al. 2017).

This article aims to provide a comprehensive review of Biosphere Reserves research to date, delineating research contributions to sustainability science and to the MAB Programme. In this article, we refer to Biosphere Reserves research as the research conducted in, with or about Biosphere Reserves. We carried out a systematic literature review, in two steps: (1) we analyzed 3,304 scientific studies conducted in Biosphere Reserves through meta-data and word occurrence analysis, and (2) we analyzed in depth the contributions of 336 articles from the latter, general data set, which applied transdisciplinary approaches. We aim to answer the following questions:

1. How is Biosphere Reserves research -in particular transdisciplinary research- spatially distributed and how has it evolved over time?
2. What topics has Biosphere Reserves research -and specifically transdisciplinary research addressed so far?
3. How diverse is Biosphere Reserves research and specifically transdisciplinary research in terms of gender and actor participation?
4. What transformative potential does transdisciplinary research in Biosphere Reserves display?

2 Methods

2.1 Data extraction

We used Web of Science and Scopus to download all publications containing “biosphere reserve*” OR “biosphere region*” OR “biosphere area*” in the title, keywords, abstract and text (later referred to as “general data set”). To identify as many transdisciplinary publications as possible within the general data set (later referred to as “transdisciplinary data set”), we used a broad range of keywords (Table S1), based on recent reviews or conceptualisations of transdisciplinary science (e.g. Lang et al. 2012; Brandt et al. 2013; Knapp et al. 2019; Chambers et al. 2021; Schäfer et al. 2021).

Following the preliminary articles identification via keywords, we screened the general data set and excluded articles based on the following criteria. We only selected articles written in English and original research articles (e.g opinion papers were excluded). Additional inclusion criteria were that the research took place in at least one UNESCO Biosphere Reserve and that articles full text should be accessible online. Based on these criteria, we retained 3,304 articles for the overview of Biosphere Reserves research. Furthermore, we screened the preliminary selection of transdisciplinary articles and excluded articles that did not involve any non-academic actors in the research process, resulting in the selection of 336 transdisciplinary publications for in-depth analysis.

The data extraction and organization was carried out by C.G. The transdisciplinary keywords were selected by C.H.D and approved by all authors. For transparency and accountability purposes, we follow the MeRIT guidelines proposed by Nakagawa et al. (2023) and report throughout the methods section who has contributed to which steps of the study.

2.2 Coding process

The selected 3,304 articles, including the 336 transdisciplinary articles, were then coded as follows. First, we coded all 3,304 articles according to geographic location of study sites and author affiliations, and authors gender distribution, based on title and abstract. We then coded the 336 transdisciplinary articles based on full-text analysis, according to participation of non-academic actors, knowledge types and leverage points (section 2.3). The coding was conducted by: F.N., S.H., B.d.F.A., C.H.D., C.G., F.W., C.M. and J.H. and the data cleaning by : C.H.D., C.G. and F.W. See Table S.1 for a summary of the review process.

To ensure validity of results across the 10 coders, the following measures were implemented. First, C.H.D., C.H. and F.W. created guidelines for all coding variables. The guidelines contained comprehensive descriptions of the coding variables and facilitated a shared understanding and consistent application of these variables across coders. In a one-day workshop, the objectives, variables, guidelines and coding procedure were presented by C.H.D., J.H., C.G. and F.W. to all coders and A.F.F. and H.v.W.. Additionally, all coders engaged in parallel analysis of several articles over the course of two weeks. They compared and discussed results in daily meetings, which ensured a consistent interpretation of the coding guidelines. Finally, a set of the variables was independently coded by two different coders in 292 randomly selected articles. By comparing these duplicates, we were able to calculate the accuracy rate in coding and quantify potential coder bias (calculations by F.W., see Fig. S4).

2.3 Coding variables

To gain an overview of the general characteristics and topics of interest in Biosphere Reserves research and of their evolution over time, we used meta data such as publication date, and word occurrence analysis. We examined all publications in terms of geographic location and gender distribution, to identify potential bias in representation and participation (Table 1). We categorized all articles according to the geographic location of first and last authors' affiliation. We also categorized the continent and country of study area. Articles studying several Biosphere Reserves in different continents were classified as "transcontinental". We then recorded the gender of the first and last authors, classified as female, male or unknown, according to genderize.io. We used this algorithm to categorize the gender of first names with a probability of at least 95% of accuracy, as proposed by e.g. Fox et al. (2019), although we have to acknowledge the limitations and potential bias of this binary gender approach.

To assess in more detail the quality of participation and diversity in transdisciplinary research, we categorized publications according to the following variables (Table 1). First, we counted the number of authors, whose affiliations were not academic, to appraise whether transdisciplinary projects fostered the participation of non-academic actors in scientific outputs. Second, we recorded whether or not the publications mentioned non-academic actors in the acknowledgements, as a further indicator of the involvement and recognition of non-academic actors in the research process. With in-depth analysis of the articles, we then categorized the type of actors involved in the research process, adapting the list of Ferreira et al. (2020). We also recorded their level of involvement, categorized as consultation, collaboration or empowerment (Brandt et al. 2013; Fritz and Binder 2020; Jahn et al. 2021).

Table 1: Description and operationalisation of review variables

Variables	Description
Diversity and inclusivity	
Geographic location of study area	Continent and country of the studied Biosphere Reserve(s)
Geographic location of first and last authors' affiliations	Continent and country of the first affiliation attributed to the first and last authors
Gender of first and last authors	Categorization of first and last authors' first names as female/male/unknown using genderize.io
Participation in transdisciplinary research	
Number of non-academic co-authors	Number of publication authors without academic affiliation
Acknowledgement of non-academic actors	Whether or not non-academic actors are acknowledged in the publication
Type of actors	Types of actors that are involved in the transdisciplinary research process, e.g. Biosphere Reserves representatives, Indigenous People, land users
Level of actor involvement	The extent of involvement of non-academic actors in the transdisciplinary research process, categorized as consultation, collaboration and/or empowerment
Transformative potential of transdisciplinary research	
Knowledge types	Types of knowledge produced in the publication, categorized as system, target, transformation and/or process knowledge
Leverage points	Types of leverage points targeted in the publication, categorized as parameters, feedbacks, design and/or intent

To capture the transformative potential of transdisciplinary research in Biosphere Reserves, we categorized transdisciplinary articles according, first, to the type of knowledge they produced (Brandt et al. 2013; Lawrence et al. 2022) and, second, to the leverage points they addressed (Dorninger et al. 2020; Riechers et al. 2021b; Zimmermann et al. 2023) (Box 1). With regard to knowledge types, we categorized the contributions of the transdisciplinary articles as systems, target, transformation or process knowledge (Table 1). Furthermore, to better appraise the contributions of transdisciplinary research to the understanding and development of solutions, we categorized articles according to the leverage points they addressed (Meadows 1999; Meadows 2012; Abson et al. 2017). The leverage points framework distinguishes interventions, such as policies or innovations, according to the more or less radical impacts they might have on the systems they target. The selection of the variables resulted from a test round of coding conducted by C.H.D, C.G., F.W., C.M., J.H.. The final selection of variables was decided by C.H.D, C.G., F.W., H.v.W. and A.F.F.

Box 1. Assessing transformative impacts of transdisciplinary publications through knowledge types and leverage points

1. Knowledge types

Different knowledge types have been identified based on the different objects of study in transdisciplinary research (e.g. Hirsch Hadorn et al. 2006; Brandt et al. 2013; Lawrence et al. 2022). Systems knowledge explores the history, root causes and functioning of specific situations and systems, e.g. exploring the root causes of ecosystem degradation. Target knowledge contributes insights into how a situation should or could be, for example studying local actors' preferences towards different land use and management systems. Transformation knowledge explores how to change a situation to the desired outcomes and how solutions could be implemented, for instance studying how to foster value and behaviour shifts. Finally, process knowledge addresses how to carry out transdisciplinary research, e.g. sharing insights on ethical requirements for transdisciplinary processes or developing new methodologies for actor involvement. In this review, we assumed that transdisciplinary studies have stronger transformative impacts when they produce target or transformation knowledge rather than systems knowledge.

2. Leverage points

Leverage points refer to interventions' shallow or deep impacts on a targeted system, i.e. the capacity of interventions to radically change a system (Meadows 1999; Meadows 2012; Abson et al. 2017). For instance, the level of parameters targets very shallow leverage points, such as adapting the level of resource use quota (Fischer and Riechers 2019). These shallow leverage points are rather easy to implement but have limited systemic impacts. Feedbacks refer to systemic interactions and feedback loops between elements of a system, such as delays and time in how the ozone hole can change after a stop on emissions (Fischer and Riechers 2019). Design leverages are more radical in that they affect information flows, the way systems are structured and organized and the power to change the systems rules, such as changes in policies or self-regulation of communities (Abson et al. 2017). Finally, leverages on the intent level, such as value shifts and institutional change, are more difficult to implement but are expected to have strong systemic, radical outcomes (Abson et al. 2017; Riechers et al. 2022). We categorized transdisciplinary publications according to whether they produced knowledge about interventions targeting parameters, feedbacks, design and/or intent and assumed that transdisciplinary studies have stronger transformative impacts when they address deep (design and intent), rather than shallow (parameters and feedbacks) leverage points.

2.4 Data analysis

In order to identify clusters within the body of literature examined by us, we used a multivariate statistical approach first developed by Abson et al. (2014). We created a corpus containing all words within each individual paper, and reduced this exhaustive list to words included in at least 5 % of the papers. This list was then manually refined to contain only words that transport a meaning, thereby excluding stopwords. Groups were then derived based on a cluster analysis using Wards method, aiming to identify relatively equally sized groups. Based on an Indicator species analysis (Dufrene and Legendre 1997) we identified significant indicator words for each group, which were subsequently visualized in a Detrended Correspondence Analysis. This linguistic analysis was conducted both for the whole dataset as well as for the subset only containing papers containing a transdisciplinary

approach. We used the R programming language v.4.3.1 (R Core Team 2023) with RStudio v.2023.06.1+524 (Rstudio Team, 2023) for all descriptive statistics and analyses.
C.G., F.W., H.v.W. analyzed and visualized the data sets.

3 Results

3.1 Research in Biosphere Reserves

3.1.1 Spatial distribution

Our analysis of 3,304 publications on Biosphere Reserves showed a research focus in North America with 27 %, Asia with 25 % and Europe with 22% of all publications (Fig. 1). Mexican and Indian Biosphere Reserves were studied the most with 825 and 390 publications, respectively (see Box 2). As of 2023, 35.3% of the 748 Biosphere Reserves are located in Europe, followed by Asia and North America. The share of studies per continent for all studies and transdisciplinary studies were relatively indifferent. Europe had the highest number of general studies and, together with Mexico, the highest number of transdisciplinary studies. Studies with a transdisciplinary approach are predominantly conducted in Europe, in North America and particularly in Mexico and India (see Box 2). Having a high number of designated Biosphere Reserves does not translate, however, in a high number of studies in the same country, with Mexico being a notable exception (Fig. S5).

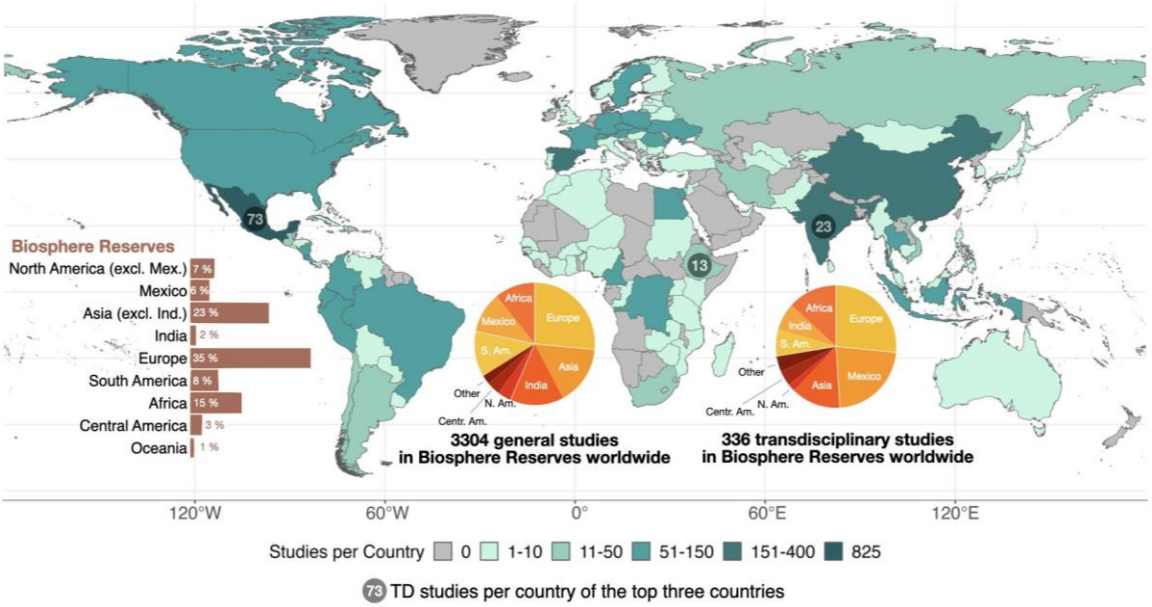

Fig. 1: World map of the general dataset with 3,304 publications of research in UNESCO Biosphere reserves. The color-coding illustrates the number of publications on Biosphere Reserves per country. The countries with the highest numbers of transdisciplinary studies are highlighted: Mexico 73, India 23 and Ethiopia 13. The share of publications per continent for 336 transdisciplinary publications and the general 3,304 publications is depicted in the pie charts. Right bar plot: Share of Biosphere Reserves per continent considering all 748 designated Biosphere Reserves as of 2023.

Research in Biosphere Reserves is primarily conducted on the continent of the first author's institution (Fig. 2 A). Also, the institutions of the first and last author tend to be on the same continent. Even though the regional research focus applies to the transdisciplinary publications on Biosphere Reserves as well, a similar pattern can be observed (Fig. 2 B). If researchers from Europe and North America study Biosphere Reserves outside of the Global

North, they focus on the Asian and African continent; hardly any researchers from there work in the Global North.

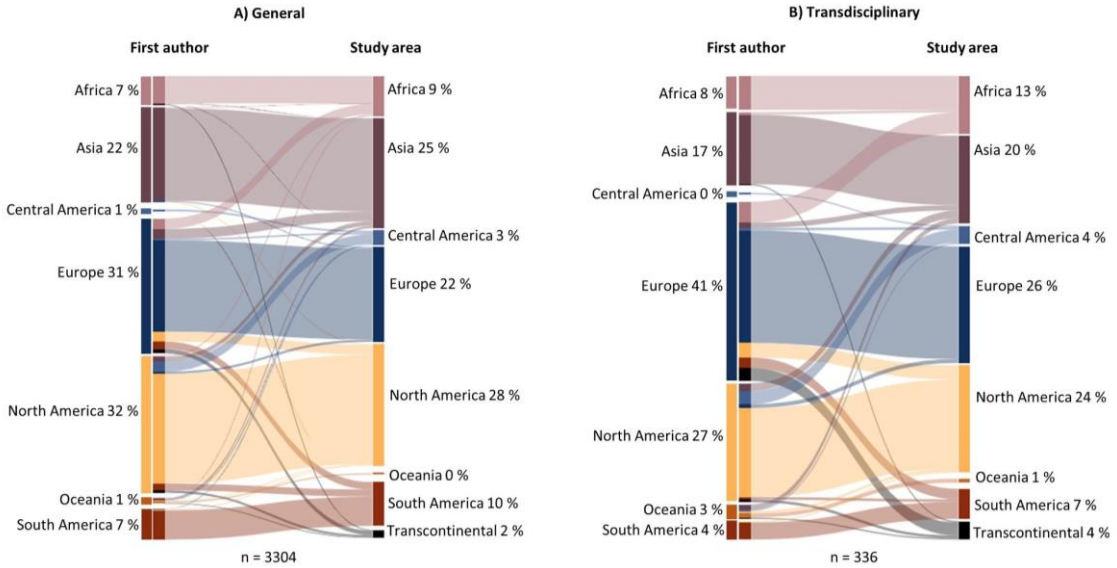

Fig. 2: Proportion of research institution of the first author at time of publication in relation to the study area for A) the general dataset and B) the transdisciplinary research in Biosphere Reserves.

3.1.2 Temporal distribution

The annual number of published studies conducted in Biosphere Reserves increased from a few articles during the late 1970s to more than 300 in 2020 (Fig. 3 A). Generally, we observed an increasing trend of annually published studies compared to the number of designated Biosphere Reserves, which is highlighted by numbers on the logarithmic scale (Fig. 3 B, supplementary material Fig. S3). UNESCO designated substantially more Biosphere Reserves per year starting in the mid-1990s.

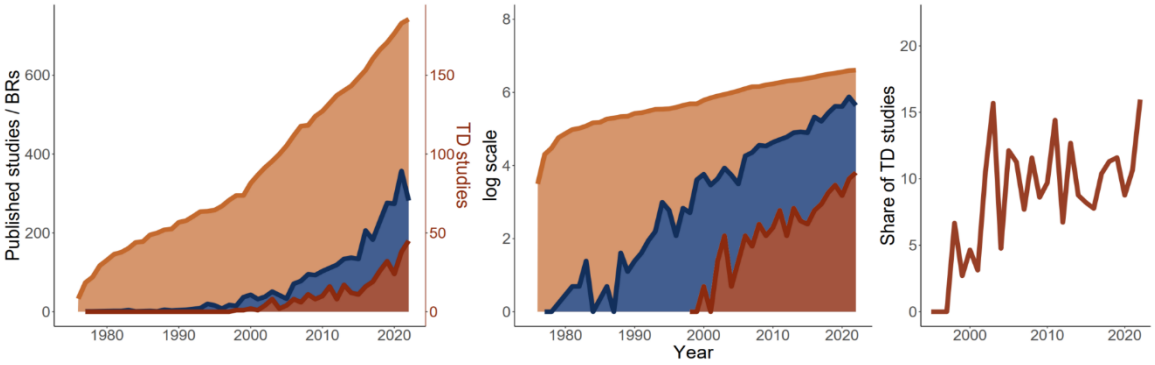

Fig. 3: Left: Cumulative number of designated Biosphere Reserves (BRs) in yellow and annual numbers of general publications in blue (n = 3,304) and transdisciplinary publications (TD) in red (n = 336) from 1975 to 2023, note the different y-axis-scales. Middle: The same on the log-scale. Right: Share of transdisciplinary publications from 1995 on.

We also explored global trends at the level of the individual continents (Supplementary Material, Fig. S1). There have been designated Biosphere Reserves on all continents (excluding Antarctica) since the late 1970s. The number of studies from North America (including Mexico) increased from the mid-1990s and faster than on other continents, while the number of studies from Europe, Asia (including India), and South America started to

notably increase only after 2000. Annual publications from African Biosphere Reserves saw only little increase until the mid-2010s after which they experienced a steep increase. First publications from Central America and Oceania also appeared during the late 1990s and early 2000s, but numbers remain relatively low until today. Overall, there is an over-proportional (compared to the share of designated Biosphere Reserves) amount of published studies originating from Asian, North American, South American, and lately African Biosphere Reserve, while European, Oceanian, and Central American Biosphere Reserves tend to be under-represented in published research.

Publications of transdisciplinary studies in Biosphere Reserves increased most notably after 2000 (Fig. 3 A in red). The share of transdisciplinary publications to all publications increased over time but fluctuates over the years (Fig. 3 B).

3.2 Research clusters

We identified seven clusters best suitable for describing the thematic foci of the publications on Biosphere Reserves (Fig. 4 A). Studies with a social focus, including words such as participation, interviews or governance, cover similar research areas as studies on perspectives on people and cultural studies. Most of the publications of the transdisciplinary dataset belong to the participation group. Spatial studies, using words such as maps and pixel, were found close to the participation and culture clusters. Studies focusing on the biological environment, including words such as water and sediment, grouped close to microbiological studies, with words such as acid, bacteria or microbial. Botanical studies, represented by words such as vegetation and abundance, are grouped close to studies on genes.

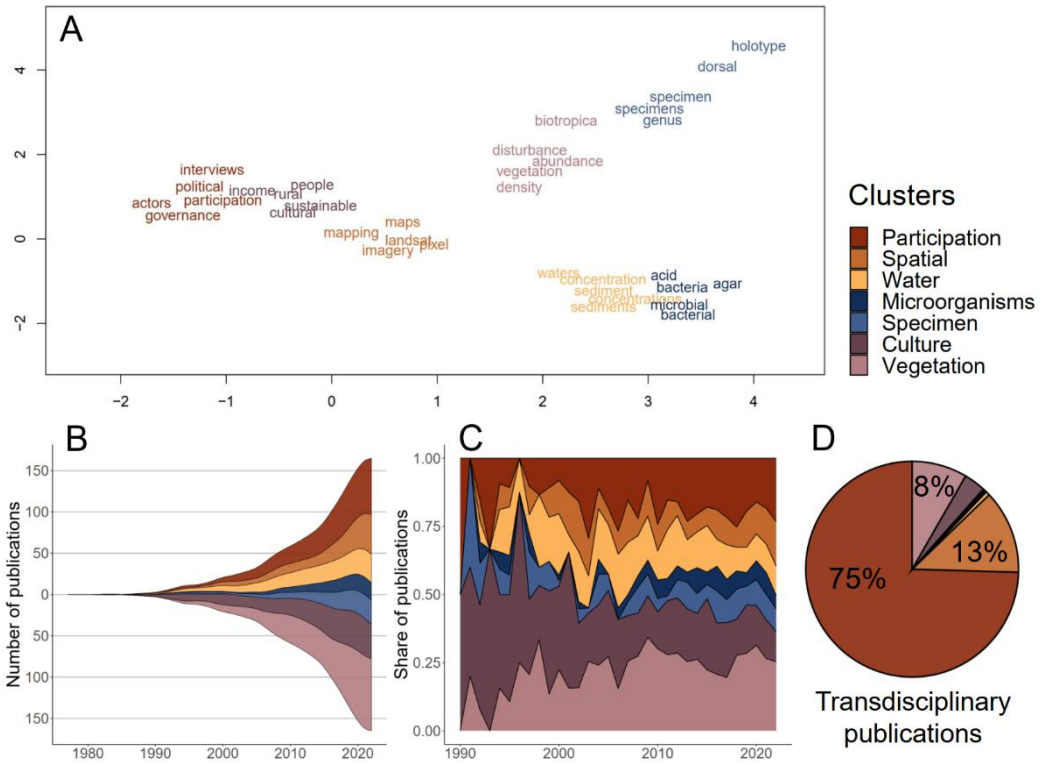

Fig. 4: Research clusters of 3,304 publications of research in Biosphere Reserves: A) Detrended component analysis results of the clusters. B) Annual total numbers, C) annual share and a D) pie-chart showing the representation of these groups in the transdisciplinary publication (n=336) only (top right).

The share of studies with a focus on people, using words like rural, sustainable and cultural (Fig. 4 B and C , culture), decreased over time, while the share of studies with words such as participation, governance and actors increased (Fig. 4 B and C, participation).

We identified more groups with a focus on natural sciences for publications in the general data set than for transdisciplinary articles. The transdisciplinary studies were clustered in groups of social and political sciences in the groups of general publications. Generally, groups were more delineated and separated in the general studies than in the transdisciplinary studies.

We identified five natural groups best suitable to describe the topics of transdisciplinary publications on Biosphere Reserves (Fig. 5 A). Research clusters focusing on politics were grouped and studies on ethnobotany were most distant. Publications tackling deforestation and degradation increased over time (Fig. 5 B and C, degradation), as well as those focussing on collaborations and stakeholder engagement (Fig. 5 B and C, collaboration).

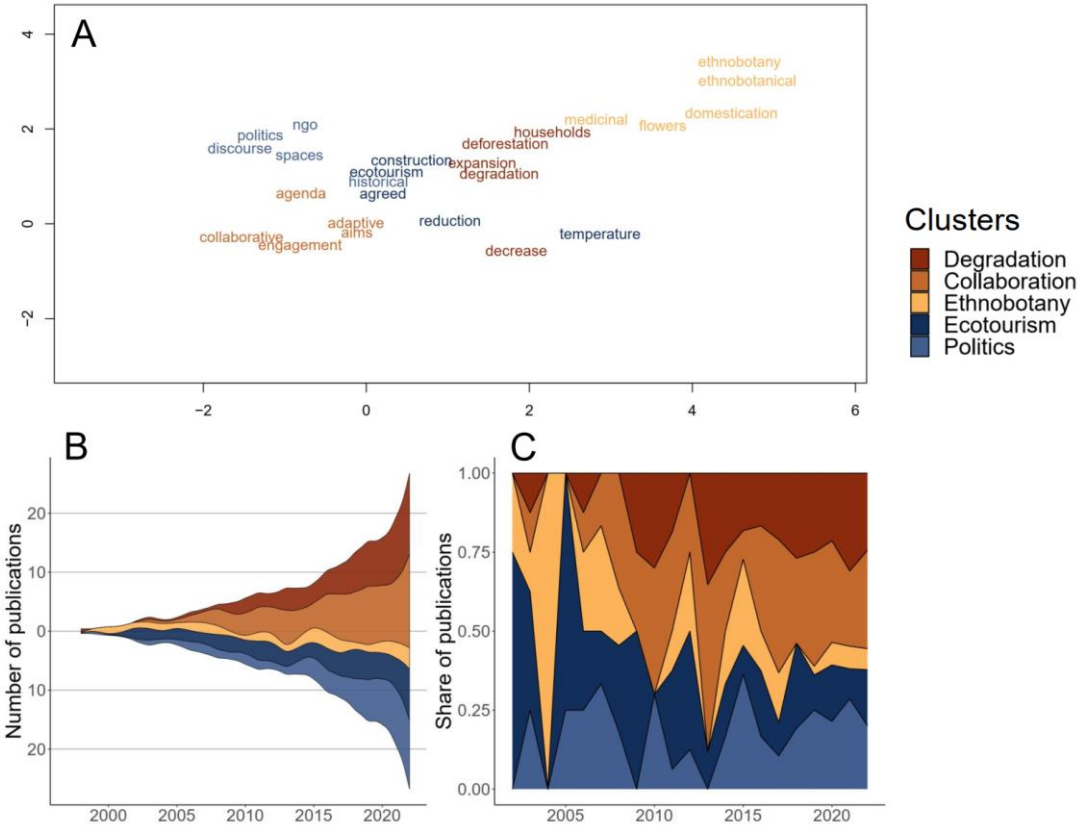

Fig. 5: Research clusters in transdisciplinary publications of research in Biosphere Reserves (n=336). A) Word cloud of research fields with five clusters, B) Annual total numbers and C) annual share.

3.3 Diversity and participation

3.3.1 Gender

We identified a higher percentage of male first authors (48%) and last authors (55%), compared to female first authors (31%) and last authors (24%) for publications studying Biosphere Reserves (Fig. 6). The pattern is also the same across continents, with South America and Asia having a higher number of female first authors. In South America there are even more female first authors than male first authors. With 43% male and 47% female first

authors, the ratio for publications with a transdisciplinary approach is closer to parity, although 55% of the last authors are male and only 32% female. There is likely a geographic bias in these results due to a very high share of unknown gender for Asia, Africa and Oceania. This originates from genderize.io generally showing lower accuracies for non-western names. Female first authors work with male (51%) and female (41%) last authors, whereas male first authors mostly work with male last authors (70%) (see Supplementary Material, Fig. S2, A). The publications with a transdisciplinary approach show a more balanced ratio (see Supplementary Material, Fig. S2, B). Regardless of the continent, more female first and last authors were identified in the transdisciplinary studies than in the general studies. It shifted not exclusively from male to female author shares, but showed a lower share of unknown gender in the transdisciplinary studies. Still, for both types of studies the majority of last authors were male. For additional percentages see the interactive supplementary material of the online version of this article.

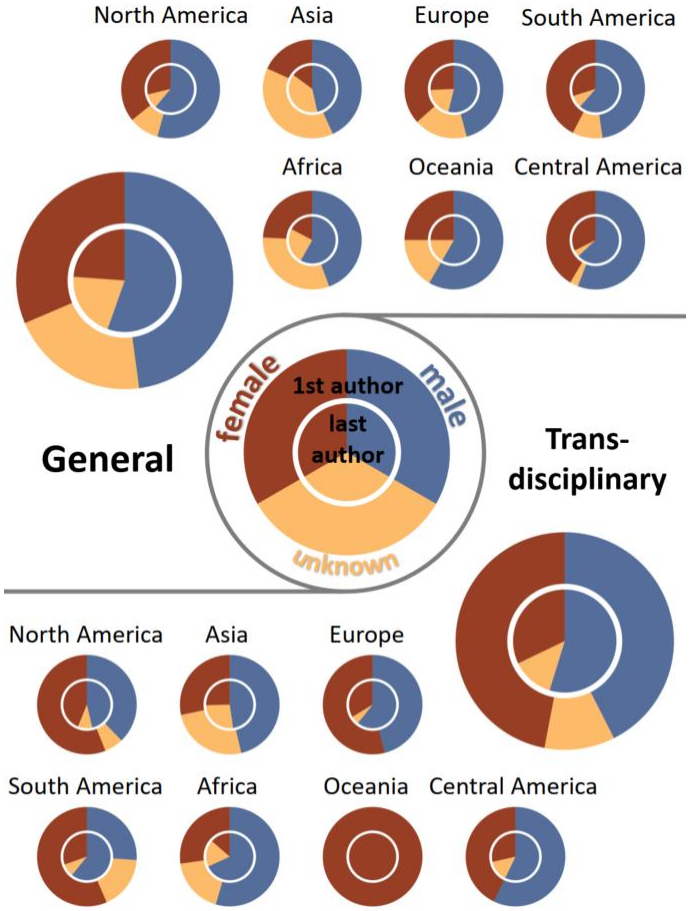

Fig. 6: Share of the gender (binary) of the first and last author for all publications of research in Biosphere Reserves (top) and for the publications with a transdisciplinary approach (bottom). Each dataset is visualized with its overall shares (large circles) and differentiated per continent of the study area (smaller circles). Absolute numbers (general/transdisciplinary): Overall (3,304/336), North America (924/82), Asia (834/67), Europe (720/89), South America (335/23), Africa (306/44), Oceania (12/3) and Central America (111/14). Transcontinental studies were excluded for this figure.

3.3.2 Actor participation in transdisciplinary research

In terms of actor types involved in transdisciplinary research in Biosphere Reserves, landusers, Indigenous People, government organizations and Biosphere Reserves

management bodies have been most involved in publications on Biosphere reserves with a transdisciplinary approach. In comparison, Youth and Women groups were least involved (Fig. 7). Despite this general pattern, some differences can be identified among clusters of publications. Ethnobotany-related research seems to engage mainly only with indigenous and land use actors, but shows a higher percentage of involvement of Women groups. Publications included in the politics cluster show, in general, a higher diversity of actors involved.

Regarding the extent of participation, actors were predominantly involved in a consultative role in transdisciplinary studies (98 %). Most studies (41%) built on collaboration with non-academic actors in the study design and only few publications (7%) reported about empowering actors. 53 of the 336 articles with a transdisciplinary approach (16%), were (co-)authored by the participating actors. Of all publications with a transdisciplinary approach, 51% acknowledged the actors, regardless of the type of participation.

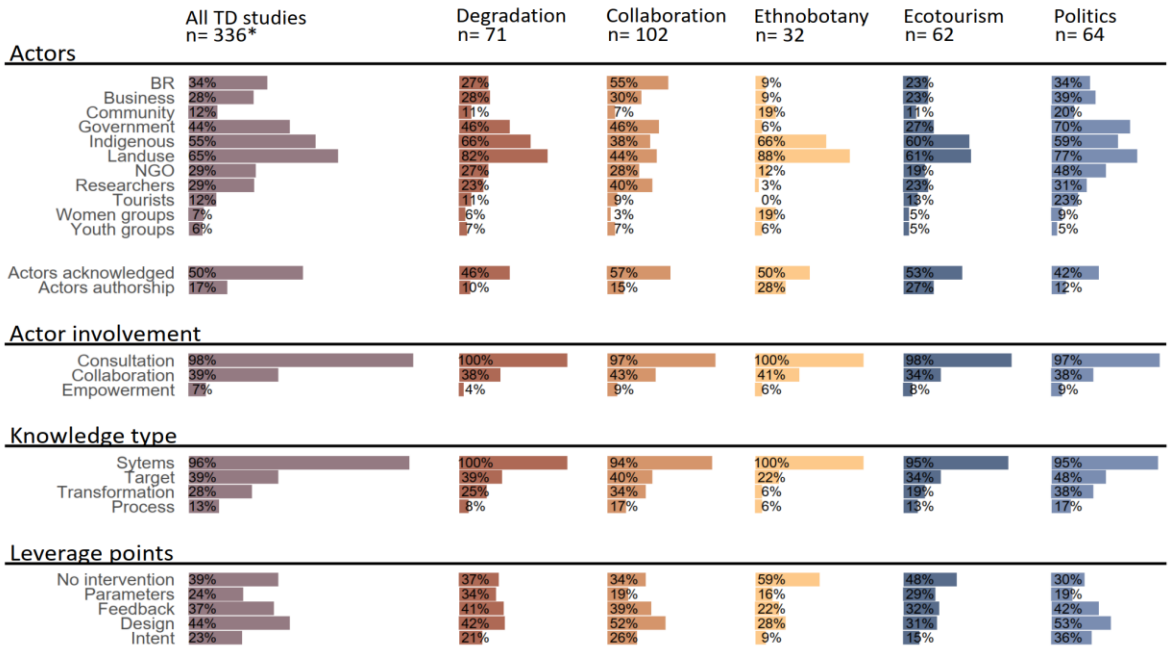

Fig. 7: Shares of actor groups, their way of involvement, generated knowledge types and leverage points in transdisciplinary studies, overall (far left) and for the five assigned research clusters. Shares for the categories of the individual variables do not add up to 100% as more than one or none of the categories could be valid for a single study. * 5 studies were not assigned to any group.

3.4 Transformative potential

We identified the creation of systems knowledge for most of the 336 publications with a transdisciplinary approach (Fig. 7). Few studies produced transformative (28 %) or process knowledge (28 %). This is reflected in the research clusters as well. Highest shares of target knowledge were identified in the (environmental) degradation, collaboration and politics research cluster. Process knowledge was mainly discussed in the collaboration and politics research cluster. We found leverage points at a design level in 44 % and at a feedback level in 37 % of the publications with a transdisciplinary approach. Parameters and intent were least studied. A rather large number of studies did not specifically explore any interventions (39%). Patterns are again similar in all research clusters. The highest shares of design and intent leverage points were found in the collaboration and politics research cluster.

4 Discussion

4.1 Temporal and spatial trends in Biosphere Reserves research

Our results showed that scientific publications about Biosphere Reserves have increased steadily in the last decades, in line with recent reviews (Kratzer 2018; Ferreira et al. 2020). However, the number of articles on Biosphere Reserves can be expected to increase substantially in the near future, as the number of scientific articles published annually is generally increasing (Fire and Guestrin 2019). The share of transdisciplinary studies in Biosphere Reserves has increased slightly in comparison to all Biosphere Reserves research. This trend could be due to a general uptake of transdisciplinary research in sustainability science (Brandt et al. 2013; Ghodsvali et al. 2019). The Seville Strategy, in 1995, recognized the need for more social sciences and humanities in exploring good practice for the implementation of the MAB programme, and the most recent MAB strategy calls for biosphere reserves to operationalize sustainability science using transdisciplinary approaches (UNESCO 2017). While these strategies have set agendas and proposed relevant issues for governance and research, Biosphere Reserves are still widely dedicated to nature conservation (Reed 2016; Pool-Stanvliet and Coetzer 2020) - and Biosphere Reserves research to natural sciences rather than transdisciplinarity, as the total number of transdisciplinary studies represent a small fraction of existing biosphere reserves' research.

Spatial trends in Biosphere Reserves research revealed that Europe, North America (mostly Mexico) and Asia (mostly India) contributed most publications, both in the general and transdisciplinary data sets. The particularly high number of publications from Mexico and India has been pointed out in recent reviews (Kratzer 2018; Ferreira et al. 2020). These numerous publications are likely due to funding opportunities from dedicated governmental agencies and specific research institutions with long-standing research history in those areas (Box 2). Although most researchers studied areas on the same continent as their professional affiliation, researchers located in the Global North worked in Biosphere Reserves in the Global South more often than the other way around, as was identified in recent reviews in Biosphere Reserves research (Ferreira et al. 2020), and in transdisciplinary research in general (Brandt et al. 2013). In Africa, this pattern was even more pronounced for transdisciplinary research, with an even higher proportion of publications than in the general data set being produced by researchers affiliated to Europe. These results may concur with what has been identified as a neocolonial pattern in scientific publications across many disciplines (Dahdouh-Guebas et al. 2003), in particular in climate and sustainability science (Sultana 2022, 2023), as well as transdisciplinary sustainability research (Zonta et al. 2023). To address power imbalances and neocolonialism in sustainability science, scholars have, for example, proposed strategies to centre knowledge, philosophies and people from the Global South (Chilisa 2017; Sultana 2023) - or methodologies and practices to foster e.g reflexivity, safe spaces, respect and meaningful benefits for communities (Pereira et al. 2020; Thambinathan and Kinsella 2021; Reed et al. 2023). In this regard, we acknowledge that the authors team, albeit international and interdisciplinary, is mostly affiliated in Europe, and thus proposed a perspective from the Global North.

4.2 Research clusters

The research clusters in the general data set revealed a disciplinary gradient, from social sciences dedicated to participation and culture, to natural sciences dedicated to species-related studies. However, most clusters included publications investigating topics related to

microorganisms, water, species, vegetation and spatial analysis. It is likely that this part of the research mostly contributes knowledge to the conservation mission of the MAB programme. Note however a slight increase in the number of publications dedicated to participation - which in turn might contribute to a better understanding of how to implement the human development mission of the MAB programme. While these results confirm recent findings showing that most research in Biosphere Reserves is still restricted to natural sciences (Kratzer 2018; Pool-Stanvliet and Coetzer 2020), the clusters also pinpointed a potential developing trend focussed on issues of participation and governance - a trend that would need confirmation by future reviews.

Transdisciplinary research in Biosphere Reserves also revealed a gradient from publications with a governance focus (politics, discourse, agenda) to social-ecological and ecological studies (ethnobotany, domestication, medicinal). Topic-wise, current transdisciplinary research in Biosphere Reserves could be classified in five clusters: ethnobotany, degradation, ecotourism, politics and collaboration. These transdisciplinary clusters were less differentiated than those in the general data set, suggesting that there are yet no clear schools within transdisciplinary research in Biosphere Reserves. The politics and collaboration clusters accounted for a majority of publications with a shared focus on governance.
Therefore, this review suggests that Biosphere Reserves seem to be used merely as interesting and logistically attractive sites to carry out research, rather than an object of research per se. Notwithstanding, the analyses also highlighted a coherent, albeit developing, literature bundle aiming to address issues related to Biosphere Reserves governance and management, and to the successful implementation of the MAB Programme and Agenda 2030 for Sustainable Development. Hence, there is still much room to explore conditions for successful Biosphere Reserves governance - and to highlight the contributions of the World Network of Biosphere Reserves to support place-based knowledge co-production in sustainability science (Barraclough et al. 2023).

4.3 Diversity and participation

In order to analyze diversity in Biosphere Reserves researchers, we recorded the gender of first and last authors. We found that research on biosphere reserves involved vastly fewer female than male authors across all continents. In particular, there were significantly fewer female last authors, often considered as Principal Investigators (PIs) - this discrepancy between the numbers of female first and last authors was particularly strong in Europe and South America. These results correspond to recent reviews showing that men still largely dominate the scientific system, especially when it comes to senior positions and e.g. co-authoring as PIs (Huang et al. 2020, Hofstra et al. 2020, Ross et al. 2022). In transdisciplinary research in Biosphere Reserves, the share of female authors increased remarkably in comparison to the general data set, while the share of authors categorized under unknown gender was reduced. In North and South America, Europe and Oceania, we observed even more female than male first authors. Although the share of female last authors was higher than in the general data set, it remained well below parity. Why Women proportionally authored more transdisciplinary publications than publications in the general data set remains unclear. Global reviews have shown that Women are better represented in specific disciplines, e.g. political science and psychology (Huang et al. 2020), or brain science and jurisprudence (Holman et al. 2018). However, there is no clear evidence so far, and to our knowledge, about the representation of Women in sustainability science, nor in transdisciplinary research. Our results call for a much stronger commitment to gender

equality in (transdisciplinary) Biosphere Reserves research. Many guidelines have been provided to address gender inequalities in science. Examples include, but are not limited to, feminist and slow scholarship (Mountz et al. 2015), mother-friendly measures within research labs (Leventon et al. 2019), policies against early-career drop out (Cardel et al. 2020) and a feminist ethos of care in transdisciplinary sustainability science (Staffa et al. 2022).

Box 2. Focus on Biosphere Reserves research in Mexico and India

With 25.1% (= 825 articles) and 22% (= 73 articles) respectively, scientists from Mexico publish the most in general and transdisciplinary studies on Biosphere Reserves as compared to all other countries. Of the 41 designated Mexican Biosphere Reserves, Calakmul, La Sepultura, El Viscaino, Sian Kaan and Mariposa Monarca are mostly studied with a transdisciplinary research design with six to ten studies each. There seem to be several catalysts for transdisciplinary research in Mexico: The National Council for Science and Technology in Mexico (CONACYT) subsidized 22 of the 73 transdisciplinary studies with grants and scholarships. 12 transdisciplinary papers were written by scientists of the National Autonomous University of Mexico. Additionally, "El Colegio de la Frontera Sur, Unidad Campeche (ECOSUR)" subsidized 10 of the transdisciplinary papers with knowledge, financial and logistical support.

India has 12 designated Biosphere Reserves and 11.8% of the general publications related to Biosphere Reserves come from there. Remarkably, the MAB programme in India was only launched in 1986 and the first Biosphere Reserve was established in 2000. All 23 transdisciplinary papers on Indian Biosphere Reserves were conducted in five Reserves, namely Nanda Devi (11), Khangchendzonga (5), Nilgiri (3), Sunderban (3) and Nokrek (1). The GB pant Institute of Himalayan Environment and Development alone supported one third of the transdisciplinary research papers and may therefore act as a catalyst for transdisciplinary research.

Publications on Biosphere Reserves in Mexico and India increased considerably in the last 10 years (Fig. Box 2). In Mexico, UNESCO designated 18 new Biosphere Reserves only in 2006. Both countries are characterized by distinct and highly vulnerable biodiversity, comprising priority regions for global conservation (Olson and Dinerstein 2002). Conservational efforts in both countries are high and research is supported. In Mexico, the National Commission of Natural Protected Areas (CONANP) manages and supports the Network of Biosphere Reserves, protecting in total more than 11,5% of Mexican land. In India government agencies, such as the Ministry of Environment, Forest and Climate Change, and the National Biodiversity Authority, provide support for scientific studies and conservation initiatives. The high research output in Mexico and India could be related to external funding as well. Mexico and India are amongst the highest recipients of biodiversity aid. From 1980-2008, India was first and Mexico 4th place with 9% and 3% respectively of worldwide biodiversity funding (Miller et al. 2013).

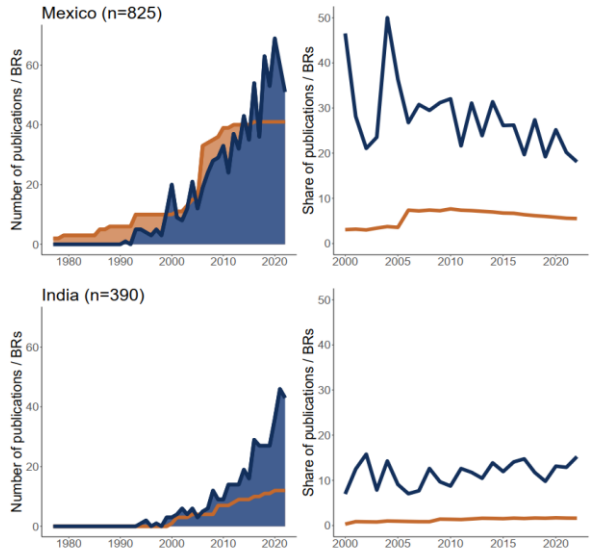

Fig. Box 2: Number of annual publications in blue and cumulative number of designated Biosphere Reserves in yellow from 1975 to 2023 for Mexico (top-left) and India (bottom-left). Share of annual publications and designated Biosphere Reserves after 2000 for Mexico (top-right) and India (bottom-right).

To better understand diversity and participation in Biosphere Reserve research, we also analyzed which actor groups were involved in transdisciplinary publications and to what extent. Our analysis revealed that land users, governmental and Biosphere Reserve representatives, but also Indigenous People were involved in several studies, regardless of research clusters. It has been shown that transdisciplinary research too often relied on elite participants, e.g. government or large NGOs, while underrepresented groups are often least involved (Turnhout et al. 2020). While this holds true in our study for Women and the Youth, it is remarkable that Indigenous People were involved in more than half of the transdisciplinary studies. Note that Indigenous People, Women, the Youth and local communities are mentioned as target groups for effective and equitable participatory planning in the most recent MAB strategy (UNESCO 2017). Nonetheless, participation was very limited in most studies and usually restrained to extracting information through e.g. interviews, questionnaires or surveys. This transdisciplinary theory-practice gap has been identified in former reviews (Brandt et al. 2013; Jahn et al. 2021). Barriers to collaborative and empowering practices include funding contexts that e.g. require short-term results (Jahn et al. 2021), difficulties in ensuring participation of various actors (Lang et al. 2012; Lawrence et al. 2022) or underlying power relations and conflicts that fail to be addressed (Pereira et al. 2020; Turnhout et al. 2020). The aspirational character of transdisciplinarity has been criticized as an extractive, power-ladden and often neocolonial pattern that should be addressed more stringently in research (Zonta et al. 2023). To address this theory-practice gap, guidelines and recommendations have been provided - notably calling for a radical engagement with power relations, conflicts and discomfort within transdisciplinary research (Fritz and Binder 2020; Ghosh 2020; Pereira et al. 2020; Turnhout et al. 2020; Barraclough et al. 2023). An example study reporting about empowering processes was found in Rivera-Arriaga et al. (2021), who reported about participatory governance processes in collaboration with governmental, scientific and Mayan community representatives, in order to prevent ecological degradation and address local socio-political issues in Los Petenes Biosphere Reserve (Mexico). The results included building local capacities and co-creating a place-based, innovative management scheme aiming to ensure community wellbeing and environmental health.

4.4 Transformative potential

Our analysis showed that most transdisciplinary studies were limited in their transformative potential. Most studies were restricted to producing systems knowledge, i.e. helping to understand the current state and root causes of a specific system or issue. This held true for all research clusters. The Ethnobotany cluster produced even less target, transformation or process knowledge than all other clusters. This cluster seemed to build on citizen science to collect e.g. botanical data, which can explain the strong focus on systems knowledge. On the contrary, the collaboration and politics clusters featured a stronger transformative potential, with more studies producing target and transformation knowledge. Yet, these results confirm the aspirational character of transdisciplinary research (Brandt et al. 2013; Zscheischler and Rogga 2015; Turnhout et al. 2020) and call for a stronger engagement to produce transformative and solution-oriented knowledge, notably to support Biosphere Reserves management and the successful implementation of the MAB programme (Barraclough et al. 2023). An example of a study producing target knowledge, or knowledge about potential solutions and visions for a Biosphere Reserve, can be found in Choudhary et al. (2021), in which strategies and recommendations are developed for Community-based Tourism, with

the goal to ensure conservation and rural development in the Majang Forest Biosphere Reserve (Ethiopia).

This review showed that transdisciplinary studies had mixed results in addressing concrete interventions for transformative change at different leverage points. For instance, a large part of the publications (regardless of research clusters) did not address any particular intervention, and only a quarter of all studies addressed interventions at intent level, or the deepest leverage (Abson et al. 2017). These mixed results mirror literature reviews on leverage points in research about food and energy systems (Dorninger et al. 2020), marine and coastal pollution (Riechers et al. 2021b) or in Arctic Indigenous food systems (Zimmermann et al. 2023). The collaboration and politics clusters seemed more impactful than all others, with many studies addressing deep leverage points at design and intent level. While the Lima Action Plan (UNESCO 2017) calls for inter- and transdisciplinary research to better understand how to improve the management and governance of Biosphere Reserves, there is much room to address potential interventions on deep leverages for this purpose. In this regard, strengthening research that addresses issues of collaboration, politics, and governance could support in leveraging this transformative potential and help bridge the gap between the concept of Biosphere Reserves and its implementation. An example of a study addressing deep leverage points can be found in Sharip et al. (2018). The study builds on focus group discussions with local actors to identify management challenges and to formulate recommendations for improved local communication and coordination of the several organizations responsible for environmental protection and governance in the Tasik Chini Biosphere Reserve (Malaysia).

4.5 Methodological challenges

Systematic literature reviews face common methodological challenges. Following recent reviews about Biosphere Reserves research (Kratzer 2018; Ferreira et al. 2020) and transdisciplinary research (Brandt et al. 2013; Zscheischler and Rogga 2015; Ghodsvali et al. 2019), we concentrated on articles available to a broad international readership, i.e. written in English in peer-reviewed scientific journals. Although the proportion of other languages in the databases we used was small, we acknowledge that reviewing literature published in other languages might be relevant to give a complete overview of global literature to date, notably for transdisciplinary research.

To study diversity in authorship, we followed recent reviews (Fox et al. 2019; Hofstra et al. 2020; Ross et al. 2022) in categorizing authors as female, male or unknown gender based on their first names, using the genderize.io algorithm. Further empirical data would be necessary for a better understanding of authorship diversity and intersectionality. Furthermore, we acknowledge the need for more gender-sensitive and less biased tools to assess diversity in authorship globally. The algorithm we used was based on a binary understanding of gender and did not account for e.g. non-binary and fluid gender identities. This algorithm revealed a geographic bias, as first names of authors affiliated in Asia and Africa were significantly more often categorized as unknown than in Europe or North America. Finally, a more fine-tuned information on all co-authors (rather than only first and last authors) would give a more accurate overview, for example for fields where the second author is usually the PI.

Finally, we encountered common challenges in capturing contributions of transdisciplinary studies. Transdisciplinary research still rarely monitors and outlines societal impacts in scientific publications (Newig et al. 2019; Jahn et al. 2021; Schäfer et al. 2021). Societal impacts may become visible only in the long-term, after scientific publications (Pereira et al. 2020; Chambers et al. 2021). Following, it appeared difficult to appraise the transformative potential of transdisciplinary research through literature review of scientific publications only. Although we acknowledge that grey literature could address this gap, such in-depth studies have been conducted on a limited number of cases only (Chambers et al. 2021; Jahn et al. 2021; Schäfer et al. 2021). Hence, it remains a common procedure for global reviews of transdisciplinary research to focus on peer-reviewed articles only (Brandt et al. 2013; Ghodsvali et al. 2019). Our results analyze this research landscape and consequently are restricted to this branch of science.

5 Conclusion

The World Network of Biosphere Reserves provides ample opportunities for knowledge co-production about a wide array of sustainability issues - and for contributing place-based insights to global scientific debates. Yet, this review showed that a large portion of Biosphere Reserves research is located in a few specific continents with a focus on natural sciences. Definitely, transdisciplinary research has contributed to exploring conditions for successful Biosphere Reserves governance. However, there is scope for enhancing the transformative potential of Biosphere Reserves research. In that regard, a stronger commitment to gender equality, empowering forms of participation and knowledge integration about a broader range of topics are necessary. This would be essential to transform research in Biosphere Reserves into research about Biosphere Reserves and to highlight these areas as model regions for sustainability transformations.

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Supplementary Material 1

Tab. S1: Review process

Review step	Procedure
Articles identification	Identification of 5,208 articles on Web of Science and 4581 Scopus in March 2023 based on search string on title, keywords and abstract: “biosphere reserve*” OR “biosphere region*” OR “biosphere area
Data cleaning	Selection of 3,304 articles based on the following criteria: (1) original research, (2) accessible full texts, (3) English language, (4) at least one study site in a Biosphere Reserve
General coding	Coding of the 3,304 selected articles according to: geographic location; authors gender
Transdisciplinary articles identification	Identification of 451 articles from the general dataset of 3,304 selected articles, based on transdisciplinary search string in title and abstract: mode 2, knowledge integration, consult*, collabor*, empower*, participatory, participation, stakeholder*, real-world, multidisciplinary, interdisciplinary, citizen science, adaptive management, co-management, co-creat*, co-produc*, action research*, indigenous knowledge, ILK, actor-based*, transformative*, transformation*
Transdisciplinary data cleaning	Selection of 336 transdisciplinary articles that complied with the inclusion criteria of involving non-academic actors in the study design
Transdisciplinary coding	In-depth coding of the 336 transdisciplinary articles based on full-text analysis on: (1) participation (non-academic actors co-authors; acknowledged actors; type of actors; and level of involvement) and (2) transformative impacts (knowledge types; leverage points)

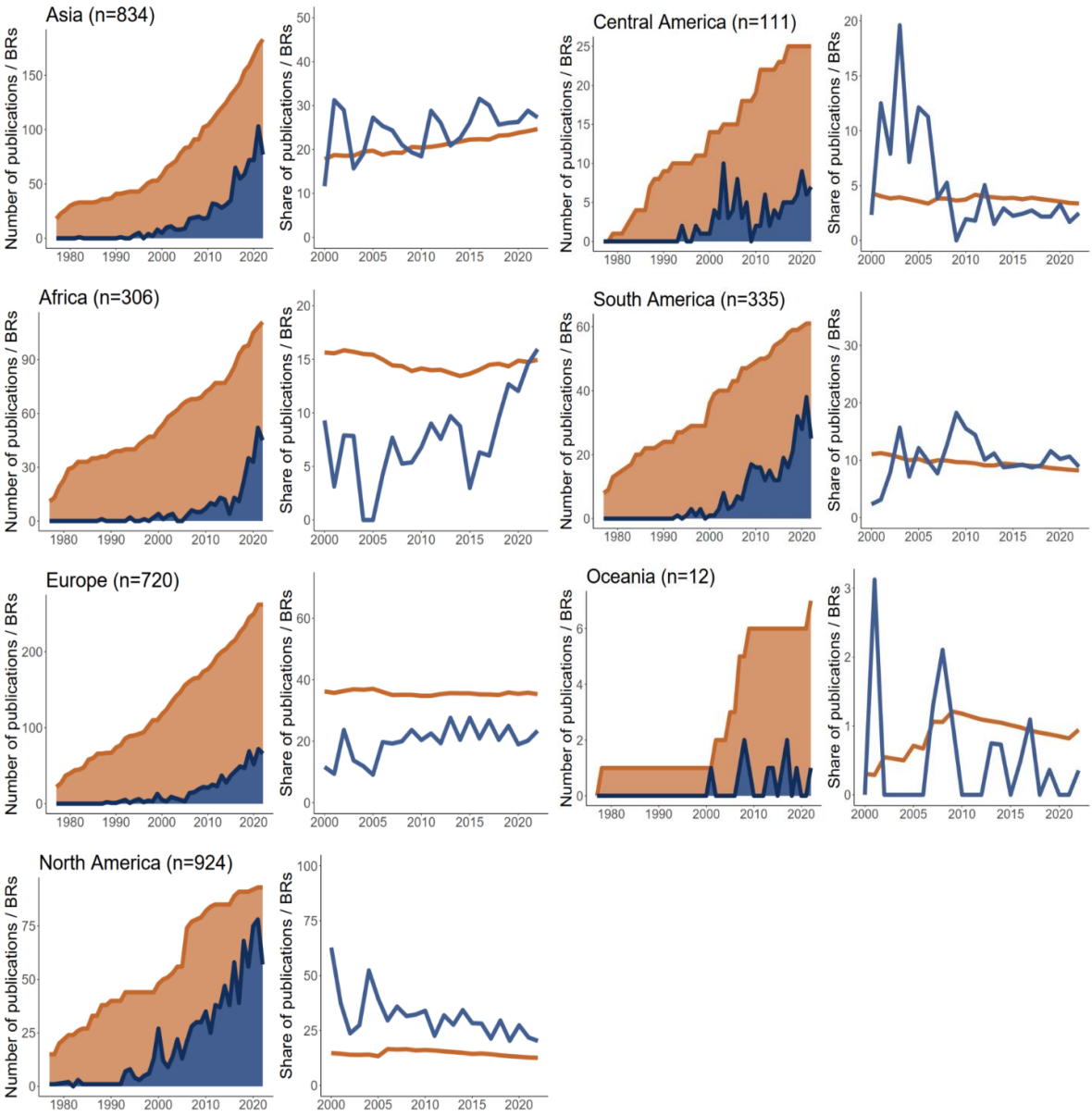

Fig. S1: Left: Cumulative number of designated Biosphere Reserves (BRs) in yellow and annual numbers of general publications on Biosphere Reserves in blue (n = 3,304) from 1975 to 2023 for all continents. Right: Annual share of Biosphere Reserves and publications in %.

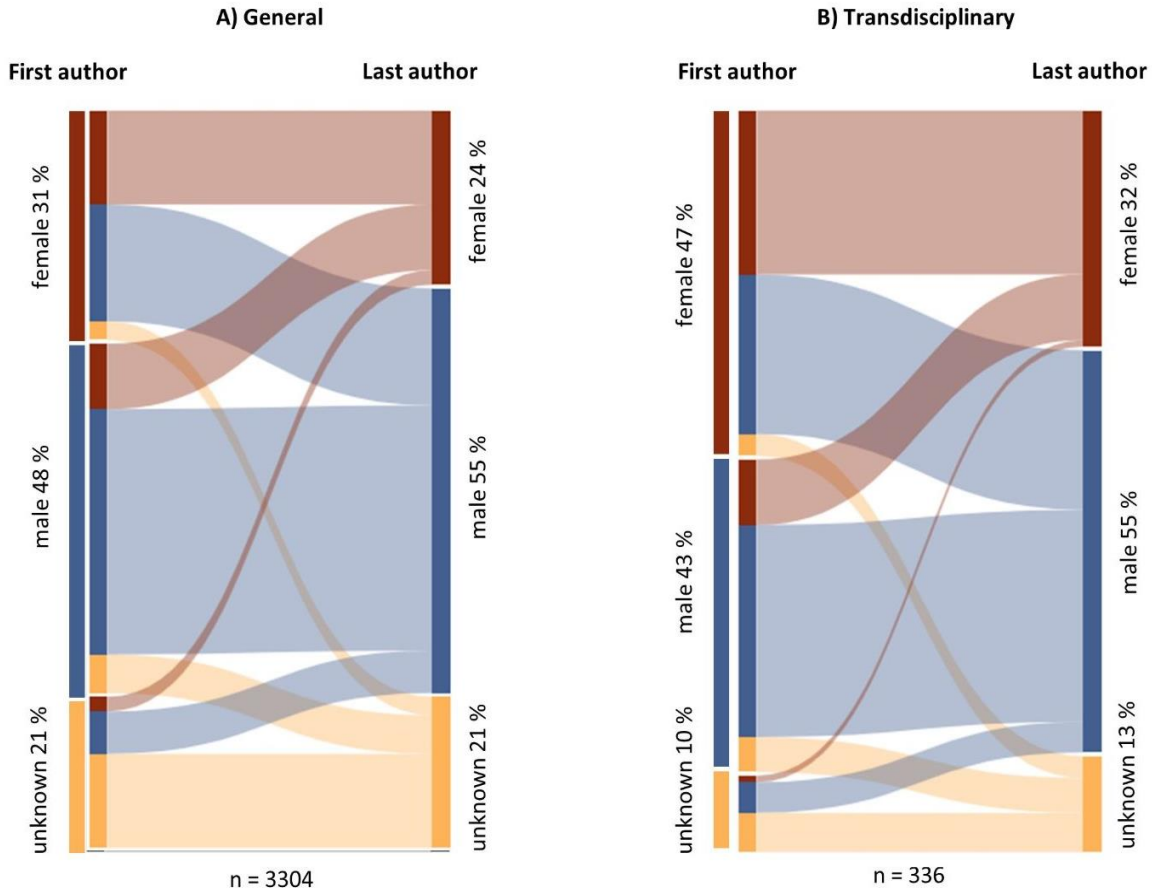

Fig. S2: Proportion of the gender of the first author in relation to the gender of the last author for A) the general dataset of research in Biosphere Reserves (n = 3,304) and B) the dataset of transdisciplinary research in Biosphere Reserves (n=336).

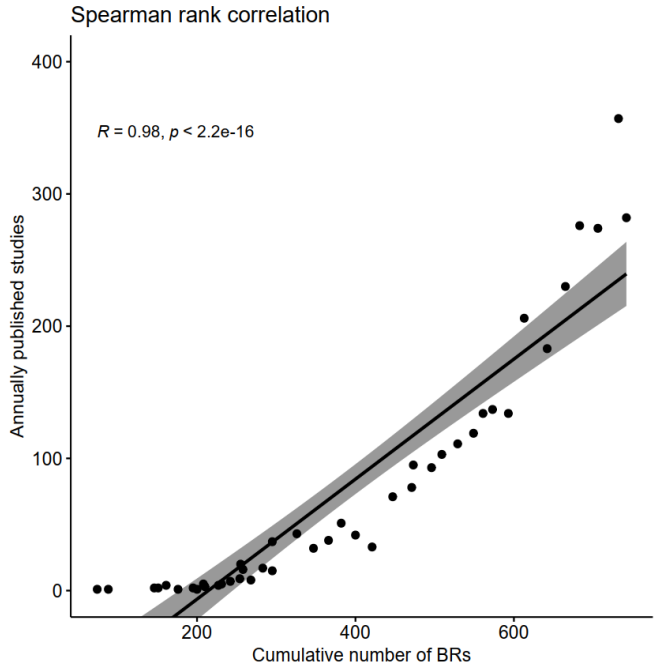

Fig. S3: Spearman rank correlation for number of annually published studies on Biosphere Reserves of the general dataset (n = 3,304) and the cumulative number of designated Biosphere Reserves (n = 748 in December 2023).

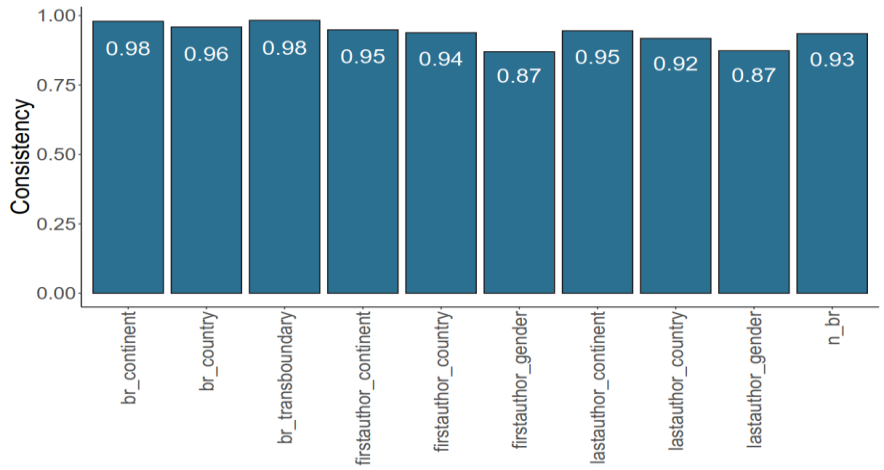

Fig. S4: Validation results for coded variables based on a set of publications (n=292) coded twice by two independent coders. The coded variables were (x-axis from left to right): Continent of the Biosphere Reserve, country of the Biosphere Reserve, transboundary Biosphere Reserve (yes/no), continent of the first authors institution, country of the first authors institution, gender of the first author, continent of the last authors institution, country of the last authors institution, gender of the last author, number of Biosphere Reserves covered in the study.

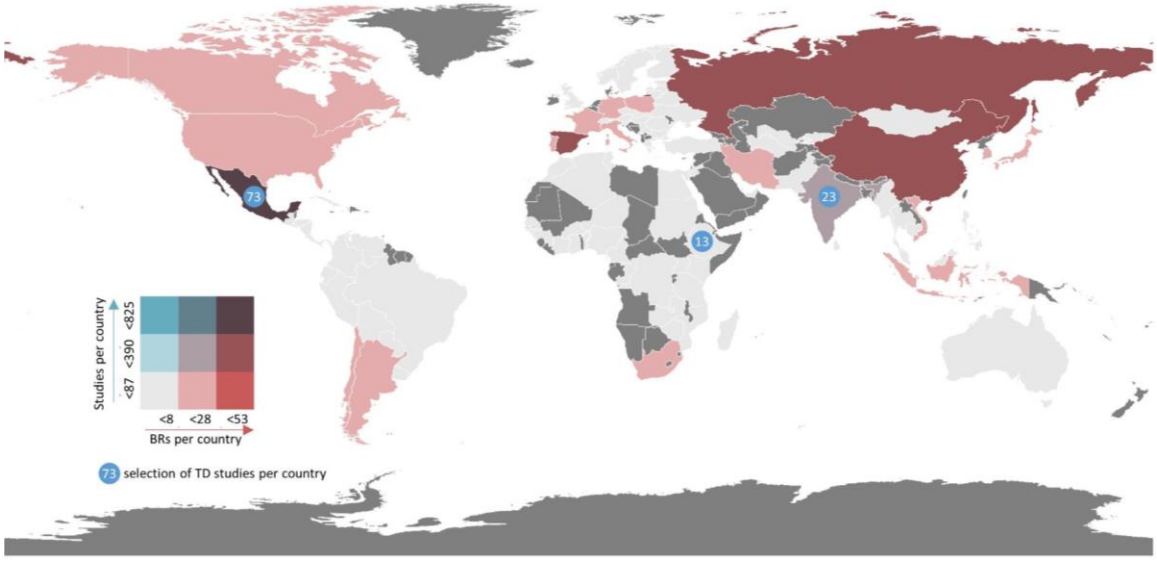

Fig S5: Bivariate map with number of general studies on Biosphere Reserves (n =3,304) and Biosphere Reserves per country. Light gray shows countries with few studies (1-87) and few Biosphere Reserves (1-8). Dark red shows countries with a high number of studies (390-825) and a high number of Biosphere Reserves (28-53). Countries with the highest numbers of TD studies are depicted. Mexico 73, India 23 and Ethiopia 13. Countries with no studies on Biosphere Reserves and no Biosphere Reserves shown in dark grey.

Supplementary material 2 will be available onlin

A.6 Eigenständigkeitserklärung

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Eigenständigkeitserklärung

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Hiermit erkläre ich, dass ich mich noch keiner Doktorprüfung unterzogen oder mich um Zulassung zu einer solchen beworben habe.

Ich versichere, dass die Dissertation „*Enhancing the transformative potential of sustainability innovations: insights from two European Biosphere Reserves*“ in der gegenwärtigen oder einer anderen Fassung noch keiner anderen Hochschule zur Begutachtung vorgelegen hat.

Ich versichere an Eides statt, dass ich die eingereichte Dissertation „*Enhancing the transformative potential of sustainability innovations: insights from two European Biosphere Reserves*“ selbstständig und ohne zulässige fremde Hilfe verfasst habe. Anderer als der von mir angegebenen Hilfsmittel und Schriften habe ich mich nicht bedient. Alle wörtlich oder sinngemäß anderen Schriften entnommenen Stellen habe ich kenntlich gemacht. Über die strafrechtlichen Folgen gemäß § 156 Strafgesetzbuch wurde ich in Kenntnis gesetzt.

Lüneburg, 15. Januar 2024

Caroline Hélène DABARD