Advancing Transformative Sustainability Science Through Research in Real-world Laboratories

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Abstract

Real-world laboratories have emerged as research settings where scientists and practitioners collaborate on sustainability challenges through experiments in real-world contexts. While real-world laboratory research is recognized for developing action-oriented knowledge, its role in advancing scientific practice itself has been less researched. This cumulative dissertation presents how research in real-world laboratories can enrich and foster transformative sustainability science. Based on long-term transdisciplinary engagement in three closely connected real-world laboratory projects, I have developed five research articles that illuminate how real-world laboratories function as incubators for scientific innovation. The findings reveal methodological innovations including a case reporting approach for knowledge transfer across contexts, a dual research design connecting local solutions with broader knowledge production, and a modular evaluation approach for complex real-world laboratory processes. Practice innovations encompass collaborative learning approaches and design principles for integrating transformative learning with research. Ontological transformations involve reconceptualizing scientific impact through "emergent impacts" from long-term collaboration processes. These innovations emerged through engagement with productive tensions that characterize real-world laboratories as boundary spaces between scientific and societal domains. By navigating such tensions between contextual specificity and generalizability, rigor and relevance, and knowledge production and action, real-world laboratories create conditions under which scientific practices can be reimagined. The research shows that real-world laboratories fulfill a dual function: they are not only settings for applying established approaches, but spaces where new scientific practices emerge. This positions real-world laboratories as crucial infrastructures for advancing transformative sustainability science.

Zusammenfassung

Reallabore haben sich als Forschungsumgebungen etabliert, in denen Wissenschaft und Praxis gemeinsam an Nachhaltigkeitsherausforderungen arbeiten und mit Experimenten in realweltlichen Kontexten neue Ansätze erproben. Während Reallaborforschung vor allem für die Entwicklung handlungsorientierten Wissens anerkannt ist, ist ihr Beitrag zur Weiterentwicklung wissenschaftlicher Praxis bisher wenig untersucht. Diese kumulative Dissertation zeigt, wie Forschung in Reallaboren die transformative Nachhaltigkeitswissenschaft bereichern und voranbringen kann. Sie basiert auf langjähriger transdisziplinärer Zusammenarbeit in drei eng miteinander verbundenen Reallaborprojekten und bündelt fünf Forschungsartikel, die aufzeigen, wie Reallabore als Inkubatoren wissenschaftlicher Innovation wirken. Die Ergebnisse verdeutlichen methodische Neuerungen wie einen Case-Reporting-Ansatz zum Wissenstransfer zwischen unterschiedlichen Kontexten, ein duales Forschungsdesign zur Verknüpfung lokaler Lösungen mit übergreifender Wissensproduktion sowie ein modulares Evaluationskonzept für komplexe Reallaborprozesse. Auf Praxisebene entstanden kollaborative Lernansätze und Gestaltungsprinzipien, die transformatives Lernen mit Forschung verbinden. Ontologische Neuerungen betreffen eine Neubestimmung wissenschaftlicher Wirkung durch "emergente Impacts", die sich aus langfristigen Kooperationsprozessen ergeben. Diese Innovationen entwickelten sich aus dem Umgang mit produktiven Spannungen, die Reallabore als Grenzräume zwischen wissenschaftlichen und gesellschaftlichen Handlungsfeldern kennzeichnen. Indem Spannungen zwischen Kontextgebundenheit und Verallgemeinerbarkeit, zwischen wissenschaftlicher Strenge und praktischer Relevanz sowie zwischen Wissensproduktion und Handeln produktiv genutzt werden, schaffen Reallabore Bedingungen, unter denen wissenschaftliche Praktiken neu gedacht werden können. Die Arbeit zeigt, dass Reallabore eine doppelte Funktion erfüllen: Sie sind nicht nur Orte zur Anwendung etablierter Ansätze, sondern auch Räume, in denen neue wissenschaftliche Praktiken entstehen. Damit werden Reallabore zu zentralen Infrastrukturen für die Weiterentwicklung einer transformativen Nachhaltigkeitswissenschaft.

Lists

Abbreviations

RwL	Real-world Laboratory
TD	Transdisciplinary
GLOCULL	Globally and Locally Sustainable Food-Water-Energy Innovation in Urban Living Labs
TIL	Transformative Innovation Lab
GTPF	German Participatory and Transdisciplinary Research Platform

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Chapter 1

Introduction

Sustainability challenges such as climate change, biodiversity loss, social inequity, and resource depletion confront humanity with unprecedented complexity and urgency. These problems transcend disciplinary, spatial, and temporal boundaries, reflecting fundamental tensions between current development pathways and the long-term viability of social-ecological systems. Addressing these issues requires a transformative change in the way societies organise, produce, consume, and interact with natural environments (Clark & Harley, 2020; Kates, 2011; Kates et al., 2001).

1.1 Transformative transdisciplinary sustainabiltiy research: an emergent field of research

Transformative sustainability research and transdisciplinarity

Transformative sustainability research has emerged as a distinctive research field that explicitly aims to contribute to sustainability transformations (Horcea-Milcu et al., 2024; T. R. Miller et al., 2014; Wiek & Lang, 2016). Unlike traditional research, which focuses primarily on understanding and explaining phenomena, transformative research is actively engaged in developing, testing, and implementing potential solutions through collaborative processes with societal actors (Caniglia et al., 2020; Schneidewind et al., 2016).

Central to this approach is transdisciplinarity–a research mode that transcends disciplinary boundaries and integrates diverse forms of knowledge through collaboration between academic and non-academic actors (Hirsch Hadorn et al., 2006; Lang et al., 2012). This collaborative mode brings together scientific expertise with practical knowledge to co-produce solutions that are both scientifically credible and socially robust, representing a fundamental shift from traditional research approaches that maintain boundaries between academia and other knowledge domains (Caniglia et al., 2023; Nowotny et al., 2001; Pohl & Hirsch Hadorn, 2007).

Recent developments in the field have further articulated the distinctive character of transformative sustainability science. As Augenstein et al. (2024) argue, transformative sustainability science or transformative transdisciplinary research (TTDR) is characterised by two core aspects: it contributes to solving complex real-world sustainability problems through collaboration between diverse actors, and it adopts an enabling approach that focuses on creating contexts and capacities that empower individuals and communities to act for transformative change.

Real-world laboratories as transformative research settings

Real-world laboratories (RwLs) have emerged as concrete settings where transformative transdisciplinary research approaches are enacted. RwLs create designated spaces where scientists, civil society actors, businesses, and government representatives collaborate to generate solution-oriented knowledge through experimentation in real-world contexts (McCrory et al., 2020; Schäpke et al., 2018).

RwLs exemplify transformative sustainability research in practice through a number of distinctive characteristics (Schäpke et al., 2018; Wanner et al., 2018). They adopt a clear normative orientation toward sustainability transformations, guiding both research questions and intervention development. Their long-term orientation and collaborative structure involves diverse actors who co-design and implement research processes, creating shared ownership of both problems and solutions (Bergmann et al., 2021). Their experimental methodology explores potential solutions in real-world settings, acknowledging complexity and context-specificity while facilitating learning from both successes and failures (Caniglia et al., 2017; Parodi et al., 2024).

A defining aspect of RwLs is their function as boundary-spanning entities connecting scientific and societal domains in novel ways (Schneidewind et al., 2018). By creating spaces where traditional roles and relationships are renegotiated, RwLs enable mutual learning and knowledge co-production across disciplinary, sectoral, and epistemological boundaries. This boundary-spanning function positions RwLs as potential incubators for new scientific approaches–spaces where researchers can experiment not only with sustainability solutions but also with the actual research approaches.

The concept of RwLs has evolved alongside similar approaches such as living labs, urban transition laboratories, and transformation labs. Collectively, these represent an important shift in sustainability science practice–moving from isolated academic inquiry towards engaged, solution-oriented research conducted through partnerships between diverse societal actors (McCrory et al., 2020).

1.2 Research gap and question

Research motivation

My engagement with RwLs began with early work on establishing such settings in Lüneburg, Germany (Bernert et al., 2016). Initially focused on creating appropriate institutional frameworks for transdisciplinary collaboration and experimentation, this work provided valuable insights into the practical challenges and opportunities of establishing RwLs as research settings. Over subsequent years, I contributed to several transdisciplinary RwL-related research projects: Zukunftsstadt Lüneburg 2030+ (later Lüneburg. Die Zukunftsstadt), GLOCULL, and the Transformative Innovation Lab (TIL).

These projects allowed me to engage deeply with transdisciplinary research through collaborative RwL processes, designing and implementing experiments and developing diverse learning activities with numerous undergraduate and master's students at Leuphana University. Through this extended engagement, my research interests evolved towards methodological and conceptual questions about how RwL settings can advance transformative research processes and outcomes–reflecting broader developments in the field, where the initial enthusiasm for the RwL approach was complemented by a growing focus on methodological rigour and conceptual clarity.

Research gap, research question, and dimensions of inquiry

Although a substantial volume of literature addresses the contributions made by RwLs to specific sustainability transformations, there is a significant gap in the understanding of how research practices within these settings might advance transformative sustainability science itself. RwLs are not merely venues for applying established approaches, but spaces where new scientific practices can emerge and develop, potentially transforming sustainability science as a field.

Specifically, the potential for RwLs to serve as spaces where new approaches to transformative science can be developed, tested, and refined remains underexplored. The current literature tends to focus on RwLs as settings for generating knowledge about specific sustainability problems and solutions, but rarely examines how RwL research practice could advance transformative sustainability science as a scientific field and foster a transformative research orientation in other fields.

Several key aspects of this gap deserve particular attention. First, transformative sustainability science faces significant methodological challenges, including the need to bridge context-specificity with generalisability and to balance scientific rigour with practical relevance (Ferraro & Agrawal, 2021; Lang & Wiek, 2022; Luederitz

et al., 2017). How RwL research practice addresses these challenges and potentially advances novel methodological approaches remains an open question. Second, while RwLs emphasise knowledge co-production within specific contexts, less is known about how knowledge transfer occurs across contexts (Adler et al., 2017; Wuelser et al., 2021) and how educational practices integrating research with transformative learning could emerge. Third, fundamental scientific concepts, such as impact, are often understood in linear, intervention-based terms, raising questions about whether RwL practice could foster alternative conceptualisations that better capture complex transformation processes.

This dissertation addresses these gaps by examining how research practices developed within RwLs can advance transformative sustainability science. The central research question guiding this work is:

> **How can research in real-world laboratories inform and foster an emergent transformative sustainability science?**

To address this overarching question, I explore my research contributions along three dimensions of transformative sustainability science:

- **RwL research as a driver of methodological innovation** - examining how research practices within RwLs advance novel methodological approaches for transformative sustainability science
- **RwL research as a catalyst for transformative practice** - exploring how RwLs generate new research practices that integrate knowledge production, transfer, and capacity-building for sustainability transformations
- **RwL research as a source of ontological transformation** - investigating how engagement in RwLs fosters new ways of understanding the relationship between science and societal change, as well as clarifying its underlying concepts

Building on these dimensions, I approach RwLs as settings where transformative science is not only applied but also developed through intentional–and often creative and experimental (Wahl, 2023)–research practice. They acknowledge the agency of researchers in advancing methodological and conceptual approaches while recognising the emergent nature of transformative science as a field.

1.3 Dissertation structure

This cumulative dissertation comprises five papers. Although originally published to address their own specific research questions, these papers are examined here

as a collective body of work addressing the central question of how research in RwLs can inform and foster an emergent transformative sustainability science. This approach allows me to synthesise insights from these publications and extract broader implications for the field.

Following this introduction, chapter 2 presents the theoretical background underpinning the dissertation, exploring transformative sustainability research as an emergent field and RwLs as distinctive research settings that operate at the boundaries of conventional scientific practice. This chapter establishes the conceptual foundation for understanding RwLs as potential incubators for scientific innovation.

Chapter 3 outlines the research approach, describing the case studies that form the empirical foundation of this work and the methodological approaches used in the five papers. This chapter also includes reflections on my own position as a transdisciplinary researcher engaged in RwL processes, acknowledging how this engagement has shaped both the research process and its interpretation.

Chapter 4 presents the five papers in their original published or draft forms. Although each paper has its own specific focus and research question, I examine them collectively as contributions to understanding how RwLs inform and foster transformative sustainability science across the three dimensions of inquiry identified above: methodological advancements, transformative science in practice, and shifts in understanding and ontologies.

Chapter 5 offers a synthesis that explicitly examines the papers through the lens of the central research question, how RwL research advances transformative sustainability science across methodological, practical, and ontological dimensions. This chapter also reflects on the limitations of the research and identifies promising directions for future investigation.

The dissertation concludes by considering the broader implications of this work for the ongoing development of transformative sustainability science and its contribution to addressing urgent sustainability challenges.

Chapter 2

Theoretical background

2.1 Transformative sustainability research: an emergent field pushing boundaries

This chapter develops a deeper theoretical understanding of transformative sustainability research as an emergent scientific field that pushes the conventional boundaries of academic practice. I organise this exploration around three key dimensions of transformative sustainability science: methodological approaches, transformative practice, and ontological understandings. These dimensions provide a framework for exploring how research in RwLs can inform and foster transformative sustainability science.

Epistemological foundations and normative orientation

Transformative sustainability research represents a fundamental epistemological shift from traditional scientific approaches. While conventional science often operates within a positivist framework that emphasises objectivity and distance between researcher and subject, transformative research acknowledges the socially constructed nature of knowledge and the impossibility of value-free inquiry (Fazey et al., 2018; Funtowicz & Ravetz, 1993; Gibbons et al., 1994; C. A. Miller & Wyborn, 2020; Popa et al., 2015). It supports an explicitly normative orientation, acknowledging that sustainability challenges are inherently value-laden (Jerneck et al., 2011; Kates et al., 2001; T. R. Miller et al., 2014; Van Der Hel, 2018).

The approach challenges conventional epistemological boundaries by suggesting that the integration of multiple ways of knowing is crucial to address complex sustainability problems (Caniglia et al., 2020; Cash et al., 2003; Lam et al., 2020; C. A. Miller & Wyborn, 2020; Nowotny et al., 2001). It recognises that no single discipline or knowledge system can adequately address sustainability challenges, and emphasises the need to draw on diverse forms of expertise to find effective solutions.

The epistemological pluralism manifests itself in several ways. First, transformative research typically adopts a transdisciplinary mode: it integrates knowledge across scientific disciplines, bringing together insights from the natural sciences, social sciences, and humanities (Hirsch Hadorn et al., 2008; Lang et al., 2012; Scholz & Steiner, 2015). Second, it values non-academic knowledge, including practical ideas, local knowledge, and indigenous knowledge systems (Caniglia et al., 2023; Cornell et al., 2013; Raymond et al., 2010; Tengö et al., 2017). Third, it acknowledges that different types of knowledge–system, target, and transformation knowledge–are needed at different stages of the research process (Hirsch Hadorn et al., 2006; Pohl & Hirsch Hadorn, 2007).

The normative dimension of transformative research requires careful attention to power dynamics. When research aims not only to understand but also to transform, questions surrounding who decides what transformations are desirable and who benefits become central (Brandt et al., 2013; Chambers et al., 2022; Fazey et al., 2018; Turnhout et al., 2020). As Temper et al. (2019) emphasise, transformative approaches must engage with questions of whose knowledge counts and whose visions of transformation are being pursued, acknowledging the inherent power dynamics in sustainability transformations.

2.2 Three dimensions of transformative sustainability science

Building on the work of Horcea-Milcu et al. (2024), I organise my understanding of transformative sustainability science around three interconnected dimensions: methodological approaches, transformative practice, and ontological understandings.

Dimension 1: Methodological approaches

The first dimension concerns the methodological innovations that characterise transformative sustainability science. Traditional research methodologies, rooted in disciplinary specialisations and aimed primarily at producing generalisable knowledge, often prove inadequate to address complex sustainability challenges that span social, ecological, and technological domains (Horcea-Milcu et al., 2024; Lang & Wiek, 2022; Wiek, 2007). In response, transformative researchers have developed novel methodological approaches that better align with the field's normative and solution-oriented goals.

Central to transformative methodologies is the emphasis on collaborative knowledge production, particularly through transdisciplinary approaches that integrate diverse forms of expertise (Bergmann et al., 2021; Jahn et al., 2012; Lang et al.,

2012; M. Reed et al., 2014). This collaboration aims not only to incorporate different perspectives but also to co-produce knowledge that is both scientifically sound and practically useful.

Experimental approaches in real-world contexts represent a key methodological innovation (Caniglia et al., 2017; Luederitz et al., 2017; Sengers et al., 2016; Wall et al., 2017). Unlike controlled laboratory experiments, these real-world interventions acknowledge the complexity and unpredictability of social-ecological systems. They require methodological approaches that can balance experimental rigour with contextual sensitivity and ethical responsibility.

Systems thinking applied to sustainability challenges shifts the focus from elements to interrelationships to understand complex sustainability challenges while emphasising the importance of contextualisation (Abson et al., 2017; Horcea-Milcu et al., 2024; Meadows, 1999; M. S. Reed et al., 2018). Systems thinking shifts the focus from elements to interrelationships and allows researchers to identify leverage points for intervention, while contextualisation recognises that sustainability problems and solutions are highly dependent on specific social, ecological, and institutional contexts.

Dimension 2: Transformative practice

The second dimension focuses on the practical aspects of doing transformative research–how transformative science manifests itself in concrete research practices and contributes to real-world change. At the heart of transformative practice is the desire to go beyond the observation and analysis of the status quo to enact change towards desirable states (Clark et al., 2016; Fazey et al., 2020; Moser, 2016; Schneidewind et al., 2016).

An important aspect of this interventional approach is the development of theories of change that articulate how and why particular interventions contribute to transformative outcomes (Schneider et al., 2019; Westley et al., 2013). These theories help researchers explain how change might happen within their projects and can serve as living monitoring, evaluation, and learning tools (B. M. Belcher et al., 2020; Wiek & Lang, 2016).

Transformative practice also emphasises the importance of learning and reflexivity, seeing co-learning as a necessary premise for reflexive collaboration (Bartels & Wittmayer, 2018; Brandt et al., 2013; Horcea-Milcu et al., 2024; Pohl et al., 2017; Popa et al., 2015; Wittmayer & Schäpke, 2014). Learning is not treated as a by-product of research but as an intentional outcome, with research designs actively creating and fostering opportunities for learning.

Another aspect of transformative practice involves explicit engagement with questions of agency, power, and decolonisation. Transformative research recognises

the limitations of traditional science-society relationships and seeks to dismantle existing hegemonies (Horcea-Milcu et al., 2024; Leach et al., 2018; Levin et al., 2012; Schneider et al., 2019). This includes critically examining who has the power to shape research agendas, whose knowledge is valued, and how research processes might reproduce or challenge existing power dynamics.

Dimension 3: Ontological understandings

The third dimension concerns the fundamental conceptual understandings and ontological assumptions that underpin transformative sustainability science. Transformative science challenges conventional understandings of the relationship between knowledge and action. Traditional models often assume a linear pathway from knowledge to action, where scientific understanding leads to technological innovation, which is then applied to solve societal problems. Transformative approaches, in contrast, recognise the complex, non-linear relationships between knowing and doing, suggesting that knowledge and action are mutually constitutive rather than separate domains (Caniglia et al., 2020; Fazey et al., 2020; West et al., 2019).

As Caniglia et al. (2020) suggest, transformative research involves reframing the relationship between knowledge and action for sustainability to 'knowledge becomes action' or 'knowledge is action. This ontological shift has profound implications for how we think about the role of science in sustainability transformations (Lotz-Sisitka et al., 2016; O'Brien & Sygna, 2013).

Another ontological aspect involves explicit engagement with values and normativity. While traditional scientific approaches often claim value neutrality, transformative approaches acknowledge that sustainability challenges are inherently normative and that addressing them requires explicit engagement with values (Abson et al., 2017; T. R. Miller et al., 2014; Raworth, 2017; Van Der Hel, 2018).

Beyond these shifts, transformative research fundamentally reimagines impact and quality in scientific practice. Traditional scientific approaches often focus on academic impacts measured through metrics such as publication counts and citation rates. Transformative approaches call for the broader understanding of impact, to include societal outcomes such as improved community relationships, social learning, trust building, and capacity-development (Bergmann et al., 2021; Horcea-Milcu et al., 2024; Luederitz et al., 2017; Williams & Robinson, 2020).

2.3 RwLs: transformative research settings in the fringe zone

Building on the foundational understanding of RwLs as outlined in the introduction, I now explore their theoretical underpinnings and position them as operating in the *fringe zones* of conventional scientific practice.

Theoretical foundations and distinguishing features

RwLs draw on diverse theoretical traditions, including transdisciplinary research (Lang et al., 2012), transition management (Loorbach, 2010; Loorbach et al., 2017), and action research (Bartels & Wittmayer, 2018; Reason & Bradbury, 2008). Rather than simply applying these frameworks, RwLs serve as spaces where theoretical approaches converge and evolve through practice. This hybrid theoretical approach allows RwLs to transcend the limitations of any single framework while maintaining coherence through their normative orientation towards sustainability (Nevens et al., 2013; Schäpke et al., 2018).

The development of RwLs as a distinct methodological approach is evident in their increasing institutionalisation. Since their conceptual introduction around 2012, the volume of RwL projects has grown significantly: particularly in the German-speaking context, where there is an established network of over 80 active and completed RwLs and a vibrant transdisciplinary community emerging around this approach (Parodi et al., 2024; Schäpke et al., 2018, 2024).

Operating at the boundaries of science and society

A defining characteristic of RwLs is their position at the intersection of scientific and societal domains–what I call the *fringe zone* of conventional scientific practice. In this boundary space, RwLs deliberately create permeable interfaces between science and society, enabling exchange and the integration of different knowledge systems and practices (Frantzeskaki et al., 2018; Sengers et al., 2016). This mirrors the development of what Cash et al. (2003) call "boundary objects"–concepts, tools, or practices that are meaningful across different domains and can facilitate communication between them.

This boundary-spanning function creates distinctive tensions that can drive both innovation and transformation. RwLs must navigate tensions between scientific standards of rigour and societal demands for relevance, between knowledge production and action, and between different temporal scales–from immediate experimental outcomes to longer-term transformative processes (Pohl & Hirsch Hadorn, 2007; Schäpke et al., 2018; Von Wirth et al., 2019). Rather than viewing these tensions

as problems to be solved, RwLs embrace them as productive dynamics that can generate novel approaches and insights.

Within this fringe zone, RwLs serve as creative spaces where the very practice of science itself can evolve. They challenge traditional notions of scientific objectivity by embracing closer engagement between researchers and research subjects (Turnheim et al., 2015; Wittmayer & Schäpke, 2014). They foster methodological innovation by creating conditions in which researchers can test new approaches to data collection, analysis, and interpretation in real-world contexts (Caniglia et al., 2017; Heiskanen et al., 2018). They also encourage conceptual development by bringing together diverse knowledge systems and disciplinary perspectives (Bergmann et al., 2021; Charli-Joseph et al., 2018).

Navigating these tensions requires what scholars have called "caring transdisciplinary research practice" (Sellberg et al., 2021)–approaches that acknowledge the relational and affective dimensions of collaborative research and are attentive to the well-being of all participants. This emphasis on care is a distinctive feature of transformative research in RwL settings, distinguishing it from more conventional research approaches that prioritise objectivity and distance.

2.4 RwLs as incubators to advance transformative sustainability science

Building on the preceding sections, I propose a novel conceptualisation of RwLs as incubators to advance transformative sustainability science itself. While the existing literature primarily frames RwLs as settings for developing and testing specific sustainability solutions, they also serve a broader role in the evolution of scientific practice. Through their unique characteristics and boundary-spanning functions, RwLs create conditions in which new scientific approaches can emerge, develop, and potentially transform how sustainability science is conducted (Pereira et al., 2020).

This incubator function operates across the three dimensions previously introduced: methodological approaches, transformative practice, and ontological understandings. RwLs serve as laboratories for methodological innovation, where new methods, tools, and approaches can be developed and refined in response to the challenges of real-world experimentation (Schäpke et al., 2024).

The collaborative orientation of these boundary-spanning space make RwLs catalysts for transformative practice, creating spaces where researchers can experiment with new roles, relationships, and modes of engagement (Hilger et al., 2021; Wahl, 2023; Wittmayer & Schäpke, 2014). These practices go beyond conventional research activities to include facilitation, boundary spanning, and change agency–roles that

require different skills and competencies to traditional academic research.

Additionally, the experimental methodology of RwLs encourages ontological shifts in how we understand the relationship between research and transformation. By challenging traditional distinctions between knowledge production and action, between researcher and research subject, and between science and society, RwLs create opportunities for new conceptualisations of what science is and how it relates to societal change (Fazey et al., 2020; Nagy et al., 2020; Schäfer et al., 2021; Williams & Robinson, 2020).

A critical aspect of the incubator function of RwLs is their nature as shared spaces co-inhabited by researchers and practitioners. As Parodi et al. (2024) emphasise, the design of RwLs as long-term infrastructures rather than temporary projects creates environments where the traditional boundaries between research and practice become increasingly permeable. Within these spaces, the lines of "who does what" often blur–scientists may engage in practical implementation while practitioners contribute to knowledge production–without compromising the dual orientation toward sustainability and rigorous knowledge generation.

2.5 Framing the inquiry: from sustainability transformations to transformative science

The theoretical perspectives presented above provide a foundation for understanding how RwLs can serve as incubators to advance transformative sustainability science. While discussions about RwLs have primarily focused on their contributions to specific sustainability transformations (McCrory et al., 2020; Parodi et al., 2018; Schäpke et al., 2018), a logical extension of this work involves examining how research practice within these settings advances the field of transformative sustainability science itself.

This perspective follows directly from the concept of RwLs as boundary spaces or *fringe zones* where scientific practice evolves through engagement with complex sustainability challenges. If RwLs foster methodological innovation, catalyse transformative practices, and enable ontological shifts–as suggested by the theoretical foundations explored above–then they not only contribute to specific transformations but also to the development of transformative science as a field.

This framing recognises transformative sustainability science as inherently emergent–developing through practice, reflection, and theoretical elaboration in response to concrete challenges. The boundary-spanning nature of RwLs creates conditions where tensions between different knowledge systems, demands for both rigour and relevance, and evolving roles can drive this emergence, potentially transforming how sustainability science is conceptualised and conducted.

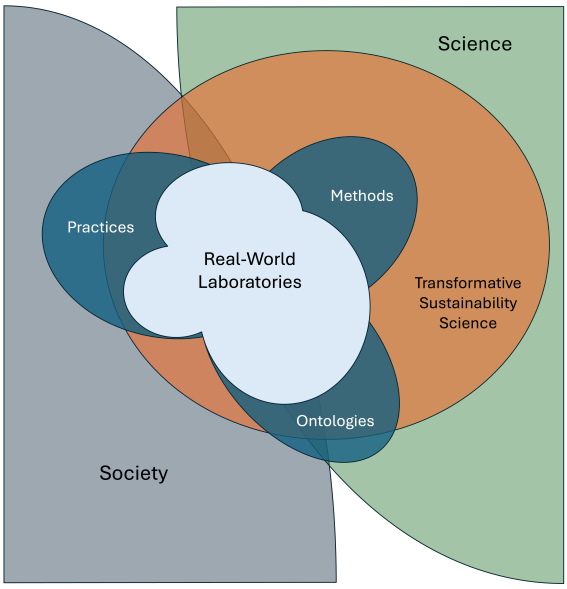

Figure 1: RwLs as transformative research settings located in a fringe zone of scientific and societal practice (own illustration)

The presentation of my research is structured around the three dimensions outlined above and illustrated in Figure 1: methodological approaches, transformative practice, and ontological understandings. These dimensions provide a framework for examining how research practice within RwLs contributes to advancing transformative sustainability science. Through this examination, I aim to contribute to our understanding of how science itself evolves to more effectively address complex sustainability challenges.

Chapter 3

Research approach

The research approach of this dissertation reflects my direct engagement with three interconnected RwL settings. Through this engagement, I encountered various challenges–practical, methodological, and conceptual–that existing approaches could not adequately address. Responding to these challenges led to the development of the contributions presented in this dissertation, which span methodological, practical, and ontological dimensions of transformative sustainability science.

These contributions arose from a convergence of factors: concrete needs within the specific RwL contexts; gaps in existing literature and practice; collaborative exploration with research partners; and a shared commitment to advancing transformative sustainability research. Rather than examining RwLs from an external perspective, this work evolved organically through active participation in these settings, where the limitations of existing approaches became apparent through practice.

The five papers that form the empirical foundation of this dissertation represent responses to different aspects of the central research question: how research in RwLs can inform and foster an emergent transformative sustainability science. They draw on three interconnected case studies, each representing a different RwL context in which I was directly involved as a transdisciplinary researcher. Table 1 provides an of the papers with the specific challenges and the methods used.

3.1 Interconnected case studies as settings for methodological innovation

Zukunftsstadt Lüneburg 2030+: a long-term urban real-world laboratory

The Zukunftsstadt Lüneburg 2030+ project (subsequently known as "Lüneburg. Die Zukunftsstadt") represents the most extensive and long-term RwL engagement in this dissertation. Initiated in 2015 as part of a national funding programme by the German Federal Ministry of Education and Research, this urban RwL evolved

through three distinct phases: (1) a participatory visioning process using structured stakeholder engagement methods (2015-2016) (Bernert et al., 2016; Wiek & Iwaniec, 2014); (2) the collaborative development of sustainability solutions (2017-2018); and (3) the implementation of 15 real-world experiments across various thematic areas (2019-2023).

Throughout these phases, the RwL involved close collaboration between Leuphana University Lüneburg, the city administration, and various civil society organisations (Kampfmann et al., 2024). This long-term collaborative process created a comprehensive *umbrella* environment that provided continuity and integration between various sustainability initiatives in the city, following a cyclical understanding of transdisciplinary RwL processes (Lang et al., 2012; Wanner et al., 2018).

Among the distinctive features of Zukunftsstadt Lüneburg was its consistent integration of higher education throughout the project phases. Students from various programmes were involved in diverse tasks, from supporting participatory workshops and documentation to conducting transdisciplinary research projects and developing real-world experiments. This integration created valuable learning opportunities while contributing to the project's capacity to simultaneously address multiple sustainability challenges.

The extended timeframe of Zukunftsstadt Lüneburg revealed important limitations in existing approaches to impact assessment and evaluation. Traditional frameworks, focusing on direct intervention effects measured over shorter periods, were inadequate for capturing the full range of impacts emerging from long-term collaborative processes. This recognition prompted us to explore alternative ways of conceptualising and documenting the impacts of extended RwL processes that would better capture their transformative potential.

GLOCULL: urban living labs at the food-water-energy nexus

The GLOCULL (Globally and Locally Sustainable Food-Water-Energy Innovation in Urban Living Labs) project involved a network of seven urban living labs across Europe, Africa, and North America. Funded under the JPI Urban Europe programme from 2018 to 2021, the project provided a unique opportunity to examine transformative research practices across diverse cultural, institutional, and thematic contexts centered around the Food-Water-Energy Nexus (Dalla Fontana et al., 2020; Wahl et al., 2021).

Rather than establishing an entirely new laboratory in Lüneburg, GLOCULL built upon the existing Zukunftsstadt infrastructure, creating a more focused experimental space within this broader context. This integration allowed for more experimental approaches with different degrees of public involvement, concentrating on specific sustainability challenges at the food-water-energy nexus.

As a member of the research team for the Lüneburg living lab within GLOCULL, I was involved in developing and implementing real-world experiments in collaboration with local businesses and community organisations. This included a collaboration with Avenir Café and Roastery, where we developed and tested experiential marketing interventions to foster sustainable consumption behaviour (Paper 2; Weber et al., 2021). Our approach followed established experimentation methods in sustainability science (Caniglia et al., 2017), specifically employing a field experiment with participatory control.

The international character of GLOCULL created unique challenges for knowledge transfer and learning across the seven different Urban Living Lab contexts. Each lab operated in a distinct cultural, institutional, and thematic setting, making it difficult to share insights and experiences across the cases in ways that were both contextually rich and comparable. This challenge required us to develop new approaches to structuring and documenting research experiences that could facilitate cross-context learning while respecting contextual differences.

Transformative innovation lab: integrating higher education learning and real-world lab research

The Transformative Innovation Lab (TIL) represented a unique integration of education and research with a RwL focus. Developed and implemented from 2018 to 2020 as a collaboration between Leuphana University Lüneburg, Freie Universität Berlin, and the Wuppertal Institute, the TIL was designed as a learning module to enable master's students to develop and implement their own real-world experiments in collaboration with local partners (Wanner et al., 2021).

The TIL in Lüneburg was located in the Zukunftsstadt 2030+ environment, creating opportunities for students to develop their projects within an established RwL context. Students were encouraged to engage with local sustainability challenges and to draw on the relationships and infrastructures already established through Zukunftsstadt, although they were also free to develop projects in other contexts. This approach built on existing research on learning in RwLs (Beecroft, 2018; Singer-Brodowski et al., 2018) and transformative learning for sustainability (Rodríguez Aboytes & Barth, 2020).

Through the implementation of the TIL, we encountered a significant gap in existing approaches to sustainability education. While many approaches focused either on theoretical understanding or practical skills development, few effectively combined transformative learning with engagement in transdisciplinary research processes. This led us to develop a more integrated educational approach that could simultaneously foster knowledge development and practical capacity for sustainability transformations. A practical guide detailing the Transformative Innovation Lab

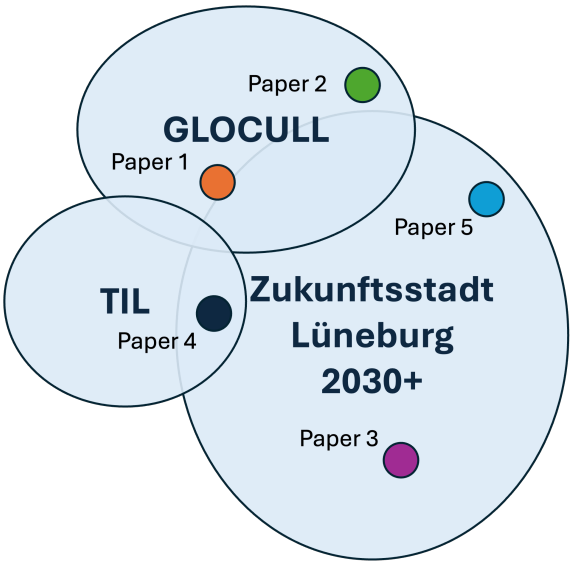

Figure 2: Research papers included in this dissertation and their location within the three interconnected cases; Paper 1: Cross-case knowledge transfer, Paper 2: Bridging local solutions and broader knowledge, Paper 3: Impacts beyond experimentation, Paper 4: Design principles for transformative learning, Paper 5: Modular evaluation approach (own illustration)

module was published in as a handbook (Wanner et al., 2020).

3.2 Methodological responses to practice-based challenges

Each of the three case studies presented unique challenges that existing methods and approaches could not adequately address. These challenges occurred at different levels–practical, methodological, and conceptual–and responding to them led to the development of the innovations presented in this dissertation. In the following section, I describe the approaches we developed to address the five key challenges encountered in our research practice. The connection of the resulting research papers to the cases is illustrated in Figure 2.

Addressing the challenge of knowledge transfer across contexts

The international character of GLOCULL highlighted the challenge of learning across different RwL contexts. Traditional case study approaches either provided rich context-specific information that was difficult to compare across cases, or overly simplified frameworks that lost important contextual nuances. To address this challenge, I co-led the development of a structured case reporting approach with Darin Wahl through an iterative co-development process involving researchers from all seven participating Urban Living Labs.

This development process began with collaborative workshops to identify the key aspects of each lab that should be captured in a reporting scheme. We then developed a logic model distinguishing between context, lab, and experiment levels, building on insights from existing frameworks and the specific experiences of participating labs. The resulting reporting scheme was tested and refined through multiple iterations, with feedback from all consortium members informing each revision.

The case reporting approach enabled us to document more systematically the experiences from each Urban Living Lab in a format that supported cross-context learning. By providing a common structure that addressed key aspects of RwL research while allowing flexibility in how each aspect was described, the approach facilitated more meaningful knowledge exchange across the diverse GLOCULL contexts. This not only improved our ability to learn from each other's experiences within the project but also provided a framework for documenting our work in a way that could be valuable for other researchers and practitioners.

Bridging the gap between context-specificity and generalisability

The collaboration with Avenir Café in GLOCULL revealed the tension between developing contextually appropriate interventions and generating more broadly applicable knowledge. To address this challenge, we developed a dual-setting research design that combined a field experiment embedded in the specific context of the local business with a parallel online study testing the same underlying mechanisms in a more controlled setting.

This approach was developed through a collaborative process involving researchers from Leuphana University and Avenir Café staff. Following a transdisciplinary co-design process, we created experiential marketing interventions tailored to the specific context and needs of the café. These interventions were then tested in a field experiment with café customers. In parallel, we developed an online study that replicated the conceptual mechanisms of these interventions in a more controlled setting with a broader pool of participants.

This dual-setting approach allowed us to develop contextually appropriate interventions that addressed the specific needs of our practice partner and validate the underlying mechanisms in a way that could inform broader application. It helped us navigate the tension between contextual specificity and generalisability that is inherent in transformative research, providing a more nuanced understanding of how experiential marketing interventions could foster sustainable consumption in different contexts. The published paper comprises both this methodological approach and the empirical findings.

Developing a modular approach to evaluating complex RwL processes

In all the case studies, but particularly in Zukunftsstadt Lüneburg, we encountered the challenge of how to evaluate the complex, multi-layered processes of RwLs. Traditional evaluation approaches focused either on specific interventions or on overall programme outcomes, without adequately addressing the distinctive structure of RwLs as settings encompassing multiple experiments and activities.

To address this challenge, we developed a modular evaluation approach through a comprehensive scoping review of evaluation studies across multiple disciplines. Teresa Kampfmann took the lead in conducting the empirical literature review and writing the paper, while I was involved in the conceptual development of the research design and contributed to the theoretical framing of the modular approach.

The resulting modular evaluation typology distinguishes between evaluation approaches suited to different targets–interventions, experiments, or lab processes–and provides guidance for selecting appropriate evaluation methods based on the specific focus and purpose of the evaluation. This approach helped us to evaluate the diverse activities and processes within our RwL contexts more effectively, allowing for the more nuanced assessment of their contributions to sustainability transformations.

Integrating transformative learning with research

In the Transformative Innovation Lab, we faced the challenge of how to effectively integrate transformative learning with transdisciplinary research practices. This challenge reflects a recognised gap between educational and research approaches in sustainability contexts. To address this challenge, we developed design principles for transformative learning through research by synthesising insights from sustainability learning literature and transformative research literature, which were the basis of our practical application in the TIL.

The development of these principles involved first reviewing relevant literature from both sustainability education and transformative research fields to identify the key elements that support both learning and research objectives. These initial principles were then tested and refined through two iterations of the TIL with distinct student cohorts, with feedback from students and observations of learning processes informing revisions.

This integrated approach enhanced our ability to create educational experiences that not only increased the students' knowledge of sustainability issues, but also developed their capacity to contribute to real-world change through transdisciplinary research. It helped bridge the gap between theoretical learning and practical engagement, creating more transformative educational experiences that prepared students to be effective change agents in sustainability contexts.

Reconceptualising impact beyond interventions

In the Zukunftsstadt Lüneburg project, we observed that many significant effects of the RwL process were not directly attributable to specific interventions or experiments, but rather emerged from the long-term collaborative process itself. Traditional impact frameworks focused on linear cause-effect relationships could not adequately capture these emergent effects. To address this challenge, we developed the concept of "emergent impacts" through a process of long-term case analysis and conceptual development.

This development involved analysing the eight-year evolution of the Zukunftsstadt Lüneburg RwL to identify effects that emerged outside of specific interventions. We examined project documentation, meeting minutes, and communication materials, supplemented by our direct experience as participants in the process. Through this analysis, we identified three key dimensions of emergent impact: impacts on education and learning, impacts on governance structures, and impacts related to the role of the lab as a public actor for sustainability.

This reconceptualisation helped us better understand and communicate the broader contributions of our RwL work beyond the specific outcomes of individual interventions or experiments. It provided a more comprehensive framework for assessing the value of long-term collaborative processes, acknowledging the complex, emergent nature of sustainability transformations.

3.3 Overview of articles and integration

The five papers included in this dissertation collectively address the central research question of how research in RwLs can inform and foster an emergent transformative sustainability science. Each paper examines a different aspect of this question, focusing on specific innovations or conceptual developments that have emerged from RwL research (see Table 1).

These papers are interconnected through several common themes and conceptual frameworks. Together, they provide responses to key challenges in transformative research practice that emerged from our direct engagement with RwL contexts. Rather than proposing abstract theoretical frameworks, they offer practical solutions grounded in specific research experiences.

The papers follow a progression from methodological approaches for documenting and transferring knowledge across contexts (Papers 1 and 2), to frameworks for evaluation and assessment (Paper 5), to broader conceptual reframing of impact and educational practice (Papers 4 and 5). This mirrors the development of my own thinking and practice through engagement with RwL contexts, moving from

Paper	**Challenge Addressed**	**Response Developed**	**Methodological Approach**
Paper 1: Cross-case knowledge transfer	Knowledge transfer across different RwL contexts while maintaining contextual richness	Structured case reporting approach with logic model and reporting scheme	Collaborative method development through iterative workshops and testing across international case studies
Paper 2: Bridging local solutions and broader knowledge (manuscript)	Tension between context-specific solution development and broader knowledge generation	Dual-setting research design combining field and online studies with conceptual replication	Field experiment with participatory control coupled with controlled online study using conceptual replication
Paper 3: Impacts beyond experimentation	Limitations of intervention-focused impact frameworks	Concept of "emergent impacts" capturing effects arising from collaborative processes	Long-term case analysis using process documentation and participant reflection across multiple project phases
Paper 4: Design principles for transformative learning	Gap between educational approaches and transdisciplinary research practice	Design principles that integrate transformative learning with research activities	Literature synthesis and iterative testing through implementation in educational modules
Paper 5: Modular evaluation approach	Complexity of evaluating multi-layered RwL processes	Modular evaluation typology for different RwL components	Scoping literature review across multiple disciplines and empirical assessment of evaluation practices

Table 1: Overview of the five papers included in this dissertation, showing the challenges addressed, responses developed, and methodological approaches used.

practical methodological concerns towards more fundamental conceptual questions about the nature and purpose of transformative research.

In the following chapter, I present these papers in their original published or draft form. In the subsequent synthesis chapter, I will examine how the responses and innovations developed in these papers collectively contribute to advancing transformative sustainability science along methodological, practical, and ontological dimensions.

Chapter 4

Research articles

This chapter presents the five papers that form the core of this dissertation. A complete overview of the bibliographical detail and my authorship contributions is included in the Appendix A

4.1 Paper 1: Cross-case knowledge transfer in transformative research

Authors

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Cross-case knowledge transfer in transformative research: enabling learning in and across sustainability-oriented labs through case reporting

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Abstract

The field of transdisciplinary sustainability research has brought forward a number of approaches aimed at fostering sustainability transformations and generating knowledge through collaborative experimentation in real-world settings. These cases are strongly embedded in their local context and thus the transfer of knowledge remains a key challenge. In this paper, we propose a case reporting approach that supports the structured and coherent reporting of such cases. This scheme is aimed at sustainability-oriented labs, where sustainability solutions are collaboratively developed through experimentation. The scheme focuses the reporting on local contexts, lab processes, and experiments. It is accompanied by a logic model and a set of four principles guiding the reporting procedure. The approach is designed to be general, in that it is applicable to diverse contexts and project designs, while its modularity allows the scheme to be adapted to the needs and specifics of each cases. The scheme was jointly developed and tested by a group of seven Urban Living Labs, each in their own unique context. With our approach we aim to contribute to knowledge transfer from and across cases of sustainability-oriented labs as emerging approaches in action-oriented research bridging the divide of case-based research and (meta) comparison.

Science highlights

- Urban Living Labs and similar sustainability-oriented labs are promising settings for exploring sustainability transformations.
- Knowledge transfer across such cases is challenged by the high degrees of context specificity.
- We present a reporting scheme that allows for a structured reporting of contexts, labs, and experiments.
- Case reporting enables knowledge transfer and cross-case learning in transdisciplinary and transformative sustainability research.

Policy and practice recommendations

- ULLs and real-world labs are research settings for exploring sustainability transformations through joint experimentation.
- The proposed case reports can be a knowledge base for research and practice.
- To enable transferability and comparison of the conducted research, case reports should cover descriptions of context, lab, and experiments.

Keywords: Urban living labs, Real-world labs, Experimentation, Evaluation, Transdisciplinarity, Reporting, Knowledge transfer

Introduction

Urban Living Labs (ULL) and other types of "sustainability-oriented labs in real-world contexts" (McCrory et al. 2020) are research settings for investigating and engaging with sustainability challenges in local contexts. These action-oriented research settings aim to contribute to sustainability transformations by establishing and enabling transdisciplinary collaborations between scientific actors and actors from other societal domains to develop sustainability solution options through joint experimentation (Nevens et al. 2013; Voytenko et al. 2016; Schäpke et al. 2018; McCrory et al. 2020). Several lab approaches have been proposed and coexist, e.g. real-world laboratories, urban living labs, transition labs, and transformation labs. These 'sustainability-oriented labs in real-world contexts' have developmental roots in socio-technical transitions (Nevens et al. 2013; Schäpke et al. 2018; Sengers et al. 2019; McCrory et al. 2020) and Schäpke et al. (2018) find that they share key dimensions including a transformative focus, experimental methods, learning and reflexivity, a long-term orientation, scalability, and transdisciplinarity.

However, there is a lack of insight into the role played by ULLs in substantiating knowledge to solve sustainability challenges beyond the local level (von Wirth et al. 2019; Laborgne et al. 2021). ULLs conduct sustainability experiments where innovative 'solutions' to sustainability problems can be tested and refined (Bulkeley et al. 2016, 2019). Approaching the often-complex societal processes through experiments provides evidence on sustainability problems and their potential solutions, through which learning and actionable knowledge are co-produced (Caniglia et al. 2017). Experiments in these settings can vary widely, from developing novel technologies to new arrangements, strategies, ways of doing or relating, business models or policy approaches (Frantzeskaki et al. 2018; Sengers et al. 2019; von Wirth et al. 2019; McCrory et al. 2020). In this regard, we agree with Hodson et al. (2017) that a "looser view of the experimental process" is helpful. However, approaching the often complex societal processes through experiments provides evidence on sustainability problems and their potential solutions, through which learning and actionable knowledge are co-produced (Caniglia et al. 2017).

Transdisciplinary research in ULLs, therefore, aims to develop knowledge that is largely case-specific and place-embedded (Frantzeskaki et al. 2018) in contrast to more classical research that tends to produce generalisable results (Adler et al. 2018). This difference can be seen as a critical challenge in terms of the knowledge generated in ULLs, the transfer of knowledge across ULLs and the learning from case studies in ULLs. The strong contextual embeddedness of every case in these settings

Table 1 The GLOCULL project

The GLOCULL project aimed to advance ULL research by grouping several ULLs under the shared theme of the FWE nexus as part of the JPI Urban Europe funding scheme SUGI (Sustainable Urbanisation Global Initiative). The ULLs in GLOCULL cover a broad range of geographical contexts, actor configurations and purposes (see Table 2). They were all deeply rooted in their local contexts, building on pre-existing relationships with local partners. The form of the ULLs differed in many ways, including their local contexts, governance structures and size. The experiments and interventions developed and realised in the GLOCULL labs adopted a broad variety of methodological approaches and addressed diverse sustainability challenges.

Through its design, the project aimed to generate new insights into 1) the development of local FWE innovations; 2) interdisciplinary international collaboration through the consortium; and – central to this paper – 3) the comparability, better generalisability and transferability of lab and experiment learning and outcomes.

leads to a high degree of individuality and a strong interdependency between the local context and the validity of the results. Although the discourse on this challenge is not new (e.g., Krohn 2017), approaches concerning the transferability of knowledge between transdisciplinary case studies are still rare (Adler et al. 2018) – and ULLs are no exception in this regard.

Against this background, we propose case reporting as a promising approach for capturing the knowledge contained and produced in ULLs. Our suggested use of case reporting is inspired by its long-established practice in the fields of medicine and public health (Marone 2012), where it is an essential practice that reliably makes single cases available to the scientific community to learn from and to generate further insights using established methodological approaches. Case reporting is key in facilitating the sharing of observations and learning from practice settings (Vandenbroucke 2001) and has proven crucial to initiate both experimentation and comparisons across cases (Albrecht et al. 2005). Case reports in the fields of medicine and public health follow a coherent structure that is designed to be searchable and familiar to other reporters and researchers. In other words, the guiding principle behind case reporting is not only to report what was accomplished, but also to explain how and why experiments were conducted to reach those outcomes and outputs.

To illustrate how a case reporting approach could be applied in ULL research and beyond, we present a comprehensive case reporting scheme (case reporting scheme) and guidelines developed in an international project consortium. This reporting approach guides researchers on how to structure reports on real-world cases to cover the crucial aspects of these cases while ensuring the coherence and comparability of the reports. The proposed scheme's development was guided by the questions: *How do we capture the diverse context specificities and design of ULLs so that the insights are relevant for both academics and actors from other societal domains in the ULL and beyond?* The presented approach was originally developed as part of the GLOCULL research project (see Tables 1 and 2), a consortium of seven ULLs engaged in developing sustainable innovations around the food, water and energy (FWE) nexus. Our approach builds on concepts around the evaluation of transition experiments (e.g., Luederitz et al. 2017) but expands the focus of reflection to the processes of the lab and its context in order to target knowledge sharing and comparison.

The case reporting scheme and approach we present are a contribution to the growing discourse around action-oriented sustainability research. We consider case

Table 2 GLOCULL labs - the ULLs, briefly described below, are diverse in terms of their context, lab design, sustainability orientation and experiments

Lüneberg, Germany - as part of the Zukunftsstadt Lüneberg 2030 + programme, the lab explored fair and sustainable supply chains and consumer interaction with independent coffee houses.
Lund, Sweden - the SustBeerLab explores the development of sustainability strategies and innovations with craft brewers in the Skåne region.
Maastricht, Netherlands - the SuperLocal Lab tests sustainable technologies and construction in a housing development community.
Phoenix, USA - the academic team partners with municipalities to run an innovation accelerator that supports small businesses in implementing sustainable practices.
São Paulo, Brazil – researchers work with municipality practitioners to co-develop a set of indicators to assess the sustainability of local agriculture initiatives.
Stellenbosch, South Africa - researchers partner with a township gardening/urban farming initiative promoting food sovereignty and fresh healthy food options.
Vienna, Austria - researchers and farmers test the impact and feasibility of using photovoltaic panels on greenhouse farms.

reporting a way forward to bridge the divide of case-based research and (meta) comparison in sustainability science.

A collaboratively developed case reporting approach for Urban Living Labs

The development of the case reporting scheme (case reporting scheme) as presented below was an iterative process comprising several phases. From the initial ideas phase and background research to testing and refinement took more than 18 months. The people involved centred on a core group of two (the lead authors of this paper) who collaborated with a working group of 12 researchers (mostly early-career) and then with the entire GLOCULL project (30 + researchers) as well as country-based teams. Many steps were iterative, requiring the core team to reach out for various feedback from the larger groups. The following section outlines the phases in more detail.

The project goals (particularly goal 3) required the development of an evaluation strategy that would allow for comparisons to be made between ULLs and their experiments. The team agreed on criteria to guide the scheme development: the scheme should be 1) *comprehensive* i.e. it should capture the scope of the potential activities, processes, impacts and influences of the labs; 2) *broad* i.e. it should be general enough to capture the range of purposes and contexts represented by the GLOCULL ULLs; and 3) *built on established frameworks* i.e. it should reflect the contributions of previous relevant and applicable research.

The idea for case reporting came from the recognition that existing evaluative frameworks were unable to capture the processes that influence the progress made in our labs in a way that makes comparison possible (Palmer et al. 2020). Recent evaluation schemes of real-world and transition experiments have been developed and applied (Luederitz et al. 2017; Luederitz et al. 2017; Williams and Robinson 2020; Kampfmann et al. 2022), although such evaluations predominantly focus on the experiments and, therefore, target innovations and their development. Furthermore, evaluation as it is often practised is predominantly inward facing, in that its target audience is the team members, funders, lab and experiment designers, and other invested parties (Williams and Robinson 2020). In addition to that function, our goal was to effectively compare these case studies in order to derive actionable knowledge relevant beyond the specific local contexts. In

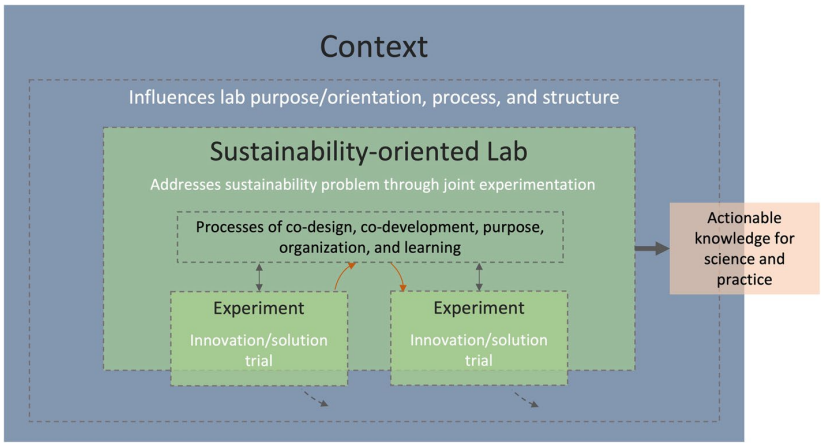

Fig. 1 The logic model shows the semi-nested nature of the context, lab and experiments, and the purposes/functions of each domain

other words, each case is communicating to people who are unfamiliar with the details of the specific case, but the intention is that the details of one case can be a space of inspiration, learning and comparison for another. In this sense, similar to Williams and Robinson (2020), the scheme we developed required a strong focus on the processes of conducting a lab and running experiments but is equally intended for an external audience.

Conceptualisation

In order to conceptualise the case reporting scheme, it was necessary to identify those elements and activities in the labs that could be compared, as well as to determine how to simultaneously include and exclude the anchoring effect of the local context. A logic model was developed to differentiate between the context of the lab, the lab elements and processes, and the experiments (see Fig. 1). This differentiation unlocked the potential for researchers to use the case reporting scheme to target specific aspects for comparison; for example, the use and impact of particular tools and methods. The characteristics related to the context could then be categorised or could be disregarded as being of no influence.

The logic model is an approach for conceptualising ULLs and related sustainability-oriented lab approaches and for structuring their reporting. The literature on the various lab approaches makes no clear distinction between the actual experiments, the supporting lab structure, and the overall local context in which both are embedded. The disambiguation of context, lab and experiment shared by Kampfmann et al. (2022) offers the potential for a clearer understanding of the purposes of each aspect and how they influence each other. The logic model follows an ideal–typical understanding of context, lab and experiment, as well as their interactions (cf. Jahn 2008; Wanner et al. 2018).

The *context* is defined by the local social, political, geographical, and economic conditions in which the Lab is situated, and which are relevant to Lab participants and activities. These conditions are crucial for understanding the work that is to be accomplished

in the ULL. Our context understanding follows the theoretical considerations by West et al. (2019) in that the *relevant* context is what the practice – the lab process and experiments – is entangled with and has to navigate (Van Steenbergen and Frantzeskaki 2018). Similar to their understanding, we view the context as the external conditions that are relevant from the case's perspective but equally need to be uncoupled from this perspective to allow for comparison between cases.

The *lab* is a 'space'[1] collaboratively created by scientists and actors from other societal domains to co-produce sustainability pathways or solutions. Within the *lab,* the processes governing its design, development, purpose and organisation are continuously negotiated and established (Wanner et al. 2018; Bulkeley et al. 2019; McCrory et al. 2020), which results in relevance, credibility and legitimacy of the work undertaken for both science and practice (Cash et al. 2003). The structure and framing of the lab create the space in which sustainability experiments are developed and carried out.

The *experiments* are deliberately designed and evaluated interventions in local real-world contexts and are the core research method of transdisciplinary and transformative lab approaches. They are collaboratively conducted and partially controlled within the *lab* space. The *experiments* produce evidence and create knowledge and other outputs that are then evaluated, integrated and in other ways processed in the lab and beyond (Castán Broto and Bulkeley 2013; Caniglia et al. 2017; Sengers et al. 2019). If the lab continues, they are used to develop successive experiments and potentially to create innovations that are scalable and/or transferable (Nevens et al. 2013; Schäpke et al. 2018). Otherwise, the new knowledge generated is integrated back into society and science through the participating actors, publications, networks and other means of communication and outreach as determined by the lab (Lang et al. 2012).

Prototyping and first application/reflection

The case reporting scheme was outlined over the course of two face-to-face project meetings in Stellenbosch, South Africa, and Tempe, USA. The methodological guidelines for a coherent evaluation process were developed during the follow-up project meeting at Leuphana University in Lüneburg, Germany. Between these meetings, as well as afterwards, GLOCULL researchers met online monthly to further develop the scheme. For the Tempe meeting in the USA, project teams developed case-specific questions based on elements they had determined as key, unusual or otherwise relevant and then categorised them according to the logic model. In the monthly meetings, the case-specific questions were integrated with evaluative questions found in the existing sustainability-oriented lab/experiment literature and then categorised and synthesised to become the scheme's guiding questions (see Tables 3, 4 and 5).

To establish context characteristics, we drew largely on Forrest et al. (2019) (see Table 6), which provided the necessary framing to describe the general relevant local context characteristics for the lab and the experiments. These categories are sufficiently broad yet provide appropriate distinctions for reporters to identify relevant case-specific

[1] This space can be both literal and metaphorical in that it could be helpful to have a physical space where participants meet and carry out activities, but more important is the metaphorical space created when parties agree and commit to participate/collaborate in the lab process.

Table 3 The context section of the case reporting scheme outlining constructs and their associated guiding questions

Context	**What are the general factors that describe the context in which the lab and its activities are located and entangled? How do they influence the lab and its activities?**
Construct	**Guiding Question**
Environmental	What are the relevant environmental factors (biological or physical), such as climate, soil type or vegetation?
Social/Cultural	What are the relevant socio-cultural factors, such as history, diversity, education, income, health, language, religion, values, beliefs and social norms?
Financial/Economic	What are the relevant socio-economic factors, such as taxes, diversity of enterprises, unemployment and diversity of workforce?
Technical/Infrastructure	What are the relevant technical or infrastructure factors, such as water and energy infrastructure, transport networks, housing stock, green infrastructure or other built environment?
Legal/Political	What are the relevant legal or political context factors, such as laws, regulations, standards, permits, dominant ideology, activism and public participation?
Organisational/Capacity	What organisational or capacity factors (such as knowledge, skills, organisational structures, networks, training programmes and support services) have a significant influence on the lab's purpose or activities?

elements and key details. To establish the lab characteristics, we began with a set of key characteristics of sustainability-oriented labs proposed by Schäpke et al. (2018). We then drew on a variety of ULL, Real-world lab, T-Lab, and Transition lab literature, including review papers (McCrory et al. 2020; e.g., Bergmann et al. 2021), along with literature on transdisciplinary sustainability research design principles (Lang et al. 2012). To establish the characteristics of the experiments and as inspiration for many of the guiding questions in the case reporting scheme, we drew on the comprehensive work of Luederitz et al. (2017), which reviewed the experiment literature to develop an evaluative scheme for sustainability experiments.

The case reporting scheme

The case reporting scheme consists of three main components following the logic model – the context, lab, and experiment – along with a short set of instructions for the reporting process. The scheme structures the processes, insights, results and experiences from sustainability-oriented lab research and its experiments in an accessible way. The structure of the scheme reflects the components of the logic model and their interconnections as described above. Each of the case reporting scheme's features is addressed through a guiding question. The case reporting scheme is presented in the tables below, followed by examples from the GLOCULL project showing how questions can be answered.[2]

Context features

These characteristics aim to represent relevant context aspects framing the lab and its experiments. The context can also be useful in capturing the system limits that cases set

[2] The scheme as presented in the following sections of this paper is an updated version of the scheme originally used in the GLOCULL project. While the general structure and most of the questions are identical, some changes were made to enhance the scheme's generalisability during the conceptualisation and writing of this paper. We are confident that the quality of the scheme has improved and is now up to date with regards to the literature it integrates.

Table 4 The lab section of the case reporting scheme outlining constructs and their associated guiding questions

Lab	**What is the general purpose, structure and composition of the lab? How were these determined/negotiated/carried out?**
Construct	**Guiding Question**
Space	
Spatial scope	What is the spatial scope of the lab's activities, such as relevant geographical and/or administrative boundaries?
Temporal scope	What is the temporal scope of the lab's activities?
	What previous work is crucial to understanding the lab's current work?
	What is the lab's future and long-term perspective?
Process	
Experimentation	What is the general experimental methodology adopted by the lab (e.g., testing innovations/exploring sustainability solutions)?
	How is the control of experiments managed/distributed? Are experiments problem or solution oriented? What are the main experiments undertaken in the lab? How were these determined?
Collaborative process	What is the general process of collaboration in setting up the lab and the accompanying experiments? How did participants collaborate (e.g., share responsibilities, organise decision-making processes, etc.)? Which groups/voices are lacking or under-represented? Why?
Learning and reflexivity	How does the lab enable learning and create spaces for reflexivity (including knowledge synthesis and integration)?
Activities	What further activities support the lab process?
Organisation	
Organisational structure	What is the general organisational structure of the lab (including the funding scheme, financing, etc.)?
	Who are the primary participants in the lab and experiment(s)? Indicate their representative roles (e.g., academic, private, municipal) within the process. What roles were determined for running and maintaining the lab and experiments? Did central roles change over the course of the lab?
	How does the lab deal with conflict situations?
Sustainability	
Sustainability orientation and purpose	What sustainability problem is addressed by the lab? What sustainability understanding is adopted to address the problem/s? How was this understanding reached? Did the understanding deepen over the course of the lab? For whom?

for themselves. We understand context as the external and environmental factors that the lab and experiments are entangled with (Van Steenbergen and Frantzeskaki 2018).

In the GLOCULL project, the context section provided an opportunity for labs to reflect on local spaces and how they interact with the lab and its activities. For instance, the SUSTBEERLAB in Lund, Sweden, identified the socio/cultural context factors as follows:

> *There is an underlying class, gender and race (middle-class, male, white) broadly associated with the craft brewing industry (both in terms of those who work in the industry and its target audience). There are some exceptions to these norms as craft brewing is a growing sector in different cultures (e.g., Japan). The industry is also dependent on those with leisure time and disposable income. These aspects form the basis of the "social" components of lab activities. Cracks, however, are emerging, especially in terms of the race and gender components (e.g., gender ambassadors, female brewing groups/female-operated breweries).*

Table 5 The experiments section of the case reporting scheme outlining constructs and their associated guiding questions

Experiment	**How were the experiments conducted; what did they generate?**
Construct	**Guiding question**
Outputs	**What kind of outputs were generated through the experiment?**
Built capacities	What capacities were created through the experiment?
Actionable knowledge	What actionable knowledge was generated through the experiment? How did it provide evidence on generating sustainability solutions?
Accountability	How did the experiment build confidence and commitment for generating and realising sustainability solutions?
Changes in physical structures	What physical changes were made to support solutions for the identified sustainability problem?
Changes in social structures	What changes in social structures were made to support solutions for the identified sustainability problem?
Transferability	How does the experiment ensure that the sustainability solution can be transferred to different contexts?
Scalability	How does the experiment indicate the method and potential for outputs to be scaled to broader applications or to higher hierarchical levels?
Unintended consequences	How does the experiment account for unintended consequences that are associated with the sustainability-oriented intervention?
Outcomes	**How did the experiment contribute to sustainability?**
Socio-ecological integrity	How did the experiment's outputs strengthen socio-ecological integrity?
Livelihood sufficiency and opportunity	How did the experiment's outputs enhance livelihood sufficiency and opportunity?
Intra- and intergenerational equity	How did the experiment's outputs improve intra- and intergenerational equity?
Resource maintenance and efficiency	How did the experiment's outputs contribute to overall resource maintenance and efficiency?
Socio-ecological stewardship and democratic governance	How did the experiment's outputs build or support socio-ecological understanding and democratic governance?
Precaution and adaptation	How did the experiment's outputs ensure precaution and adaptation?
Processes	**How was the experiment designed and conducted?**
Sequence of actions	Was the experiment structured in a meaningful sequence of actions?
Sound methodology	What was the methodology used to conduct the experiment?
Collaboration	How did the experiment facilitate collaboration among relevant stakeholders?
Reflexivity and learning	How did the experiment foster reflexivity and learning throughout the process?
Transparency	How did the experiment ensure transparency throughout the process?
Inputs	**What were the enabling factors of the experiment?**
Awareness	What was the level of awareness of the need for transformational change?
	How did the experiment involve participants aware of the need for transformational change?
Commitment	What commitment did the experiment build on?
Expertise	What skills and knowledge did the experiment build on?
Trust	What trust among collaborators did the experiment build on?
Support	What support was secured for the realisation of the experiment?

Table 6 The general framing and topic areas/characteristics of the context, lab and experiment for the case reporting scheme and the corresponding literature

Context Features	**References**
Environmental, social/cultural, financial/economic, technical/infrastructure, legal/political, organisational/capacity	Forrest et al. 2019; Van Steenbergen and Frantzeskaki 2018; West et al. 2019
Lab Features	**References**
Space	McCrory et al. 2020
Geographical embeddedness, real-world problem as a starting point, boundaries: lab demarcations – content, space, location and scope	Voytenko et al. 2016; Wanner et al. 2018; Bulkeley et al. 2019
Background and history, long-term orientation	Forrest et al. 2019; Schäpke et al. 2018; Bulkeley et al. 2019
Process	McCrory et al. 2020
Experiments as core research method, experimentation and learning, real-world intervention	Voytenko et al. 2016; Wanner et al. 2018; Schäpke et al. 2018; Caniglia et al. 2017
Transdisciplinarity as core research mode; systems, target and transformation knowledge; participation and user involvement; participants, power, legitimacy, credibility, salience, inclusion	Voytenko et al. 2016; Wanner et al. 2018; Adler et al. 2018; Schäpke et al. 2018; Sengers et al. 2019; Lam et al. 2020a, b; Caniglia et al. 2017; Cash et al. 2003; Bergmann et al. 2021; Avelino 2017; De Geus et al. 2022
Learning and reflexivity, cyclical learning: reflection and variation, evaluation (of actions and impacts) and refinement of knowledge; capacity building	Voytenko et al. 2016; Wanner et al. 2018; Schäpke et al. 2018; Singer-Brodowski et al. 2018; Ness and Wahl 2022; Lang et al. 2012; Wiek et al. 2017; Bergmann et al. 2021
Participatory methods, tools, exercises, workshops for e.g., skill and capacity development, system thinking and definition	Bulkeley et al. 2019; Lang et al. 2012; Bergmann et al. 2021
Organisation	McCrory et al. 2020
Leadership and ownership of ULLs, TD collaboration (co-leadership)	Voytenko et al. 2016; Wanner et al. 2018
Collaboration, responsibility, time allocation, organisational process, organisational champion	Wittmayer & Schäpke 2014; Wittmayer et al. 2017; Ness and Wahl 2022
Facilitation, trust, communication	Lang et al. 2012; Ness and Wahl 2022
Sustainability	McCrory et al. 2020
Contribution to transformation, normative framing, real-world problem, purpose, scalability and transferability of results (amplification), empowerment of change agents	Wanner et al. 2018; Schäpke et al. 2018; Forrest et al. 2019; Lam et al. 2020a, b; Lang et al. 2012; Pereira et al. 2020; Wiek et al. 2017
Experiment Features	**Reference**
Outputs	Luederitz et al. 2017
Built capacities, actionable knowledge, accountability, changes in physical structures, changes in social structures, transferability, scalability, accounting for unintended consequences associated with uptake	
Outcomes	
Socio-ecological integrity, livelihood sufficiency and opportunity, intra- and intergenerational equity, resource maintenance and efficiency, socio-ecological stewardship and democratic governance, precaution and adaptation	
Processes	
Sequence of actions, sound methodology, collaboration, reflexivity and learning, transparency	
Inputs	
Awareness, commitment, expertise, trust, support	

It also provided a space for reflection on the connections between the context conditions and the practices of the lab's local partners. For instance, the ULL in Vienna, Austria, explained:

> *The environmental factors are to some extent controlled inside the greenhouse. Coconut fiber is used instead of soil. The type of vegetables grown inside the greenhouse determines the necessary inside temperature, sunshine or shading and watering. According to the gardeners, the levels of sunshine are more important than the outside temperature for regulating the optimum temperature inside the greenhouse for growing vegetables. Climate conditions, including wind, influence to what extent the gardeners need power for ventilation and for irrigation in the greenhouses, which affects the consumption of energy (the energy is produced by PV panels). The economic potential of the ULL generally depends on climatic conditions and their change over time. More precise measurements with respect to environmental conditions were beyond the scope of our experiment.*

Laboratory features

We propose to use the four categories identified by McCrory et al. (2020) in their review of real-world lab types to structure this section: space, process, organisation and sustainability. These categories consider where a lab is located, why and when a lab is convened, what and how actions are taken, the roles and influences of and on lab participants, and their intended sustainability purpose.

GLOCULL labs answered the lab section in a variety of ways, with some offering narrative and detailed answers, while others preferred a concise academic approach like the following from the ULL in Lüneberg, Germany, in their response to the experimentation questions:

> *The central experiment conducted in the lab (the co-development and implementation of a communication strategy for transparency in sustainable coffee businesses) is considered a type 5 experiment, i.e. an experiment on sustainability solutions with participatory control (Caniglia et al. 2017), with an embedded analytical aspect that adopts a methodological approach from business psychology (Weber et al. 2021). The topic/real-world problem was selected as a crucial aspect of the café's transition to becoming a collectively-managed sustainable coffee shop with a local roastery devoted to transparent business practices.*

In response to the sustainability questions, the same ULL explained:

> *The experiment in the lab mainly revolved around the aspect of "transparency". This focused on the coffee supply chain as well as having the general aim of making contributions to increase sustainability in the food-water-energy nexus. Related social questions, such as income and the living/working conditions of producers, were also considered. On a local level, the lab aims to encourage the residents of Lüneburg to adopt more sustainable consumption patterns.*

Experiment features

The experiment features build on the comprehensive evaluation scheme presented by Luederitz et al. (2017), which deconstructs experiments into inputs, processes, outcomes and outputs. The four categories correspond to the answers to the following general questions: *What was generated?* (outputs); *what was accomplished?* (outcomes); *how was it completed?* (process); and *what was invested?* (inputs) (Luederitz et al. 2017). While we have adopted this overall framing, we have added or changed the guidance to highlight the related processes using *how* questions along with *what* questions.

Used as a reflexive tool, the case reporting scheme can identify process challenges from multiple perspectives. For example, in response to the *transparency* questions, the Sao Paulo GLOCULL team reported the following:

> *With the aim of ensuring transparency throughout the process, the decision was made to focus on communication between actors and a formal agreement was drawn up. However, some participants recognised that there were flaws in the communication process in the ULL, since the goals initially agreed by the group were adjusted along the process and not all the participants were notified. This highlights the importance of establishing transparent modes of communication between all the actors. An agreement between the university and the Municipal Secretariat of Urban Development and Licensing was developed and signed. However, due to changes in the public administration and bureaucracy, this agreement was never fully formalised. This impacted on the information sharing from the municipality and, consequently, on the compilation of the sustainability indicators forms. Nevertheless, some participants pointed out that shared responsibilities had been clearly established at the beginning of the process, which was helpful for building trust within the group. (Researchers' perspective, interviews with ULL participants)*

Reporting procedure

Our structured case reporting scheme aims to support and simplify reporting practice. Yet, For the reporting to meet its potential to increase learning across cases and improve the comparability of cases, the process needs to be coherent.

Therefore, we have developed a brief list of principles to guide the reporting:

1) *Start from the experiment.* Centering the reporting around the experiment provides the necessary focus for a pragmatic and target-oriented reporting process. By putting the experiment at the centre of the report, the cases can be constructed/reconstructed more easily as the description of the lab and context is guided by the question of what was relevant to the experiment.
2) *Use available data*. The reporting suggested in this paper does not necessarily require the collection of new data. We have learned in our research practice that much of the required information is already available in the form of meeting minutes, research and reflection journals, schedules, annual and midterm reports, etc. The reporting does not aim to replace empirical methodologies where they are needed, but rather

provides a coherent structure for communicating project characteristics and transdisciplinary research insights.

3) *Disambiguate context, lab, and experiment*. The reporting builds on an intentional disambiguation of context, lab, and experiment. While in reality these three aspects of lab-based action-oriented research are inherently interconnected, they need to be described separately to enhance their understanding from an outside perspective. The deliberate disentangling of cases facilitates the transferability of the case report content, as a first step in conceptualising real-world research.
4) *Adapt to case specifics*. We suggest viewing the case reporting scheme as a modular tool. It should reflect the goals and purpose of each case study, meaning that questions central to a particular case can be answered in greater detail where others may be more generally described. It is also important to note that each experiment in a case should have its own reporting space. In many cases, labs conduct more than one experiment. Moreover, if the questions are too broad for the purpose, they can be given more detail using what we call horizontal specification: the original features and questions of the scheme remain as categories but are complemented by additional case-specific questions.

Discussion

The case reporting scheme as a pragmatic tool balancing comprehensiveness and specificity through modularity

The scheme as presented in this paper was designed as a tool for a reporting approach that is integrative and thus applicable in a diversity of contexts, lab designs and experiments. The case reporting scheme balances the need for a structural framework that enables comparisons between cases with the flexibility necessary to adapt to the specifics of cases, designs and context that are inherent in transdisciplinary and transformative research in ULLs. Consequently, the features of the scheme and the questions cover a broad range of lab features, context qualities and aspects of sustainability-oriented experiments. With the aim of generating research reports that are more comprehensive, the case reporting scheme has the potential to better capture emergent results from transdisciplinary labs and experiments in a structured manner.

While the scheme itself is designed as a descriptive tool and built around a clear disambiguation of context, lab process and experiments, it recognises these three aspects as inherently interconnected. By centering the reporting around the experiment and lab process, the intention is to describe the context *relevant* to the research practice, adopting the notion of contexts as constructed by this practice (West et al. 2019). While this might seem complicated at first, in practice a reporting sequence starting from the experiment, describing the lab process around it and then the context factors relevant for the case, allows the reporting process to follow these considerations.

The case reporting scheme is purposefully designed to be fairly general in order to integrate a diversity of cases: it is intended to be adapted to meet the specifics of case study contexts and labs, as well as experiment designs. Through the bottom-up (initial collection of the case-specific questions) and top-down (alignment with existing frameworks) process of developing the case reporting scheme, we were able to ensure that

the scheme is appropriately case-oriented and, therefore, functional for researchers and actors in transdisciplinary research settings.

However, the case reporting scheme is intended to be customised in such a way to enable comparability beyond an individual case/project – and to achieve that, most questions should remain constant. However, specific elements can be highlighted in questions to target case/project specific priorities. Furthermore, questions can be added to the scheme; for example, to allow for a particular type of analysis. It should be noted, however, these amendments and adaptations should be discussed and decided upon at an early stage in the research to align research design, assessment, and evaluation. Beyond the content of the case reporting scheme, questions regarding who should complete the report and who has what data or knowledge are significant – especially if the decision is taken that parts of the report are to be completed as a reflexive activity with non-academic participants.

One of the key aspects of the case reporting scheme lies in its modularity. It enables the reporting to trace the uniqueness of each project through the reported aspects in each section. Consequently, that uniqueness is made explicit in each of the sections and the influence of certain characteristics are seen as they interact with processes and decisions taken in the lab and during the experiments. Furthermore, the modularity creates the potential for the case reporting scheme to be adapted to the specific interests of projects without the need to develop an entirely new reporting structure.

The case reporting scheme as a reflexive tool for collaborative planning and learning

Through its comprehensive design, the case reporting scheme includes a wide range of aspects to consider when designing and planning lab-based sustainability-oriented research settings. The case reporting scheme can be used as a guide for developing context understanding and reflecting on the research design, in terms of *inter alia* priority setting, data collection, purpose setting, methods or activity planning. It is particularly useful for guiding the discussion of these aspects at an early stage, for example, in anticipation of cross-case comparisons and developing methods and tools. The case reporting scheme can be used iteratively to track changing perspectives, project, lab or experiment evolutions, participating-actor turnover or additions, or major changes in local contexts e.g., COVID-19 and associated restrictions.

The case reporting scheme and the theoretical understandings from which it is derived have proven useful for critically inspecting lab designs and addressing aspects that may have been initially overlooked. In some cases, the case reporting scheme has proven especially useful for supporting the development and planning of experiments that were only described in vague terms at the outset of the project. At international consortium level where cooperation between research teams from different labs is essential, the case reporting scheme (and its development process) has played a crucial role in aligning research approaches by establishing a shared methodological understanding as a basis for the individual lab work.

In this context, the case reporting scheme can be used reflexively as a participatory or non-participatory tool to enable mutual learning. The more users engage in the process of thinking about how the questions relate to their case, the more the answers can reveal unexpected learnings. In such instances, the case reporting scheme can support

a structured learning and reflection process that integrates different perspectives in the research. While our case reporting scheme offers a structure for reporting on crucial aspects of contexts, labs, and experiments, integrating a quality assessment not only fosters learning within cases, but also enriches the knowledge conveyed in case reports (Williams and Robinson 2020; Jain and Rohracher 2022).

Knowledge transfer and comparison

Compared to other modes of research, knowledge generated in transdisciplinary and transformative research settings is characterised by a high degree of context-specificity, creating knowledge based on (single) cases that may potentially be applied to other (single) cases. The challenges of knowledge transfer in these contexts was made clear by Adler et al. (2018). They argue that it must be distinguished from the traditional notion of generalising knowledge across cases, and instead the authors suggest the building of analogies.

Our case reporting scheme approach aligns with this notion and can provide a basis for such analogy-based knowledge transfer. We follow the idea that "insights" or "results" from lab-based research processes cannot be implemented "as is" in different contexts, let alone be replicated in its entirety elsewhere (in contrast to traditional experiments). Instead, case reports can be a basis for building analogies. By offering a comprehensive perspective on (single) cases, case reports enable researchers to find similarities and dissimilarities and identify that knowledge which is applicable to their own and other cases. By making context, lab design, and experiments explicit, our case reporting scheme provides the basis for exploring amplification strategies for solutions that have been developed and tested in other contexts (Lam et al. 2020a, b).

By enabling researchers to communicate their case-specific research coherently and comprehensively, case reports can play a role in bridging modes and approaches. Instead of highlighting differences, the case reporting scheme frames cases as complementary to each other: all parts of a gradient ranging from highly case-specific and impactful approaches able to recognise existing local sustainability initiatives (Lam et al. 2020a) to more generalisable and empirically rigorous methodologies, such as harmonised experimentation (Ferraro and Agrawal 2021), randomised controlled trials (Bilotta et al. 2014) or meta-analytical approaches.

Case reports are data. While this data may be less generalisable than the insights generated through more rigorous methodologies and study designs, structured and collaborative case reporting can be representative of the ecological validity (Scholz and Tietje 2002) of transdisciplinary research. Consequently, case reports could be a promising data source in the field of sustainability research for generating hypotheses through comparative approaches appropriate for dealing with complex and often mixed data, e.g. Rough Set Analysis (Pawlak 1997; e.g., Nijkamp et al. 2002; e.g., Lutz et al. 2017) or Qualitative comparative analyses (e.g., Hilger et al. 2018).

Case reports can be written and considered as case narratives. Following the case reporting process and thinking of external readers can shift the way cases are communicated between researchers and add a *thick description* (Geertz 1973) to the otherwise focused and therefore narrower perspectives offered by case studies. A narrative storytelling approach rich with detail and aimed at process understanding puts the

transdisciplinary aspects of the research at the centre, allowing others to learn from the trials and tribulations of cases (e.g., Schwartz-Shea and Yanow 2013). Kenter et al., (2019) suggest Loving the Mess while navigating transdisciplinary collaborations, and while we agree, we think that sharing the mess with others will facilitate future process navigations.

Through a case reporting practice shared across the field of action-oriented research, a rich knowledge-base on sustainability approaches could be built. We recognize that a number of journals already publish article types aimed at sharing process and design knowledge from transdisciplinary research constellations (e.g., Sustainability Science and GAIA) that enable learning from real-world cases. Basing such articles on a shared reporting scheme such as the one presented here, would further establish these articles as a rich knowledge base for enabling sustainability transformations while incentivizing case reporting through peer-reviewed publications. Furthermore, the establishment of dedicated sustainability-oriented case report journals in combination with open-access and dynamic databases could be possible avenues to creating new learning opportunities from case-based research.

Case reporting in action-oriented sustainability research – a way forward

Over the last two decades sustainability science has established a research field dealing with pressing global societal challenges. While the field has generated a wide spectrum of transdisciplinary, action-oriented and transformative approaches, the evolving research landscape is still characterised by division (Lang et al. 2017) and the focus on either context-specific research or research striving for generalisable results has created two separate communities (Lang et al. 2017).

The case reporting approach and the scheme we propose in this paper are clearly located in the former community, which recognises the local context as the arena where sustainability transformations can be collaboratively investigated through joint experimentation. However, while our case reporting scheme has been developed with the clear intention of fostering knowledge transfer between such cases, we also think it has the potential to contribute to bridging the aforementioned divide.

As argued by Lang et al. (2017), transdisciplinary (i.e. case-specific) and disciplinary (i.e. typically striving for generalisation) research approaches are equally necessary to contribute to sustainability transformations on a global scale. In our experience, published results from transdisciplinary research currently often address either highly specific aspects of a study or zoom in on results from analyses without adequately representing the overall character of the case study. Consequently, these results do not meet the expectations of either community as they are seen as being either too case-specific (and of little relevance beyond the individual case) or lacking in context (and therefore inadequate for knowledge transfer and/or learning) (Adler et al. 2018).

We see the case reporting scheme approach as a possible solution to the lack of a suitable format for adequately communicating the knowledge gained from transdisciplinary research and our scheme as a pragmatic tool for structuring the research conducted in ULLs and similar forms of transformative transdisciplinary and action-oriented research. We also consider our case reporting scheme a first proposal built on existing frameworks

in an attempt to reflect some of the contemporary understandings and concepts of the research field we are addressing. With the case reporting scheme, we hope to spark a discussion about how the field of action-oriented and transdisciplinary sustainability research communicates not only its results, but also its overall processes from which others can gain knowledge and inspiration.

Supplementary Information

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Additional file 1.

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Authors' contributions
Philip Bernert and Darin Wahl share the first authorship of this article and have contributed equally to the work. Henrik von Wehrden and Daniel J. Lang have jointly supervised and critically revised the work. All authors have read and approved the final manuscript.

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Availability of data and materials
Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

Declarations

Competing interests
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References

Adler C, Hirsch Hadorn G, Breu T, Wiesmann U, Pohl C. Conceptualizing the transfer of knowledge across cases in transdisciplinary research. Sustain Sci. 2018;13(1):179–90. https://doi.org/10.1007/s11625-017-0444-2.

Albrecht J, Meves A, Bigby M. Case reports and case series from Lancet had significant impact on medical literature. J Clin Epidemiol. 2005;9:6.

Avelino F. Power in sustainability transitions: analysing power and (dis)empowerment in transformative change towards sustainability. Environ Policy Gov. 2017;27(6):505–20. https://doi.org/10.1002/eet.1777.

Bergmann M, Schäpke N, Marg O, Stelzer F, Lang DJ, Bossert M, Gantert M, Häußler E, Marquardt E, Piontek FM, Potthast T, Rhodius R, Rudolph M, Ruddat M, Seebacher A, Sußmann N. Transdisciplinary sustainability research in real-world labs: success factors and methods for change. Sustain Sci. 2021. https://doi.org/10.1007/s11625-020-00886-8.

Bilotta GS, Milner AM, Boyd I. On the use of systematic reviews to inform environmental policies. Environ Sci Policy. 2014;42:67–77. https://doi.org/10.1016/j.envsci.2014.05.010.

Bulkeley H, Coenen L, Frantzeskaki N, Hartmann C, Kronsell A, Mai L, Marvin S, McCormick K, van Steenbergen F, Voytenko Palgan Y. Urban living labs: governing urban sustainability transitions. Curr Opin Environ Sustain. 2016;22:13–7. https://doi.org/10.1016/j.cosust.2017.02.003.

Bulkeley H, Marvin S, Palgan YV, McCormick K, Breitfuss-Loidl M, Mai L, von Wirth T, Frantzeskaki N. Urban living laboratories: conducting the experimental city? Eur Urban Reg Stud. 2019;26(4):317–35. https://doi.org/10.1177/0969776418787222.

Caniglia G, Schäpke N, Lang DJ, Abson DJ, Luederitz C, Wiek A, Laubichler MD, Gralla F, von Wehrden H. Experiments and evidence in sustainability science: a typology. J Clean Prod. 2017;169:39–47. https://doi.org/10.1016/j.jclepro.2017.05.164.

Cash DW, Clark WC, Alcock F, Dickson NM, Eckley N, Guston DH, Jäger J, Mitchell RB. Knowledge systems for sustainable development. Proc Natl Acad Sci USA. 2003;100(14):8086–91. https://doi.org/10.1073/pnas.1231332100.

Castán Broto V, Bulkeley H. A survey of urban climate change experiments in 100 cities. Glob Environ Chang. 2013;23(1):92–102. https://doi.org/10.1016/j.gloenvcha.2012.07.005.
De Geus T, Wittmayer JM, Vogelzang F. Biting the bullet: addressing the democratic legitimacy of transition management. Environ Innov Soc Trans. 2022;42:201–18. https://doi.org/10.1016/j.eist.2021.12.008.
Ferraro PJ, Agrawal A. Synthesizing evidence in sustainability science through harmonized experiments: community monitoring in common pool resources. Proc Natl Acad Sci USA. 2021;118(29):e2106489118. https://doi.org/10.1073/pnas.2106489118.
Forrest N, Stein Z, Wiek A. Water-independent residential properties as a transformational solution to achieve water sustainability in desert cities? J Clean Prod. 2019;214:1038–49. https://doi.org/10.1016/j.jclepro.2018.12.309.
Frantzeskaki N, van Steenbergen F, Stedman RC. Sense of place and experimentation in urban sustainability transitions: the Resilience Lab in Carnisse, Rotterdam, The Netherlands. Sustain Sci. 2018;13:1045–59. https://doi.org/10.1007/s11625-018-0562-5.
Geertz C. Thick description: towards an interpretive theory of culture. In: Geertz C, editor. The Interpretation of Cultures. Basic Books. 1973.
Hilger A, Rose M, Wanner M. Changing faces-factors influencing the roles of researchers in real-world laboratories. Gaia. 2018;27(1):138–45. https://doi.org/10.14512/gaia.27.1.9.
Hodson M, Geels F, McMeekin A. Reconfiguring Urban sustainability transitions. Anal Multiplicity Sustain. 2017;9(2):299. https://doi.org/10.3390/su9020299.
Jahn T. Transdisziplinarität in der Forschungspraxis. In: Bergmann M, Schramm E, editors. Transdisziplinäre Forschung. Integrative Forschungsprozesse verstehen und bewerten. Frankfurt/New York: Campus Verlag; 2008. p. 21–37.
Jain M, Rohracher H. Assessing transformative change of infrastructures in urban area redevelopments. Cities. 2022;124:103573. https://doi.org/10.1016/j.cities.2022.103573.
Kampfmann T, Bernert P, Lang DJ. Toward a modular evaluation approach of real-world laboratories: findings from a literature review. Res Eval. 2022:rvac029. https://doi.org/10.1093/reseval/rvac029.
Kenter JO, Raymond CM, van Riper CJ, Azzopardi E, Brear MR, Calcagni F, Christie I, Christie M, Fordham A, Gould RK, Ives CD, Hejnowicz AP, Gunton R, Horcea-Milcu AI, Kendal D, Kronenberg J, Massenberg JR, O'Connor S, Ravenscroft N, Rawluk A, Raymond IJ, Rodríguez-Morales J, Thankappan S. Loving the mess: navigating diversity and conflict in social values for sustainability. Sustain Sci. 2019;14(5):1439–61. https://doi.org/10.1007/s11625-019-00726-4.
Krohn W. Interdisciplinary cases and disciplinary knowledge: epistemic challenges of interdisciplinary research. In: Frodeman R, editor. The Oxford Handbook of Interdisciplinarity. Oxford: Oxford University Press; 2017. p. 40–52. https://doi.org/10.1093/oxfordhb/9780198733522.013.5.
Laborgne P, Ekille E, Wendel J, Pierce A, Heyder M, Suchomska J, Nichersu I, Balaican D, Ślebioda K, Wróblewski M, Goszczynski W. Urban Living Labs: how to enable inclusive transdisciplinary research? Urban Transform. 2021;3(1):11 https://doi.org/10/gn46k4.
Lam DPM, Horcea-Milcu AI, Fischer J, Peukert D, Lang DJ. Three principles for co-designing sustainability intervention strategies: experiences from Southern Transylvania. Ambio. 2020a;49(9):1451–65. https://doi.org/10.1007/s13280-019-01302-x.
Lam DPM, Martín-López B, Wiek A, Bennett EM, Frantzeskaki N, Horcea-Milcu AI, Lang DJ. Scaling the impact of sustainability initiatives: a typology of amplification processes. Urban Transform. 2020b;2(1):1–24. https://doi.org/10.1186/s42854-020-00007-9.
Lang DJ, Wiek A, Bergmann M, Stauffacher M, Martens P, Moll P, Swilling M, Thomas CJ. Transdisciplinary research in sustainability science: practice, principles, and challenges. Sustain Sci. 2012;7(S1):25–43. https://doi.org/10.1007/s11625-011-0149-x.
Lang DJ, Wiek A, von Wehrden H. Bridging divides in sustainability science. Sustain Sci. 2017. https://doi.org/10.1007/s11625-017-0497-2.
Luederitz C, Schäpke N, Wiek A, Lang DJ, Bergmann M, Bos JJ, Burch S, Davies A, Evans J, König A, Farrelly MA, Forrest N, Frantzeskaki N, Gibson RB, Kay B, Loorbach D, McCormick K, Parodi O, Rauschmayer F, Schneidewind U, Stauffacher M, Stelzer F, Trencher G, Venjakob J, Vergragt PJ, von Wehrden H, Westley FR. Learning through evaluation – a tentative evaluative scheme for sustainability transition experiments. J Clean Prod. 2017;169:61–76. https://doi.org/10.1016/j.jclepro.2016.09.005.
Lutz LM, Fischer L-B, Newig J, Lang DJ. Driving factors for the regional implementation of renewable energy - a multiple case study on the German energy transition. Energy Policy. 2017;105:136–47. https://doi.org/10.1016/j.enpol.2017.02.019.
Marone U. Case reports: more than anectodal evidence. J Clin Case Rep. 2012;2(4):1. https://doi.org/10.4172/2165-7920.1000e111.
McCrory G, Schäpke N, Holmén J, Holmberg J. Sustainability-oriented labs in real-world contexts: an exploratory review. J Clean Prod. 2020;277:123202. https://doi.org/10.1016/j.jclepro.2020.123202.
Ness B, Wahl D. Getting personal with collaborative sustainability experimentation: reflections and recommendations from a transdisciplinary partnership with the Swedish craft beer sector. Ambio. 2022;51(12):2544–56. https://doi.org/10.1007/s13280-022-01751-x.
Nevens F, Frantzeskaki N, Gorissen L, Loorbach D. Urban Transition Labs: co-creating transformative action for sustainable cities. J Clean Prod. 2013;50:111–22. https://doi.org/10.1016/j.jclepro.2012.12.001.
Nijkamp P, van der Burch M, Vindigni G. A Comparative Institutional evaluation of public-private partnerships in Dutch Urban land-use and revitalisation projects. Urban Studies. 2002;39(10):1865–80. https://doi.org/10.1080/0042098022000002993.
Palmer H, Polk M, Simon D, Hansson S. Evaluative and enabling infrastructures: supporting the ability of urban co-production processes to contribute to societal change. Urban Transform. 2020;2(1):6. https://doi.org/10.1186/s42854-020-00010-0.
Pawlak Z. Rough set approach to knowledge-based decision support. Eur J Oper Res. 1997;99(1):48–57. https://doi.org/10.1016/S0377-2217(96)00382-7.

Pereira L, Drimie S, Zgambo O, Biggs R. Planning for change: transformation labs for an alternative food system in Cape Town, South Africa. Urban Transform. 2020;2(1):13. https://doi.org/10.1186/s42854-020-00016-8.
Schäpke N, Stelzer F, Caniglia G, Bergmann M, Wanner M, Singer-Brodowski M, Loorbach D, Olsson P, Baedeker C, Lang DJ. Jointly experimenting for transformation? Shaping real-world laboratories by comparing them. GAIA Ecol Perspect Sci Soc. 2018;27(1):85–96. https://doi.org/10.14512/gaia.27.S1.16.
Scholz R, Tietje O. Embedded case study methods. Thousand Oaks: SAGE Publications Inc; 2002.
Schwartz-Shea P, Yanow D. Interpretive research design. 1st ed. New York: Routledge; 2013. https://doi.org/10.4324/9780203854907.
Sengers F, Wieczorek AJ, Raven R. Experimenting for sustainability transitions: a systematic literature review. Technol Forecast Soc Chang. 2019;145:153–64. https://doi.org/10.1016/j.techfore.2016.08.031.
Singer-Brodowski M, Beecroft R, Parodi O. Learning in real-world laboratories: a systematic impulse for discussion. GAIA Ecol Perspect Sci Soc. 2018;27(1):23–7. https://doi.org/10.14512/gaia.27.S1.7.
Van Steenbergen F, Frantzeskaki N. The importance of place for urban transition experiments: Understanding the embeddedness of urban living labs. In: Urban Living Labs: Experimenting with City Futures; 2018.
Vandenbroucke JP. In defense of case reports and case series. Ann Intern Med. 2001;134(4):330–4. https://doi.org/10.7326/0003-4819-134-4-200102200-00017.
von Wirth T, Fuenfschilling L, Frantzeskaki N, Coenen L. Impacts of urban living labs on sustainability transitions: mechanisms and strategies for systemic change through experimentation. Eur Plan Stud. 2019;27(2):229–57. https://doi.org/10.1080/09654313.2018.1504895.
Voytenko Y, McCormick K, Evans J, Schliwa G. Urban living labs for sustainability and low carbon cities in Europe: towards a research agenda. J Clean Prod. 2016;123:45–54. https://doi.org/10.1016/j.jclepro.2015.08.053.
Wanner M, Hilger A, Westerkowski J, Rose M, Stelzer F, Schäpke N. Towards a cyclical concept of real-world laboratories: a transdisciplinary research practice for sustainability transitions. disP Plan Rev. 2018;54(2):94–114. https://doi.org/10.1080/02513625.2018.1487651.
Weber H, Loschelder DD, Lang DJ, Wiek A. Connecting consumers to producers to foster sustainable consumption in international coffee supply – a marketing intervention study. J Mark Manag. 2021;37(11–12):1148–68. https://doi.org/10.1080/0267257X.2021.1897650.
West S, van Kerkhoff L, Wagenaar H. Beyond "linking knowledge and action": towards a practice-based approach to transdisciplinary sustainability interventions. Policy Studies. 2019;40(5):534–55. https://doi.org/10.1080/01442872.2019.1618810.
Wiek A, Kay B, Forrest N. Worth the Trouble?!: an evaluative scheme for Urban Sustainability Transition Labs (USTLs) and an Application to the USTL in Phoenix, Arizona. In: Frantzeskaki N, CastánBroto V, Coenen L, Loorbach D, editors. Urban sustainability transitions. New York: Routledge; 2017. p. 227–56.
Williams S, Robinson J. Measuring sustainability: an evaluation framework for sustainability transition experiments. Environ Sci Policy. 2020;103:58–66. https://doi.org/10.1016/j.envsci.2019.10.012.
Wittmayer JM, Schäpke N. Action, research and participation: roles of researchers in sustainability transitions. Sustain Sci. 2014;9(4):483–96. https://doi.org/10.1007/s11625-014-0258-4.
Wittmayer JM, Avelino F, van Steenbergen F, Loorbach D. Actor roles in transition: insights from sociological perspectives. Environ Innov Soc Trans. 2017. https://doi.org/10.1016/j.eist.2016.10.003.

Publisher's Note

4.2 Paper 2: Bridging the gap between local solution development and broader knowledge generation

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Manuscript

Bridging the gap between local solution development and broader knowledge generation: Insights from a marketing intervention study on sustainable coffee supply

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Abstract

Small- and medium-sized enterprises (SMEs) are key drivers of sustainability transformations through local innovation and community engagement. However, sustainability science struggles to translate context-specific solutions into broader, transferable knowledge. We present a transdisciplinary collaboration with a sustainability-oriented SME to develop and validate scalable interventions. We co-created three experiential marketing tools—a graphic novel, mindful audio guide, and promotional video—designed to communicate supply chain transparency and promote sustainable consumption. Testing through a real-world field experiment (N = 204) and online study (N = 460) showed that interventions, particularly the graphic novel and video, significantly enhanced consumer perceptions of transparency and trust, strengthening sustainable purchase intentions. Methodologically, this demonstrates how conceptual replication can systematically validate transdisciplinary interventions while maintaining transformative potential, bridging localized solutions with generalizable evidence for sustainability transformations.

Introduction

Small and medium-sized enterprises (SMEs) are emerging as powerful catalysts for broader societal transformations toward sustainability. SMEs can contribute through their direct operations and their potential to shape consumption patterns in their communities (Jansson et al., 2017; Klewitz & Hansen, 2014). As innovation drivers and change agents in local economies (Leonidou et al., 2017), many SMEs, particularly in the food sector, are pioneering approaches that go beyond conventional sustainability practices. Innovative business models include worker cooperatives, collaborative ownership structures, and deep engagement in local economies (Eiseman & Jonsson, 2019; Weber et al., 2020, 2021). This paper complements the existing literature by exploring experiential marketing strategies in both a controlled virtual and a highly realistic field environment, conducted within a transdisciplinary real-world experiment (Caniglia et al., 2017, 2020; Parodi et al., 2024). We also assess our approach as a methodological contribution to the crucial challenge facing transdisciplinary and transformative sustainability research: the need to bridge the gap between local solution development and the generation of robust evidence for sustainability solutions.

Despite their transformative potential, sustainability-oriented businesses often struggle to fully leverage their influence on consumer behaviour. While implementing sustainable practices in supply chains is crucial, research suggests that in isolation this often fails to foster sustainable consumption behaviour among customers (Weber et al., 2021). The key challenge lies in effectively transforming traditional business-consumer relationships into active partnerships for sustainability (Lüdeke-Freund & Dembek, 2017; Prothero et al., 2011), which requires businesses to build trust and engagement with their customers through effective communication strategies (Hustvedt & Kang, 2013).

Transparency has emerged as a critical mechanism to address this challenge. Although transparency initiatives are increasingly mandated across economic sectors (Schäfer, 2022), they currently focus primarily on supply chain accountability (Garcia-Torres et al., 2017). Their transformative potential is largely unexplored. SMEs particularly struggle to leverage transparency effectively, often lacking the marketing practices necessary to translate their sustainability efforts into consumer behavioural change in their local communities (Font et al., 2017; Leonidou et al., 2017). The coffee sector exemplifies these challenges (and opportunities), given that small-scale roasters increasingly engage in direct trade and community-supported business models (Weber et al., 2021).

In this context, experiential marketing offers a promising approach for linking sustainability efforts to consumer engagement. Past research suggests that while sustainable behaviour is influenced by information availability (Leire & Thidell, 2005), emotions and experiences also play a crucial role in driving behavioural change (Ives et al., 2018; O'Brien, 2013). Despite the established success of experiential marketing in brand engagement (Brakus et al., 2009), empirical evidence of its effectiveness in supporting sustainability transformations remains limited (Follows & Jobber, 2000). Equally, our understanding of *why* experiential marketing interventions exert beneficial effects is limited (e.g., Loschelder et al., 2019; Vlasceanu et al., 2024). While initial studies suggest that experiential marketing has the potential to foster sustainable consumption (Weber et al.,

2021), systematically validating and scaling such approaches requires methodological innovation and empirical analyses.

To effectively advance these approaches, sustainability science needs new methodological frameworks that balance real-world impact with scientific rigour. Recent calls emphasise the need to develop approaches that systematically validate and transfer insights from context-specific solutions while maintaining their transformative potential (Caniglia et al., 2017; Ferraro & Agrawal, 2021; Lang et al., 2012; Wiek & Lang, 2016). Transdisciplinary case studies excel at generating context-specific knowledge and solutions, but systematically transferring insights from these studies across cases remains a key challenge (Adler et al., 2018). Conceptual replication—in controlled virtual *and* mundane-realistic field experiments—offers a promising but under-exploited methodological framework to foster the latter, allowing researchers to validate not only specific hypotheses but also to corroborate underlying theoretical frameworks and explanatory mechanisms (see Boenke et al., 2022; Hudson, 2023).

In this study, we advance practical and methodological frontiers in sustainability research through a transdisciplinary study of experiential marketing interventions in a realistic field experiment and a controlled virtual setting. Building on Weber et al.'s (2021) work with Teikei Coffee, we collaborate with Avenir Café and Roastery to examine how and why experiential marketing tools can help SMEs to foster sustainable consumption behaviour by approaching their consumers as allies. Specifically, through three interventions targeting consumers' transparency perceptions—a promotional video, a graphic novel, and an audio-guided mindful coffee supply chain journey—we used a real-world field experiment (Study 1; N=204) and an anonymous, controlled online sample (Study 2; N=460) to test how carefully designed conceptual replications can bridge the gap between solution-oriented case studies and broader scientific knowledge generation. This innovative dual-setting approach not only provides practical insights for sustainability-oriented businesses but also advances methodological development in transformative sustainability research by investigating how real-world experiments can be systematically validated beyond their original context while maintaining their transformative potential.

In the following, we first review ourcase, together with interventions and hypotheses. We then outline the methodology of the two empirical studies (real-life field experiment and online) and the larger transdisciplinary setting, before presenting data from these two studies. Finally, we discuss the results and the applied methodology, highlighting their contribution to an advanced understanding of experiential marketing for sustainability and the further development of transformative transdisciplinary research (TTDR).

Case Description

Avenir Café and Roastery is a sustainability-oriented SME aiming to contribute to broader sustainability transformations beyond its own operations. Originally founded in 2014 by a student initiative engaged in direct-trade coffee imports, the business has evolved into a collectively owned enterprise focusing explicitly on fostering sustainable consumption patterns in its local community. Since 2021, Avenir has undergone a significant transition towards a sustainable business model characterised by collective ownership and complete supply chain transparency (see FairFive GmbH, 2024). This transition included strengthening direct import relationships with producers to establish equitable supply chains. Avenir's coffee is distributed through an annual subscription model with consumers paying in advance, which shares the risk between the consumers and Avenir (and thereby the producers), while ensuring fair payment practices along the entire supply chain from producer to consumer.

This case lends itself to studying how experiential marketing can foster sustainable consumption behaviour for three main reasons. First, as a collectively owned business focused on transparency, Avenir explicitly aims to transform traditional business-consumer relationships into partnerships for sustainability. Second, Avenir combines local community engagement with international supply chain responsibility, enabling research into how these connections can be effectively communicated. Third, having transitioned to a more sustainability-focused business model, Avenir needs to communicate these changes to both existing and potential customers.

The empirical studies presented emerged from a longer transdisciplinary collaboration between Avenir and researchers at Leuphana University Lüneburg as part of the GLOCULL research project. Building on insights from previous research into Teikei Coffee (Weber et al., 2021), which demonstrated the potential for experiential marketing to foster sustainable consumption behaviour, our collaboration focused on developing and testing experiential marketing tools specifically adapted to Avenir's context and needs, and examined the impact that transparency-targeted interventions have on customers' perceptions and behaviours.

Through this collaborative process, we developed three experimental marketing interventions that were tested with Avenir's local customers and in a more controlled and higher-powered virtual, online setting. This dual approach allowed us to examine how and why experiential marketing tools can help sustainability-oriented businesses engage their consumers as partners in sustainability transformations while maintaining methodological rigour and transferability through conceptual replication.

The jointly developed experiential marketing tools were:

- a **graphic novel (A)** illustrating the coffee's journey from producer to consumer and highlighting transparency aspects of Avenir's business concept.
- a **mindful coffee journey (B)**: an audio guide to listen to while drinking Avenir coffee, enabling the consumer to experience the coffee mindfully. It included transparency information about the coffee's origins and its production.
- a **promotional video (C)** about Avenir's transparent business concept and supply chain activities, including statements from Avenir members.

Theoretical background and development of hypotheses

Sustainable consumption behaviour

Sustainable consumption behaviour —i.e., satisfying consumer needs without compromising the ecological and socioeconomic conditions of current and future generations to meet their own needs (Geiger et al., 2018)—is regarded as a crucial factor for transformation towards sustainable economies. Following previous research (see Weber et al., 2021), we focus on five proxies for participants' sustainable consumption behaviour: their attitudes to sustainable consumption (Brombach & Bergmann, 2020), motivation to consume, willingness to pay (Braun et al., 2016; Dost & Wilken, 2012; Loschelder et al., 2016; T. Wang et al., 2007), intention for action for sustainable coffee consumption (Boenke et al., 2022; Dang et al., 2020; Kang et al., 2013; J. Wang et al., 2020; Wesley et al., 2012; Wiebe et al., 2017), and mindful consumption (Gupta & Sheth, 2024).

In the following hypotheses, "sustainable consumption behaviour" is represented by these five sustainability proxies. While the first hypothesis explores the general link between our experiential marketing interventions (A, B, C – see chapter case description) and sustainable consumption behaviour, hypotheses 2 – 5 explore different underlying mechanisms as mediating effects to explain *why* the experiential marketing tools impact on sustainable consumption behaviour.

1) Relative to a control group, we predict that all three experiential marketing interventions (A, B, C) will have a positive effect on *consumers' consumption behaviour*.

Relational proximity

To explain *why* our interventions impact positively on consumers' sustainable behaviour, we reasoned that an increased sense of relational proximity—feeling more closely connected with Avenir, i.e. its team members—would explain the positive intervention effects on sustainable consumption (Weber et al., 2021).

2) We predict that *relational proximity* has a mediating effect between the three experiential marketing interventions (A, B, C) and consumers' consumption behaviour.

Trust

Second, we propose that trust plays a crucial role in sustainability efforts and supply chain practices, specifically highlighting the role of transparency in building consumer reliance (Hustvedt & Kang, 2013; Kang & Hustvedt, 2014). In line with this proposition, Guenzi et al. (2009) suggest that trust is a fundamental element in fostering long-term relationships between businesses and consumers, especially in the context of sustainable consumption.

3) We predict that *trust* has a mediating effect between the three experiential marketing interventions (A, B, C) and consumers' consumption behaviour.

Transparency

Transparency along supply chains is increasingly enforced by governing bodies to help foster the sustainability transformation of economies (Schäfer, 2022). Therefore, companies strive to enhance this transparency to meet new regulations and promote sustainable consumption behaviour among consumers (Kraft et al., 2022). While the regulatory frameworks focus on the disclosure of information concerning responsible social and environmental practices, the transformative potential lies in the ability of transparency to enhance consumers' trust and perception of an enterprise (Kang & Hustvedt, 2014).

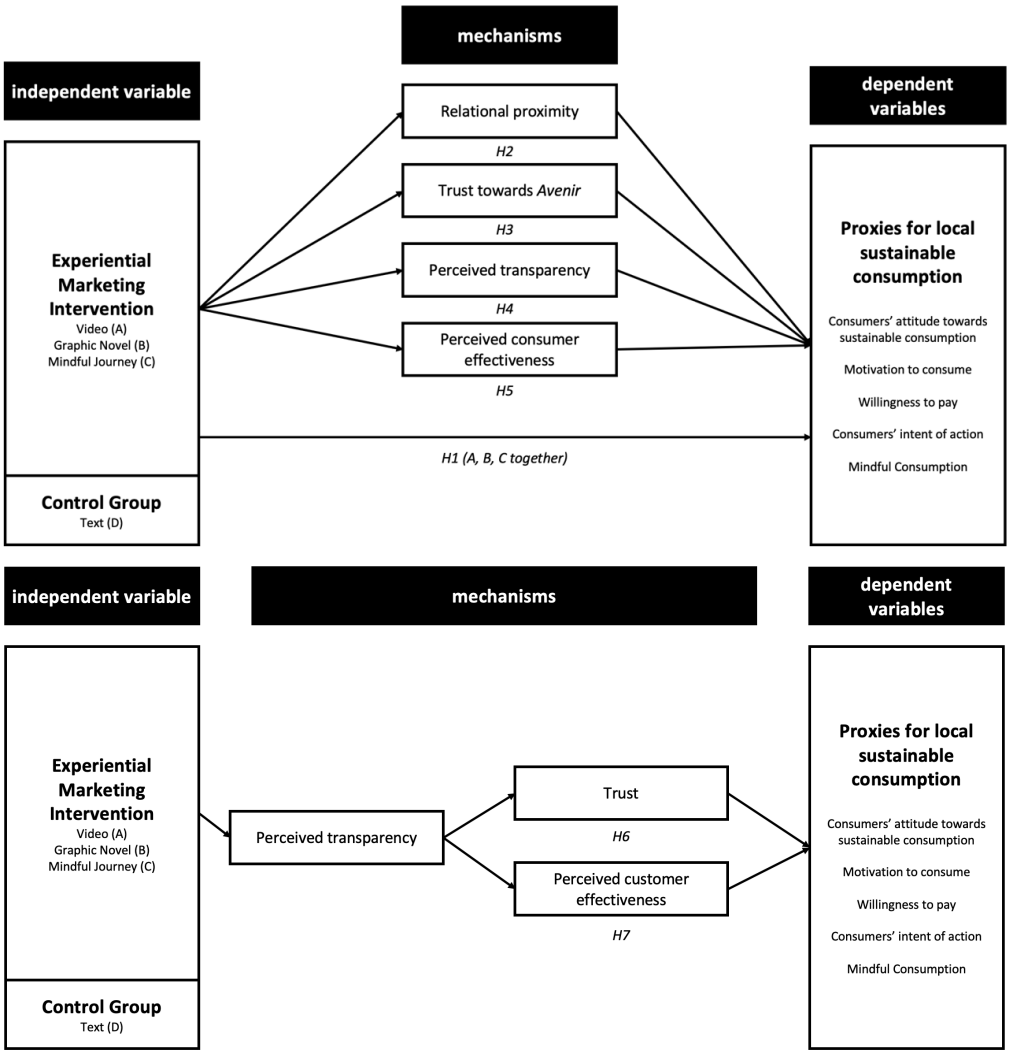
4) We predict that *transparency* has a mediating effect between the two experiential marketing interventions (A, B) and consumers' consumption behaviour.

Perceived consumer effectiveness

Perceived consumer effectiveness is understood as the consumers' belief in their ability to make a meaningful and positive impact on the environment, society, and economy through their purchasing decisions. It reflects the individual's confidence in their capacity to contribute to sustainability and make a difference through their choices (J. Wang et al., 2020). Integrating the concept of perceived consumer effectiveness into the study's theoretical framework provides valuable insights into the motivational factors influencing consumers' sustainable behaviour. By understanding how consumers perceive their ef-

Figure 1

Theoretical model for Predictive and Exploratory effects



fectiveness in driving positive impacts through their purchasing decisions, our study assesses how this perception impacts on their consumption behaviour in the context of Avenir's marketing interventions.

5) We predict that *perceived consumer effectiveness* has a mediating effect between the three experiential marketing interventions (A, B, C) and consumers' consumption behaviour.

In addition to these hypotheses, we tested two *exploratory predictions*. As outlined in the introduction, a company's perceived transparency serves as a key factor in fostering consumers' sustainable behaviour and in motivating them to become partners and allies in the sustainable transformation process.

6) We examine whether *transparency and trust* have a serial mediating effect on consumers' consumption behaviour.
7) We examine whether transparency and perceived consumer effectiveness have a serial mediating effect on consumers' consumption behaviour.

Setting, pilot workshops, methodology and transdisciplinary research process

The experiments presented in this paper adopt a transformative transdisciplinary research approach (Lang et al., 2012; Wiek & Lang, 2016). They were conducted as part of the GLOCULL research project, an international project consortium of seven Urban Living Labs working on issues in the food-water-energy nexus funded under the JPI Urban Europe programme.

The study was designed collaboratively with Avenir after a one-year development process to identify sustainability problems that could be jointly addressed through an experimental research approach. This initial phase of problem identification involved two other local businesses – Karacho Café, another sustainable coffee shop and roastery, and Brauhaus Nolte, a sustainability-oriented craft beer brewery. All three businesses were part of the same regional economy.

The tools presented and tested empirically in this paper were co-developed during a series of workshops with members of Avenir and two other SMEs working closely with Avenir along the supply chain. In these workshops, appropriate and targeted approaches for communicating Avenir's sustainability approach were jointly identified and developed; these sought to integrate both the present scientific status quo (e.g., Weber et al., 2021) and Avenir's preferences and strategic decisions. The workshops were facilitated by researchers and a member of Avenir. Once the experiential marketing interventions had been identified and developed, we conducted an empirical study in a randomised, real-world setting (Experiment 1), and tested the same hypotheses in a controlled, virtual setting using Prolific—an online research platform with high data quality (Peer et al., 2022, see Experiment 2).

The use of these two settings allowed for comparisons between the potential effects on Avenir's regular customer base and on an anonymous group of people without prior knowledge of the café or its sustainable business model. We thereby sought to generalise the findings. The results are presented in the following sections. While the overall transdisciplinary research process was highly specific to the situation and interests of Avenir, the concrete experimental design was chosen to allow for a conceptual replication of the experimental findings across recruited participant samples and data collection modalities, with the goal of expanding our understanding of the effectiveness of experiential marketing tools (Derksen & Morawski, 2022; Hudson, 2023).

Experiment 1 – Real-Life Field Intervention

Experiment 1 empirically contrasted a control condition with three experiential marketing interventions to improve café customers' attitude regarding sustainable consumption, motivation to consume, willingness to pay, intention for action for sustainable coffee consumption, and mindful consumption. We tested our theoretical model (see Figure 1) in a multiple mediation analysis to explore *why* consumers changed their behaviour as they did.

Methods and Procedure

Study setting

Participants were customers of Avenir in Lüneburg, Germany. They were recruited on site by researchers through conversation on entering the café or whilst already seated. Data was collected over three days (Friday, Saturday, Sunday) during the café's opening hours (9am – 5pm). Participants had to be at least 18 years old and self-identify as coffee drinkers. As remuneration, participants were entered in a lottery to win one of five packs of Avenir coffee (250g), each worth €7.90.

Participants, sample size, and power analysis

We recruited a total of *N* = 231 participants. As pre-registered (https://doi.org/10.17605/OSF.IO/ACNVU)(Weber et al., 2022), we excluded outliers whose *z*-scores exceeded +/- 2.5 *SD* from the condition mean of the respective dependent variable. 28 participants were excluded due to missing answers (*n* = 2 in control, *n* = 7 in graphic novel, *n* = 8 in audio, and *n* = 10 in video condition). The total sample size was thus *N* = 204 participants (*n* = 51 for control group; *n* = 50 for novel; *n* = 53 for audio; *n* = 50 for video). An a-priori sample size analysis in G*Power 3.1 (Faul et al., 2007) had revealed that for a one-way ANOVA with four conditions, an alpha type-I error level = .05, an assumed power of 1-β = .90, and a theoretically assumed, conventionally 'moderate' effect of *f* = 0.325, a minimal total sample of *N* = 140 (*n* = 35 per condition) would be needed. The recruited sample thus yielded markedly more statistical power to find the predicted effect.

Independent variable: experiential marketing interventions

The questionnaire was conducted using the digital platform *SoSciSurvey*, which randomly assigned participants to one of the experimental conditions (i.e., drawing randomly from an array without replacement).

The no-intervention control condition comprised a conservative, strong control condition in that participants were presented with transparent information about Avenir,

featuring text about the café and its logo. The text comprised transparent information about Avenir's business concept (i.e., a collective), its supply chain activities, business partners, sustainability, and transparency aspects. The text was 295 words long. Participants read it on a tablet.

The graphic novel condition (A) featured a comic illustrating the journey of Avenir coffee from its origin (coffee farmers) to the consumer's cup. It also included transparent information about Avenir's business concept (i.e., a collective), supply chain activities, business partners, its people, sustainability aspects, and concrete numbers about the payments between producers and Avenir. The graphic novel was eight pages long. Participants read it on a tablet.

The mindful coffee journey condition (B) featured an audio that encouraged participants to drink their Avenir coffee mindfully, paying attention to their senses (smell, taste, touch). It also made participants aware of the people involved in the coffee supply chain and urged them to reflect on their role as coffee consumers. The mindful journey did *not* include any information about Avenir's business concept (i.e., a collective) or sustainability aspects. It focused on product quality, participants' senses, the supply chain, and mindfulness. Participants listened to the audio, which lasted 7:45 minutes, on a tablet with headphones.

The video condition (C) featured a promotional video of the business including short statements from Avenir team members and their business partners, and close-ups and wide-angle shots of the café and the roastery. The video included transparent information about Avenir's business concept (i.e., a collective), its supply chain activities, business partners, its people, and sustainability aspects. Participants watched the video, which lasted 2:50 minutes, on a tablet with headphones.

Dependent variables

Participants were presented with a questionnaire after completing the intervention (or reading the text in the control condition). As our key dependent variable, we

measured customers' sustainable consumption (consisting of five dimensions as detailed below), as well as four mediating variables to explain *why* the effects occur (on 7-point Likert scales). The questionnaire with verbatim items is uploaded and transparently accessible in the associated project on the *Open Science Framework* (OSF; https://doi.org/10.17605/OSF.IO/ACNVU).

Sustainable consumption. We assessed five dimensions of the participants' sustainable consumption: (1) attitude to sustainable consumption (e.g., "It is important for me that my groceries are produced under fair pay for everyone involved"; α = .84; 5 items); (2) purchase intentions (e.g., "I can imagine myself buying Avenir coffee"; α = .80; 4 items); (3) mindful consumption (building on the findings from Brombach et al. (2020)) (e.g., "I try to enjoy my coffee with all my senses"; α = .75; 6 items[1]); (4) motivation to consume sustainably (e.g., "Buying coffee at Avenir for me is primarily to acquire sustainable coffee"; α = .86; 4 items); and (5) willingness to pay (WTP) for the product (Loschelder et al., 2016). We chose an open-ended approach where WTP is elicited as a range with properly defined boundaries (Dost & Wilken, 2012; T. Wang et al., 2007, i.e., "above which price for one cup of coffee from the Avenir would you definitely not buy the product, because you don't think it was worth the money?"; and "Below which price would you say you would not buy the product because you would start to be sus-picious of its quality?"). This allows for preference uncertainties in responses (Braun et al., 2016).

Mediating variables. In addition to these measures of consumers' sustainable behaviour, we also assessed the underlying, mediating mechanisms of our theoretical model (see Figure 1) that seek to explain *why* the interventions exerted their respective effects on consumer behaviour. As the first mediating variable, we assessed participants' perceived relational proximity to Avenir (Weber et al., 2021). We used a 7-point version of the Inclusion of Other in Self (IOS) scale (Aron et al., 1992), with two circles at each point indicating a perceived degree of overlap between self and the coffee collective:

[1] One of the original 7 items (i.e., "When drinking coffee, I mainly think about the caffeine-kick") was excluded from analyses as the scale's Cronbach's alpha increased markedly from .66 to .75 without this item.

"Which picture best describes your relationship with Avenir and the people behind it?" We also used a 7-point Likert scale to assess perceived proximity expressed in three statements (e.g., "I identify with the Avenir collective"; α = .88).

As the second mediating variable, we assessed participants' perceived transparency of Avenir. In accordance with Schnackenberg et al. (2021), we asked about the three dimensions of disclosure, clarity, and accuracy using a 7-point Likert scale (e.g., "The information I receive from Avenir completely contains what I want to know"; α = .85; 4 items).

As a third mediating variable, we assessed participants' trust in Avenir, using a 7-point Likert scale building on Hustvedt and Kang (2013) and Guenzi et al. (2009) (e.g., "One can trust the Avenir collective"; α = .94; 7 items).

As the fourth and last mediating variable, we assessed participants' perceived consumer effectiveness. In accordance with Antonetti and Marklan (2014), we used a 7-point Likert scale (e.g., "When I buy products, I try to consider how it affects others and the environment"; α = .62; 4 items).

Control variables. As control variables, we assessed the degree to which participants were already familiar with Avenir, with the concept of 'alternative economy', and with the city of Lüneburg and its local economy (using the scale 1 = *not at all familiar;* 7 = *very familiar*). Finally, as demographic data, we collected participants' age, postal code, gender, highest educational degree, net monetary income per month per household, political orientation, and importance of sustainable consumption in their own life.

Results

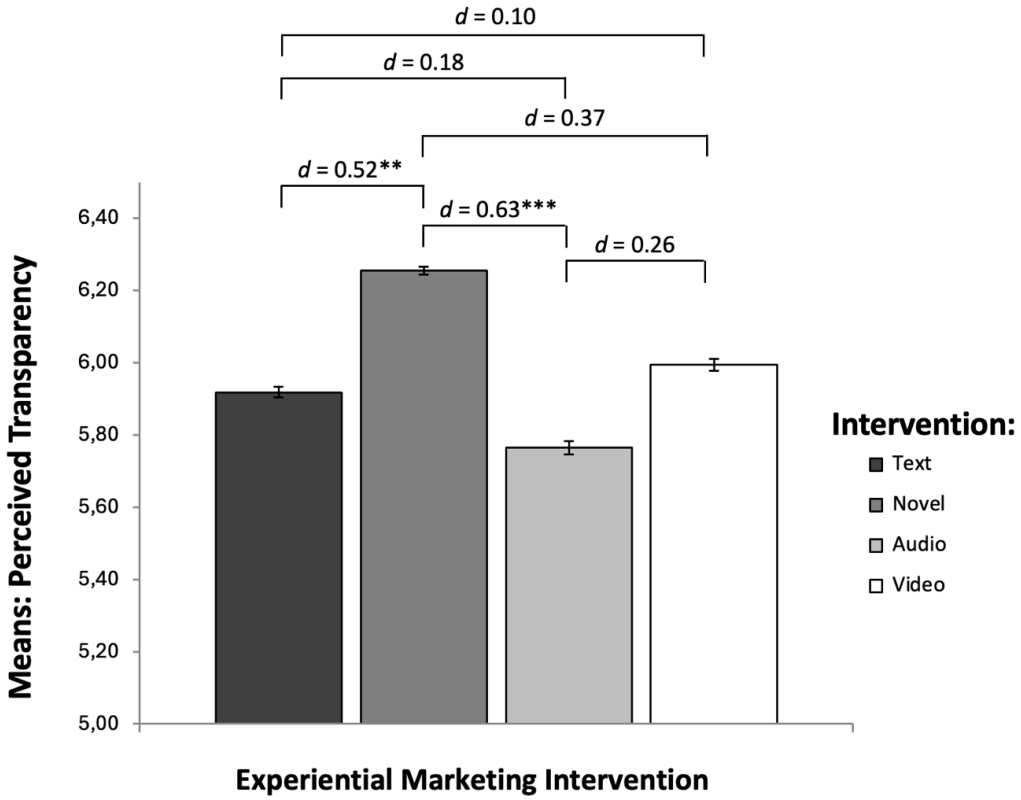
We compared all interventions against the control condition with one-way ANOVAs—first examining the four mediator variables and then focusing on the five dimensions of the participants' reported sustainable consumption behaviour.

Perceived Transparency

In accordance with our predictions (Figure 1), we found a significant main effect of the interventions on consumers' perceived transparency, $F(3, 194) = 3.51$, $p = .016$, $\eta_p^2 = .05$. We separately compared the three intervention conditions against the control

Figure 2

Perceived Transparency as a function of Experiential Marketing Interventions



Note. Error bars reflect +/- 1 SEM.

group (i.e., planned contrast analyses with -1 = control group, 1 = intervention) to explore how each intervention impacted on perceived transparency. We found significant improvements in transparency only for the graphic novel intervention, $t(90.23^2) = 2.58$, $p = .011$, $d = 0.52$ (see Figure 2). For the other interventions, no significant differences emerged.

[2] Because of variance heterogeneity, we corrected the degrees of freedom (*df*s) for this *t*-value.

Relational Proximity

For consumers' relational proximity, descriptive differences but no significant results emerged, $F(3, 194) = 2.62$, $p = .052$, $\eta_p^2 = .04$ (for details, please see SOM).

Trust

No significant effects of the interventions on consumer's trust towards Avenir emerged, $F(3, 197) = 1.50$, $p = .22$, $\eta_p^2 = .02$.

Perceived Consumer Effectiveness

Finally, no significant differences emerged for the perceived consumer effectiveness compared to the control group, $F(3, 198) = 0.53$, $p = .66$, $\eta_p^2 = .01$.

Customers' Sustainable Consumption

No significant intervention effects emerged for the customers' attitudes towards sustainable consumption, $F(3, 197) = 0.13$, $p = .94$, $\eta_p^2 < .01$, their reported purchase intentions, $F(3, 199) = 0.36$, $p = .78$, $\eta_p^2 < .01$, mindful coffee consumption, $F(3, 199) = 0.57$, $p = .64$, $\eta_p^2 = .01$, motivation to consume sustainably, $F(3, 199) = 0.56$, $p = .64$, $\eta_p^2 = .01$, maximum WTP, $F(3, 108) = 0.31$, $p = .82$, $\eta_p^2 = .01$, or their minimum WTP, $F(3, 77) = 1.60$, $p = .20$, $\eta_p^2 = .06$.

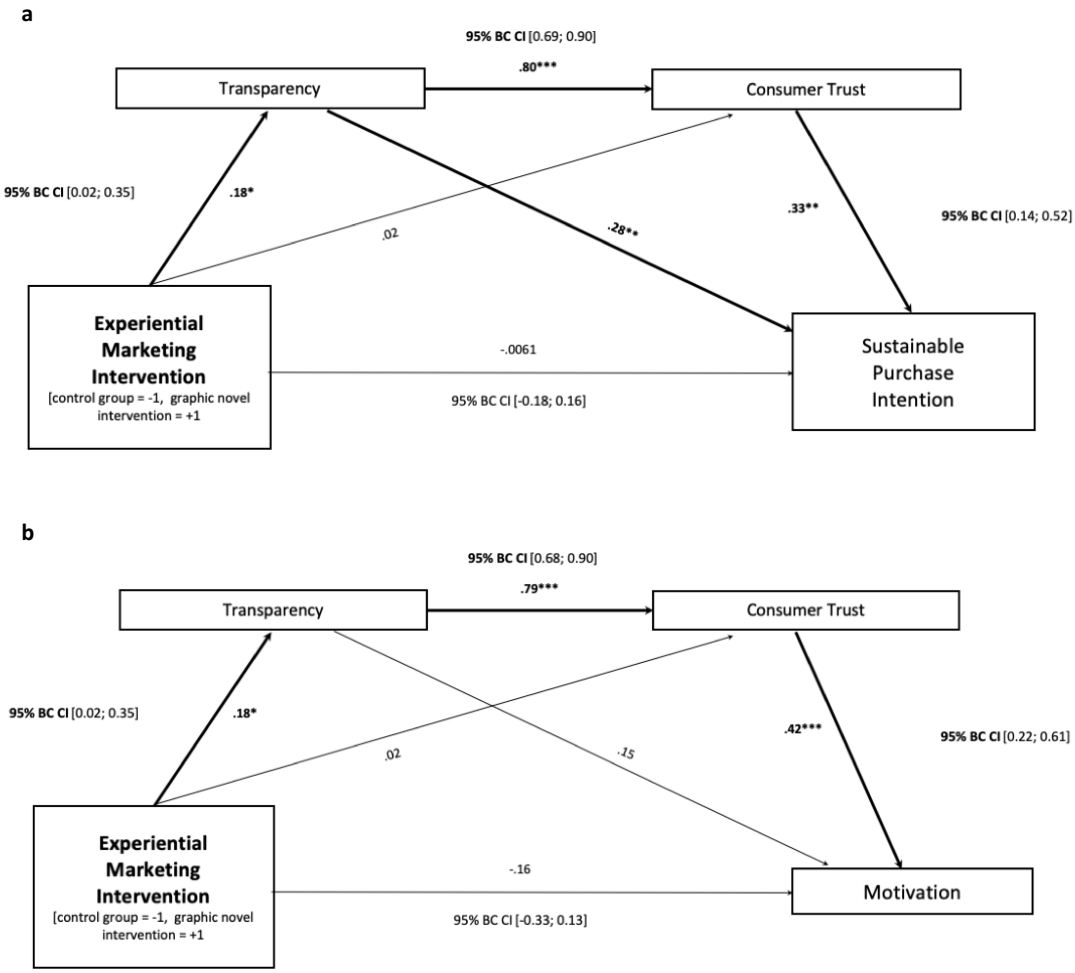
Mediation Analyses

Despite the interventions not exerting significant direct effects on the customers' sustainable consumption behaviour, we sought to expand our theoretical understanding by examining whether the underlying mediator variables (see model in Figure 1) could account for consumers' reported consumption behaviour via indirect effects. Some of these indirect effects might have cancelled each other out, thus preventing the emergence of a significant direct effect. Hence, we performed mediation analyses for indirect effects. We conducted separate mediation analyses per intervention comparing the respective intervention with the control condition (coded: -1 = control, +1 = intervention;

using 5,000 bootstrapping iterations, process macro (Hayes, 2022)). Explorative analyses yielded several significant indirect effects (model 6; Figure 3a and 3b (Hayes, 2022)). The

Figure 3

Transparency and Trust as Mediators for Sustainable Purchase Intention and Motivation



data suggest that the graphic novel intervention did evoke higher transparency perceptions of Avenir, leading to higher consumer trust and ultimately fostering higher sustainable purchase intentions (Figure 3a) and higher purchase motivation (Figure 3b). Given the overall total effect was not significant, this indicates that – although the indirect pathways were strong – other underlying mechanisms counteracted (and ultimately undermined) significant intervention effects. Further research is needed to examine these counteractive mechanisms.

Experiment 2 – A Simulated Online Replication

Experiment 2 sought to replicate Experiment 1 in a more controlled, online setting with a broader but larger sample comprising less informed participants, thus yielding higher statistical power to detect potentially smaller true effects. Additionally, we wanted to identify potential differences between consumers connected to Avenir and people with no connection. We aimed to replicate Experiment 1 by empirically contrasting a control condition with the three experiential marketing interventions—a graphic novel, an audio-guide to mindful coffee drinking, and a promotional video—to improve consumers' perceptions, purchase intentions, and willingness to pay.

Method and Procedure

Study setting

We chose to conduct Experiment 2 using the same constructs in an online environment with a larger, less informed sample yielding higher statistical power, making it more sensitive to detecting empirically smaller effect sizes. Due to reported problems and negative feedback on the audio intervention in Experiment 1 (and the evident challenges of conducting mindful coffee drinking in an online research environment), this condition was ultimately excluded from Experiment 2.

Participants, sample size, and power analysis

Participants, who were recruited via the platform Prolific, had to be at least 18 years old, speak German, be resident in Germany, and drink coffee (self-reported). Every participant received £1.65 as remuneration. Based on an a-priori G*Power sample size analysis for a one-factorial ANOVA with three experimental conditions (α =.05; power of 1-β = .90; a conventionally 'small-to-medium' effect size of f = 0.175), our target sample size was at least N = 417 participants—n = 139 per intervention and control group. Data collection was terminated after 472 participants had submitted their answers to account for potential dropout (see Experiment 1) of up to 10% compared to the a-priori power analysis. 12 participants were excluded due to missing answers (n = 2 in the control, n =

7 in the novel, and *n* = 3 in the video condition), making the total sample size *N* = 460 participants (*n* = 157 for control; *n* = 152 for novel; *n* = 151 for video). Again, as pre-registered, we excluded outliers when participants' *z*-scores exceeded +/- 2.5 *SD* from the condition mean in the respective dependent variable. As before, individuals were randomly assigned to an experimental condition via *SoSciSurvey*.

Independent and dependent variables

We used the same conservative control condition (text-based information about Avenir) as in Experiment 1, as well as the graphic novel and the video intervention. We also used the same dependent variables: participants' attitude to sustainable consumption (α = .84); their purchase intentions (α = .84); mindful consumption (α = .75[3]); motivation to consume (α = .80); and willingness to pay. To empirically test our theoretical model, we assessed the same underlying mechanisms: perceived relational proximity (α = .90); perceived transparency of Avenir (α = .71); trust in Avenir (α = .91); and perceived consumer effectiveness (α = .74). For demographic data, we again recorded participants' age, postal code, gender, highest educational degree, net monetary income per month per household, political orientation, and importance of sustainable consumption in their own life.

[3] We removed the same item as in Experiment 1 from the analyses to improve Cronbach's alpha from .69 to .75 (i.e., "When drinking coffee, I mainly think about the caffeine-kick").

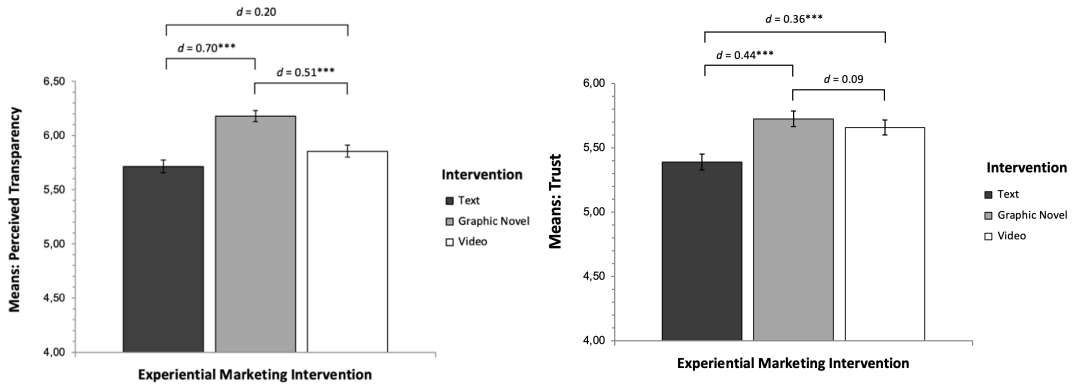
Results

Perceived Transparency and Trust

In line with our predictions (and Experiment 1), we found significant intervention effects on the consumers' perceived transparency, $F(2, 446) = 18.96$, $p < .001$, $\eta_p^2 = .08$, and their trust of Avenir, $F(2, 450) = 8.67$, $p < .001$, $\eta_p^2 = .04$ (see Figure 4). Subsequent contrast analyses (-1 = control group, +1 = intervention) again found significant improvements between the control group and the graphic novel intervention regarding consumers' perceived transparency of Avenir, $t(300.89^4) = 1.75$, $p = .017$. For the other compar-

Figure 4

Perceived Transparency and Trust as a function of Experiential Marketing Interventions



Note. Error bars reflect +/- 1 SEM.

isons, we did not find significant differences between the control and intervention conditions.

Relational Proximity and Consumer Effectiveness

The one-way ANOVA did not show differences in relational proximity, $F(2, 451) = 2.10$, $p = .12$, $\eta_p^2 = .01$.

[4] Because of violated variance homogeneity we corrected the degrees of freedom for this *t*-value.

Similarly, the perceived consumer effectiveness did not show difference as a function of experimental intervention, $F(2, 446) = 1.70$, $p = .19$, $\eta_p^2 = .01$.

Consumers' Sustainable Consumption

As in Experiment 1, no significant intervention effects emerged for the consumers' attitude towards sustainable consumption, $F(2, 446) = 0.54$, $p = .58$, $\eta_p^2 < .01$, their purchase intentions, $F(2, 448) = 0.62$, $p = .54$, $\eta_p^2 < .01$, mindful coffee consumption, $F(2, 447) = 2.40$, $p = .09$, $\eta_p^2 = .01$., motivation to consume sustainably, $F(2, 448) = 1.44$, $p = .24$, $\eta_p^2 < .01$, maximum WTP, $F(2, 291) = 0.05$, $p = .95$, $\eta_p^2 < .001$, or minimum WTP, $F(2, 223) = 0.09$, $p = .92$, $\eta_p^2 < .01$.

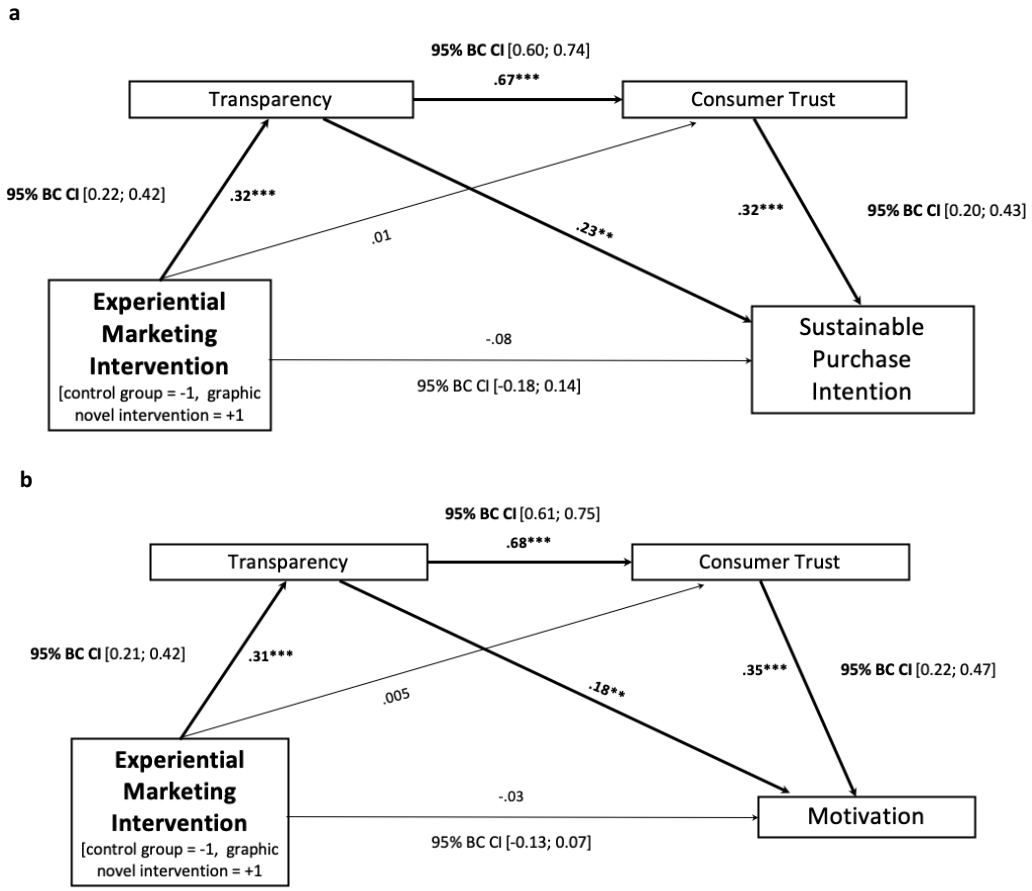
Mediation Analyses

As in Experiment 1, we performed mediation analyses to expand our theoretical understanding of how our mediating variables explain customers' sustainable consumption behaviour. We again conducted separate mediation analyses comparing the respective intervention with the control condition (-1 = control, +1 = intervention; 5,000 bootstrapping iterations, process macro; (Hayes, 2022)).

As in Experiment 1, the explorative mediation analyses showed significant indirect effects. Regarding the graphic novel intervention, we were able to fully replicate our sequential mediation findings: the intervention led to higher transparency, which in turn created more trust and ultimately fostered higher sustainable purchase intentions and higher purchase motivation (Figure 5; see Experiment 1).

Figure 5

Sequential mediation analysis for graphic novel intervention in Experiment 2

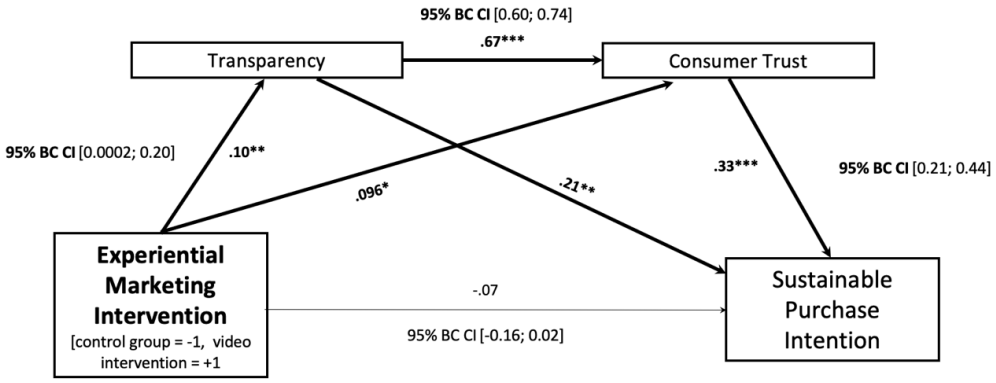


Note. The sequential indirect effects via perceived transparency and consumers' trust on sustainable purchase intentions (a) and consumer's purchase motivation (b) were both significant.

We also found significant indirect effects when comparing the promotional video intervention and the control group. As Figure 6 illustrates, the promotional video intervention fostered the consumers' perceived transparency, which in turn increased their

Figure 6

Sequential mediation analysis for video intervention in Experiment 2



trust and sustainable purchase intentions.

Discussion

Empirical Evidence for the Role of Experiential Marketing in Fostering Sustainable Consumption

This study aimed to determine how experiential marketing tools can help sustainability-oriented businesses leverage their transformative potential to foster sustainable consumption among their customers. Results from the real-world and online experiments demonstrate that experiential marketing interventions had significant effects on consumers' perceived transparency, with the graphic novel yielding particularly strong positive effects. These findings align with previous research by Weber et al. (2021) on the potential of experiential marketing to create connections between consumers and producers in sustainable food systems.

Moreover, our mediation analyses revealed that the graphic novel increased the consumers' transparency perceptions of Avenir, which indirectly increased trust and fos-

tered higher sustainable purchase intentions in both experimental settings. This relationship between transparency, trust, and sustainable consumption behaviour supports previous findings about the importance of trust in sustainability efforts and supply chain practices (Hustvedt & Kang, 2013). The results also align with research suggesting that transparency can enhance consumers' trust and perception of sustainability initiatives (Kang & Hustvedt, 2014).

The consistency of effects across the real-world and online settings is particularly noteworthy, although in an unexpected way: While our initial experimental design included the online setting primarily to increase statistical power and generalisability, the successful replication in this anonymous online environment with a broader, less informed sample arguably provides even stronger evidence for the effects of the experiential marketing tools. In the local setting, results could have been influenced by customers' existing relationship with Avenir and potential social desirability bias—i.e., participants might have responded more positively because they were physically present in the café and interacting with staff (although one could argue that this would have also elevated customers' responses in the control condition). The online setting eliminated this potential bias, as participants had no prior connection to or investment in Avenir. The fact that significant effects on transparency perceptions and mediating effects on sustainable consumption intentions were still observed suggests that these marketing tools work via their intended mechanisms—by creating a transparent understanding and trusting connection—rather than via pre-existing relationships or social pressure. The field experimental setting, however, increases the ecological validity and embeddedness of the results, meaning they are not only observed in an abstract "decontextualised" environment but with Avenir's "real customers", increasing the likelihood that insights are relevant on a generic level and have an immediate and tangible impact.

Methodological Innovation through Conceptual Replication in Sustainability Research

This study represents an innovative methodological approach to sustainability research through its use of conceptual replication and dual experimental settings. Following Hudson's (2023) framework, our study exemplifies how conceptual replication can validate specific hypotheses and corroborate underlying theoretical frameworks. We expand

Weber et al.'s (2021) experimental approach to a new context and examine novel theoretical constructs, thereby testing how and why experiential marketing interventions can foster sustainable consumption through multiple mechanisms. Specifically, our findings support theoretical frameworks linking transparency to trust and consumer engagement (Hustvedt & Kang, 2013; Kang & Hustvedt, 2014), while also validating broader theories about how businesses can serve as change agents in local economies (Leonidou et al., 2017) and engage customers as active partners in sustainability transformations (Prothero et al., 2011; White et al., 2019). On a less conceptual level we developed insights from the study of Weber et al. (2021) to create and inform concrete experiential marketing measures that Avenir could use to advance their non-commercial aim of fostering sustainability transformation.

The transdisciplinary research process was crucial for developing effective experiential marketing interventions. Our close collaboration with Avenir enabled us to create tools that represented their business model and sustainability efforts while meeting practical needs. This context-specific co-creation process resulted in interventions that proved highly effective in the local setting. However, transdisciplinary sustainability research is often criticised for the context-dependency of its findings and solutions, raising questions about broader applicability (Wiek & Lang, 2016). As Adler et al. (2018) and Wuelser et al. (2021) note, while each transdisciplinary case generates valuable context-specific knowledge, the systematic transfer of insights across cases remains a key challenge.

Our dual-setting approach—combining a real-world field experiment with a high-powered virtual, online study—offers a novel methodological solution to this challenge. While the transdisciplinary process was essential for developing realistic and effective interventions, testing these tools in an anonymous online setting allowed us to examine their effectiveness independent of local context and participants' pre-existing knowledge/expectations. This approach aligns with Ferraro and Agrawal's (2021) call for the development of robust knowledge in sustainability science through systematic experimentation and replication across contexts. We expand Weber et al.'s (2021) study by

adapting the methodology to a new context, and show how conceptual replications across recruited samples and data collection settings can facilitate knowledge transfer across transdisciplinary cases (Adler et al., 2018).

This methodological innovation addresses a fundamental challenge in sustainability science: the need to generate both context-specific solutions and broadly applicable knowledge. By combining rigorous experimental design with solution-oriented transdisciplinary research, we demonstrate how case-specific interventions can be systematically validated beyond their original context while maintaining their transformative potential. This approach responds directly to recent calls for advancing transformative transdisciplinary research (Augenstein et al., 2024) by showing how to bridge the gap between local solution development and broader knowledge generation. The replication of effects in an anonymous setting not only validates the specific interventions developed with Avenir (and particularly their underlying mechanisms) but also establishes a methodological pathway for testing and scaling sustainability solutions while maintaining scientific rigour—a key priority for the field of transformative research (Augenstein et al., 2024; Ferraro & Agrawal, 2021).

Conclusion

In this study, we tested the effect of three experiential marketing interventions on sustainable consumption behaviour in a real-world and online setting. In both settings, we found these interventions had the greatest effect on transparency and trust. We consistently found transparency and trust to be the most significant mediators.

Our findings suggest that experiential marketing tools, particularly when theoretically grounded and carefully designed, can help sustainability-oriented businesses engage consumers as partners in broader sustainability transformations. The success of the graphic novel intervention in terms of consumers' transparency perceptions indicates that businesses can effectively communicate complex sustainability initiatives while building consumer trust and engagement.

These results point to several promising research directions, including investigating how similar approaches might work in different sectors or with other sustainability initiatives. However, future research should carefully consider the balance between maintaining scientific rigour through systematic replication and adapting methods to specific contextual needs. The dual approach of this study is a promising example of how to achieve this balance.

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Competing Interests

The authors have no competing interests to declare that are relevant to the content of this article.

Generative AI Use

Generative AI tools (Claude and ChatGPT) were used for text editing and language improvement to enhance clarity and conciseness of the manuscript. All content remains the original work of the authors, who have reviewed and verified the accuracy of all materials.

Ethics Statement

This study received ethical exemption from the Research Commission of the School of Management and Technology at Leuphana University Lüneburg. The ex-

emption was granted as the research met all necessary criteria established by international guidelines (DFG, Leopoldina, GDPR, APA, AOM), including: informed consent from all participants, voluntary participation with confidentiality protections, anonymous data collection, no processing of sensitive personal data, no deception, no risk of physical or psychological distress, and participant right to withdraw data. Data collection procedures complied with EU General Data Protection Regulation (GDPR) requirements for minimal-risk survey research.

Data

The pre-registration of this study is available at:
https://doi.org/10.17605/OSF.IO/ACNVU

Data is stored openly at:
https://doi.org/10.17605/OSF.IO/FX6BM

Author Contributrions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Hanna Weber, David Loschelder, Tiberius Tóth and Philip Bernert. The first draft of the manuscript was written by Philip Bernert, Hanna Weber, Tiberius Tóth and David Loschelder and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

References

Adler, C., Hirsch Hadorn, G., Breu, T., Wiesmann, U., & Pohl, C. (2018). Conceptualizing the transfer of knowledge across cases in transdisciplinary research. *Sustainability Science*, *13*(1), 179–190. https://doi.org/10.1007/s11625-017-0444-2

Antonetti, P., & Maklan, S. (2014). Feelings that Make a Difference: How Guilt and Pride Convince Consumers of the Effectiveness of Sustainable Consumption Choices. *Journal of Business Ethics*, *124*(1), 117–134. https://doi.org/10.1007/s10551-013-1841-9

Aron, A., Aron, E. N., & Smollan, D. (1992). Inclusion of Other in the Self Scale and the Structure of Interpersonal Closeness. *Journal of Personality and Social Psychology*, *63*(4), 596–612. https://doi.org/10.1037/0022-3514.63.4.596

Augenstein, K., Lam, D. P., Horcea-Milcu, A.-I., Bernert, P., Charli-Joseph, L., Cockburn, J., Kampfmann, T., Pereira, L. M., & Sellberg, M. M. (2024). Five priorities to advance transformative transdisciplinary research. *Current Opinion in Environmental Sustainability*, *68*, 101438. https://doi.org/10.1016/j.cosust.2024.101438

Boenke, L., Panning, M., Thurow, A., Hörisch, J., & Loschelder, D. D. (2022). Who can nudge for sustainable development? How nudge source renders dynamic norms (in-)effective in eliciting sustainable behavior. *Journal of Cleaner Production*, *368*, 133246. https://doi.org/10.1016/j.jclepro.2022.133246

Brakus, J. J., Schmitt, B. H., & Zarantonello, L. (2009). Brand Experience: What Is It? How Is It Measured? Does It Affect Loyalty? *Journal of Marketing*, *73*(3), 52–68. https://doi.org/10.1509/jmkg.73.3.52

Braun, C., Rehdanz, K., & Schmidt, U. (2016). Validity of Willingness to Pay Measures under Preference Uncertainty. *PLOS ONE*, *11*(4), e0154078. https://doi.org/10.1371/journal.pone.0154078

Brombach, C., & Bergmann, K. (2020). *Wertschätzung und Mehrzahlungsbereitschaft für Lebensmittel* (Bundesverband des Deutschen Lebensmittelhandels e.V. (BVLH), Ed.). https://www.bvlh.net/fileadmin/redaktion/downloads/pdf/2020/BVLH-ZHAW_Wertschätzung-MZB_LDR_2020.pdf

Caniglia, G., Luederitz, C., von Wirth, T., Fazey, I., Martín-López, B., Hondrila, K., König, A., von Wehrden, H., Schäpke, N. A., Laubichler, M. D., & Lang, D. J. (2020). A pluralistic and integrated approach to action-oriented knowledge for sustainability. *Nature Sustainability*. https://doi.org/10.1038/s41893-020-00616-z

Caniglia, G., Schäpke, N., Lang, D. J., Abson, D. J., Luederitz, C., Wiek, A., Laubichler, M. D., Gralla, F., & von Wehrden, H. (2017). Experiments and evidence in sustainability science: A typology. *Journal of Cleaner Production*, *169*, 39–47. https://doi.org/10.1016/j.jclepro.2017.05.164

Dang, V. T., Nguyen, N., & Pervan, S. (2020). Retailer corporate social responsibility and consumer citizenship behavior: The mediating roles of perceived consumer effectiveness and consumer trust. *Journal of Retailing and Consumer Services*, *55*, 102082. https://doi.org/10.1016/j.jretconser.2020.102082

Derksen, M., & Morawski, J. (2022). Kinds of Replication: Examining the Meanings of "Conceptual Replication" and "Direct Replication." *Perspectives on Psychological Science*, *17*(5), 1490–1505. https://doi.org/10.1177/17456916211041116

Dost, F., & Wilken, R. (2012). Measuring willingness to pay as a range, revisited: When should we care? *International Journal of Research in Marketing*, *29*(2), 148–166. https://doi.org/10.1016/j.ijresmar.2011.09.003

Eiseman, D., & Jonsson, M. (2019). Leveraging the coffee experience as a tool for engagement with climate change. *Qualitative Market Research*, *22*(4), 570–581. https://doi.org/10.1108/QMR-07-2018-0084

FairFive GmbH. (2024). *Avenir Statut*. https://avenir-kaffee.de/wp-content/uploads/2022/10/Statut_Avenir-Kollektiv.pdf

Ferraro, P. J., & Agrawal, A. (2021). Synthesizing evidence in sustainability science through harmonized experiments: Community monitoring in common pool resources. *Proceedings of the National Academy of Sciences*, *118*(29), e2106489118. https://doi.org/10.1073/pnas.2106489118

Follows, S. B., & Jobber, D. (2000). Environmentally responsible purchase behaviour: A test of a consumer model. *European Journal of Marketing*, *34*(5/6), 723–746. https://doi.org/10.1108/03090560010322009

Font, X., Elgammal, I., & Lamond, I. (2017). Greenhushing: The deliberate under communicating of sustainability practices by tourism businesses. *Journal of Sustainable Tourism*, *25*(7), 1007–1023. https://doi.org/10.1080/09669582.2016.1158829

Garcia-Torres, S., Rey-Garcia, M., & Albareda-Vivo, L. (2017). Effective Disclosure in the Fast-Fashion Industry: From Sustainability Reporting to Action. *Sustainability*, *9*(12), 2256. https://doi.org/10.3390/su9122256

Geiger, S. M., Fischer, D., & Schrader, U. (2018). Measuring What Matters in Sustainable Consumption: An Integrative Framework for the Selection of Relevant Behaviors. *Sustainable Development*, *26*(1), 18–33. https://doi.org/10.1002/sd.1688

Guenzi, P., Johnson, M. D., & Castaldo, S. (2009). A comprehensive model of customer trust in two retail stores. *Journal of Service Management*, *20*(3), 290–316. https://doi.org/10.1108/09564230910964408

Gupta, S., & Sheth, J. (2024). Mindful consumption: Its conception, measurement, and implications. *Journal of the Academy of Marketing Science*, *52*(5), 1531–1549. https://doi.org/10.1007/s11747-023-00970-2

Hayes, A. F. (2022). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach* (Third edition). The Guilford Press.

Hudson, R. (2023). Explicating Exact versus Conceptual Replication. *Erkenntnis*, *88*(6), 2493–2514. https://doi.org/10.1007/s10670-021-00464-z

Hustvedt, G., & Kang, J. (2013). Consumer Perceptions of Transparency: A Scale Development and Validation. *Family and Consumer Sciences Research Journal*, *41*(3), 299–313. https://doi.org/10.1111/fcsr.12016

Ives, C. D., Abson, D. J., von Wehrden, H., Dorninger, C., Klaniecki, K., & Fischer, J. (2018). Reconnecting with nature for sustainability. *Sustainability Science*, *13*(5), 1389–1397. https://doi.org/10.1007/s11625-018-0542-9

Jansson, J., Nordlund, A., & Westin, K. (2017). Examining drivers of sustainable consumption: The influence of norms and opinion leadership on electric vehicle adoption in Sweden. *Journal of Cleaner Production*, *154*, 176–187. https://doi.org/10.1016/j.jclepro.2017.03.186

Kang, J., & Hustvedt, G. (2014). Building Trust Between Consumers and Corporations: The Role of Consumer Perceptions of Transparency and Social Responsibility. *Journal of Business Ethics*, *125*(2), 253–265. https://doi.org/10.1007/s10551-013-1916-7

Kang, J., Liu, C., & Kim, S.-H. (2013). Environmentally sustainable textile and apparel consumption: The role of consumer knowledge, perceived consumer effectiveness and perceived personal relevance: Environmentally sustainable textile and apparel consumption. *International Journal of Consumer Studies*, *37*(4), 442–452. https://doi.org/10.1111/ijcs.12013

Klewitz, J., & Hansen, E. G. (2014). Sustainability-oriented innovation of SMEs: A systematic review. *Journal of Cleaner Production*, *65*, 57–75. https://doi.org/10.1016/j.jclepro.2013.07.017

Kraft, T., Valdés, L., & Zheng, Y. (2022). Consumer trust in social responsibility communications: The role of supply chain visibility. *Production and Operations Management*, *31*(11), 4113–4130. https://doi.org/10.1111/poms.13808

Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., & Thomas, C. J. (2012). Transdisciplinary research in sustainability science: Practice, principles, and challenges. *Sustainability Science*, *7*(S1), 25–43. https://doi.org/10.1007/s11625-011-0149-x

Leire, C., & Thidell, A. (2005). Product-related environmental information to guide consumer purchases—A review and analysis of research on perceptions, understanding and use among Nordic consumers. *Journal of Cleaner Production*, *13*(10–11), 1061–1070. https://doi.org/10.1016/j.jclepro.2004.12.004

Leonidou, L. C., Christodoulides, P., Kyrgidou, L. P., & Palihawadana, D. (2017). Internal Drivers and Performance Consequences of Small Firm Green Business Strategy: The Moderating Role of External Forces. *Journal of Business Ethics*, *140*(3), 585–606. https://doi.org/10.1007/s10551-015-2670-9

Loschelder, D. D., Friese, M., Schaerer, M., & Galinsky, A. D. (2016). The too-much-precision effect: When and why precise anchors backfire with experts. *Psychological Science*, *27*(12), 1573–1587. https://doi.org/10.1177/0956797616666074

Loschelder, D. D., Siepelmeyer, H., Fischer, D., & Rubel, J. A. (2019). Dynamic norms drive sustainable consumption: Norm-based nudging helps café customers to avoid disposable to-go-cups. *Journal of Economic Psychology*, *75*, 102146. https://doi.org/10.1016/j.joep.2019.02.002

Lüdeke-Freund, F., & Dembek, K. (2017). Sustainable business model research and practice: Emerging field or passing fancy? *Journal of Cleaner Production*, *168*, 1668–1678. https://doi.org/10.1016/j.jclepro.2017.08.093

O'Brien, K. (2013). Global environmental change III: Closing the gap between knowledge and action. *Progress in Human Geography*, *37*(4), 587–596. https://doi.org/10.1177/0309132512469589

Parodi, O., Ober, S., Lang, D. J., & Albiez, M. (2024). Reallabor versus Realexperiment: Was macht den Unterschied? *GAIA - Ecological Perspectives for Science and Society*, *33*(2), 216–221. https://doi.org/10.14512/gaia.33.2.4

Peer, E., Rothschild, D., Gordon, A., Evernden, Z., & Damer, E. (2022). Data quality of platforms and panels for online behavioral research. *Behavior Research Methods*, *54*(4), 1643–1662. https://doi.org/10.3758/s13428-021-01694-3

Prothero, A., Dobscha, S., Freund, J., Kilbourne, W. E., Luchs, M. G., Ozanne, L. K., & Thøgersen, J. (2011). Sustainable Consumption: Opportunities for Consumer Research and Public Policy. *Journal of Public Policy & Marketing*, *30*(1), 31–38. https://doi.org/10.1509/jppm.30.1.31

Schäfer, N. (2022). Making transparency transparent: A systematic literature review to define and frame supply chain transparency in the context of sustainability. *Management Review Quarterly*, *73*(2), 579–604. https://doi.org/10.1007/s11301-021-00252-7

Schnackenberg, A. K., Tomlinson, E., & Coen, C. (2021). The dimensional structure of transparency: A construct validation of transparency as disclosure, clarity, and accuracy in organizations. *Human Relations*, *74*(10), 1628–1660. https://doi.org/10.1177/0018726720933317

Vlasceanu, M., Doell, K. C., Bak-Coleman, J. B., Todorova, B., Berkebile-Weinberg, M. M., Grayson, S. J., Patel, Y., Goldwert, D., Pei, Y., Chakroff, A., Pronizius, E., Van Den Broek, K. L., Vlasceanu, D., Constantino, S., Morais, M. J., Schumann, P., Rathje, S., Fang, K., Aglioti, S. M., … Van Bavel, J. J. (2024). Addressing climate change with behavioral science: A global intervention tournament in 63 countries. *Science Advances*, *10*(6), eadj5778. https://doi.org/10.1126/sciadv.adj5778

Wang, J., Nguyen, N., & Bu, X. (2020). Exploring the Roles of Green Food Consumption and Social Trust in the Relationship between Perceived Consumer Effectiveness and Psychological Wellbeing. *Int. J. Environ. Res. Public Health*.

Wang, T., Venkatesh, R., & Chatterjee, R. (2007). Reservation Price as a Range: An Incentive-Compatible Measurement Approach. *Journal of Marketing Research*, *44*(2), 200–213. https://doi.org/10.1509/jmkr.44.2.200

Weber, H., Lang, D. J., Loschelder, D. D., & Bernert, P. (2022). *Advancing sustainability/ sustainable consumption in the local food economy through experiential marketing: An intervention study with a coffee roaster in Germany*. OSF Registries. https://doi.org/10.17605/OSF.IO/ACNVU

Weber, H., Loschelder, D. D., Lang, D. J., & Wiek, A. (2021). Connecting consumers to producers to foster sustainable consumption in international coffee supply – a marketing intervention study. *Journal of Marketing Management*, *37*(11–12), 1148–1168. https://doi.org/10.1080/0267257X.2021.1897650

Weber, H., Wiek, A., & Lang, D. J. (2020). Sustainability entrepreneurship to address large distances in international food supply. *Business Strategy and Development*, *3*(3), 318–331. https://doi.org/10.1002/bsd2.97

Wesley, S. C., Lee, M.-Y., & Kim, E. Y. (2012). The Role of Perceived Consumer Effectiveness and Motivational Attitude on Socially Responsible Purchasing Behavior in South Korea. *Journal of Global Marketing*, *25*(1), 29–44. https://doi.org/10.1080/08911762.2012.697383

White, K., Habib, R., & Hardisty, D. J. (2019). How to SHIFT consumer behaviors to be more sustainable: A literature review and guiding framework. *Journal of Marketing*, *83*(3), 22–49. https://doi.org/10.1177/0022242919825649

Wiebe, J., Basil, D. Z., & Runté, M. (2017). Psychological distance and perceived consumer effectiveness in a cause-related marketing context. *International Review on Public and Nonprofit Marketing*, *14*(2), 197–215. https://doi.org/10.1007/s12208-016-0170-y

Wiek, A., & Lang, D. J. (2016). Transformational Sustainability Research Methodology. In H. Heinrichs, P. Martens, G. Michelsen, & A. Wiek (Eds.), *Sustainability Science* (pp. 31–41). Springer Netherlands. https://doi.org/10.1007/978-94-017-7242-6_3

Wuelser, G., Adler, C., Breu, T., Hirsch Hadorn, G., Wiesmann, U., & Pohl, C. (2021). On which common ground to build? Transferable knowledge across cases in transdisciplinary sustainability research. *Sustainability Science*, *16*(6), 1891–1905. https://doi.org/10/gmgfkr

4.3 Paper 3: Impacts beyond experimentation

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Impacts beyond experimentation – Conceptualising emergent impacts from long-term real-world laboratory processes

Real-world laboratories are settings for joint experimentation on sustainability challenges, through the transdisciplinary collaboration of diverse actor groups. By approaching a real-world laboratory from three perspectives, this paper uncovers the emergent impacts of a long-term collaborative process.

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Abstract
Real-world laboratories have become a recognised research format for addressing sustainability challenges. In these transdisciplinary settings, actors from civil society, local government, and academia work together using a transdisciplinary research approach to jointly experiment and learn about sustainability transformations. While these labs are considered to have potential, their impact has not yet been fully measured. Therefore, in our paper we explore the case of the *Zukunftsstadt Lüneburg 2030+* process to uncover the impacts that this long-term effort has generated over the past eight years. By examining the process and its design features from three analytical perspectives, we identify emergent impacts in three dimensions: education, governance, and the lab as an actor for sustainability. Based on our case study, we suggest that real-world labs contribute to sustainability on a local level, beyond the intentional experiments, through impacts that emerge over the course of the joint operation of the lab.

Keywords
emergent impact, process design, real-world laboratory, transdisciplinary sustainability research, transformative research

Real-world laboratories (RwLs) are widely recognised and established as settings for collaborative and transdisciplinary research (Bergmann et al. 2021, Kanning et al. 2021, Parodi et al. 2021, Schäpke et al. 2018, Schneidewind et al. 2018). They are characterised by their orientation towards sustainability, and their long-term, transdisciplinary mode of collaboration, which provides a setting for the exploration of sustainability transformations through experimentation (Schäpke et al. 2018, McCrory et al. 2020). As settings in which different actors from science and society come together to collaborate, RwLs have been associated with a variety of benefits (Kok et al. 2023, Pärli et al. 2022). However, we view the discussion around the impacts of such research projects as being centred around the idea of an impact resulting directly from an intervention – as in the case of real-world experiments. While this perspective may be appropriate for real-world experiments, where the goal is to find causal links between interventions or sustainability solutions and outcomes, it is not necessarily suitable for assessing the impact of RwLs. Although there is a body of research into approaches for assessing the impacts of real-world experiments (e. g., Luederitz et al. 2017, Williams and Robinson 2020), the impacts generated as part of the collaborative RwL processes have not been studied in the same way.

In an attempt to fill this research gap, we suggest a revised approach for assessing RwL impacts based on our experiences in designing and participating in an eight-year RwL process in the city of Lüneburg. This approach is intended to complement the prevalent framing and understanding of impact, and to high-

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TABLE 1: Three analytical perspectives for assessing the impacts of the real-world laboratory (RwL) *Zukunftsstadt Lüneburg 2023+*. The analytical perspectives result from eight categories of impact[a] suggested by Schäfer et al. (2021) and from the benefits of RwLs, as proposed in the literature.

CATEGORIES OF IMPACT	PROPOSED BENEFITS OF RWLS	ANALYTICAL PERSPECTIVES FOR ASSESSING THE RWL PROCESS
learning and capacity building	RwLs as places to facilitate learning (Singer-Brodowski et al. 2018, Beecroft 2018)	**focus on educational features**
■ network formation ■ influence on law and regulations ■ further structural effects	RwLs as places to establish inter-institutional collaborations (Marquardt 2019, Libbe and Marg 2021, Marg et al. 2019)	**focus on collaborative governance features**
■ increase in reputation ■ continuation of activities in the project context ■ new concepts ■ influence on public discourse	interactions and roles in transdisciplinary sustainability research, such as RwLs (Wittmayer and Schäpke 2014, Hilger et al. 2021)	**focus on public interaction features**

[a] Two of the ten impact categories from Schäfer et al. (2021) are only relevant at the level of experiments or interventions and are therefore not applicable at the RwL level. As such, the following two categories have been removed from our investigation: 1. improving the situation; and 2. transfer to other spatial contexts.

light its specific meaning in the context of long-term collaborative RwL processes. We start with the observation that the joint process of operating an RwL comprises many different iterative design features, such as activities, events, features, and actions, all of which follow their own purpose and achieve their own outcomes. Going beyond this, however, we are suggesting that the greater impact that these collaborative processes (and all their elements) make is better understood when approached as emergent; namely as an impact achieved through the combination and interplay of many individual design features and actions.

We aim to address the following research question: what impacts emerge from RwL processes? To investigate this question, we present the case of the RwL *Zukunftsstadt Lüneburg 2030+*, an RwL established in the city of Lüneburg by members of Leuphana University Lüneburg, the local city administration, and actors from civil society. The RwL was initiated in 2015, as part of the *Zukunftsstadt* funding programme[1] of the German Federal Ministry of Education and Research (BMBF), and was developed over three project phases: 1. a joint sustainability visioning process; 2. the collaborative development of solution ideas; and 3. the experimentation in an RwL setting.

We approach the lab process from three perspectives: 1. the lab as a space for learning and education; 2. the lab as a space for new governance structures; and 3. the lab as a public actor for sustainability, all of which we investigate as dimensions of potential impact. Through our approach, we identify and describe impacts that the joint work of the RwL has created in the Lüneburg context. We offer a novel perspective that complements the understanding of impacts as direct or indirect effects of intentional interventions. We conceptualise the impacts achieved in our RwL as emerging from different design features and their complex interplay as developed and implemented during the RwL process.

1 *www.fona.de/de/massnahmen/foerdermassnahmen/wettbewerb-zukunftsstadt.php*

Approaching the impacts of real-world labs

The impacts of RwL processes are not easily identified. RwL processes are typically designed collaboratively, and they evolve over the course of their duration, adapting new goals, trying and failing with different actions and design features (Bergmann et al. 2021). Moreover, the many and diverse features of an RwL process are not all selected and implemented in pursuit of a larger impact goal. In many cases, the RwL adapts to the needs of the actors involved at any given point in the process. Consequently, a pre-post evaluative methodology is in many cases neither suitable, nor possible (Walter et al. 2007).

Therefore, our analytical approach integrates a number of theoretical understandings to approach these impacts (figure 1, p. 20). First, we adopt the understanding of transdisciplinary research impacts by Schäfer et al. (2021), as well as the proposed benefits of RwLs as discussed in the recent literature (McCrory et al. 2020, Schäpke et al. 2018, Singer-Brodowski et al. 2018). Further, we adopt the analytical understanding by Wiek et al. (2014a). This approach recognises collaborative processes as drivers of impacts and aims to attribute these impacts to the participatory events of a given process. Integrating these understandings enables us to conceptualise the impacts that have emerged over the course of the long-term RwL process *Zukunftsstadt Lüneburg 2030+*.

In our case study, we present exemplary lab features as identified by the research team through joint reflection, building on the experiences from the research process, as well as synthesising available case data from the project documentation and communications throughout. To focus our investigation on the lab process, we disambiguate the lab process and the experiment following the approaches of Kampfmann et al. (2022) and Bernert et al. (2023): they view "experiments" as processes closely linked to the concept realisation of interventions, whereas "lab" describes the broader collaborative process that forms the conceptual context within which experiments are conducted. >

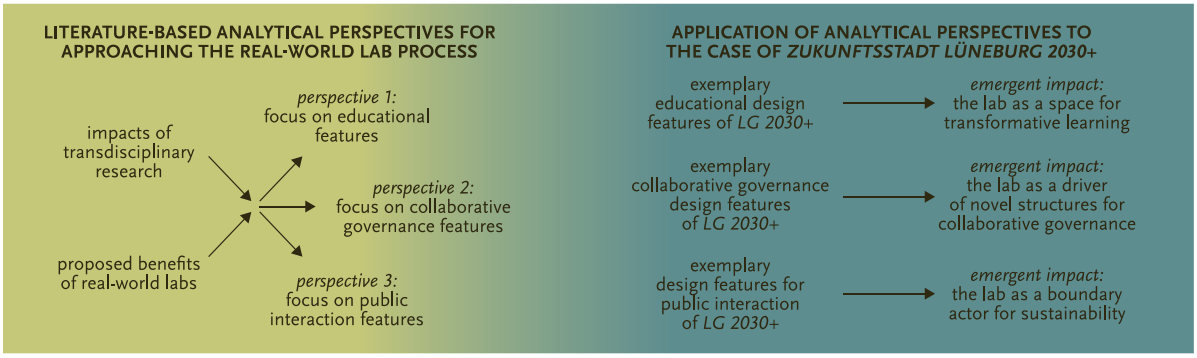

FIGURE 1: The research approach for uncovering and conceptualising impacts from the real-world lab process of *Zukunftsstadt Lüneburg 2030+* in Lüneburg, Germany. The perspectives are derived from the literature and then applied to our case to identify emergent impacts of the long-term process.

Societal impacts of transdisciplinary research: Three analytical perspectives for investigating real-world lab processes

Previous analytical papers on RwLs have focused on aspects such as the role of structuration (Schneidewind et al. 2018) or success factors (Bergmann et al. 2021), but they have not attempted to evaluate the impacts generated by operating a lab. Therefore, we base our understanding of such impacts, and their appraisal, on a number of approaches that have been put forward in the context of transdisciplinary and transformative research (e. g., Lux et al. 2019, Schäfer et al. 2021). Schäfer et al. (2021) systematise categories for approaching the societal effects of transdisciplinary research that can be differentiated as first, second, and third order effects depending on how closely the observed effects may be linked to the project under investigation. From this set of categories, eight are particularly suitable for assessing the impacts of the RwL itself (as opposed to the experiment level). Summarising these categories into three analytical perspectives enables us to describe the impacts of the *Zukunftsstadt Lüneburg 2030+* RwL (table 1, p. 19).

As shown (table 1), the impacts of transdisciplinary research identified by Schäfer et al. (2021) are matched with literature on the proposed benefits and qualities of RwLs to form the three perspectives on which we base our investigation. These benefits cover the notion that RwLs are spaces that facilitate different types of learning, which might "profit from a differentiated educational perspective for their methodological development, by systematically including learning as a characteristic of their design" (Singer-Brodowski et al. 2018). Moreover, RwLs create contexts in which governance arrangements (in the sense of inter-institutional collaborations between state and non-state actors) are established (Marquardt 2019) to foster societal problem-solving (Wolfram et al. 2019). By institutionalising transdisciplinary research in local contexts, the actors within RwLs may also represent diverse roles associated with this mode of research (Wittmayer and Schäpke 2014, Hilger et al. 2021).

Table 1 summarises our identification of the three analytical perspectives that stem from the impact categories by Schäfer et al. (2021) and the proposed benefits of RwLs. We focus our investigation of the *Zukunftsstadt Lüneburg 2030+* RwL process through the lens of these perspectives. In the following case study section (box 1, p. 21), we identify three exemplary process features for each of the perspectives. These features are then used as a reference for the emergent impacts that we conceptualise in each of the three perspectives.

Case study: Uncovering emergent impacts through three perspectives

In the following sections, we approach the *Zukunftsstadt Lüneburg 2030+* RwL process through the three perspectives as outlined above. We briefly introduce these perspectives, drawing on the RwL literature, and the impact categories suggested by Schäfer et al. (2021). We then reconstruct the process by presenting exemplary design elements. From these design elements and their individual contributions, we then abstract and conceptualise the related emergent impacts.

Perspective 1: Educational features of the lab process

The RwL process of *Zukunftsstadt Lüneburg 2030+* is characterised by the *close connection of activities in the lab with teaching and learning at the local university*. This aspect was central throughout the three project phases, and it unfolded in diverse ways, as demonstrated by the *inclusion of many educational features throughout the lab's process*. We present and describe three such features in the table below (table 2, p. 21).

Emergent impact 1: The real-world lab as a novel space for transdisciplinary and transformative education and learning.

The experiences undergone in the *Zukunftsstadt Lüneburg 2030+* RwL address several levels of learning within RwLs, as conceptualised by Singer-Brodowski et al. (2018). The long process (over many years) leading to the creation of the *Zukunftsstadt Lüneburg 2030+* RwL opened up a window of opportunity for the development of students' individual competences (i. e., system and anticipatory thinking), which was strongly fostered through ex-

BOX 1: The *Zukunftsstadt Lüneburg 2030+* real-world laboratory (RwL)

Lüneburg is a medium-sized town of about 80,000 residents, located within the Hamburg metropolitan area. The *Zukunftsstadt Lüneburg 2030+* RwL was established as a result of a long-standing and continuously evolving collaboration between actors from the city administration, the civil society, and the university (Bernert et al. 2016). Due to the logic of its public funding line, the RwL consisted of three subsequent phases: 1. from 2015 to 2016, a large-scale visioning process for a sustainable city in the year 2030 and beyond; 2. from 2017 to 2018, the participatory and transdisciplinary development of 17 sustainability solution strategies; 3. from 2019 to 2023, the realization of 15 real-world experiments building on the solution strategies. As of 2019, the process was closely linked to, and officially intertwined with, the formation of a city-wide integrated development concept (ISEK), initiated by the city council of Lüneburg[a] (Hansestadt Lüneburg 2019).

Despite its inherently open and evolving character, the *Zukunftsstadt Lüneburg 2030+* RwL was designed along general principles, including a strong sustainability orientation due to the framing of the project as a local implementation and interpretation of the *Sustainable Development Goals*. The establishment of a steering group, tasked with democratically making all the basic project decisions, was a key feature of the overall project design. The steering group consisted of members from the city administration, the university, and the civil society.

The collaborative process of *Zukunftsstadt Lüneburg 2030+* in all three project phases combined open work phases in different group constellations (e. g., sharing visions for the future in student-stakeholder teams), as well as work steered and conducted by the project team (e. g., to integrate interim results). Each phase ended with a large-scale participatory event (the so-called *Zukunftstadt-Tag*). Students from the local university were closely involved in all the stages, and they contributed their own perspectives from their studies in different areas. In parallel to the project, a case study office was installed to support the students' research and the teaching endeavours (Kirst et al. forthcoming).

The 15 real-world experiments conducted in the third phase were designed to address a variety of sustainability issues in the city, such as sustainable logistics and mobility in the local economy, youth participation for sustainability, supporting biodiversity efforts of civil society initiatives, or the sustainable design of public spaces.

[a] Christ et al. (2024, in this issue) present an evaluation of another long-term urban RwL in Flensburg, Germany.

perience-based (Caniglia et al. 2016) and project-based (Wiek et al. 2014b) teaching and learning settings. This also facilitated social learning processes that supported collective meaning-making and reflexivity (Singer-Brodowski et al. 2018). The normative orientation created learning opportunities for both students and other actors in the project, in the sense of individual learning (e. g., normative thinking), as well as social learning (as it potentially led to a higher level of reflexivity) and the capability to jointly deal with mistakes in an iterative collaborative process (Singer-Brodowski et al. 2018). The strong focus on linking the RwL with teaching activities at the local university was a key design feature in this respect, and one that led to emergent impacts in both directions within the educational-research sphere. The RwL created a fruitful learning environment for the students in- >

TABLE 2: Exemplary educational design features of the real-world lab (RwL) process for *Zukunftsstadt Lüneburg 2030+*.

DESIGN FEATURES	DESCRIPTION	DIRECT OUTCOMES	LITERATURE[a]
higher education teaching continuously embedded in the project	■ continuous student involvement based on inter- and transdisciplinary study model ■ experience-based teaching alongside real-world developments in the RwL (e. g., co-developing sustainability visions; supporting the realisation of experiments)	■ >1500 students of all levels were involved in project-related teaching ■ many results are documented in a case study database	Barth et al. 2017, Weiser et al. 2023
development of new teaching formats relating to the RwL	■ lab as context for the development of new teaching formats, in established curricula and new learning modules (e. g., the *Transformative Innovation Lab*)	■ new teaching models and seminar designs deeply involving students in lab and experiments ■ principles for the design of transformative teaching	Bernert et al. 2022, Wanner et al. 2021, 2020
capacity-building around sustainability as a reoccurring lab activity	■ capacity-building for sustainability among the core project members and with external actors and visitors ■ continuous reflection of sustainability understandings in context of current developments in Lüneburg (e. g., COVID-19 pandemic) ■ regular visits from researchers (e. g., tdAcademy; PostDoc Academy, international consortia) as capacity-building formats and to support reflexivity within the project team	■ capacity-building with three cohorts of 20 participants each in the Postdoc Academy ■ adaptable teaching materials as introductions to the RwL approach within the project	Postdoc Academy for Transformational Leadership[b]

[a] Further readings and project-related sources related to the design feature. | [b] *www.bosch-stiftung.de/en/project/postdoc-academy-transformational-leadership*

volved, while the students' activities also helped to support and advance the RwL itself. At times, these activities developed their very own dynamic that contributed to social learning processes far beyond the classroom. In this way, the RwL established a space for fostering transformative transdisciplinary learning and further developing teaching approaches.

Perspective 2: Design features fostering collaborative governance

The RwL process of *Zukunftsstadt Lüneburg 2030+* is characterised by *close collaboration between members of the city administration, the civil society, and the university*. This aspect was central throughout the three project phases and unfolded in diverse ways (table 3). Together, these developments have created an emergent impact that can be conceptualised as establishing the *Zukunftsstadt Lüneburg 2030+* RwL as a *novel institutionalised form of collaborative governance* (for sustainability) in its surrounding local context.

Emergent impact 2: The real-world lab as a driver of novel structures for collaborative governance

While the collaboration between the civil society, the city administration, and the university has a long-standing history in the city of Lüneburg, the RWL process of the *Zukunftsstadt Lüneburg 2030+* has institutionalised and deepened this mode of joint collaborative governance. The RwL has helped to establish both formal and informal networks between state and non-state actors, as well as fostering political plans and structural changes. *Zukunftsstadt Lüneburg 2030+* can be seen as a context in which urban stakeholders could expand their capacities for advocating for urban sustainable development in the future. Through their engagement in the RwL process, members of Lüneburg's city administration were able to gain experience in the fields of inclusive, multiform, urban governance, as well as creating visions for the future and experimenting with sustainability solutions. Both are crucial components of the urban transformative capacity framework (Wolfram et al. 2019, Castán Broto et al. 2019). The *Zukunftsstadt Lüneburg 2030+* RwL created impact through forming, as well as consolidating, urban transformative capacity, which in turn led to the creation of informal networks, influenced political agendas, and altered the formal structures for fostering sustainability and citizen engagement.

Perspective 3: Design features for public interaction

The RwL process of *Zukunftsstadt Lüneburg 2030+* is characterised by the *close involvement of Lüneburg residents* throughout the three project phases. This involvement was enabled through many design features, which unfolded in a variety of ways. These are presented in this section (table 4, p. 23). Together, these developments created impacts that can be conceptualised as establishing the *Zukunftsstadt Lüneburg 2030+* RwL as a *novel boundary actor for sustainability in its local context.*

Emergent impact 3: The real-world lab as a boundary actor for sustainability

Due to its implementation of diverse activities with a strong focus on public involvement in the context of sustainability questions, we argue that the RwL gained the role of a public boundary actor for sustainability during the project. As a boundary actor, the lab was able to foster active networking among local actors and support numerous sustainability-oriented initiatives by civil society actors, as well as local businesses. By facilitating (and occasionally mediating) the public exchange on sustainability issues, the lab acted as a hub to connect actors with administrative representatives, researchers, and other actors and initiatives. Complementing the efforts of a diverse landscape of sustainability initiatives, the lab institutionalised many of the roles attributed to transdisciplinary researchers (Wittmayer and Schäpke 2014, Hilger et al. 2021).

TABLE 3: Exemplary design features of the *Zukunftsstadt Lüneburg 2030+* real-world lab (RwL) process fostering collaborative governance.

DESIGN FEATURES	DESCRIPTION	DIRECT OUTCOMES	LITERATURE[a]
joint leadership of the RwL process	the RwL process is carried out by the city administration, the university, and local civil society	decisions on structural changes in the city administration were discursively linked to the RwL process	Purschwitz 2023
biannual advisory board meetings	■ the RwL board consisted of members of political parties on the city council, interest groups, and university representatives ■ RwL experiments and further work were discussed at meetings	transdisciplinary working approach and group composition were transferred to a novel project focusing on a resilient city centre	Hansestadt Lüneburg 2021
connected to the Integrated Urban Development Process (ISEK)	RwL and ISEK processes were intentionally linked to each other (e.g., represented in one brand)	■ learning from evaluations of the events held during the RwL process ■ ISEK events were located in isolated city districts to gather the opinions of residents from those areas	Hansestadt Lüneburg 2019

[a] Further readings and project-related sources related to the design feature.

TABLE 4: Exemplary design features of the *Zukunftsstadt Lüneburg 2030+* real-world lab (RwL) process for public interaction.

DESIGN FEATURES	DESCRIPTION	DIRECT OUTCOMES	LITERATURE[a]
large-scale public events	■ large public events (e. g., *Zukunftsstadttage*) during all project phases to educate about the project and invite actors to participate ■ during the COVID pandemic, *Zukunftsstadt-magazine:* broadcast events involving experts and local representatives discussing sustainability in Lüneburg and beyond	■ different event formats have reached up to 2,000 people ■ the opening day of the third phase was attended by 300 to 400 people	*Zukunftsstadt-magazine* avalaible on *www.youtube.com/@Leuphana*
RwL as a service agency	■ both steering committee and lab activities were designed to be open to citizens and actors interested in collaborations ■ RwL promoted direct connections with local actors and occupied a central position between the actor groups, the city administration, and the university ■ realisation of this role was supported through formats such as open-office days	■ support for new alliances and initiatives (e. g., *Tauschregal*, setting up open exchange shelves for unused goods) ■ recognition of *Zukunftsstadt* as a strong local actor	internal meeting minutes
continuous information about the project's sustainability activities and cooperation with other actors	■ regular information through newsletters and monthly pages in the local newspaper, *Landeszeitung*, to report on project activities and sustainability initiatives in Lüneburg ■ creation of the shared brand *Lüneburg. Die Zukunftsstadt.* for the RwL and ISEK process ■ social media presence on Instagram to inform about the project's progress and activities in Lüneburg	■ continuous information of general public about sustainability activities using diverse channels of communication (e. g., newspaper with a circulation of over 20,000, Instagram page with over 1,500 followers)	Purschwitz 2023

[a] Further readings and project-related sources related to the design feature.

Towards an understanding of emergent impacts of real-world labs

In our case study, we identified several impacts of a long-term RwL process. By reflecting on the eight-year process of the *Zukunftsstadt Lüneburg 2030+* project, we uncovered and conceptualised the impacts in three dimensions.

1 ***Emergence as an inherent quality of the impacts of collaborative processes.*** The impacts we identified, while not accidental, were not planned for at the beginning of the process and were not achieved due to a specific experiment or intervention. Instead, they emerged from a continuous, collaborative process between the city administration, the civil society, and Leuphana University Lüneburg. All of these participants brought their interests, motivations, and capacities to the process of jointly operating a lab that aimed to contribute to a local sustainability transformation. As we have illustrated in our case study, the process of operating a lab comprises many diverse and small-scale design elements that together build the long-term complex process that is *Zukunftsstadt Lüneburg 2030+*.

However, approaching these single design elements from a cause-and-effect perspective would not enable a reflection of these larger impacts that are, in our view, crucial for answering the question: "Why use RwLs?". We are aware that the conceptual impact understanding we offer may not meet the desire to quantify the impacts of RwL research. Explicitly recognising emergent impacts may, however, serve to complement such a perspective, providing a space to reflect upon "success" (in the sense of local contributions and transformative change enabled through its operation) and the transferability of process features. Furthermore, the recognition of RwL impacts beyond the experiment supports their further development as institutions that are not just experimental extensions of transdisciplinarity, or spaces for innovation testing (Parodi 2019).

2 ***Using an emergent impact understanding in RwL design.*** Future labs may use descriptions of emergent impacts from other labs, not to rebuild the exact same process, but to formulate more differentiated understandings of desired impacts. This could support a deeper shared understanding of the interests, perspectives, and capacities present among actors in the lab to develop a more future-oriented guiding perspective. Thus, while the impacts at the lab level may remain difficult to grasp from a cause-and-effect perspective, the practice of describing and conceptualising these impacts may make them more tangible. This could serve to better align certain design choices with, on the one hand, day-to-day realities (e. g., semester planning, "Vereinsarbeit" or voluntary work, the daily tasks of a city administration) and, on the other hand, with the overall objectives of the RwL. >

While the impacts that have emerged from the *Zukunftsstadt Lüneburg 2030+* case are strongly intertwined with the local context, we argue that the dimensions in which these impacts lie – labs as spaces of transformative learning, labs as collaborative governance arrangements, and labs as boundary actors – are also relevant for better understanding the value and contribution of RwL processes in other contexts. Moreover, by presenting the design features in addition to the emergent impacts, we have also aimed to provide insights regarding the "knowledge how" (Caniglia et al. 2020).

3 ***Developing new methods for impact assessment.*** The methods for capturing and conceptualising emergent impacts of RwLs need to be further refined and integrated with similar approaches (Marg et al. 2019, Schäfer et al. 2021). Our tentative analysis has integrated different theoretical considerations to identify impacts by adopting three perspectives. This should be further explored in close cooperation with other RwLs to identify further emergent impacts. Future research could also focus on adequate approaches for the creation of stronger evidence bases for such impacts. However, we are convinced that one strength of our tentative analysis lies in the recognition of the crucial design features of RwL research.

With our contribution to the debate around the impacts of RwL research, we hope to highlight the value of engaging with the emergent impacts of RwLs. We look forward to future developments in this field and to the creation of effective tools for capturing and further conceptualising these impacts.

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References

Barth, M., D. J. Lang, P. Luthardt, U. Vilsmaier. 2017. Mapping a sustainable future: Community learning in dialogue at the science-society interface. *International Review of Education* 63: 811–828. https://doi.org/10.1007/s11159-017-9687-5.

Beecroft, R. 2018. Embedding higher education into a real-world lab: A process-oriented analysis of six transdisciplinary project courses. *Sustainability* 10/10: 3798. https://doi.org/10.3390/su10103798.

Bergmann, M. et al. 2021. Transdisciplinary sustainability research in real-world labs: Success factors and methods for change. *Sustainability Science* 16: 541–564. https://doi.org/10.1007/s11625-020-00886-8.

Bernert, P., A. Haaser, L. Kühl, T. Schaal. 2016. Towards a real-world laboratory: A transdisciplinary case study from Lüneburg. *GAIA* 25/4: 253–259. https://doi.org/10.14512/gaia.25.4.7.

Bernert, P., D. Wahl, H. von Wehrden, D. J. Lang. 2023. Cross-case knowledge transfer in transformative research: Enabling learning in and across sustainability-oriented labs through case reporting. *Urban Transformations* 5: 12. https://doi.org/10.1186/s42854-023-00056-w.

Bernert, P., M. Wanner, N. Fischer, M. Barth. 2022. Design principles for advancing higher education sustainability learning through transformative research. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-022-02801-w.

Caniglia, G. et al. 2016. An experience-based learning framework: Activities for the initial development of sustainability competencies. *International Journal of Sustainability in Higher Education* 17/6: 827–852. https://doi.org/10.1108/IJSHE-04-2015-0065.

Caniglia, G. et al. 2021. A pluralistic and integrated approach to action-oriented knowledge for sustainability. *Nature Sustainability* 4: 93–100. https://doi.org/10.1038/s41893-020-00616-z.

Castán Broto, V., G. Trencher, E. Iwaszuk, L. Westman. 2019. Transformative capacity and local action for urban sustainability. *Ambio* 48: 449–462. https://doi.org/10.1007/s13280-018-1086-z.

Christ, M. et al. 2024. Putting sufficiency into practice. Transdisciplinary sufficiency research in urban development: The *Hafen-Ost* real-world laboratory in Flensburg, Germany. *GAIA* 33/S1: 26–34. https://doi.org/10.14512/gaia.33.S1.5.

Hansestadt Lüneburg. 2019. *Integriertes Stadtentwicklungskonzept Lüneburg 2035*. Lüneburg: Rat der Hansestadt Lüneburg. https://ratsinfo.stadt.lueneburg.de/bi/to020.asp?TOLFDNR=40128 (accessed November 15, 2023).

Hansestadt Lüneburg. 2021. *Auszug: Wichtige Mitteilungen der Verwaltung*. Lüneburg: Rat der Hansestadt Lüneburg. https://ratsinfo.stadt.lueneburg.de/bi/to020.asp?TOLFDNR=47975 (accessed November 15, 2023).

Hilger, A., M. Rose, A. Keil. 2021. Beyond practitioner and researcher: 15 roles adopted by actors in transdisciplinary and transformative research processes. *Sustainability Science* 16: 2049–2068. https://doi.org/10/gnsnnh.

Kampfmann, T., P. Bernert, D. J. Lang. 2023. Toward a modular evaluation approach of real-world laboratories: Findings from a literature review. *Research Evaluation* 32/1: 128–143. https://doi.org/10.1093/reseval/rvac029.

Kanning, H., B. Richter-Harm, B. Scurrell, Ö. Yildiz. 2021. Real-world laboratories initiated by practitioner stakeholders for sustainable land management – Characteristics and challenges using the example of *Energieavantgarde Anhalt*. In: *Sustainable Land Management in a European Context*. Volume 8. Edited by T. Weith, T. Barkmann, N. Gaasch, S. Rogga, C. Strauß, J. Zscheischler. Cham: Springer. 207–226. https://doi.org/10.1007/978-3-030-50841-8_11.

Kirst, E., T. Schroth, S. Meyer. Forthcoming. Nachhaltigkeitsorientierung in der Forschung als hochschulumfassende Aufgabe. In: *Nachhaltige Entwicklung von Hochschulen. Erkenntnisse und Perspektiven zur gesamtinstitutionellen Transformation*. Edited by M. Rieckmann, B. Giesenbauer, B. Nölting, T. Potthast, C. T. Schmidt. Opladen: Verlag Barbara Budrich.

Kok, K. P. W., M. G. van der Meij, P. Wagner, T. Cesuroglu, J. E. W. Broerse, B. J. Regeer. 2023. Exploring the practice of Labs for sustainable transformation: The challenge of "creating impact". *Journal of Cleaner Production* 388: 135994. https://doi.org/10.1016/j.jclepro.2023.135994.

Libbe, J., O. Marg. 2021. *Urbane Reallabore und Stadtentwicklung. Erfahrungen und Perspektiven für Forschung und Praxis urbaner Transformation*. Synthese Paper 3. Berlin: Gröschel Branding. www.nachhaltige-zukunftsstadt.de/downloads/SynVerZ_Synthesebericht_Reallabore.pdf (accessed January 23, 2024).

Luederitz, C. et al. 2017. Learning through evaluation – A tentative evaluative scheme for sustainability transition experiments. *Journal of Cleaner Production* 169: 61–76. https://doi.org/10.1016/j.jclepro.2016.09.005.

Lux, A. et al. 2019. Societal effects of transdisciplinary sustainability research – How can they be strengthened during the research process? *Environmental Science and Policy* 101: 183–191. https://doi.org/10.1016/j.envsci.2019.08.012.

Marg, O., M. Kreß-Ludwig, A. Lux. 2019. *Wirkungen transdisziplinärer Stadtforschung in den Projekten der Förderlinien "Leitinitiative Zukunftsstadt" und "Nachhaltige Transformation urbaner Räume". Wirkungskategorien, Projektprofile und Handreichung zur Selbstreflexion.* https://orlis.difu.de/handle/difu/281459 (accessed January 14, 2024).

Marquardt, E. 2019. Hochschule und Stadt als Partner in Reallaboren. Neue Wege für ein konstruktives Miteinander. *Beiträge zur Hochschulforschung* 41/1: 108–123.

McCrory, G., N. Schäpke, J. Holmén, J. Holmberg. 2020. Sustainability-oriented labs in real-world contexts: An exploratory review. *Journal of Cleaner Production* 277: 123202. https://doi.org/10.1016/j.jclepro.2020.123202.

Pärli, R., M. Stauffacher, S. L. Seigo, M. Probst, B. Pearce. 2022. Designing interventions for sustainable change in a real-world laboratory. *Environment, Development and Sustainability.* https://doi.org/10.1007/s10668-022-02659-y.

Parodi, O. 2019. Wider eine Engführung des Reallabor-Konzepts. *Ökologisches Wirtschaften* 2: 8–9. https://doi.org/10.14512/OEW340208.

Parodi, O., S. Ober, O. Lah, A. Steglich, F. Wagner, A. Podann. 2021. Herausforderung Reallabor: Werkstattbericht zur Reallaborforschung. *GAIA* 30/4: 286–288. https://doi.org/10.14512/gaia.30.4.15.

Purschwitz, A. 2023. *Lüneburg 2030+* geht auf die Zielgerade. *Landeszeitung für die Lüneburger Heide,* January 28: 16. www.lueneburg2030.de/wp-content/uploads/2023/02/Zukunftsstadt_280123.pdf (accessed January 23, 2024).

Schäfer, M., M. Bergmann, L. Theiler. 2021. Systematizing societal effects of transdisciplinary research. *Research Evaluation* 30/4: 484–499. https://doi.org/10.1093/reseval/rvab019.

Schäpke, N. et al. 2018. Jointly experimenting for transformation? Shaping real-world laboratories by comparing them. *GAIA* 27/S1: 85–96. https://doi.org/10.14512/gaia.27.S1.16.

Schneidewind, U., K. Augenstein, F. Stelzer, M. Wanner. 2018. Structure matters: Real-world laboratories as a new type of large-scale research infrastructure: A framework inspired by Giddens' structuration theory. *GAIA* 27/S1: 12–17. https://doi.org/10.14512/gaia.27.S1.5.

Singer-Brodowski, M., R. Beecroft, O. Parodi. 2018. Learning in real-world laboratories: A systematic impulse for discussion. *GAIA* 27/S1: 23–27. https://doi.org/10.14512/gaia.27.S1.7.

Walter, A. I., S. Helgenberger, A. Wiek, R. W. Scholz. 2007. Measuring societal effects of transdisciplinary research projects: Design and application of an evaluation method. *Evaluation and Program Planning* 30/4: 325–338. https://doi.org/10.1016/j.evalprogplan.2007.08.002.

Wanner, M., P. Bernert, N. Fischer, M. Schmitt. 2021. Creating learning and teaching spaces for transformative and transdisciplinary research: The *Transformative Innovation Lab. DIDAC* 78: 49–59. https://doi.org/10.48102/didac.2021..78_JUL-DIC.83.

Wanner, M., M. Schmitt, N. Fischer, P. Bernert. 2020. *Transformative Innovation Lab: Handbook to facilitate student's real-world laboratory projects to promote transformative and transdisciplinary competencies.* Wuppertal: Wuppertal Institut für Klima, Umwelt, Energie.

Weiser, A., S. Meyer, P. Bernert, D. J. Lang. 2023. Problem- und projektorientierte Lehre transdisziplinär gestalten. In: *Bildung für Nachhaltige Entwicklung in der Hochschule. Wege und Wirkungen am Beispiel der Leuphana Universität Lüneburg.* Edited by M. Barth, D. Fischer, G. Michelsen. Opladen: Verlag Barbara Budrich. 25–44. https://doi.org/10.2307/jj.7762637.6.

Wiek, A., S. Talwar, M. O'Shea, J. Robinson. 2014a. Toward a methodological scheme for capturing societal effects of participatory sustainability research. *Research Evaluation* 23/2: 117–132. https://doi.org/10.1093/reseval/rvt031.

Wiek, A., A. Xiong, K. Brundiers, S. van der Leeuw. 2014b. Integrating problem- and project-based learning into sustainability programs: A case study on the *School of Sustainability* at Arizona State University. *International Journal of Sustainability in Higher Education* 15/4: 431–449. https://doi.org/10.1108/IJSHE-02-2013-0013.

Williams, S., J. Robinson. 2020. Measuring sustainability: An evaluation framework for sustainability transition experiments. *Environmental Science and Policy* 103: 58–66. https://doi.org/10.1016/j.envsci.2019.10.012.

Wittmayer, J. M., N. Schäpke. 2014. Action, research and participation: Roles of researchers in sustainability transitions. *Sustainability Science* 9: 483–496. https://doi.org/10.1007/s11625-014-0258-4.

Wolfram, M., S. Borgström, M. Farrelly. 2019. Urban transformative capacity: From concept to practice. *Ambio* 48: 437–448. https://doi.org/10.1007/s13280-019-01169-y.

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4.4 Paper 4: Design principles for advancing higher education sustainability learning

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S.I. : TRANSFORMATIVE LEARNING FOR URBAN SUSTAINABILITY

Design principles for advancing higher education sustainability learning through transformative research

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Abstract

A growing number of transformative research practices that redefine the role of science in engaging with local–mostly urban–transformation processes have emerged in recent decades. However, while education is considered a key driver for sustainability transformations, higher education has been slow to develop and implement dedicated, appropriate and effective transformative education programmes and learning modules. In this paper, we present a framework of design principles for transformative learning modules in higher education. These principles are derived from two growing discourses: higher education *sustainability learning*, and *transdisciplinary and transformative research*—both of which are centrally anchored in the field of sustainable development and sustainability science. The principles presented provide guidance for course leaders in higher education to create learning modules aimed at enabling students to become engaged in transdisciplinary and transformative research that fosters sustainability transitions in local and urban contexts. We use the Transformative Innovation Lab (TIL)—a learning course developed and tested at two German universities—as an example of how the design principles can be applied. The module, which runs over two semesters, supports Masters students in their process of developing real-world laboratories and exploring urban sustainability transitions through collaborative experimentation with local practice partners. We discuss the factors that enable and limit the implementation of transformative learning modules and outline aspects of the novel roles adopted by lecturers in transformative teaching environments. Moreover, we highlight the need for both institutional change and transformative teaching formats that go beyond transformative research as key for driving universities to take responsibility for collaboratively fostering sustainability transitions in their local contexts.

Keywords Higher education sustainability learning · Transformative learning · Transformative research · Transdisciplinarity · Real-world laboratories · Design principles

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1 Introduction

There is widespread consensus that education can be a key driver in enabling people to actively steer transition processes (Brundiers et al., 2021; Sterling et al., 2017). However, to achieve this potential, new transformative education programmes that complement the traditional disciplines are needed to better empower people across all age groups to contribute to sustainability transitions (Lange, 2012). Through its close links to the sciences, higher education is traditionally considered to be at the forefront of such developments and recent reforms, such as the Bologna process in Europe, have contributed to a higher degree of flexibility in this domain (Barth, 2016). Over the past two decades, universities and higher education institutions have begun to redefine their role in driving and supporting sustainable development. Moving beyond simple economy-driven technological knowledge transfer, an increasing number of universities are engaging in co-creative sustainability transition projects in order to transform their own cities and regions (Trencher et al., 2014). Many of these projects employ experimental approaches, such as urban or sustainable living laboratories, urban transition laboratories, real-world laboratories or similar (for an overview see McCrory et al., 2020). Some temporarily use the installed laboratory as a learning environment for students. However, few universities have introduced ongoing and structured sustainability-oriented programmes of study that use these formats and educate students in higher education to use transformative research approaches to deal with sustainability problems, analyse them and contribute to solutions (Evans et al., 2015; Larsson & Holmberg, 2018; Pohl et al., 2018). Such programmes are rare compared to programmes rooted in traditional scientific disciplines (Weiss & Barth, 2019). Furthermore, few of the available programmes include modules based on research approaches, such as real-world laboratories and experiments, despite the recent call for a stronger orientation towards the generation of action-oriented knowledge for sustainability (Caniglia et al., 2020). Overall, such education programmes—and the relevant guidance for their development—is lacking. Therefore, in this paper, we draw on discourses around *sustainability learning* and *transdisciplinary and transformative research*. Based on these recent theoretical and conceptual approaches, we derive design principles. The principles provide guidance for educational practitioners who want to educate students to generate action-oriented knowledge in local contexts by developing and conducting transformative research in small-scale real-world laboratories. The principles were originally developed in the context of a three-year research and teaching project and guided the design of the Transformative Innovation Lab (TIL) learning module. We share insights from the TIL to illustrate how the design principles can be applied. Reflecting on the principles and our experiences in the TIL, we discuss the challenges and opportunities of the application of such learning formats for both lecturers/tutors and institutions and their potential to foster urban transitions.

2 Learning and researching for sustainability transformations

In the context of the ongoing discussion around sustainability and sustainable development (e.g. Grunwald & Kopfmüller, 2012), a wide range of concepts have emerged in terms of integrating sustainability-oriented education into higher education. Two strands of research and practice figure prominently, which share many links and commonalities. *Sustainability learning* in higher education is largely based on contributions from educational science and

provides an innovative impetus to higher education by integrating sustainability. *Transdisciplinary and transformative research* forms a new research mode which has introduced the question of how and to what extent higher education contributes to sustainable development in society. The following sections provide a brief overview of these concepts in terms of their approaches to transformative learning programmes and associated insights.

2.1 Sustainability learning in higher education

The implementation of sustainability learning in higher education has proved that innovation can be brought about by new areas in teaching and learning and can create new ideas and formats by introducing new methods or new learning settings. By 'doing things differently', sustainability learning has provided answers to some of today's expectations of higher education, namely through its interdisciplinary nature, its intercultural dimension and its transdisciplinary orientation (Barth, 2016). This is particularly visible in its contributions to problem-based and project-based learning where higher education introduces complex real-world problems and a strong solution orientation (Brundiers & Wiek, 2013; Tejedor et al., 2019), as well as in engagement-oriented formats such as service learning which are further developed through integrating transdisciplinary learning (Barth et al., 2014; Stauffacher et al., 2006). More recently, sustainability learning has been drawing from transformative learning theory, questioning the intent and outcomes of the traditional learning and teaching approaches of higher education and Education for Sustainable Development (ESD) (Rodríguez Aboytes & Barth, 2020; Singer-Brodowski, 2016a, 2016b). The approach was originally introduced by Mezirow in the context of personal development and adult learning (Mezirow, 1991). It aims to foster "autonomy, individuation, empowerment, ecological consciousness, social action, citizenship and democracy" (Cranton & King, 2003; Mezirow, 1997, 2003; as cited in Rodríguez Aboytes & Barth, 2020, p. 996) by transforming problematic frames of reference, namely fixed "habits of mind, meaning perspectives and mindsets" (Mezirow, 2003, p. 58). Transformative learning adds to sustainability learning by explicitly addressing and critically reflecting on underlying moral assumptions and embracing diverse knowledge and experiences (Brookfield, 2000, p. 130).

The above-mentioned efforts have been accompanied by a growing body of research, which offers insights into learning outcomes and processes. Learning objectives as the intended learning outcomes of higher education for sustainable development are still discussed with reference to the foundation documents of the United Nations Educational Scientific and Cultural Organization (UNESCO). These documents advocate for the capabilities of active societal participation and life-long learning (UNESCO, 2005). In the literature on education for sustainable development, several approaches share the UNESCO vision of enabling people and specify the learning objectives as the knowledge, skills, and attitudes for the transformation towards sustainability (de Haan, 2008; Rieckmann, 2012; Stibbe, 2009). These contributions use various concepts for defining skills, literacy, competencies, or capabilities (Barth, 2016). Against the background of this diversity, agreement has been growing that the sought-after outcomes should be framed around key competencies in sustainability, defined as "complexes of knowledge, skills, and attitudes that enable successful task performance and problem solving with respect to real-world sustainability problems, challenges, and opportunities" (Wiek et al., 2011, p. 204).

With respect to learning processes, researchers have elaborated on the need for novel teaching and learning settings to support the development of sustainability competencies (Rowe, 2007; Sterling & Thomas, 2006). Problem-based and project-based learning

(Brundiers & Wiek, 2013; Dale & Newman, 2005) in general, with adaptations such as design charrettes (Foley et al., 2017) and real-world laboratories (Singer-Brodowski et al., 2018), figure prominently in such settings and provide examples of how to help students experience sustainability problems and make first-hand contributions to solutions. It is reasoned that these teaching and learning settings provide students with opportunities to contend with the complexity of sustainability problems and develop viable solution options. Consequently, how to design such teaching and learning settings as open learning environments is the subject of much debate.

2.2 Transdisciplinary and transformative research

The question of the contribution that science can make to overcoming global challenges is a leitmotif of sustainability research. The need to develop adequate approaches for tackling sustainability problems has led the scientific community to enter a profound reflection process, discussing solution-oriented and interventional research designs. One of the most influential contributions stemming from this debate was the proclamation of the so-called Mode-2 research approach (Gibbons et al., 1994; Nowotny et al., 2001). This stimulated the discourse around transdisciplinary research, which subsequently developed into a core research practice in the field of sustainability. Transdisciplinary research takes societal problems as a starting point and integrates various disciplinary bodies of knowledge and practical experience and wisdom, with the aim of producing socially robust knowledge. Frameworks, concepts, guidelines, and quality standards have been developed for transdisciplinary research (Bergmann et al., 2005; Hirsch Hadorn et al., 2006; Jahn et al., 2012; Klein, 2006; Lang et al., 2012; Scholz et al., 2006), and international scientific networks and programmes for studying the earth sciences and social sciences have called for greater transdisciplinary activity in order to co-create sustainability knowledge (Mauser et al., 2013). Following a similar line of thought, the German Advisory Council on Global Change has characterised two specific research approaches: transformation research, which focuses on describing, analysing, and explaining global change processes, and transformative research, which engages with current debates and actions to actively strengthen sustainable development (WBGU, 2011). In related fields, scholars and practitioners have developed intervention-focussed approaches, building on and calling for an experimental turn in the social sciences (Overdevest et al., 2010). Blending experience from decades of (participatory) action research (Kemmis & McTaggart, 2000; Ozanne & Saatcioglu, 2008), concepts of transition management, strategic niche management (Kemp et al., 1998, 2007) and new experimental modes, a broad range of action-oriented formats such as (urban/sustainable) living laboratories (Liedtke et al., 2015; Voytenko et al., 2016), urban transition laboratories (Nevens et al., 2013), transformation laboratories (Pereira et al., 2020), and real-world laboratories (Parodi et al., 2018; Schneidewind, 2014) have been established. Many of these explicitly focus on urban areas as spaces and loci with pressing sustainability issues of high complexity but also with significant opportunities for creativity: an atmosphere conducive to innovation and a critical mass of progressive change agents and early adopters. Among these approaches, the real-world laboratory discourse is closest to fulfilling the transdisciplinary quality criteria. The concepts of ideal-type processes (Wanner et al., 2018) and success factors (Bergmann et al., 2021) were developed to create actionable real-world laboratory settings. Luederitz et al. (2017) and Caniglia et al. (2017) contributed a formative evaluation scheme and a typology embedding real-world experiments into the experimental methodology of sustainability research.

However, despite the establishment of such action-oriented knowledge research approaches over the past decade (Caniglia et al., 2020), higher education institutions have not yet systematically harnessed their potential as learning environments (Singer-Brodowski et al., 2018).

3 Design principles

While theoretical discussions around sustainability learning in higher education have introduced valuable learning and teaching concepts, incorporating such approaches into higher education programmes remains a challenge for both programme directors and lecturers. The theoretical concepts presented in the preceding section of this paper represent our understanding of the central approaches in this field.

This literature base was crucial for informing the development of the TIL that we implemented in two different universities over two years. A more detailed presentation of the TIL is provided in chapter 4.

In this paper, we address the question of how the literature can inform the development of courses in contexts beyond the pilot study programmes at the two universities where we applied our course design. We identify principles that can inform other courses by making sense of the broad discussions found in the literature for educators in the field. In this section, we present a comprehensive set of principles for sustainability-oriented courses building on transformative learning and transformative research approaches.

The framework is designed to provide a point of reference for reflection when designing and teaching such study courses. From our experience, the reality of developing learning modules and teaching these courses involves careful planning beforehand and constant re-adjustment during the semester(s). Our design principles offer a framework to support lecturers (and students) during both phases to better integrate the theoretical advancements of sustainability learning and transdisciplinary and transformative research into the courses.

Our suggested set of eight coherent design principles was developed through extensive joint interdisciplinary discussion, which built on the reflection of our experiences from teaching in the TIL, discussions with peer course leaders regarding the purpose of such design principles and a deep re-examination of the literature used for the TIL design.

To make the development process of the suggested principles and their rootedness in the literature transparent, we adopted a Sankey-style diagram to illustrate our thought process (see Fig. 1). This shows the principles on the right-hand side and the discourses that informed these principles on the left.

The eight principles depicted in the Sankey-style diagram (Fig. 1) are considered as a coherent set, and thus, each principle has equal importance for the design of the module as a whole. The design principles complement each other: they are strongly interlinked and influence the general course design as well as specific learning modules and the single activities within them. Consequently, we chose to depict each design principle the same size (right-hand column). However, they differ with regard to the number of discourses they are informed by, which explains why the source nodes differ in size (left-hand column). Neither the size of the nodes nor the width of the flows should—or could—be interpreted quantitatively.

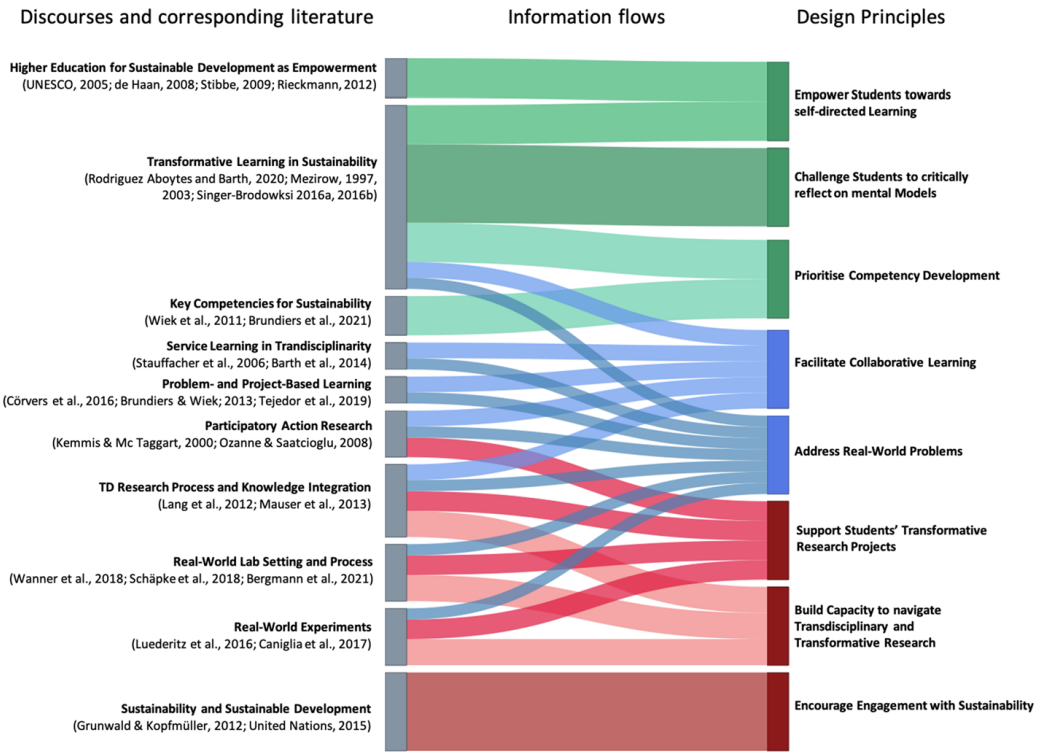

Fig. 1 Sankey-style diagram of eight design principles for higher education sustainability learning through transformative research (right) and their corresponding roots in discourses and the literature (left). Colours (green, blue, and red) refer to the clustering of the eight principles in three key areas of course design: green = teaching mindset, blue = learning environment, red = research activities (see also Fig. 2)

3.1 Design principles in detail

In the following section, we outline and explain the principles in more detail. The principles are formulated as guidance for those responsible for course design and are clustered according to the higher-level key areas of course design. *Teaching mindset* refers to the specific attitude towards learning, the course, and the students that course leaders should take account of when designing and delivering a course. This mindset could—depending on personal teaching style—differ significantly from 'classic' approaches to teaching. *Learning environment* emphasises the setting, atmosphere, and context for the course as part of the design. The principles to consider in this area could include how to arrange the teaching/learning space or who to employ to deliver the course.

The area of *research activities* relates closely to the course content and focuses on topics, themes, and activities that are central for transformative education courses (see Fig. 2).

3.1.1 Teaching mindset

3.1.1.1 Empower students towards self-directed learning Sustainability learning (and higher education for sustainable development) aims to empower students towards self-directed learning from a procedural perspective (UNESCO, 2005). Consequently, the role of the course leader is to develop an inspiring learning environment (Singer-Brodowski

Fig. 2 Depiction of the eight design principles for higher education sustainability learning through transformative research (outer ring) and their superordinate key areas of course design (inner ring). The circular arrangement without hierarchy or numbering is intended to depict our understanding of all the principles as being part of a coherent and equally important set

et al., 2018) and to create adequate learning opportunities, rather than to focus on specific content inputs (de Haan, 2008; Rieckmann, 2012; Stibbe, 2009). It is crucial to foster an empowering teaching mindset towards students, encouraging them to take responsibility for their own learning journey while providing a safe space to learn in experimental settings. This includes guidance for reflection, as well as self-care and emotional coping strategies.

3.1.1.2 Challenge students to critically reflect on mental models Following the theoretical considerations of transformative learning discourses, students should be challenged to reflect on the content, processes, and premise of their own mental models (Mezirow, 1997, 2003; Singer-Brodowski, 2016a, 2016b). For students to be able to reflect on sustainability issues, the ability to critically reflect on their own presuppositions is considered crucial. However, transformative learning should not only be considered a means of achieving transformative action but also as an aspiration in itself (Rodríguez Aboytes & Barth, 2020).

3.1.1.3 Prioritise competency development Teaching in higher education sustainability learning contexts is competency-oriented, with the aim of enabling students to address sustainability problems and contribute to their solutions as change agents. Competency development as a learning goal should guide the design of learning modules as a whole and the

selection of formats and the arrangement of specific learning units. The focus on competency development should be communicated transparently and be adequately represented through reflexive examination approaches. Key competencies in this context include normative competence, systems thinking competence, interpersonal competence, anticipatory competence, and strategic competence (Brundiers et al., 2021; Wiek et al., 2011).

3.1.2 Learning environment

3.1.2.1 Facilitate collaborative learning Collaborative learning is a key feature of transformative learning modules in higher education. For students to benefit from collaboration with their peers, adequate formats should be established for students to meet together, and discussions should be facilitated by lecturers (Cörvers et al., 2016; Stauffacher et al., 2006). Collaboration opportunities in multi-stakeholder settings should be supported by providing contact with practitioners and training exercises for collaborative methods.

3.1.2.2 Address real-world problems Engaging with actual real-world problems is a crucial feature of learning modules that aim at transformative learning and competency development through transformative research. Identifying manageable local challenges for students to engage in and developing trusted relationships with practitioners are crucial factors for creating spaces where students can learn. Actively managing the expectations of both students and practitioners allows for the development of collaborative settings where failure can be embraced without negative consequences.

3.1.3 Research activities

3.1.3.1 Support students' transformative research projects Lecturers in transformative research-oriented learning environments must play the key role of supporting students in the design and realisation of their own projects. Regular individual and group sessions with students allow for the joint critical reflection of research and experiment designs. Offering entry points to a demanding research process by inviting students into established collaborative research settings allows students to quickly engage with actors and build on trusted relationships. Lecturers must take on the role of coaches who closely accompany students, react quickly to their challenges, and respond adequately to specific and individual questions.

3.1.3.2 Build the capacity to navigate transdisciplinary and transformative research To be able to create their own transformative research projects, students need to develop the ability to navigate the discourses of transdisciplinary and transformative research approaches. Students need to be supported to position their work within the current discourse and build on established concepts in this field of research. This includes reflecting on the normative and ethical implications of transformative research. A particular focus lies on familiarising students with methods and approaches that can inform their research, such as methods of collaboration with practice partners, the design of interventions, and knowledge integration.

3.1.3.3 Encourage engagement with sustainability The discourse around sustainability encompasses a wide field of concepts and topics; consequently, critical engagement with different notions and issues should be encouraged. Jointly exploring, discussing, and reflecting on own perceptions, theoretical concepts (Grunwald & Kopfmüller, 2012) and

political frameworks (e.g. Sustainable Development Goals (SDGs)) (UN, 2015) allow students to position themselves and their research. This enables students to identify motivating and challenging topics with which to engage.

4 Applying the design principles: the example of the Transformative Innovation Lab (TIL)

Project context The TIL was developed as part of the EEVA project (the development, testing, and dissemination of new qualification offer for 'change agents' for transformative learning using the real-world laboratory approach). In two pilots, a TIL was integrated into the Futures Studies Masters programme at Freie Universität Berlin and the Sustainability Science Masters programme at Leuphana University Lüneburg. The project was coordinated by the Wuppertal Institute and ran from 2017 to 2020 and was funded by the German Federal Environmental Foundation (DBU). Two student cohorts with 34 students in total participated in the TIL pilots.

Over the course of the project and based on joint reflection with our students and their feedback, the teaching approach was iteratively improved. Following the conclusion of the project, we can present the TIL as a promising approach for realising many of the aspects discussed in the literature around sustainability learning, transformative research, and sustainability. The project outcomes have since inspired discussions on transformative research practices in the German sustainability learning community.

4.1 Applying the design principles to the overall course design

To illustrate how the design principles can be applied, the following section builds on our experience in designing and conducting a higher education teaching module as part of the three-year EEVA research project (Wanner et al., 2021a, 2021b). The TIL was designed as an experimental space offering a safe environment in which students could explore both themselves and the transformative research approach as potential sustainability change agents. Students from two different Masters programmes at two German universities were jointly invited to develop their own real-world laboratories and explore sustainability transitions through collaborative experimentation with local practice partners.

We designed the course to focus on the learning process, building on transdisciplinary and transformative research processes as a guiding structure. The practical engagement of students in a *real-world context and with real-world problems* formed our starting point. From the outset, students were encouraged to identify and engage with real-world sustainability problems in their respective local contexts, e.g. sustainable mobility, the role of church communities as drivers of sustainability transformations or renewable energy transitions in local economies. Over the course of the seminar, students worked on their *own transformative research projects*, with the aim of developing research projects that contributed to the solution of sustainability problems. We guided the students, step by step, in developing and realising their own research projects, linking *engagement with sustainability*, building the *capacity to navigate the discourses and methodologies of transdisciplinary and transformative research* to the students' own research activities.

In the learning environment we designed, we focussed strongly on the *development of competencies*, both through dedicated exercises and by transferring the learnings to students' own projects. The hands-on approach that our students followed in designing and planning their own research projects with partners was a central feature of the course design, which enabled competency development in and through transdisciplinary collaboration.

We aligned inputs, critical discussions, and options for reflection and feedback needed to support the students in each step. Through a variety of formats, we c*hallenged students to make their own mental models explicit*, to take a critical stance towards theories and methodologies and to reflect on their own processes and individual developments.

Furthermore, the TIL encompassed continuous reflection and feedback within the teaching team and between the teaching team and the students, which also supported the iteration of the course design. We explicitly integrated the different competencies, knowledge areas, and needs of the group (including the teaching team) and built on teamwork and peer exchange (e.g. the formation of small student groups for feedback and support) to *foster a collaborative learning setting*. The open reflection and exchange on the course development and the peer feedback contributed to creating a safe learning setting for the students that allowed for failures and redesigns, thereby supporting the *empowerment of the students* to set their own goals and directions for their learning journey.

4.2 Example: a kick-off retreat as the foundation for a transformative sustainability learning process

The following section describes the kick-off of the TIL to illustrate the application of the principles within a single learning unit of the TIL. It complements the description (above) of how the principles are applied within the general course design. For a detailed description of the TIL and its modules, please refer to the handbook (Wanner et al., 2020) and the bi-lingual overview article (Wanner et al. 2021a, 2021b). Rather than connecting single aspects of this learning unit to specific design principles, we want to highlight how the principles support the design of such a learning unit and help to lay a foundation for applying the principles within the whole course.

The TIL started with a five-day kick-off retreat in which the group of 20 students from different Masters programmes and the interdisciplinary teaching team gathered at a hostel in a rural location. The kick-off was crucial for setting the overall atmosphere and framework for the TIL. Part of the aim of the retreat was to establish common (theoretical) ground and to find starting points for the students' own research projects. However, the overriding purpose of the kick-off retreat was to allow everyone to experience a specific teaching and learning mindset and learning environment. Consequently, getting to know each other and developing an atmosphere of trust were central aspects of the kick-off. Therefore, we dedicated time to team building exercises, peer exchange, and group dynamics in general and ensured that the students were invited not only to design their own learning journeys, but also to co-design our kick-off.

The activities at the kick-off retreat combined multiple principles, which interlinked mindset, learning environment, and transformative research activities. For example, we played a simulation game in which students adopted different roles in fictitious countries, trying to balance well-being, economic development, and natural resource consumption. This game combined team building, engagement with sustainability discussions, systems thinking, and team competency training and allowed for critical (self-) reflection. It also

fostered a collaborative learning setting and supported an atmosphere of experimentation, mutual trust, and open (self-) critical discussion.

We also established a common understanding of transformative research. We combined inputs from teachers and students, invited discussions and presentations of existing knowledge, and facilitated peer exchange. We used a 'buzzword-bingo' game to create a safe space for asking questions that might otherwise seem too obvious to ask, with the aims of fostering critical discussion of concepts and theories and of identifying potential topics for subsequent inputs. Moreover, we combined theoretical aspects with input from guest speakers' case studies, transferring theory to practical examples. To enable self-directed learning, we prepared some of the basic input and planned time for emerging topics.

To kick-off the project work, we started by asking the students to personally reflect on their favourite SDG. This exercise engaged students in sustainability discussions and supported them to find an anchor point for research into real-world sustainability challenges. This activity simultaneously served as a team-building exercise to connect students who shared similar interests, which supported subsequent project team formation. With a first direction in mind, we invited students to a 'fast forward exercise'. In groups, they 'ran' through a transformative research project in the fashion of a thought experiment. They started by brainstorming and choosing a real-world problem, before brainstorming different potential practice partners and stakeholders, deliberately ranging from close and easily accessible ones to actors out of their reach. After discussing potential practical issues for a selected stakeholder, the students brainstormed potential interventions and experiments, again ranging from the small and easy to a large-scale real-world laboratory. Finally, the students jointly discussed how they could evaluate, measure, and document this process from the perspective of scientific research requirements. This exercise, again, supported team building, translated theoretical and methodological concepts into the TIL environment, fostered strategic competencies, and encouraged the students in their own research work.

These examples illustrate that applying the principles means approaching the course design with a simultaneous focus not only on the content needed to enable the students' project work, but also on the collaborative and safe atmosphere and how to foster the emergence of individual learning journeys.

5 Discussion

In this discussion, we reflect on three critical aspects involved in advancing sustainability learning in higher education through transformative learning and transformative research: (1) the challenges for course leaders and students in such learning formats; (2) the potential and limitations of the presented principles for designing learning modules; and (3) the importance of such learning formats for universities to adopt new roles as drivers of urban sustainability transitions.

5.1 What purpose do the design principles serve?

The design principles aim to support programme directors and lecturers in higher education institutions to implement sustainability learning-oriented courses by building on transformative learning and transformative research. Both concepts are considered crucial for fostering sustainability transformations. On an individual level, transformative learning

builds capacities to reflect on and actively address sustainability problems. In a complementary way, transformative research involves designing transition processes and generates robust knowledge based on interventions.

However, implementing courses that integrate these perspectives is challenging due to institutional inertia and the demanding complexity of teaching in such settings. We deem these to be the main reasons why the various pilot projects and experimental teaching modules that have been developed have only occasionally been transferred into regular curricula and teaching culture (Dabaieh et al., 2018; Pfau & Uhl, 2018).

In this context, the design principles serve two purposes. First, as a comprehensive set, the principles allow for the holistic planning of courses without having to reinvent the wheel and without being overly specific to a single context or location. Second, the principles serve as a tool for reflection during the teaching phases of other pilots or current modules, offering orientation and areas for discussion concerning crucial teaching and research concepts.

Therefore, the strength of the design principles lies in a high degree of practicality, which makes the highly advanced discourses of sustainability learning theory and transformative research accessible. While a course that is designed according to single principles can already contribute to enhancing the learning experiences of students, this set is intended to be used holistically as an overall design in which the principles complement each other. This creates a better representation of the current concepts of sustainability learning and transdisciplinary and transformative sustainability research.

Although the principles address and encompass the content, organisation, and didactics of higher education sustainability learning through transformative learning and transformative research, they do not tackle the fundamental aspects concerning the need to embed such modules and programmes in higher education institutions. A chapter in the handbook does focus on aspects to be aware of when integrating such modules into study programmes (Wanner et al., 2020, p. 52), including the selection of an appropriate study programme, the importance of considering semester schedules and study programme structures, as well as examination requirements, group sizes, and the promotion of the course. However, local educational actors must meet the challenge of how to ensure that there is both the will and adequate resources to embed such modules into higher education institutions. This action must happen from the top down by ambitious academic leaders in higher education institutions via mission statements, changes to institutional structure and resource allocation, and from the bottom up by engaged academic staff who choose to develop and lead suitable educational programmes.

5.2 Challenges for teaching

As suggested in the literature, teaching sustainability learning-oriented courses necessitates novel understandings around modes of collaboration and engagement with students. Creating safe environments for students to learn in a self-directed way and to explore sustainability problems with practitioners demands a high degree of support from course leaders. While teaching in the TIL, we found ourselves covering a wide range of activities, such as providing input, practical guidance, emotional and psychological support, managing contact with practice partners, organising peer learning encounters outside the university, and supervising Masters theses. In a similar way in which researchers adopt diverse roles in transdisciplinary settings (Wittmayer & Schäpke, 2014), course leaders are forced to adopt

wide-ranging roles that in many ways transcend the traditional understanding of teaching in higher education (namely that of passing on knowledge).

We therefore advise that further investigation should be carried out into the necessary roles and competencies of lecturers in these contexts. Moreover, we encourage lecturers in this field to further connect, mutually reflect on their experiences, and establish support networks across institutions where they can jointly address the challenges they encounter in their practice. This would be especially valuable for early-career researchers at universities who are often highly motivated to teach demanding real-world focussed courses but are ultimately often left alone to experience learning-by-doing. In addition, such options for exchange could and would facilitate interdisciplinary exchange locally and (inter-) nationally. In universities that are still structured according to the different disciplines, interdisciplinarity—as a basis for transdisciplinary projects—is particularly hard to achieve in single study programmes.

A specific issue to be aware of is the potential for the students to experience emotionally challenging and individually disorienting dilemmas. Transformative learning as an approach that encompasses profound individual reflection ideally calls for demanding situations in order to open a window for questioning personal perspectives and transforming problematic frames of reference. Although this approach seems rational and effective, it is difficult to manage. Inviting students to create their own learning environment and journey is not a sure-fire method of inducing a disorienting dilemma—and if such a dilemma is induced, this can raise psychological and ethical questions. Accordingly, the challenge is to provide students with sufficient incentives and a safe space that enables them to create a situation that is individually challenging but not overwhelming.

5.3 Universities as drivers for experimental urban and regional transformations

As stated in introduction, the world needs scaled and accelerated transformation processes towards sustainable development. Universities as relevant hubs for innovation, modern higher education, and regional development play an important role in urban and regional development. At stake is the role of universities as drivers for a new, co-creative, and sustainability-oriented transfer and third mission (Evans et al., 2015; Karvonen & van Heur, 2014; Schneidewind, 2020; Trencher et al., 2014). The complex cycle of technical innovation through to market launch was thoroughly and effectively developed in the twentieth century, but the greatest task currently facing the world is to ideologically divest from fossil fuels and other unsustainable industries and technologies and focus on clean, future-proof innovation. In the realm of social innovation, we still need a similarly developed complex of mechanisms for producing socially robust knowledge between universities and society. If universities want to play an influential role in this sphere—which they should—they must develop widely institutionalised, thematically differentiated, and socially effective means of teaching and researching (see also König, 2013). The various approaches already mentioned in this paper (urban or sustainable living laboratories, urban transition laboratories, real-world laboratories, or similar) illustrate the multi-faceted search for adequate research formats for such a sustainable and socially robust third mission. We assert that developing a variety of learning options at every university, based on the principles we have set out, would be an important and necessary step towards fruitful teaching formats. Taken together, transformative research formats, transformative teaching offerings, and the associated necessary institutional changes would fulfil the idea of an encompassing

transformative science (Schneidewind et al., 2016). The principles outlined in this paper aim to contribute to this discourse and to institutional change.

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Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

References

Barth, M., Adomßent, M., Fischer, D., Richter, S., & Rieckmann, M. (2014). Learning to change universities from within: A service-learning perspective on promoting sustainable consumption in higher education. *Journal of Cleaner Production, 62*, 72–81. https://doi.org/10.1016/j.jclepro.2013.04.006

Barth, M. (2016). *Implementing sustainability in higher education: Learning in an age of transformation*. Routledge.

Bergmann, M., Schäpke, N., Marg, O., Stelzer, F., Lang, D. J., Bossert, M., Gantert, M., Häußler, E., Marquardt, E., Piontek, F. M., Potthast, T., Rhodius, R., Rudolph, M., Ruddat, M., Seebacher, A., & Sußmann, N. (2021). Transdisciplinary sustainability research in real-world labs: Success factors and methods for change. *Sustainability Science*. https://doi.org/10.1007/s11625-020-00886-8

Bergmann, M., Brohmann, B., Hoffmann, E., Loibl, M. C., Rehaag, R., Schramm, E., & Voß, J.-P. (2005). *Quality Criteria of Transdisciplinary Research. A Guide for the Formative Evaluation of Research Projects.* Institut für sozial-ökologische Forschung (ISOE). http://www.isoe.de

Brookfield, S. D. (2000). Transformative learning as ideology critique. In J. Mezirow (Ed.), *Learning as transformation: Critical perspectives on a theory in progress* (pp. 125–148). USA: Jossey-Bass.

Brundiers, K., & Wiek, A. (2013). Do we teach what we preach? An international comparison of problem- and project-based learning courses in sustainability. *Sustainability, 5*(4), 1725–1746. https://doi.org/10.3390/su5041725

Brundiers, K., Barth, M., Cebrián, G., Cohen, M., Diaz, L., Doucette-Remington, S., Dripps, W., Habron, G., Harré, N., Jarchow, M., Losch, K., Michel, J., Mochizuki, Y., Rieckmann, M., Parnell, R., Walker, P., & Zint, M. (2021). Key competencies in sustainability in higher education—Toward an agreed-upon reference framework. *Sustainability Science, 16*(1), 13–29. https://doi.org/10.1007/s11625-020-00838-2

Caniglia, G., Schäpke, N., Lang, D. J., Abson, D. J., Luederitz, C., Wiek, A., Laubichler, M. D., Gralla, F., & von Wehrden, H. (2017). Experiments and evidence in sustainability science: A typology. *Journal of Cleaner Production, 169*, 39–47. https://doi.org/10.1016/j.jclepro.2017.05.164

Caniglia, G., Luederitz, C., von Wirth, T., Fazey, I., Martín-López, B., Hondrila, K., König, A., von Wehrden, H., Schäpke, N. A., Laubichler, M. D., & Lang, D. J. (2020). A pluralistic and integrated approach to action-oriented knowledge for sustainability. *Nature Sustainability*. https://doi.org/10.1038/s41893-020-00616-z

Cörvers, R., Wiek, A., de Kraker, J., Lang, D. J., & Martens, P. (2016). Problem-Based and Project-Based Learning for Sustainable Development. In H. Heinrichs, P. Martens, G. Michelsen, & A. Wiek (Eds.), *Sustainability Science* (pp. 349–358). Netherlands: Springer.

Cranton, P., & King, K. P. (2003). Transformative Learning as a Professional Development Goal. *New Directions for Adult and Continuing Education, 2003*(98), 31–38. https://doi.org/10.1002/ace.97

Dabaieh, M., El Mahdy, D., & Maguid, D. (2018). Living Labs as a Pedagogical Teaching Tool for Green Building Design and Construction in Hot Arid Regions. *International Journal of Architectural Research: Archnet-IJAR, 12*(1), 338. https://doi.org/10.26687/archnet-ijar.v12i1.1285

Dale, A., & Newman, L. (2005). Sustainable development, education and literacy. *International Journal of Sustainability in Higher Education, 6*(4), 351–362. https://doi.org/10.1108/14676370510623847

de Haan, G. (2008). Gestaltungskompetenz als Kompetenzkonzept der Bildung für nachhaltige Entwicklung. In I. Bormann & G. de Haan (Eds.), *Kompetenzen der Bildung für nachhaltige Entwicklung* (pp. 23–43). VS Verlag für Sozialwissenschaften. https://doi.org/10.1007/978-3-531-90832-8_4

Evans, J., Jones, R., Karvonen, A., Millard, L., & Wendler, J. (2015). Living labs and co-production: University campuses as platforms for sustainability science. *Current Opinion in Environmental Sustainability, 16*, 1–6. https://doi.org/10.1016/j.cosust.2015.06.005

Foley, R., Wiek, A., & Kay, B. (2017). Nanotechnology Development as if People and Places Matter. *NanoEthics, 11*(3), 243–257. https://doi.org/10.1007/s11569-017-0300-y

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Peter, S., & Trow, M. (1994). *The new production of knowledge: The dynamics of science and research in contemporary societies*. Uk: Sage.

Grunwald, A., & Kopfmüller, J. (2012). *Nachhaltigkeit: Eine Einführung*. Germany: Campus Verlag.

Hirsch Hadorn, G., Bradley, D., Pohl, C., Rist, S., & Wiesmann, U. (2006). Implications of transdisciplinarity for sustainability research. *Ecological Economics, 60*(1), 119–128. https://doi.org/10.1016/j.ecolecon.2005.12.002

Jahn, T., Bergmann, M., & Keil, F. (2012). Transdisciplinarity: Between mainstreaming and marginalization. *Ecological Economics, 79*, 1–10. https://doi.org/10.1016/j.ecolecon.2012.04.017

Karvonen, A., & van Heur, B. (2014). Urban Laboratories: Experiments in reworking cities: Introduction. *International Journal of Urban and Regional Research, 38*(2), 379–392. https://doi.org/10.1111/1468-2427.12075

Kemmis, S., & McTaggart, R. (2000). Participatory action research. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research.* UK: Sage Publications.

Kemp, R., Schot, J., & Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. *Technology Analysis & Strategic Management, 10*(2), 175–198. https://doi.org/10.1080/09537329808524310

Kemp, R., Loorbach, D., & Rotmans, J. (2007). Transition management as a model for managing processes of co-evolution towards sustainable development. *International Journal of Sustainable Development & World Ecology, 14*(1), 78–91. https://doi.org/10.1080/13504500709469709

Klein, J. T. (2006). Resources for Interdisciplinary Studies. *Change the Magazine of Higher Learning, 38*(2), 50–56. https://doi.org/10.3200/CHNG.38.2.50-56

König, A. (2013). *Regenerative Sustainable Development of Universities and Cities*. Edward Elgar Publishing. https://doi.org/10.4337/9781781003640

Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., & Thomas, C. J. (2012). Transdisciplinary research in sustainability science: Practice, principles, and challenges. *Sustainability Science, 7*(S1), 25–43. https://doi.org/10.1007/s11625-011-0149-x

Lange, E. A. (2012). Transforming Transformative Learning Through Sustainability and the New Science. In E. W. Taylor & P. Cranton (Eds.), *The handbook of transformative learning: Theory, research, and practice* (1st ed., pp. 195–211). USA: Jossey-Bass.

Larsson, J., & Holmberg, J. (2018). Learning while creating value for sustainability transitions: The case of Challenge Lab at Chalmers University of Technology. *Journal of Cleaner Production, 172*, 4411–4420. https://doi.org/10.1016/j.jclepro.2017.03.072

Liedtke, C., Baedeker, C., Hasselkuß, M., Rohn, H., & Grinewitschus, V. (2015). User-integrated innovation in Sustainable LivingLabs: An experimental infrastructure for researching and developing sustainable product service systems. *Journal of Cleaner Production, 97*, 106–116.

Luederitz, C., Schäpke, N., Wiek, A., Lang, D. J., Bergmann, M., Bos, J. J., Burch, S., Davies, A., Evans, J., König, A., Farrelly, M. A., Forrest, N., Frantzeskaki, N., Gibson, R. B., Kay, B., Loorbach, D., McCormick, K., Parodi, O., Rauschmayer, F., … Westley, F. R. (2017). Learning through evaluation – A tentative evaluative scheme for sustainability transition experiments. *Journal of Cleaner Production, 169*, 61–76. https://doi.org/10.1016/j.jclepro.2016.09.005

Mauser, W., Klepper, G., Rice, M., Schmalzbauer, B. S., Hackmann, H., Leemans, R., & Moore, H. (2013). Transdisciplinary Global Change Research: The Co-creation of Knowledge for Sustainability. *Current Opinion in Environmental Sustainability, 5*(3–4), 420–431. https://doi.org/10.1016/j.cosust.2013.07.001

McCrory, G., Schäpke, N., Holmén, J., & Holmberg, J. (2020). Sustainability-oriented labs in real-world contexts: An exploratory review. *Journal of Cleaner Production, 277*, 123202. https://doi.org/10.1016/j.jclepro.2020.123202

Mezirow, J. (1991). *Transformative dimensions of adult learning* (1st ed.). USA: Jossey-Bass

Mezirow, J. (1997). Transformative Learning: Theory to Practice. *New Directions for Adult and Continuing Education, 1997*(74), 5–12. https://doi.org/10.1002/ace.7401

Mezirow, J. (2003). Transformative Learning as Discourse. *Journal of Transformative Education, 1*(1), 58–63.https://doi.org/10.1177/1541344603252172

Nevens, F., Frantzeskaki, N., Gorissen, L., & Loorbach, D. (2013). Urban Transition Labs: Co-creating transformative action for sustainable cities. *Journal of Cleaner Production, 50*, 111–122. https://doi.org/10.1016/j.jclepro.2012.12.001

Nowotny, H., Scott, P., & Gibbons, M. (2001). *Re-thinking science: Knowledge and the public in an age of uncertainty*. UK: Polity Press.

Overdevest, C., Bleicher, A., & Gross, M. (2010). The Experimental Turn in Environmental Sociology: Pragmatism and New Forms of Governance. In M. Gross & H. Heinrichs (Eds.), *Environmental Sociology* (pp. 279–294). Netherlands: Springer.

Ozanne, J. L., & Saatcioglu, B. (2008). Participatory Action Research. *Journal of Consumer Research, 35*(3), 423–439. https://doi.org/10.1086/586911

Parodi, O., Waitz, C., Bachinger, M., Kuhn, R., Meyer-Soylu, S., Alcántara, S., & Rhodius, R. (2018). Insights into and recommendations from three real-world laboratories: An experience-based comparison. *GAIA - Ecological Perspectives for Science and Society, 27*(1), 52–59. https://doi.org/10.14512/GAIA.27.S1.12

Pereira, L., Drimie, S., Zgambo, O., & Biggs, R. (2020). Planning for change: Transformation labs for an alternative food system in Cape Town South Africa. *Urban Transformations, 2*(1), 13. https://doi.org/10.1186/s42854-020-00016-8

Pfau, N., & Uhl, E. (2021). *B: Inter- and transdisciplinary teaching and learning within the Reallabor (Real-World Laboratory for Sustainable Mobility Culture)*. Stuttgart : Reallabor für nachhaltige Mobilitätskultur - Future City Lab. Stuttgart. https://doi.org/10.18419/opus-11756

Pohl, C., Krütli, P., & Stauffacher, M. (2018). Teaching Transdisciplinarity Appropriately for Students' Education Level. *GAIA - Ecological Perspectives for Science and Society, 27*(2), 250–252. https://doi.org/10.14512/gaia.27.2.14

Rieckmann, M. (2012). Future-oriented higher education: Which key competencies should be fostered through university teaching and learning? *Futures, 44*(2), 127–135. https://doi.org/10.1016/j.futures.2011.09.005

Rodríguez Aboytes, J. G., & Barth, M. (2020). Transformative learning in the field of sustainability: A systematic literature review (1999–2019). *International Journal of Sustainability in Higher Education, 21*(5), 993–1013. https://doi.org/10.1108/IJSHE-05-2019-0168

Rowe, D. (2007). Sustainability: Education for a Sustainable Future. *Science, 317*(5836), 323–324. https://doi.org/10.1126/science.1143552

Schneidewind, U. (2014). Urbane Reallabore – ein Blick in die aktuelle Forschungswerkstatt. *Pnd Online, 3*, 1–7.

Schneidewind, U., Singer-Brodowski, M., Augenstein, K., & Stelzer, F. (2016). *Pledge for a transformative science: A conceptual framework*. Wuppertal papers. http://nbn-resolving.de/urn:nbn:de:bsz:wup4-opus-64142

Schneidewind, U. (2020). *Hochschulen nach Corona – der urbane Campus als neues Organisationsprinzip von Lehre und Forschung?. Merton. https://merton-magazin.de/hochschulen-nach-corona-der-urbane-campus-als-neues-organisationsprinzip-von-lehre-und-forschung. retrieved on Dec 16, 2022*

Scholz, R. W., Lang, D. J., Wiek, A., Walter, A. I., & Stauffacher, M. (2006). Transdisciplinary case studies as a means of sustainability learning: Historical framework and theory. *International*

Journal of Sustainability in Higher Education, 7(3), 226–251. https://doi.org/10.1108/14676370610677829

Singer-Brodowski, M., Beecroft, R., & Parodi, O. (2018). Learning in Real-World Laboratories: A Systematic Impulse for Discussion. *GAIA - Ecological Perspectives for Science and Society, 27*(1), 23–27. https://doi.org/10.14512/gaia.27.S1.7

Singer-Brodowski, M. (2016a). Transformative Bildung durch transformatives Lernen Zur Notwendigkeit der erziehungswissenschaftlichen Fundierung einer neuen Idee. *ZEP Zeitschrift Für Internationale Bildungsforschung Und Entwicklungspädagogik, 39*(1), 13–17. https://doi.org/10.25656/01:15443

Singer-Brodowski, M. (2016b). Transformatives Lernen als neue Theorie-Perspektive in der BNE. *Im Wandel - Jahrbuch Bildung für nachhaltige Entwicklung*. Umweltdachverband GmbH. Vienna.

Stauffacher, M., Walter, A. I., Lang, D. J., Wiek, A., & Scholz, R. W. (2006). Learning to research environmental problems from a functional socio-cultural constructivism perspective: The transdisciplinary case study approach. *International Journal of Sustainability in Higher Education, 7*(3), 252–275. https://doi.org/10.1108/14676370610677838

Sterling, S., Glasser, H., Rieckmann, M., & Warwick, P. (2017). 10. "More than scaling up": A critical and practical inquiry into operationalizing sustainability competencies. In P. B. Corcoran, J. P. Weakland, & A. E. J. Wals (Eds.), *Envisioning futures for environmental and sustainability education* (pp. 153–168). Wageningen Academic Publishers. https://doi.org/10.3920/978-90-8686-846-9_10

Sterling, S., & Thomas, I. (2006). Education for sustainability: The role of capabilities in guiding university curricula. *International Journal of Innovation and Sustainable Development, 1*(4), 349. https://doi.org/10.1504/IJISD.2006.013735

Tejedor, G., Segalàs, J., Barrón, Á., Fernández-Morilla, M., Fuertes, M., Ruiz-Morales, J., Gutiérrez, I., García-González, E., Aramburuzabala, P., & Hernández, À. (2019). Didactic strategies to promote competencies in sustainability. *Sustainability, 11*(7), 2086. https://doi.org/10.3390/su11072086

Stibbe, A. (Ed.). (2009). *The handbook of sustainability literacy: Skills for a changing world*. UK: Green.

Trencher, G., Yarime, M., McCormick, K. B., Doll, C. N. H., & Kraines, S. B. (2014). Beyond the third mission: Exploring the emerging university function of co-creation for sustainability. *Science and Public Policy, 41*(2), 151–179. https://doi.org/10.1093/scipol/sct044

UN - United Nations. (2015). *Resolution adopted by the General Assembly on 25 September 2015* (A/RES/70/1; Transforming Our World: The 2030 Agenda for Sustainable Development). United Nations. https://undocs.org/en/A/RES/70/1

UNESCO. (2005). *United Nations Decade of Education for Sustainable Development (2005–2014): International Implementation Scheme* (ED/DESD/2005/PI/01).

Voytenko, Y., McCormick, K., Evans, J., & Schliwa, G. (2016). Urban living labs for sustainability and low carbon cities in Europe: Towards a research agenda. *Journal of Cleaner Production, 123*, 45–54. https://doi.org/10.1016/j.jclepro.2015.08.053

Wanner, M., Hilger, A., Westerkowski, J., Rose, M., Stelzer, F., & Schäpke, N. (2018). Towards a Cyclical Concept of Real-world Laboratories: A Transdisciplinary Research Practice for Sustainability Transitions. *DisP - the Planning Review, 54*(2), 94–114. https://doi.org/10.1080/02513625.2018.1487651

Wanner, M., Schmitt, M., Fischer, N., & Bernert, P. (2020). *Transformative Innovation Lab Handbook to facilitate student's real-world laboratory projects to promote transformative and transdisciplinary competencies*. Wuppertal Institut.

Wanner, M., Bernert, P., Fischer, N., & Schmitt, M. (2021a). Creación de espacios de aprendizaje y enseñanza para la investigación transformadora y transdisciplinar: El Laboratorio de Innovación Transformadora. *DIDAC*, *78 JUL-DIC*, 60–71. https://doi.org/10.48102/didac.2021..78_JUL-DIC.80

Wanner, M., Bernert, P., Fischer, N., & Schmitt, M. (2021b). Creating Learning and Teaching Spaces for Transformative and Transdisciplinary Research: The Transformative Innovation Lab. *DIDAC*, *78 JUL-DIC*, 49–59. https://doi.org/10.48102/didac.2021..78_JUL-DIC.83

WBGU - German Advisory Council on Global Change. (2011). *World in Transition – A Social Contract for Sustainability*. Wiss. Beirat d. Bundesregierung Globale Umweltveränderungen. https://www.wbgu.de/en/publications/publication/world-in-transition-a-social-contract-for-sustainability

Weiss, M., & Barth, M. (2019). Global research landscape of sustainability curricula implementation in higher education. *International Journal of Sustainability in Higher Education, 20*(4), 570–589. https://doi.org/10.1108/IJSHE-10-2018-0190

Wiek, A., Withycombe, L., & Redman, C. L. (2011). Key competencies in sustainability: A reference framework for academic program development. *Sustainability Science, 6*(2), 203–218. https://doi.org/10.1007/S11625-011-0132-6

Wittmayer, J., & Schäpke, N. (2014). Action, research and participation: Roles of researchers in sustainability transitions. *Sustainability Science, 9*(4), 483–496. https://doi.org/10.1007/s11625-014-0258-4

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4.5 Paper 5: Toward a modular evaluation approach of real-world laboratories

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Toward a modular evaluation approach of real-world laboratories: Findings from a literature review

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Abstract

The number of real-world laboratories (RwLs) as research settings to address sustainability problems by using collaborative and experimental approaches has been growing steadily over the past years. RwLs are widely considered promising settings for the production of action-orientated knowledge in order to contribute solving wicked real-world problems such as climate change. However, empirically tested evaluative approaches are rare. We argue that evaluations within RwLs are crucial for ensuring high-quality and impactful research, amplifying tested solution approaches, and driving innovative forms of transdisciplinary collaboration. At the same time, evaluations within RwLs seem difficult due to the multilayered structure of RwLs. In order to provide guidance regarding the evaluation in RwLs- for researchers and practitioners, we conduct a scoping literature review that encompasses a comprehensive understanding of RwLs. We identify studies in which the specific components of RwLs lab context, experiments, and interventions—are empirically evaluated. Drawing on our findings, we derive different types of approaches that can be used for evaluating RwLs in practice. Based on how labs, experiments, and interventions in real-world settings have been evaluated in practice so far, we suggest to design evaluation approaches depending on (1) what should exactly be evaluated in the specific RwL, (2) for which purpose, and (3) by whom. We hope this targeted, modular evaluation approach based on evaluation types found in literature will help actors engaged in RwLs to make evaluations more feasible and impactful.

Key words: real-world laboratories; evaluation; transdisciplinary sustainability research; RwLs; transformation research

1. Introduction

In light of sustainability challenges, such as climate change, loss of biodiversity, or problems associated with ongoing and rapid urbanization, science is asked to not only describe and analyze such problems (Wiek and Lang 2016) but also contribute transforming them through the codevelopment of action-oriented knowledge: i.e. the 'knowledge how' (Caniglia et al. 2021; Hölscher et al. 2021). Sustainability science and especially the field of transdisciplinary (td) sustainability research have brought forward a number of diverse approaches to generating such knowledge through different kinds of interventions (Bernstein et al. 2016; Wiek and Lang 2016; Taïbi, Antheaume and Gibassier 2020). In this context, transformative research in real-world laboratories (RwLs) has gained significant momentum (Wanner et al. 2018; Räuchle 2021).

As part of the ongoing discussions around definitions and methods of RwL research (Parodi 2019; Wagner and Grunwald 2019; Bergmann et al. 2021), the essential need for evaluation of and in these research settings has been pointed out repeatedly (Rose, Wanner and Hilger 2019). The evaluation of RwLs and tested sustainability solutions are crucial in terms of scaling-up and amplifying tested sustainability options (Lam et al. 2020a; Lang and Wiek 2022). At the same time, RwLs are described as learning environments. In these ways, the evaluation processes become important not only when assessing the approach to a sustainability problem or discussing related dissemination approaches but also when focusing on learning processes in RwLs (Singer-Brodowski, Beecroft and Parodi 2018).

Despite the importance of evaluations of RwLs, the actual implementation of evaluative approaches is considered to be difficult

(Schäpke et al. 2017). This is partly due to the complex structure of RwLs and their embeddedness in diverse contexts. If one follows common definitions, RwLs are research settings where experiments in the sense of contextualized interventions are conducted (Schneidewind 2014). RwLs comprise aspects of lab design, experiments, and interventions. We therefore argue that in the context of RwL evaluations these different levels as well as their interactions need to be recognized. We use the term levels to disambiguate an RWL's context, i.e. its social structure and the experiments and interventions carried out by and typically within the lab. The levels therefore follow no hierarchical order and could be seen as nested in each other. Depending on the focus of the evaluation, the emphasis may be on one particular level or several. Accordingly, evaluative approaches can be designed in a variety of ways. While some theoretical approaches are available to evaluate RwLs (Bergmann et al. 2021) and associated real-world experiments (Luederitz et al. 2017; Williams and Robinson 2020), little is known about how evaluation has been conducted in practice. To the best of our knowledge, there are no overview studies yet that outline how evaluations of RwLs and their components were empirically conducted. However, such an overview could inform the practices when faced with the task of evaluating an RwL or individual elements of it.

While RwL research has gained increasing attention in sustainability science, similar approaches to test and evaluate real-world solutions within a defined context have been used in other fields for a long time. In the field of public health, for instance, there are numerous approaches to real-world experiments and interventions and how they can be evaluated (Franzkowiak 2015). Looking at these fields as well and learning from their practices seems to be very promising to inform RwL research.

In this article, we therefore take a comprehensive approach in two ways. On the one hand, we adopt a comprehensive view of RwLs. We acknowledge the multidimensional structure of this research setting with the levels 'lab context', 'experiment', and 'intervention'. Second, we take a comprehensive approach in including studies across academic disciplines. In this way, we follow the transdisciplinary understanding of RwLs (Wanner et al. 2018). RwLs deal with a variety of topics on real-world (sustainability) problems which can be addressed by several disciplines as 'wicked problems'. Noting this, we do not limit the number of scientific fields that provide examples for empirical evaluations of labs, experiments, and interventions in real-world contexts. RwLs aim to produce socially robust knowledge by integrating knowledge from various scientific and societal sources (Huning, Räuchle and Fuchs 2021). This research paradigm has to be maintained in evaluation processes in RwLs as well. Knowledge on evaluating components of RwLs can be derived from multiple scientific fields.

We aim to analyze how empirical evaluations have been conducted so far and what can be learned for future evaluation of (aspects of) RwLs. For this, we systematically collect, analyze, and structure studies that evaluate (1) labs, (2) experiments, or (3) interventions in real-world settings. In doing so, an overview is given on how practical evaluation has been carried out at these different levels. This article aims to answer the following research questions: How has evaluation of interventions, experiments, and lab designs been conducted in different academic disciplines? What methods have been used for evaluation? What insights and recommendations for action can be gained from these evaluation studies regarding the evaluation of an RwL and its levels?

We first look at the terms 'intervention', 'experiment', and 'lab'. In doing so, we approach the question of how these terms are related to each other in RwLs (Section 2). In the next section, we describe the methodological approach used in our study. We present how studies have been identified and selected. Subsequently, we outline how the extraction of the studies took place. In the fourth section, we provide an overview of the identified studies. We then discuss the definitions offered by the authors of the identified studies. The main findings are presented in the sixth section. This results in a typology of the evaluation approaches that helps identifying which evaluation study might be helpful for someone's own RwL-based research. The article concludes with a discussion.

2. Acknowledging structure: a comprehensive perspective on lab, experiments, and interventions

When it comes to evaluation, we suggest to acknowledge the different components of an RwL, as suggested in literature. The concept of RwLs is often explained by using the concept of experiments (Beecroft and Parodi 2016; Parodi 2019; von Wirth and Levin-Keitel 2020). These experiments are referred to as real-world experiments (Schneidewind 2014) or transformative experiments (Parodi et al. 2016). Rogga, Zscheischler and Gaasch (2018) assume '(t)he core methodology of conducting an RwL appears to be experimentation in social contexts'. Interventions are defining aspects of the experiments in RwLs (Schneidewind 2014), as experiments primarily consist of interventions (Caniglia et al. 2017; Schäpke et al. 2017). Interventions are referred to as 'actions that can induce change in the objects investigated' (Caniglia et al. 2017). An established understanding is that real-world experiments use interventions to generate evidence on sustainability solutions. These experiments are conducted in RwLs as research settings, which leads to an intertwined structure pictured below (Figure 1). This understanding is crucial to respond to the different foci of evaluative approaches found in the literature.

Although lab, experiment, and intervention are key concepts of td sustainability research, less attention is given defining these terms exactly. While clear definitions of these terms would be helpful for better understanding the existing research projects following an RwL approach, we recognize a lack of clarity in the literature with regards to the disambiguation of the terms lab, experiment, and intervention. For the purpose of our review, we therefore follow the definitions used by the authors of the papers we included in our study.

3. Methods

3.1 Scoping literature review

The scoping review conducted here is based on the Joanna Briggs Institute methodology for Scoping Reviews (Peters et al. 2015). Scoping reviews follow a similar approach to systematic reviews. But they answer broader questions that go beyond those related to the effectiveness of treatments or interventions (Munn et al. 2018). As Munn et al. suggest, Scoping Reviews are especially suitable for examining 'how research is conducted on a certain topic or field'. Similar to systematic reviews, in scoping reviews, the preferred reporting items and the transparent reporting as well as the meta-analyses 'PRISMA' flowchart is used (Peters et al. 2015).

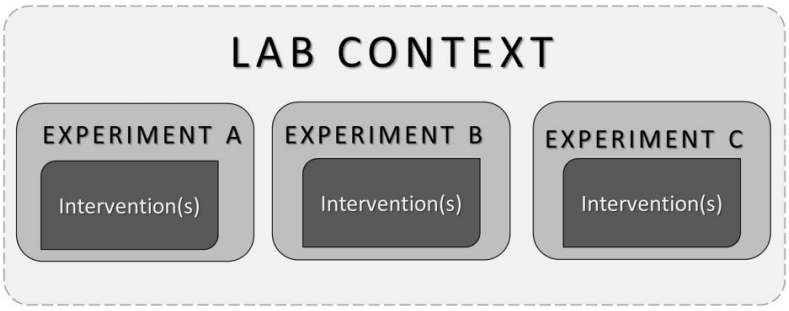

Figure 1. Three-layered understanding of an RwL.

Table 1. List of search themes, and terms used for the search strategy

Search themes	Search terms	Search strategy
1 Labs	'real-world lab*', 'innovation lab*', 'home lab', 'transition lab*', 'urban laborator*',[a] 'campus lab', 'living lab*'	Title/abstract
2 Experiment	'real-world experiment*', 'transition experiment*', 'sustainability experiment*', 'niche experiment*', 'socio-technical experiment*', 'urban experiment*'	Title/abstract
3 Intervention	'real-world intervention*'	Title/abstract
4 Evaluation	Evaluation, evaluative	Title/abstract

[a]In order to avoid results regarding urban labor market, the ending laborator* was used.

3.2 Search strategy

This scoping review aims to systematically identify studies in which different types of laboratories, experiments, and interventions have been empirically evaluated. Studies in which evaluation concepts have just been theorized are excluded. Only studies in which the process of evaluation has been explained methodologically are included in the review.

The search was performed in Ebsco, Web of Science, and Scopus with date of publication no later than September 2020. We combined four search themes with Boolean Operators (Table 1). Search Themes 1–3 have been connected with an OR to build Block A. Block A is combined with an AND with Search Theme 4.

3.3 Study selection

Following the literature search, the screening procedure was based on predefined inclusion and exclusion criteria and consisted of two consecutive phases. First, titles and abstracts were screened to exclude articles that did not meet the eligibility criteria. In a second step, full texts were reviewed. Eligible studies included articles that

1. were peer-reviewed journal articles
2. written in the English language
3. reported on the evaluation of a specific lab, experiment, or intervention
4. were empirically conducted.

A total of 1,340 articles were retrieved during the database search. After removal of duplicates, 925 articles were screened by title and abstract. 128 articles were included in the full-text screening. Where it was not clear from the title and abstract alone if the study met the inclusion criteria, the full text of the study was retrieved to enable the second stage of screening. The inclusion criteria were met by 27 articles (Figure 2).

3.4 Data extraction

Data were extracted into an *a priori* developed and pretested extraction form. A random sample of 10% of the data extraction was done by two reviewers independently for quality reasons. Discrepancies were resolved by discussion, with the involvement of a third reviewer if necessary.

The extraction form consists of three parts. One part includes codes giving an overview of the studies (e.g., author, year, evaluation object divided in intervention, experiment, and lab and used definition, country where the object is located). In the second part, we consider central TD research discourses regarding evaluation (codes TD1 and TD2). The third division of the extraction form relates to general premises of evaluation research (codes E1 and E2). TD research considerations and general evaluation aspects have overlaps. One regarding methods can be seen in Code TDE. Bellow, the codes TD1, TD2, TDE, E1, and E2 are explained in more detail.

3.4.1 TD1: The role of the evaluators

In TD research contexts, researchers cover a broad spectrum of roles (Schneidewind and Singer-Brodowski 2015; Rose, Wanner and Hilger 2019; Verwoerd et al. 2020). For evaluating RwLs, it is considered important to constantly reflect on the evaluator's roles (Huning, Räuchle and Fuchs 2021). Wittmayer and Schäpke (2014) distinguish five ideal-type roles for researchers in process-oriented sustainability science. The ideal-type reflective scientist, self-reflexive scientist, knowledge broker, process facilitator and change agent differ in terms of ownership, action, and power. The intensity with which they drive transformative research, and the ways in which they are involved in it, varies considerably (Figure 3).

Based on these ideal types, we distinguish which role the evaluators in the identified studies most closely correspond to. We coded

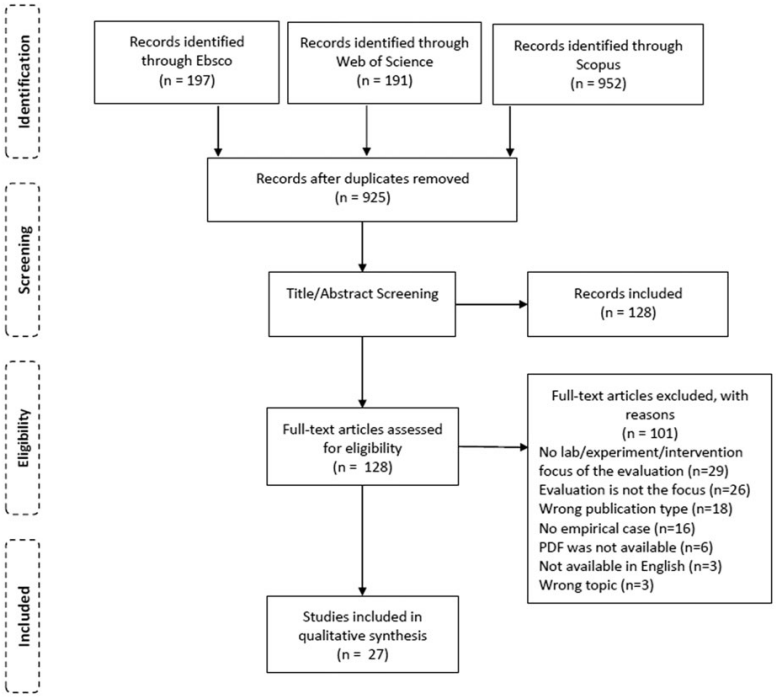

Figure 2. Study flow diagram according to PRISMA statement (Page et al. 2021, modified).

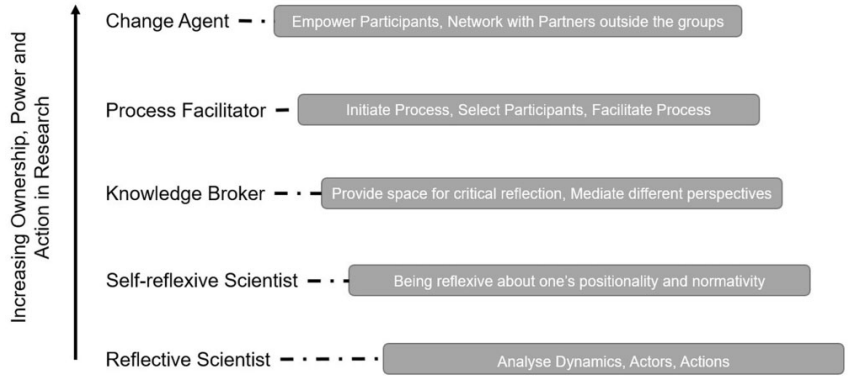

Figure 3. Ideal-type roles of researchers (Wittmayer and Schäpke 2014, modified).

passages of text in the studies that indicated which of the five ideal types the evaluators most closely matched.

3.4.2 *TD2: Participants involvement in the evaluation*

Seebacher, Alcántara and Quint (2018) emphasize the importance of practitioners' involvement for the success of RwLs. Similarly, Rose, Wanner and Hilger (2019) argue with respect to the evaluation of RwLs. Like other authors in the TD context, they suggest reintegration of knowledge and formative evaluations with the involvement of both science and practice as suitable paradigm of RwL research. We use the approach of Stauffacher et al. (2008) which is based on Arnstein's (1969) ladder of citizen participation to distinguish different intensities of participants involvement in evaluation. We use the term participants involvement in order to describe the way nonscientific actors are in involved in carrying out evaluations within the specific labs, experiments, and interventions. Stauffacher et al. (2008) demarcate different intensities of participation in transdisciplinary research processes from a science perspective. The proposed distinction of participants' involvement consists of information, consultation, cooperation, collaboration, and empowerment (Figure 4).

3.4.3 *TDE: Methods used*

There is an ongoing discussion on suitable methods in td research, especially in evaluating RwLs (Defila and Di Giulio 2019; Hölscher et al. 2021). At the same time, the methodology chosen to evaluate is a central component for all kinds of evaluative approaches (Döring 2019). Therefore, we will extract the entirety of methods the authors chose for the evaluation of labs, experiments, and interventions.

3.4.4 *E1: Criteria*

In addition to evaluative methods used, a key component of evaluation studies is criteria that determine what exactly is being evaluated (Heinrich 2018; Döring 2019). As chosen criteria are highly contextualized and depend on the purpose of the evaluation (OECD DAC Network on Development Evaluation (EvalNet) 2021), we decided not to analyze what criteria were exactly chosen, but focus if the chosen criteria were linked to literature or were developed based on the case characteristics. Accordingly, we code if the evaluation studies rely on theory-based or exploratory criteria.

3.4.5 *E2: Temporality*

A common distinction to differentiate evaluation studies is the division into summative (usually ex-post) and formative evaluation (usually during the entire process) (Döring 2019). Summative evaluation pursues the goal of a final assessment. Formative evaluation provides results that are intended to serve the improvement of the object of evaluation. Since we deliberately kept our search for studies open, and studies from disciplines such as education science are to be expected, we also introduced Pre–Post assessment (Sanders 2019). Here, measurements were taken before the evaluation objective was carried out and again afterwards. Thus, the before–after condition is compared.

4. Overview of the identified studies

A total of 27 articles published from 2007 to 2020 were included in the final analysis. The fields of study include information and technology (n = 8), public health and health care (n = 7), sustainability science (n = 5), political and social sciences (n = 5), and educational science (n = 2). Studies were assigned to specific disciplines based on the journal in which the studies were published. All studies have in common that they are limited to only one evaluation object. This means that the studies focus on either lab(s), experiment(s), or intervention(s).

Identified studies from the field of educational science only covered evaluations on the intervention level. Given our search query as well as the inclusion and exclusion criteria, we developed in Section 3, the discipline of sustainability science emerges as the only discipline that comprise studies that focused on the evaluation of all three objectives interventions, experiments, and labs (Table 2). The majority of the identified studies concentrate on labs (n = 15), followed by interventions (n = 7) and experiments (n = 5).

In seven studies, the authors evaluated not only one specific case but also focused on several labs resp. experiments in real-world settings. In six studies, multiple labs were evaluated. Hubeau, Marchand and van Huylenbroeck (2017) evaluated several experiments within one study.

The evaluation studies that were identified focused on labs, experiments, and interventions conducted in 24 countries. The majority of the 27 identified studies evaluated labs, experiments, or interventions that were located in Europe. Only about one-fourth of the evaluation studies focused on research objects situated in countries of the Global South.

The labs, experiments, and interventions in the identified studies cover a broad spectrum of thematic areas (Table 3).

5. Definitions used

In this article, we analyze studies that evaluate labs, experiments, and interventions in real-world contexts, i.e. research that is not conducted in closed lab settings. As described before, the terms interventions, experiments, and lab lack commonly used definitions. Therefore, we describe the definitions the authors have been used in the 27 identified studies. While differences regarding the conceptualizations are apparent and can be attributed to the various disciplines present in our sample, across the cases (within the three groups of labs, experiments, and interventions), we consider the conceptual understandings to be close enough for a comparison. Our analysis carries a notion of comparatively aggregating and structuring methods and approaches of evaluation of an emerging research practice that spans disciplinary boundaries.

Table 2. Overview of the 27 identified studies

Discipline	Lab	Experiment	Intervention	Total
Information and Technology	6	2	–	8
Public Health/Health Care	3	–	4	7
Sustainability Science	2	2	1	5
Political Science	4	1	–	5
Educational Science	–	–	2	2
Total	15	5	7	27

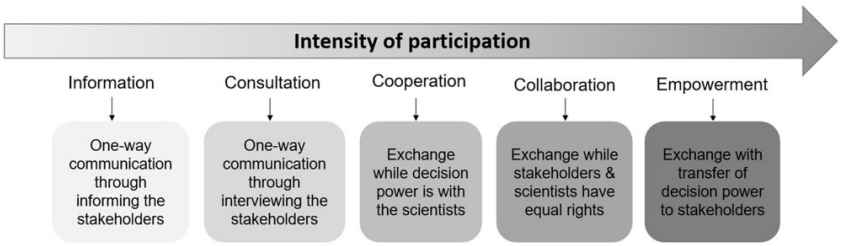

Figure 4. Intensity levels of participation (Stauffacher et al. 2008, modified).

5.1 Interventions

Studies, in which interventions were evaluated, rarely offered definitions of interventions in real-world settings. One of the occasional definitions that can be found was provided by Nastasi and Hitchcock (2009) in the field of public health. They base their understanding of interventions on a concept from psychology that was originally developed by Schensul and Trickett (2009). Here, an intervention is described as a 'specific strategy designed to incur behavioral or social change in individuals, groups or larger structures or settings'. For their research, Nastasi and Hitchcock specified the intervention they evaluated as *multilevel intervention* that aims to incur (or cause) change at two or more levels.

Not only the explanation by Caniglia et al. (2017) introduced in Section 2 but also the approaches within the other six intervention-based studies identified here, match this definition, irrespective of their different disciplines. In all studies evaluating interventions, a specific strategy is tested in order to incur behavioral or social change, whether in individuals (Massey, Boroughs and Armstrong 2007; Kaida and Kaida 2015; McClain Burke et al. 2019), groups (Bellei 2013; Dubuy et al. 2014), or both in the form of multilevel intervention (Wood et al. 2013).

5.2 Experiments

Studies evaluating experiments in real-world contexts provided more exact definitions of terms related to experimentation. The studies differentiated between transition experiments (Porter, Claassen and Timmermans 2015), sustainability experiments (Hubeau, Marchand and van Huylenbroeck 2017), collaborative experimentation (Andersson 2015), experiments (Doyon et al. 2020), and real-world experiments (Cats, Reimal and Susilo 2014). Nevertheless, despite their specific terminology and that these studies come from different disciplines, a common understanding of what constitutes experimentation in real-world contexts is apparent.

Transition experiments were described as 'innovative, small-scale experiments that are conducted in practice to address persistent societal problems, based on the core notion that sustainable development requires searching, learning, and experimenting. Hence, transition experiments are not a goal in themselves, but an instrument to explore and learn about sustainable ways of meeting societal needs, for current and future generations' (Porter, Claassen and Timmermans 2015).

For Hubeau, Marchand and van Huylenbroeck (2017), a *sustainability experiment* means 'a highly innovative initiative to improve the sustainability state of the whole chain through new arrangements of collaborations'.

Doyon et al. (2020) adopt Luederitz' et al. (2017) general definition for *experiments* in the field of political science as 'small-scale initiatives that are research endeavors as they produce evidence regarding both the persistent unsustainability of dominant regimes and the possible solutions that are replicable, transferable, and scalable to society at large'.

In terms of literature references and accuracy, the concepts adopted in the other two studies differ greatly from the three already mentioned. Andersson (2015) defines collaborative experimentation in the field of sustainability science by stressing that 'the scope of experimentation [...] goes beyond mere technology demonstration, with the process of inquiry in itself becoming equally as important as its specific outcomes'. Cats, Reimal and Susilo (2014) provide no definition at all for the experiment they have evaluated in the field of information/technology.

5.3 Labs

The authors of the studies that evaluated (different forms) of labs in real-world contexts mostly provided definitions for the specific lab approach that was focus of the evaluation. The framing of labs consisted of living lab, policy lab, public innovation lab, urban living lab, and rehabilitation living lab.

Regarding the term living lab, we can see minor differences match the different foci of the analyzed studies: They all share a strong recognition of the real-world settings, in which living labs operate. Some of the authors highlight the innovation aspect. Within their definitions of living labs, the authors emphasize that something innovative is cocreated and validated within the labs (Brankaert, den Ouden and Brombacher 2015; Ley et al. 2015; Paskaleva and Cooper 2018; Ondiek and Moturi 2019; Plaisier et al. 2019; Mačiulienė and Skaržauskienė 2020). Apart from that, the collaboration and learning between different stakeholders coming from different institutional settings are stressed (Falk-Kessler, Benson and Witchger Hansen 2007; Brankaert, den Ouden and Brombacher 2015; van Geenhuizen 2018; Plaisier et al. 2019; Mačiulienė and Skaržauskienė 2020, Mastelic, Sahakian and Bonazzi 2015). These cited studies cover a wide range of academic disciplines. They originate from the fields of information and technology, sustainability science, political science, and public health/health care.

Most of the authors using the term Living Lab provided literature-based definition. The term policy lab used in the study from Whicher and Crick (2019) has no literature references as well. They describe policy labs as 'multi-disciplinary government teams developing public services and public policies using innovation methods to engage citizens and stakeholders at multiple stages of the development process'. This understanding contrasts public innovation labs, urban living labs, and rehabilitation living labs. The latter two are not explained in general terms in the associated studies and are very case-specific.

6. Findings

In the following, we present the main findings of our study according to the codes defined in Section 3.4. All subfindings are differentiated for the specific components of RwLs (Section 2). This means we compare lab, experiment, and intervention-related evaluation studies according to the above-mentioned aspects. We reveal in which categories evaluation studies regarding lab, experiment, or intervention resemble and differ.

6.1 The role of evaluator(s)

Based on ideal-type roles for researchers that Wittmayer and Schäpke (2014) developed, we distinguish which role the evaluators in the identified studies most closely represented. In the majority of the studies analyzed, the evaluators did not operate like researchers instantiating and driving the intervention, lab, or experiment. In 20 of the studies, the evaluators rather took on the role of observing researchers, acting most likely as ideal-types reflective and self-reflexive scientists. They evaluated from an observer role and interpreted results. In several cases, the evaluators representing the ideal-type reflective scientists conducted research from external

Table 3. Overview of the 27 identified studies, sorted according to the level of implementation

Authors (year)	Study focus	Country setting	Discipline	Topical area
Bellei (2013)	Intervention	Chile	Educational Science	Intervention in low-performing schools in Chile to increase academic achievement.
Dubuy et al. (2014)	Intervention	Belgium	Public Health/Health Care	Intervention promoting positive dietary habits and physical activity for socially disadvantaged children.
Kaida and Kaida (2015)	Intervention	Sweden	Sustainability Science	Real-world intervention policy of traffic congestion charging that impacted various pro-environmental behaviors.
Massey, Boroughs and Armstrong (2007)	Intervention	USA	Educational Science	Two programs that address violent and disruptive behaviors in schools.
McClain Burke et al. (2019)	Intervention	Mozambique	Public Health/Health Care	Economic and social empowerment intervention to reduce girls' vulnerability to HIV in rural Mozambique.
Nastasi and Hitchcock (2009)	Intervention	India	Public Health/Health Care	Evaluating multilevel interventions, using as an example a public health project
Wood et al. (2013)	Intervention	Australia	Public Health/Health Care	Use hand drumming as medium enabling participants in schools to explore connections between making music together as a group and the development of healthy relationships.
Andersson (2015)	Experiment	Uganda	Sustainability Science	Use of human urine as a crop fertilizer within an experiment with local farmers in Uganda.
Cats, Reimal and Susilo (2014)	Experiment	Estonia	Information and Technology	Test Fare-free public transport (FFPT) in Tallinn.
Doyon et al. (2020)	Experiment	Australia	Political Science	The Council Alliance for a Sustainable Built Environment (CASBE) as an urban experiment seeking to influence development and planning decisions.
Hubeau, Marchand and van Huylenbroeck (2017)	Experiment	Belgium (case studies)	Sustainability Science	The developed Sustainability Experiment Systems Approach (SESA) is tested on case studies of sustainability experiments in the agri-food system in Flanders.
Porter, Claassen and Timmermans (2015)	Experiment	The Netherlands	Information and Technology	The Framework by Bosch-Ohlenschlager is applied to evaluate the WGM program and the Eenhoorn project as transition experiment.
Brankaert, den Ouden and Brombacher (2015)	Lab	The Netherlands	Information and Technology	Lab cases that take place in the homes of people with dementia and their caregivers.
Dabaieh et al. (2019)	Lab	Egypt	Information and Technology	Testing Trombe Walls in Sinai, Egypt, as a retrofitting solution in a remote desert area in a real urban living lab.
Falk-Kessler, Benson and Witchger Hansen (2007)	Lab	USA	Public Health/Health Care	Creating a living lab in one study course at university to gain an insight how an experimental lab can help students learning.
Kovács (2016)	Lab	Austria, Hungary	Political Science	Introducing the evaluation methodology of Living Labs in the field of renewable energy industry.
Ley et al. (2015)	Lab	UK, Germany	Information and Technology	Evaluating and Comparing two 4-year Living Lab projects within the domain of Social TV.
Mačiulienė and Skaržauskienė (2020)	Lab	Lithuania, Portugal, Italy, Belgium	Sustainability Science	Research how Living Labs are being applied as a mechanism to open up the innovation processes through online and offline collaborations between the urban policymakers, nonprofit organizations, citizens and other stakeholder groups.
Mastelic, Sahakian and Bonazzi (2015)	Lab	Switzerland	Information and Technology	Explore how Living Labs might be evaluated based on criteria that build on the current efforts of the ENoLL.

(continued)

Table 3. Continued

Authors (year)	Study focus	Country setting	Discipline	Topical area
Mazer et al. (2015)	Lab	Canada	Public Health/Health Care	The RehabMaLL is designed to study how to best address the needs of persons of all ages with physical, sensory and cognitive disabilities.
Ondiek and Moturi (2019)	Lab	Kenya (case studies)	Information and Technology	Find out why the Living Labs in Kenya are not sustainable.
Paskaleva and Cooper (2018)	Lab	UK, Belgium, Germany, Italy	Information and Technology	Development and trialing of a novel Co-evaluation Framework, indicators and reporting categories, used to support the co-production of smart city services in an EU-funded project.
Plaisier et al. (2019)	Lab	Nigeria	Sustainability Science	Reducing postharvest losses in tomato value chains in Nigeria to improve food security in the country.
Ramey et al. (2019)	Lab	Canada	Public Health/Health Care	Innovate example of youth engagement for youth health, findings and challenges of this.
van Geenhuizen (2018)	Lab	The Netherlands, Denmark, Canada	Political Science	The study draws on the extended literature on living labs, general literature on evaluation and boundary-spanning or intermediation, and on six (four concrete) case studies of living labs.
Whicher and Crick (2019)	Lab	UK	Political Science	Northern Ireland Public Sector Innovation Lab (iLab) is evaluated.
Zurbriggen and González Lago (2019)	Lab	Uruguay	Political Science	Development of an experimental evaluation tool for public innovation as part of an action-research process in a laboratory within the Uruguayan Government.

positions and were not involved in the intervention, experiment, or lab design implementation at all.

Depending on whether the evaluation focus was on labs, experiments, or interventions, we notice differences with regards to the role evaluators take on (Table 4). Evaluators focusing on interventions in the selected studies, only acted as reflective (n = 5) or self-reflexive scientists (n = 2). They did not shape the interventions they evaluated. In these studies, the evaluators most likely took the roles of 'traditional' researchers. Evaluators focusing on experiments and labs represented a more diverse sets of roles. Two out of five evaluation studies with experiment focus were conducted by researchers that took reflective scientist roles (Cats, Reimal and Susilo 2014; Hubeau, Marchand and van Huylenbroeck 2017). In one study, the evaluators acted as self-reflexive scientists (Doyon et al. 2020). In one experiment evaluation, the evaluators acted as knowledge broker (Porter, Claassen and Timmermans 2015). Andersson (2015) took a process facilitator role in evaluating an experiment. Lab evaluation studies were conducted by researchers representing all ideal-type roles. It stands out that the ideal-type change agent, which is involved most intensely in the research process, is only recognizable among evaluators involved within labs (Falk-Kessler, Benson and Witchger Hansen 2007). In this case, the lab was created, modified as well as proactively evaluated by the authors (together with the students), led by the goal to actively confront a real-world problem.

6.2 Criteria used

We grouped the criteria that were used in the evaluation of the specific labs, experiments, or interventions in the 27 selected studies. We examined if the authors referred to a theoretical approach in order to derive criteria for their specific evaluation or if they used an exploratory approach. If authors started implementing their studies based on theory-based criteria and then supplemented them with exploratory criteria, these studies were also assigned to applying theory-driven criteria. About half of the studies draw on existing theoretical concepts (n = 14), for example SWOT analysis (Andersson 2015). In 13 studies, criteria were chosen for the evaluation that were not linked to theoretical approaches. They were more or less exploratory (e.g., Falk-Kessler, Benson and Witchger Hansen 2007).

Here, we took a look on differences between labs, experiments, and interventions as well. Out of seven identified intervention evaluation studies, five studies used exploratory criteria. Experiments were more often evaluated using theory-based criteria. Only in one evaluation study focusing on an experiment, exploratory developed criteria were applied (Cats, Reimal and Susilo 2014). Within the labs evaluated, theoretically derived and exploratory criteria were used in roughly equal numbers (Table 5).

In the studies reviewed here, the type of criteria used for evaluation did not influence whether authors make practical recommendations for the audience. In most of the studies that analyzed not only one but several cases, theory-based criteria were applied within the evaluation. In five out of six studies that evaluated several labs, the evaluators used theory-driven criteria (Kovács 2016; Paskaleva and Cooper 2018; van Geenhuizen 2018; Ondiek and Moturi 2019; Mačiulienė and Skaržauskienė 2020). In the study by Hubeau, Marchand and van Huylenbroeck (2017), in which several experiments were evaluated, the authors used a theory-based category scheme for the evaluation, too.

6.3 Methods used

In total, 14 evaluation studies applied a qualitative approach. In seven studies, a quantitative approach was used. Six studies were

Table 4. Ideal-type roles of evaluators by level of implementation

Focus of evaluation	Reflective scientist	Self-reflexive scientist	Knowledge broker	Process facilitator	Change agent
Intervention	5	2	–	–	–
Experiment	2	1	1	1	–
Lab	7	3	2	2	1

Table 5. Criteria for evaluation by level of implementation

Focus of evaluation	Theory-driven criteria	Exploratory criteria
Intervention	2	5
Experiment	4	1
Lab	8	7

conducted utilizing a mixed-methods approach (Massey, Boroughs and Armstrong 2007; Nastasi and Hitchcock 2009; Mazer et al. 2015; Kovács 2016; Plaisier et al. 2019; Mačiulienė and Skaržauskienė 2020). Mixed-methods approaches refer to the combination of qualitative and quantitative methods (Flick 2011).

Methodological approaches differ depending on whether labs, experiments, or interventions were evaluated (Table 6). In the identified studies, interventions never were evaluated using a purely qualitative approach. In contrast, the evaluation of labs and experiments was most often carried out using purely qualitative data.

In most of the studies more than one method was used to evaluate the corresponding intervention, experiment, or lab. Nevertheless, few authors explicitly designate this approach as triangulation or mixed-methods (exceptions are Doyon et al. 2020; Falk-Kessler, Benson and Witchger Hansen 2007; Hubeau, Marchand and van Huylenbroeck 2017; Mazer et al. 2015; Nastasi and Hitchcock 2009; Zurbriggen and González Lago 2019).

Over the 27 studies, multiple methods were used for the evaluations. They range from traditional surveying methods such as interviews to rare ones, like reflective journals and diaries. Methods for data gathering as well as methods for data analysis that were used in the identified studies are listed below (Table 7).

Previously, we showed that methodological approaches (qualitative, quantitative, mixed-methods) in evaluations differed depending on what is being evaluated. This is also evident if we take a closer look at the methods that were used. In evaluation studies that focus on interventions, descriptive statistics approaches were used much more often. In general, interventions were evaluated using a less diverse set of methods, compared to experiments and labs (Figure 5).

6.4 Temporality

Concerning when the evaluation in the identified studies was performed, differences can be seen regarding the foci of evaluation studies. Evaluations of labs were exclusively formative. A different picture emerges for the evaluations of interventions and experiments. Although more than half of these were also evaluated formatively, there are cases of pre–post assessments and ex-post evaluations as well (Table 8).

The aspects of methodological approach and temporality of evaluation seem to be related. Evaluations using only qualitative data were conducted formatively in most cases (Table 9). Qualitative evaluation studies never followed a pre–post approach and only in a few cases an ex-post investigation. The two qualitative evaluation studies following an ex-post approach only focused on experiments (Andersson 2015; Doyon et al. 2020).

6.5 Involvement of participants in evaluation

After the discussion of who (role of evaluator) evaluated how (criteria, methods) and at what point in time, we focus on how participants of the lab, experiment, and intervention were involved in the evaluation. As described before, by the term participants, we mean non-scientific actors who were involved in the evaluation of the specific interventions, experiments, and lab. Depending on the evaluation focus, the involvement of participants in the evaluation differs. Lab evaluations particularly stand out. In the context of experiment and intervention evaluation studies, there is at least one case each in which participants were only informed about the evaluation. In these examples, there was no exchange on how the participants personally experienced the intervention (Bellei 2013) or the experiment (Cats, Reimal and Susilo 2014). According to the model of Stauffacher et al. (2008), this represents the level of information (Section 3.4). In the labs that were evaluated, the participants were never only informed about the evaluation. The participants were involved in the lab evaluation more intensely. In evaluation studies with lab focus, the lowest form of involvement was consultation. The highest form of involvement, empowerment, was only perceivable within lab evaluations. In evaluation studies regarding interventions or experiments, participants were never involved to this high degree (Table 10).

The methodological approach chosen to evaluate and the involvement of participants in the specific evaluation are closely related. Qualitative schemes do not include evaluations in which participants were only involved on the lowest level, i.e. information. Qualitative evaluations were conducted with a higher degree of participants involvement than quantitative evaluation studies (Table 11).

Lastly, we address the link between participants involvement and ideal-typical roles. Evaluators coded as reflective scientists or self-reflexive scientists enable any form of participants involvement in the studies we identified. The situation is different for evaluators acting as process facilitators or change agents (Table 12). The studies show that evaluators representing these ideal types tend to involve participants more: They evaluate together on levels of collaboration (Falk-Kessler, Benson and Witchger Hansen 2007 for labs; Andersson 2015 for experiments) and empowerment (Plaisier et al. 2019; Ramey et al. 2019 both for labs).

7. Designing a typology of evaluation studies

Based on our findings in Section 5, we classified the studies according to the approach of Kluge (2000) in different types. Kluge describes four steps for the empirically grounded construction of types in qualitative social research. After having the relevant comparison dimension between studies already established within our extraction of the identified studies (Section 3.4), we grouped the cases and searched for empirical regularities. As step 3, we analyzed

Table 6. Methodological approach used for evaluation by level of implementation

Focus of evaluation	Qualitative research	Mixed-methods research	Quantitative research
Intervention	–	2	5
Experiment	4	–	1
Lab	10	4	1

Table 7. Frequency of the methods used in the evaluation studies

Interviews	20
In-depth, semistructured, unstructured, expert, individual, random walking, follow-up, quantitative, key informant and telephone interviews	
Descriptive statistics	17
Logistic regression model, regression-based difference-in-difference approach, repeated measures analysis of variance, multivariate analysis, matching procedure/control and intervention group, before-after analysis of data, exploratory factor analysis, secondary data analysis, Cramer-index	
Field observations and notes	15
Visual observations, summaries of meetings, written record of operations, output of workshops and conference meetings, case records, monitoring protocol, written feedback, participant observation, self-report measure/ethnographic survey	
Questionnaires	12
Self-administered, baseline and follow-up, structured, online and hard copy questionnaires	
On site monitoring/testing	9
Temperature and humidity measurements, measurement tool (impact on weight and quality), data log that measured the activity, probe method, digital monitoring, medical testing for STIs (sexually transmitted infections), Rosenberg self-esteem scale, Social Development Program Evaluation for each participant, field tests	
Literature review	8
Collection and analysis of web data, desk-based research, analysis of related policy documents, extensive, systematic literature reviews	
Workshops	7
Evaluation workshop, design game workshop, timeline workshop, eye-opener workshop, participative visioning and back-casting,	
Group discussions	7
Focus Group, Reflection	
Systematic analysis	5
Of Project Documents, cross case, content analysis, open and axial coding, thematic	
Reflective journals, diaries	2
Surveys	2
Household, structured	
Participatory diagramming	1
Ranking tools	1

contextual meaning and formed the types. Last, we characterized the types formed. We formed six types of studies, two for each level.

We formed two superordinate evaluation types (A and B—Table 13). On the one hand, there is an evaluation type that follows a narrow scope. On the level of interventions, this means that direct results and effects of the intervention are measured—primarily quantitatively (Massey, Boroughs and Armstrong 2007; Bellei 2013; Wood et al. 2013; Dubuy et al. 2014; McClain Burke et al. 2019). Narrow-focus evaluations of experiments refer to performance and collaboration in the context of the experiment (Cats, Reimal and Susilo 2014; Hubeau, Marchand and van Huylenbroeck 2017; Doyon et al. 2020). Evaluations with narrow focus on labs aim to increase working mechanisms within the labs, e.g. for future actions that are planned or for improving collaboration within the labs (Falk-Kessler, Benson and Witchger Hansen 2007; Brankaert, den Ouden and Brombacher 2015; Ley et al. 2015; Mazer et al. 2015; Dabaieh et al. 2019; Ramey et al. 2019; Zurbriggen and González Lago 2019). All evaluation studies of type A have in common that internal aspects are in the foreground.

Studies of the second type B comprise evaluations with a broader focus. For linked evaluations focusing on interventions, this indicates that not only the direct effects are considered but also a distinction is made between effects at different levels and/or spill-over effects are evaluated (Nastasi and Hitchcock 2009; Kaida and Kaida 2015). Broad focus evaluations which analyze experiments, link their results closely to a real-world problem. The identified real-world problem marks the initiation of the experiment and is referred to in the evaluation as well (Andersson 2015; Porter, Claassen and Timmermans 2015). Type B evaluation studies that focus on labs use evaluation to provide an overview of specific labs or to test an evaluative model (Kovács 2016; Paskaleva and Cooper 2018; van Geenhuizen 2018; Ondiek and Moturi 2019; Whicher and Crick 2019; Mačiulienė and Skaržauskienė 2020). Mostly, type B evaluation studies focusing on labs follow a theory-driven criteria approach. All evaluation studies of type B design the evaluation beyond the respective individual intervention, experiment, or lab.

8. Discussion

In this review, we aimed at providing a systematic overview of approaches used to evaluate labs, experiments, and interventions in

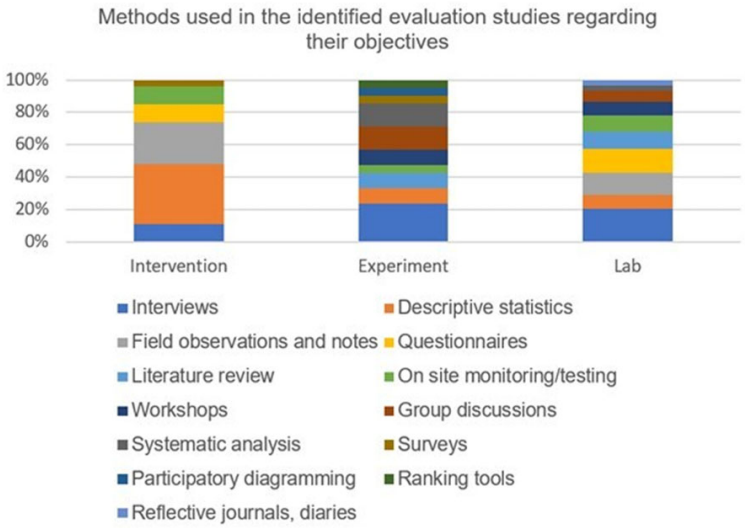

Figure 5. Methods used in the identified evaluation studies regarding focus on labs, experiments, or interventions.

Table 8. Temporality of evaluation according to the level of implementation

Focus of evaluation	Pre-post	Formative	Ex-post
Intervention	3	4	–
Experiment	1	2	2
Lab	–	15	–

Table 9. Temporality of evaluation according to the methodological approach

Methodological approach	Pre-post	Formative	Ex-post
Qualitative	–	12	2
Quantitative	3	4	–
Mixed-methods	1	5	–

real-world contexts in sustainability research and neighboring fields. In the following discussion, we highlight the inherent complexity of evaluation as a crucial practice in RwL research. Furthermore, we point out the learning opportunities that approaches and practices from other fields bear for advancing evaluative practices in the RwL research context and beyond. Finally, we discuss some of the limitations of our review and propose further research.

8.1 Evaluation of RwLs: a complex task in an emerging research field

RwLs as spaces designed, managed, and used by a multitude of actors from different backgrounds are complex social structures with a high degree of context dependency (Schneidewind et al. 2018; McCrory et al. 2020). Through evaluative approaches, researchers and practitioners are enabled to better understand the processes of their joint research as well as the performance of the interventions and experiments realized in the respective labs (Lang et al. 2012). At the same time, evaluation findings are crucial for exploring the scalability and transferability of tested sustainability solutions (Schäpke et al. 2017; Lam et al. 2020b).

The need for evaluations of complex RwLs (or at least components of them) is undisputed. However, the actual implementation of these evaluation approaches is difficult. This is partly due to the multidimensional structure of an RwL. Several processes take place in parallel. In addition, there are numerous actors from different institutions and backgrounds simultaneously involved. In this article, we tried to break down this complexity. Just as we saw different evaluation approaches for interventions, labs, and experiments in real-world contexts, we appeal to address the different components of RwLs with different evaluation logics. In doing so, evaluations of RwLs can be conducted in a modular way.

Evaluations of interventions can be conducted differently than evaluations of experiments or labs. In our analysis, we found that scientists evaluating interventions are generally less involved in action-oriented processes and act in more traditional way of research practice. Experiment focused evaluators take more diverse roles—reaching from reflective scientist to process facilitator. What stands out here is that evaluators explicitly bridging the evaluation to the real-world problem are involved to a higher degree than evaluators concentrating on internal experiment findings. Regarding lab evaluations, we noted an even wider range of roles that evaluators take (ranging from reflective scientist to change agent). Evaluators analyzing several labs within one study become more likely to represent the more traditional role as a researcher—representing only the types reflective and self-reflexive scientists in five out of six studies. The one exception is found within the study from Ley et al. (2015). In the only evaluation study focusing on several experiments, the evaluators also acted as reflective scientists (Hubeau, Marchand and van Huylenbroeck 2017). What stands out from all analyzed evaluation studies except for one (mixed-methods approach), is that in the studies with highly involved evaluators (change agent, process facilitator, knowledge broker) only qualitative approaches were used.

Table 10. Participants' involvement in evaluation according to the level of implementation

Focus of evaluation	Information	Consultation	Cooperation	Collaboration	Empowerment
Intervention	1	5	–	1	–
Experiment	1	–	2	2	–
Lab	–	4	4	2	5

Table 11. Participants' involvement in evaluation according to the methodological approach

Methodological approach	Information	Consultation	Cooperation	Collaboration	Empowerment
Qualitative	–	2	5	3	4
Quantitative	2	5	–	–	–
Mixed-methods	–	2	1	2	1

Table 12. Participants' involvement in evaluation according to ideal-type roles of evaluators

Ideal-type roles	Information	Consultation	Cooperation	Collaboration	Empowerment
Reflective scientist	1	8	1	1	2
Self-reflexive Scientist	1	1	3	1	1
Knowledge broker	–	–	2	1	–
Process facilitator	–	–	–	1	2
Change agent	–	–	–	1	–

Table 13. Evaluation types formed

Type A: Narrow Evaluation Focus		
Intervention	Experiment	Lab
Identify immediate impact, effectiveness or results of the intervention.	Concentrate on internal experiment aspects: collaboration, processes, performance.	Evaluation is directed on the lab itself, with focus on improvement in future.
Type B: Broad Evaluation Focus		
Intervention	Experiment	Lab
Measure more complex results: spillover effects, multilevel evaluation.	Address an identified real-world problem with experiment findings.	Identify success conditions for several labs, test evaluation concepts

The evaluation of components of RwLs can also differ regarding the set of criteria, as our findings suggest. Interventions often followed an explorative approach while on the level of the experiment more often theory-based approaches were applied. Within the evaluation studies focusing on labs, there is no dominance of a preferred categorical system. In cross-case evaluation studies, whether focusing on experiments or labs, theory-based category systems were used in most cases. The use of criteria for evaluation studies based on theoretical approaches seems to facilitate the comparison of the analyzed labs resp. experiments within cross-case studies.

Regarding methods used, we see remarkable differences between intervention, experiment, and lab-focused evaluation studies. The method set applied in the evaluation of interventions is less diverse than the sets used to evaluate experiments and labs. This can possibly be explained by the increasing complexity of the different levels from intervention to lab. Connecting these findings to the role of researchers in these evaluation studies, it seems like evaluations of interventions tend to follow more traditional, already proven concepts of research compared to the evaluation studies focusing on experiments and labs. This could partly be due to the disciplinary context of the intervention focused evaluation studies analyzed here: Out of seven studies, six are attributable to the fields of educational science and public health. These disciplines encompass long tradition of implementing and evaluating interventions in real-world contexts with well-established (quantitative) methods (Craig et al. 2017; Outhwaite, Gulliford and Pitchford 2020).

In terms of when the evaluation is conducted, evaluation studies differ considerably according to what is being evaluated. Labs were evaluated formatively without exception. For interventions and experiments a more heterogenous picture emerges. The reason that labs are invariably evaluated formatively could possibly be due to the fact that mutual learning processes are in the foreground—and thus the participants of the lab are involved to a higher degree. Another explanation might be that evaluation processes seem to be closely linked to the other activities in labs. Evaluation processes are considered as an integral (rather than subsequent) aspect of labs.

The proclaimed higher involvement of participants in the evaluation of labs can be seen in two points: First, information as the weakest form of involvement according to Stauffacher et al. (2008) could not be identified within the lab evaluation studies analyzed here. In contrast, there have been intervention and experiment focused studies that did not aim to involve participants at all (Bellei 2013; Cats, Reimal and Susilo 2014). Second, only within the evaluation studies of labs, the level empowerment for participants to shape evaluation approaches was addressed. For intervention as well as experiment focused evaluation studies, collaboration was the highest form of participants' involvement. Out of seven evaluation studies focusing on interventions, Nastasi and Hitchcock (2009) are the only ones to involve participants on collaboration level. Regarding the evaluation of experiments, collaboration is represented in two out of five studies (Andersson 2015; Hubeau, Marchand and Van Huylenbroeck 2017). There was no case, where participants of experiments were empowered to shape the evaluation study.

8.2 Findings from empirical evaluation cases: approaching the concepts of lab context and real-world experiments

While the diversity of evaluative approaches we found is a rich knowledge base for developing appropriate evaluative approaches for a given case, the lack of clarity regarding the disambiguation of laboratories, experiments, and interventions leads to a certain vagueness in the discussion around evaluation in this research field. It would be important to establish common terms so that experiments and labs are strengthened as contexts for trying out solutions to (sustainability) problems as interventions in system. In the studies considered here, not all authors provided definitions for the evaluation objects lab, and experiment (which are vaguer then the term intervention). We have tried to synthesize the definitions that were given in some of the studies in order to provide an orientation.

Combining the definitions that had been given, we suggest to frame lab context within RwLs as following:

In cocreational processes (Ondiek and Moturi 2019; Mačiulienė and Skaržauskienė 2020) challenges are addressed in an innovative manner (Brankaert, den Ouden and Brombacher 2015; Paskaleva and Cooper 2018; Ondiek and Moturi 2019; Zurbriggen and González Lago 2019) by developing and applying experimental (Plaisier et al. 2019; Whicher and Crick 2019; Zurbriggen and González Lago 2019) as well as participatory mechanisms (Brankaert, den Ouden and Brombacher 2015; Mastelic, Sahakian and Bonazzi 2015) in real-life contexts in order to foster collaborative learning (Falk-Kessler, Benson and Witchger Hansen 2007) and innovation (Ley et al. 2015; Kovács 2016; Paskaleva and Cooper 2018; van Geenhuizen 2018; Ondiek and Moturi 2019).

Based on the definitions that were given, real-world experiments (within RwLs) could be described as follows:

Experiments are small-scale (Porter, Claassen and Timmermans 2015; Doyon et al. 2020) initiatives where actors collaboratively (Hubeau, Marchand and van Huylenbroeck 2017) respond to specific societal problems (Porter, Claassen and Timmermans 2015) by testing possible solutions (Doyon et al. 2020) in order to generate usable knowledge (Andersson 2015) which is transferable and scalable (Doyon et al. 2020).

While some similarities regarding the definitions of experiments and labs are noticeable, we stress the aspects in which they differ according to the synthesized definitions:

- Experiments are described as being small scale, labs are not. The latter seem to cover broader contexts.
- In labs, experimental mechanisms are applied, which strengthen our multilayered understanding and the intended relationship between labs and experiments.

As conceptual ambiguities still exist, we suggest to define central concepts transparently before starting the (co-)evaluation. A precise distinction between interventions, experiments, and the lab process, which is jointly made by the actors in the to-be-evaluated RwLs, is crucial for small scale component evaluation.

8.3 Addressing complexity by learning from neighboring scientific fields

In sustainability oriented RwLs, sustainability solutions are experimentally developed and tested in order to initiate transformation processes and to perpetuate corresponding scientific and social learning processes (Parodi et al. 2016). Thereby, transdisciplinary collaboration is central (Wanner et al. 2018), in which researchers from different disciplines as well as actors outside academia work together. In our view, this essential working mechanism has to be considered in evaluation activities as well, as evaluation processes are described as an essential phase of RwLs (Rose, Wanner and Hilger 2019).

Besides our suggesting to apply smaller scale modular evaluation approaches by addressing the prior identified components of RwLs differently, we suggest to learn from fields that are not considered that close to the field of td sustainability science. The fields of information and technology science, public health/health care as well as educational Science are disciplines that provided studies in which labs, experiments, and intervention in real-world context are empirically evaluated. Although many of the studies that are located in these disciplines used 'common methods' that are also applied in works from td sustainability research—for example document analysis, semistructured interviews, workshops, and/or observations (e.g. Falk-Kessler, Benson and Witchger Hansen 2007; Porter, Claassen and Timmermans 2015; Ramey et al. 2019), we see study examples in which evaluation methods were applied that are less frequently utilized in the field of td sustainability research. In studies focusing on interventions in real-world contexts from the disciplines of public health as well as educational science, approaches to evaluate interventions by forming control and intervention groups in order to work with comparative models were applied. Dubuy et al. (2014) as well as Massey, Boroughs and Armstrong (2007) implemented and evaluated interventions within a small group of pupils. They compared the attitudes and behavior of students who were affected by the intervention with those of students who did not experience the intervention. A similar approach was applied within the evaluation of an educational intervention by using larger datasets of pupils' characteristics (Bellei 2013). The effectiveness of these interventions was assessed through comparison between intervention and control group(s).

Another mechanism we have seen in studies from the field of public health as well as information and technology is baseline and follow-up measurement in order to evaluate interventions (Bellei 2013; Wood et al. 2013; Dubuy et al. 2014) and experiments (Cats,

Reimal and Susilo 2014). Dubuy et al. (2014) and Wood et al. (2013) collected baseline and follow-up measurements within a relatively small group prior and after the intervention. Cats, Reimal and Susilo (2014) used larger data sets. In their study, before and after numbers of extensive automatic vehicle location and automatic passenger counts within a fare-free public transport experiment were analyzed. Bellei (2013) compared student- and school level data before and after the intervention took place.

For evaluating interventions and experiments in real-world settings, forming control and intervention groups as well as assessing baseline and follow-up measurement might be suitable. Other methods that studies from these 'neighboring fields' suggest, are on-site monitoring. This includes approaching the effectiveness of new, tested interventions in real-world context in the field of information and technology studies (Brankaert, den Ouden and Brombacher 2015; Dabaieh et al. 2019) or medical examinations (Nastasi and Hitchcock 2009).

8.4 Limitations and further steps

Due to our search query as well as the inclusion and exclusion criteria we applied, we analyzed 27 studies in which labs, experiments, and intervention in real-world settings were evaluated. This number is too small to draw general conclusions from this study population. Nevertheless, the studies support the approach of a small-scale, modular evaluation with the inclusion of empirical experiences from other fields than td sustainability science. It also suggests that empirical studies evaluating interventions, experiments, or labs in real-world context that are specifically named as such are rare—at least in the field of peer-reviewed studies. When systematically analyze grey literature, this could result in identifying a larger number of studies in which interventions, experiments, and labs in real-world settings are evaluated. One challenge we encounter within this approach is the transparent and structured selection of studies. Nevertheless, this could be a promising approach for future research.

The various evaluation approaches at the three levels in the RwL (which differ, e.g. in terms of choice of method, time frame, and evaluator role) would pave the way to be a methodologically sound overall evaluation for the RwL when brought together. However, the aspect how these single evaluation studies within one RwL can and should be connected needs to be further explored. One suggestion still under discussion can be to review the single small-scale evaluation studies that were conducted within RwLs, led by their different foci. Similarly, as mentioned above, we take the position that RwLs are not generic, they differ contextually, in content and organization. This means a conclusive answer to the question is not possible (so far).

9. Conclusion

Evaluating RwLs, especially when they consist of multiple experiments and sometimes even more interventions, can be a giant task, not manageable with the resources typically available through current funding schemes. Finding ways to deal with this challenge is possible. One can take advantage of the multilayered structure of RwLs. There are several components that can be evaluated using various approaches. At the same time, one can draw on more than just studies from td sustainability research to evaluate lab context, experiments, and interventions that are part of RwLs. Transdisciplinary research seeks to cross the boundaries between disciplines, as well as between academia and other societal domains. We should apply this paradigm to evaluation studies as well.

In our article, we revealed that empirically conducted evaluation studies related to lab contexts, experiments, and interventions in real-world settings each follow different logics. Based on these findings, we have formed an evaluation study typology. Analyzed evaluation approaches—while diverse—can be distinguished by having a narrow or broad scope (related to all three highlighted components of RwLs). Furthermore, we aimed to provide a practicable application.

For transformative td research, we need to think holistically and learn from other disciplines—especially when we aim to explore amplification possibilities of sustainability solutions tested in RwLs. These solutions are more urgent today than ever before. Concomitantly feasible and thorough evaluations of interventions, experiments, and RwLs are increasingly needed. We hope this article contributes to accommodating this need.

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References

Andersson, E. (2015) 'Turning Waste into Value: Using Human Urine to Enrich Soils for Sustainable Food Production in Uganda', *Journal of Cleaner Production*, 96: 290–8.

Arnstein, S. (1969) 'A Ladder of Citizen Participation', *Journal of the American Institute of Planners*, 35: 216–24.

Beecroft, R., and Parodi, O. (2016) 'Reallabore als Orte der Nachhaltigkeitsforschung und Transformation', *TATuP*, 25: 4–8.

Bellei, C. (2013) 'Supporting Instructional Improvement in Low-Performing Schools to Increase Students' Academic Achievement', *The Journal of Educational Research*, 106: 235–48.

Bergmann, M., Schäpke, N., Marg, O., Stelzer, F., Lang, D. J., Bossert, M., Gantert, M., Häußler, E., Marquardt, E., Piontek, F. M., Potthast, T., Rhodius, R., Rudolph, M., Ruddat, M., Seebacher, A., and Sußmann, N. (2021) 'Transdisciplinary Sustainability Research in Real-World Labs: Success Factors and Methods for Change', *Sustainability Science*, 16: 541–64.

Bernstein, M. J., Wiek, A., Brundiers, K., Pearson, K., Minowitz, A., Kay, B., and Golub, A. (2016) 'Mitigating Urban Sprawl Effects: A Collaborative Tree and Shade Intervention in Phoenix, Arizona, USA', *Local Environment*, 21: 414–31.

Brankaert, R., den Ouden, E., and Brombacher, A. (2015) 'Innovate Dementia: The Development of a Living Lab Protocol to Evaluate Interventions in Context', *Info*, 17: 40–52.

Burke, H. M., Field, S., González-Calvo, L., Eichleay, M. A., and Moon, T. D. (2019) 'Quasi-Experimental Evaluation Using Confirmatory Procedures: A Case Study of an Economic and Social Empowerment Intervention to Reduce Girls' Vulnerability to HIV in Rural Mozambique', *Evaluation and Program Planning*, 77: 101721.

Caniglia, G., Luederitz, C., von Wirth, T., Fazey, I., Martín-López, B., Hondrila, K., König, A., von Wehrden, H., Schäpke, N. A., Laubichler,

M. D., and Lang, D. J. (2021) 'A Pluralistic and Integrated Approach to Action-Oriented Knowledge for Sustainability', *Nat Sustain*, 4: 93–100.

Caniglia, G., Schäpke, N., Lang, D. J., Abson, D. J., Luederitz, C., Wiek, A., Laubichler, M. D., Gralla, F., and von Wehrden, H. (2017) 'Experiments and Evidence in Sustainability Science: A Typology', *Journal of Cleaner Production*, 169: 39–47.

Cats, O., Reimal, T., and Susilo, Y. (2014) 'Public Transport Pricing Policy', *Transportation Research Record*, 2415: 89–96.

Craig, P., Katikireddi, S. V., Leyland, A., and Popham, F. (2017) 'Natural Experiments: An Overview of Methods, Approaches, and Contributions to Public Health Intervention Research', *Annual Review of Public Health*, 38: 39–56.

Dabaieh, M., Maguid, D., El Mahdy, D., and Wanas, O. (2019) 'An Urban Living Lab Monitoring and Post Occupancy Evaluation for a Trombe Wall Proof of Concept', *Solar Energy*, 193: 556–67.

Defila, R., and Di Giulio, A. (2019) *Transdisziplinär und Transformativ Forschen, Band 2. Eine Methodensammlung*. Wiesbaden: Springer Fachmedien Wiesbaden.

Döring, N. (2019) 'Evaluationsforschung'. In: Baur, N., and Blasius, J. (ed.) *Handbuch Methoden der Empirischen Sozialforschung*, 2nd edn, pp. 173–89. Wiesbaden: Springer Fachmedien Wiesbaden.

Doyon, A., Moore, T., Moloney, S., and Hurley, J. (2020) 'Evaluating Evolving Experiments: The Case of Local Government Action to Implement Ecological Sustainable Design', *Journal of Environmental Planning and Management*, 63: 2042–63.

Dubuy, V., De Cocker, K., De Bourdeaudhuij, I., Maes, L., Seghers, J., Lefevre, J., De Martelaer, K., Brooke, H., and Cardon, G. (2014) 'Evaluation of a Real World Intervention Using Professional Football Players to Promote a Healthy Diet and Physical Activity in Children and Adolescents from a Lower Socio-Economic Background: A Controlled Pretest-Posttest Design', *BMC Public Health*, 14: 457.

Falk-Kessler, J., Benson, J. D., and Witchger Hansen, A. M. (2007) 'Moving the Classroom to the Clinic: The Experiences of Occupational Therapy Students during a "Living Lab"', *Occupational Therapy in Health Care*, 21: 79–91.

Flick, U. (2011) *Triangulation: Eine Einführung*, 3rd edn. Wiesbaden: VS Verlag für Sozialwissenschaften (Qualitative Sozialforschung).

Franzkowiak, P. (2015) *Gesundheitswissenschaften/Public Health*. Köln: BZGA – Bundeszentrale für gesundheitliche Aufklärung. https://doi.org/10.17623/BZGA:224-i061-1.0.

Heinrich, L. J. (2018) 'Bedeutung von Evaluation und Evaluationsforschung in der Wirtschaftsinformatik'. In: Heinrich, L. J., and Häntschel, I. (ed.) *Evaluation und Evaluationsforschung in der Wirtschaftsinformatik. Handbuch für Praxis, Lehre und Forschung*, Reprint 2018, pp. 7–22. Berlin, Boston: Oldenbourg Wissenschaftsverlag.

Hölscher, K., Wittmayer, J. M., Hirschnitz-Garbers, M., Olfert, A., Walther, J., Schiller, G., and Brunnow, B. (2021) 'Transforming Science and Society? Methodological Lessons from and for Transformation Research', *Research Evaluation*, 30: 73–89.

Hubeau, M., Marchand, F., and van Huylenbroeck, G. (2017) 'Sustainability Experiments in the Agri-Food System: Uncovering the Factors of New Governance and Collaboration Success', *Sustainability*, 9: 1027.

Huning, S., Räuchle, C., and Fuchs, M. (2021) 'Designing Real-World Laboratories for Sustainable Urban Transformation: Addressing Ambiguous Roles and Expectations in Transdisciplinary Teams', *Sustainability Science*, 16: 1595–607.

Kaida, N., and Kaida, K. (2015) 'Spillover Effect of Congestion Charging on Pro-Environmental Behavior', *Environment, Development and Sustainability*, 17: 409–21.

Kluge, S. (2000) 'Empirisch Begründete Typenbildung in der Qualitativen Sozialforschung', *Forum Qualitative Sozialforschung*, 1/1: Art. 14.

Kovács, K. (2016) 'Evaluation and Practice of Interactive Value Production in Living Labs', *Periodica Polytechnica Social and Management Sciences*, 24: 52–9.

Lam, D. P. M., Horcea-Milcu, A. I., Fischer, J., Peukert, D., and Lang, D. J. (2020b) 'Three Principles for Co-Designing Sustainability Intervention Strategies: Experiences from Southern Transylvania', *Ambio*, 49: 1451–65.

Lam, D. P. M., Martín-López, B., Wiek, A., Bennett, E. M., Frantzeskaki, N., Horcea-Milcu, A. I., and Lang, D. J. (2020a) 'Scaling the Impact of Sustainability Initiatives: A Typology of Amplification Processes', *Urban Transformations*, 2: 1–24.

Lang, D. J., and Wiek, A. (2022) 'Structuring and Advancing Solution-Oriented Research for Sustainability', *Ambio*, 51: 31–5.

Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., and Thomas, C. J. (2012) 'Transdisciplinary Research in Sustainability Science: Practice, Principles, and Challenges', *Sustainability Science*, 7: 25–43.

Ley, B., Ogonowski, C., Mu, M., Hess, J., Race, N., Randall, D., Rouncefield, M., and Wulf, V. (2015) 'At Home with Users: A Comparative View of Living Labs', *Interacting with Computers*, 27: 21–35.

Luederitz, C., Schäpke, N., Wiek, A., Lang, D. J., Bergmann, M., Bos, J. J., Burch, S., Davies, A., Evans, J., König, A., Farrelly, M. A., Forrest, N., Frantzeskaki, N., Gibson, R. B., Kay, B., Loorbach, D., McCormick, K., Parodi, O., Rauschmayer, F., Schneidewind, U., Stauffacher, M., Stelzer, F., Trencher, G., Venjakob, J., Vergragt, P. J., von Wehrden, H., and Westley, F. R. (2017) 'Learning through Evaluation—A Tentative Evaluative Scheme for Sustainability Transition Experiments', *Journal of Cleaner Production*, 169: 61–76.

Mačiulienė, M., and Skaržauskienė, A. (2020) 'Sustainable Urban Innovations: Digital Co-Creation in European Living Labs', *Kybernetes*, 49: 1969–86.

Massey, O. T., Boroughs, M., and Armstrong, K. H. (2007) 'School Violence Interventions in the Safe Schools/Healthy Students Initiative', *Journal of School Violence*, 6: 57–74.

Mastelic, J., Sahakian, M., and Bonazzi, R. (2015) 'How to Keep a Living Lab Alive?', *Info*, 17: 12–25.

Mazer, B., Kairy, D., Guindon, A., Girard, M., Swaine, B., Kehayia, E., and Labbé, D. (2015) 'Rehabilitation Living Lab in the Mall Community of Practice: Learning Together to Improve Rehabilitation, Participation and Social Inclusion for People Living with Disabilities', *International Journal of Environmental Research and Public Health*, 12: 4439–60.

McCrory, G., Schäpke, N., Holmén, J., and Holmberg, J. (2020) 'Sustainability-Oriented Labs in Real-World Contexts: An Exploratory Review', *Journal of Cleaner Production*, 277: 123202.

Munn, Z., Peters, M. D. J., Stern, C., Tufanaru, C., McArthur, A., and Aromataris, E. (2018) 'Systematic Review or Scoping Review? Guidance for Authors When Choosing between a Systematic or Scoping Review Approach', *BMC Medical Research Methodology*, 18: 143.

Nastasi, B. K., and Hitchcock, J. (2009) 'Challenges of Evaluating Multilevel Interventions', *American Journal of Community Psychology*, 43: 360–76.

OECD DAC Network on Development Evaluation (EvalNet) (2021) *Evaluation Criteria—OECD* (16 Jul 2021) <https://www.oecd.org/dac/evaluation/daccriteriaforevaluatingdevelopmentassistance.htm.> accessed 21 December 2021.

Ondiek, M. A., and Moturi, C. (2019) 'An Assessment of the Sustainability of Living Labs in Kenya', *Innovation & Management Review*, 16: 391–403.

Outhwaite, L. A., Gulliford, A., and Pitchford, N. J. (2020) 'A New Methodological Approach for Evaluating the Impact of Educational Intervention Implementation on Learning Outcomes', *International Journal of Research & Method in Education*, 43: 225–42.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., Stewart, L. A., Thomas, J., Tricco, A. C., Welch, V. A., Whiting, P., and Moher, D. (2021) 'The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews', *BMJ*, 372: n71.

Parodi, O. (2019) 'Wider eine Engführung des Reallabor-Konzepts', *Ökologisches Wirtschaften*, 2: 8–9.

Parodi, O., Beecroft, R., Albiez, M., Quint, A., Seebacher, A., Tamm, K., and Waitz, C. (2016) 'Von 'Aktionsforschung' Bis 'Zielkonflikte': Schlüsselbegriffe Der Reallaborforschung', *Technikfolgenabschätzung, Theorie und Praxis*, 25: 9–18.

Paskaleva, K., and Cooper, I. (2018) 'Open Innovation and the Evaluation of Internet-Enabled Public Services in Smart Cities', *Technovation*, 78: 4–14.

Peters, M. D. J., Godfrey, C. M., Khalil, H., McInerney, P., Parker, D., and Soares, C. B. (2015) 'Guidance for Conducting Systematic Scoping Reviews', *International Journal of Evidence-Based Healthcare*, 13: 141–6.

Plaisier, C., Sibomana, M., Van der Waal, J., Clercx, L., Van Wagenberg, C. P. A., and Dijkxhoorn, Y. (2019) 'Approach for Designing Context-Specific, Locally Owned Interventions to Reduce Postharvest Losses: Case Study on Tomato Value Chains in Nigeria', *Sustainability*, 11: 247.

Porter, N., Claassen, M., and Timmermans, J. (2015) 'Transition Experiments in Amsterdam: Conceptual and Empirical Analysis of Two Transition Experiments in the WATERgraafsmeer Program', *Technological Forecasting and Social Change*, 90: 525–37.

Ramey, H. L., Rayner, M.-E., Mahdy, S. S., Lawford, H. L., Lanctot, J., Campbell, M., Valenzuela, E., Miller, J., and Hazlett, V. (2019) 'The Young Canadians Roundtable on Health: Promising Practices for Youth and Adults Working in Partnership', *Canadian Journal of Public Health = Revue Canadienne de Sante Publique*, 110: 626–32.

Räuchle, C. (2021) 'Social Encounter by Experiment? Potentials and Pitfalls of Real-World Labs for Urban Planning', *Urban Planning*, 6: 208–20.

Rogga, S., Zscheischler, J., and Gaasch, N. (2018) 'How Much of the Real-World Laboratory Is Hidden in Current Transdisciplinary Research?', *GAIA - Ecological Perspectives for Science and Society*, 27: 18–22.

Rose, M., Wanner, M., and Hilger, A. (2019) *Das Reallabor als Forschungsprozess und—Infrastruktur für Nachhaltige Entwicklung. Konzepte, Herausforderungen und Empfehlungen*. Wuppertal: Wuppertal Institut für Klima, Umwelt, Energie gGmbH.

Sanders, S. (2019) *A Brief Guide to Selecting and Using Pre-Post Assessments*. Washington, DC: American Institutes for Research, The National Technical Assistance Center for the Education of Neglected or Delinquent Children and Youth.

Schäpke, N., Stelzer, F., Bergmann, M., Singer-Brodowski, M., Wanner, M., Caniglia, G., and Lang, D. J. (2017) 'Reallabore im Kontext Transformativer Forschung. Ansatzpunkte Zur Konzeption Und Einbettung in Den Internationalen Forschungsstand', *Ietsr Discussion Papers in Transdisciplinary Sustainability Research, 1*. Lüneburg: Leuphana Universität Lüneburg, Institut für Ethik und Transdisziplinäre Nachhaltigkeitsforschung.

Schensul, J. J., and Trickett, E. (2009) 'Introduction to Multi-Level Community Based Culturally Situated Interventions', *American Journal of Community Psychology*, 43: 232–40.

Schneidewind, U. (2014) 'Urbane Reallabore—Ein Blick in Die Aktuelle Forschungswerkstatt', *Pnd Online*, 3: 1–7.

Schneidewind, U., and Singer-Brodowski, M. (2015) 'Vom Experimentellen Lernen Zum Transformativen Experimentieren: Reallabore als Katalysator für eine Lernende Gesellschaft Auf Dem Weg zu Einer Nachhaltigen Entwicklung', *Zeitschrift für Wirtschafts und Unternehmensethik*, 16: 10–23.

Schneidewind, U., Augenstein, K., Stelzer, F., and Wanner, M. (2018) 'Structure Matters: Real-World Laboratories as a New Type of Large-Scale Research Infrastructure: A Framework Inspired by Giddens' Structuration Theory', *GAIA - Ecological Perspectives for Science and Society*, 27: 12–7.

Seebacher, A., Alcántara, S., and Quint, A. (2018) 'Akteure in Reallaboren—Reallabore Als Akteure'. In: Di Giulio, A., and Defila, R. (ed.) *Transdisziplinär und Transformativ Forschen*, pp. 155–9. Wiesbaden: Springer Fachmedien Wiesbaden.

Singer-Brodowski, M., Beecroft, R., and Parodi, O. (2018) 'Learning in Real-World Laboratories: A Systematic Impulse for Discussion', *GAIA - Ecological Perspectives for Science and Society*, 27: 23–7.

Stauffacher, M., Flüeler, T., Krütli, P., and Scholz, R. W. (2008) 'Analytic and Dynamic Approach to Collaboration: A Transdisciplinary Case Study on Sustainable Landscape Development in a Swiss Prealpine Region', *Systemic Practice and Action Research*, 21: 409–22.

Taïbi, S., Antheaume, N., and Gibassier, D. (2020) 'Accounting for Strong Sustainability: An Intervention-Research Based Approach', *Sustainability Accounting, Management and Policy Journal*, 11: 1213–43.

van Geenhuizen, M. (2018) 'A Framework for the Evaluation of Living Labs as Boundary Spanners in Innovation', *Environment and Planning C: Politics and Space*, 36: 1280–98.

Verwoerd, L., Klaassen, P., van Veen, S. C., De Wildt-Liesveld, R., and Regeer, B. J. (2020) 'Combining the Roles of Evaluator and Facilitator: Assessing Societal Impacts of Transdisciplinary Research While Building Capacities to Improve Its Quality', *Environmental Science & Policy*, 103: 32–40.

von Wirth, T., and Levin-Keitel, M. (2020) 'Lokale Nachhaltigkeitsexperimente als Raumwirksame Interventionen: Theoretische Grundlagen und Handlungskonzepte', *GAIA - Ecological Perspectives for Science and Society*, 29: 98–105.

Wagner, F., and Grunwald, A. (2019) 'Reallabore Zwischen Beliebtheit und Beliebigkeit: Eine Bestandsaufnahme des Transformativen Formats', *GAIA - Ecological Perspectives for Science and Society*, 28: 260–4.

Wanner, M., Hilger, A., Westerkowski, J., Rose, M., Stelzer, F., and Schäpke, N. (2018) 'Towards a Cyclical Concept of Real-World Laboratories', *disP - The Planning Review*, 54: 94–114.

Whicher, A., and Crick, T. (2019) 'Co-Design, Evaluation and the Northern Ireland Innovation Lab', *Public Money & Management*, 39: 290–9.

Wiek, A., and Lang, D. J. (2016) 'Transformational Sustainability Research Methodology'. In: Heinrichs, H. , Martens P., Michelsen, G., and Wiek, A. (ed.) *Sustainability Science: An Introduction*, pp. 31–41. Dordrecht: Springer Netherlands.

Williams, S., and Robinson, J. (2020) 'Measuring Sustainability: An Evaluation Framework for Sustainability Transition Experiments', *Environmental Science & Policy*, 103: 58–66.

Wittmayer, J. M., and Schäpke, N. (2014) 'Action, Research and Participation: Roles of Researchers in Sustainability Transitions', *Sustainability Science*, 9: 483–96.

Wood, L., Ivery, P., Donovan, R., and Lambin, E. (2013) '"To the Beat of a Different Drum": Improving the Social and Mental Wellbeing of At-Risk Young People through Drumming', *Journal of Public Mental Health*, 12: 70–9.

Zurbriggen, C., and González Lago, M. (2019) 'An Experimental Evaluation Tool for the Public Innovation Lab of the Uruguayan Government', *Evidence & Policy A Journal of Research Debate and Practice*, 15: 437–51.

Chapter 5

Synthesis

This chapter synthesises the findings of the five papers presented to address the central research question: how can research in RwLs inform and foster an emergent transformative sustainability science? Drawing on the conceptual framework introduced in chapter 2, I examine how RwLs function as incubators across three dimension: methodological innovation, transformative practice, and ontological transformation. These dimensions serve as analytical lenses to integrate and interpret the diverse contributions of the individual papers, highlighting shared patterns and key divergences. Together, they provide insight into how research practice itself evolves through sustained engagement in RwL settings.

I view transformative sustainability science as an inherently emergent field–one that develops through case-based research, diverse sustainability orientations, and rich epistemological traditions. My contributions, represented in the five papers analysed here, are meant as additions to this ongoing development rather than definitive statements. Within the broader community, these ideas have already sparked new initiatives: a working group within the RwL network developing a case reporting database, a case reporting newspaper as part of the Real-World Lab Network Conference 2024 in Dresden, a series of training workshops on incorporating transdisciplinary and transformative learning in various disciplines at Carl-Albrecht-University Kiel in 2023/2024 (facilitated by Matthias Wanner and me), and shaping discussions in the German Transdisciplinary and Participatory Research Platform (GTPF), particularly in the working group on impact.

While I understand transformative sustainability science as being emergent, I do not view this emergence as an accidental process. Rather, it builds on intentional, theoretically and empirically grounded, experientially informed and open-for-discussion-and-debate, reflexive shaping by researchers. As illustrated by my research articles, RwLs provide crucial settings where researchers can gain the experiences and insights needed to participate meaningfully in this shaping of the field.

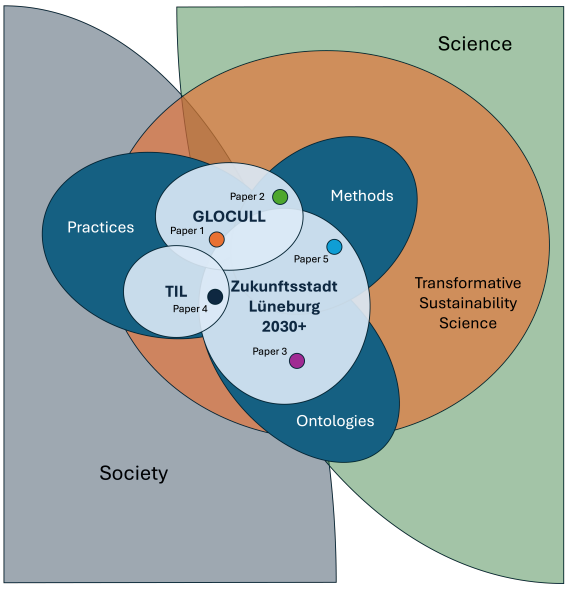

Figure 3: Research papers and their RwL cases in relation to the dimensions in which they inform and foster an emergent transformative sustainability science at the fringe of science, or a science-society boundary space (own illustration)

5.1 Methodological innovations emerging from RwL research

Three of the papers in this dissertation–on case reporting (Paper 1), conceptual replication (Paper 2), and modular evaluation (Paper 5)–respond to key methodological challenges in RwL research: knowledge transfer across contexts, the tension between contextual specificity and generalisability, and the complexity of evaluating multi-layered processes. These innovations emerged not from abstract design, but through situated engagement in real-world settings.

Responding to the challenge of knowledge transfer

A key methodological tension in transformative sustainability research is how to generate knowledge that is both contextually rich and transferable across settings. The case reporting approach developed in Paper 1 in the GLOCULL context responds to this challenge by facilitating cross-case learning in RwLs while maintaining sensitivity to local context.

Existing practices of knowledge transfer in transdisciplinary and transformative research often swing between richly detailed but non-transferable case descriptions and abstracted principles detached from real-world practice. The case reporting framework offers a structured alternative that supports reciprocal cross-case learning while preserving contextual nuance enabling (Adler et al., 2017; Nagy et al., 2020; Wuelser et al., 2021).

A key innovation of the case reporting approach lies in its clear distinction between the core components of RwLs–context, lab, and experiment–captured through a simple logic model. This differentiation supports not only more targeted knowledge transfer but also enhances conceptual clarity in RwL research, aligning with recent calls for more precise analytical distinctions (Parodi et al., 2024).

Bridging contextual specificity and generalisability

The dual-setting research design and conceptual replication approach developed in Paper 2 addresses a central methodological challenge in transformative research: bridging the gap between context-specific solution development and broader knowledge generation (Lang et al., 2017; Scholz & Steiner, 2015; Von Wehrden, 2023). This reflects the field's dual mandate to engage with situated sustainability problems while contributing to generalisable scientific understanding.

The methodological innovation lies in adapting conceptual replication within and across analogous RwL cases to balance context-specific societal relevance with the production of transferable, action-oriented knowledge (Caniglia et al., 2020). Rather than abstracting from context, this approach builds on similarities across cases to test theoretical mechanisms and generate sustainability-relevant insights that are both generalisable and grounded (Derksen & Morawski, 2022; Hudson, 2023).

This approach was developed in the context of the GLOCULL project, where interdisciplinary collaboration with colleagues in psychology sparked the idea of testing co-developed interventions across different settings. Working with Avenir Café, we designed a field experiment to assess the effects of sustainability-oriented marketing tools in a real-world context building on a analogous study by Weber et al. (2021). Encouraged by the results, we developed a parallel online study to examine the same mechanisms in a broader, more controlled environment. This dual-setting design enabled us to validate and refine our findings while maintaining their contextual relevance, illustrating how RwLs can support both situated experimentation and broader knowledge generation.

Developing nuanced approaches to evaluation

The modular evaluation approach developed in Paper 5 addresses the challenge of evaluating the complex, layered processes that characterise RwLs. It recognises that distinct components–such as context, lab processes, and experiments–serve different functions and thus require tailored evaluation strategies. This structural distinction mirrors the logic model used in the case reporting scheme presented in Paper 1, reflecting a shared understanding across the two papers of the layered nature of RwLs.

This differentiated approach moves beyond one-size-fits-all evaluation models and aligns with recent calls for more context-sensitive and reflective evaluation practices in transformative research (B. Belcher & Claus, 2025; Luederitz et al., 2017; Schäfer et al., 2021; Wiefek et al., 2024; Williams & Robinson, 2020). It enables a more precise understanding of how RwLs contribute to change, while preserving the rigour expected of sustainability science.

Conditions enabling methodological innovation in RwLs

The methodological innovations developed in these three papers emerged through direct engagement with challenges encountered in RwL practice. Rather than following a linear model of theoretical elaboration followed by empirical testing, they reflect what might be called *situated methodology development*–a process of responding to context-specific needs by drawing on and adapting existing approaches across disciplinary boundaries.

Several characteristics of RwLs appear to foster this form of methodological innovation. Their transdisciplinary research mode brings together diverse methodological traditions that can be creatively re-combined in response to real-world challenges and re-integrated into scientific discourse (Jahn et al., 2012; Lang et al., 2012; Schäpke et al., 2018; Wanner et al., 2018). Their experimental methodology supports not only the testing of interventions, but also the refinement of research approaches themselves–making methodological development an integral part of the research process.

While the reintegration of practice-based insights into scientific discourse is a core aspiration of transdisciplinary research, RwLs are sometimes criticised for prioritising societal impact over methodological development. The cases presented in this dissertation illustrate how this limitation can be addressed when RwLs are embedded in reflexive research practice that engages in advancing the field of transformative sustainability research through new methodologies.

5.2 Transformative science in practice

Transformative research in real-world laboratories–and in transformative sustainability science more broadly–is not defined solely by its methods, but by the shared and collaborative practices that reflect the transformative orientation of all actors involved. This section synthesises how the RwL research presented in this dissertation contributes to understanding such practices in action. Drawing on Paper 1 and Paper 4, it explores how RwLs function as settings for higher education sustainability learning and for enabling knowledge transfer through practice-oriented formats such as case reporting. These contributions highlight how transformative research

unfolds not only in designed interventions, but in ongoing processes of co-production, reflection, and learning.

Knowledge transfer as collaborative learning

While the case reporting approach addresses the methodological challenges of knowledge transfer in transdisciplinary research (Adler et al., 2017; Wuelser et al., 2021), it is best understood not merely as a method but as a collaborative research practice. Rather than following a sender–receiver model–where researchers produce knowledge and others apply it–case reporting conceptualises knowledge transfer as a situated, interactive process of documentation, reflection, and shared learning. Although it has methodological elements, its primary contribution lies in fostering conditions for mutual understanding and sense-making across contexts.

This shift in practice is reflected both in the development of the reporting scheme and in its intended use. The scheme emerged through an iterative process within the GLOCULL project, informed by discussions and exchanges among researchers working across seven Urban Living Labs. Rather than serving solely as a documentation tool, it is intended as a reflective practice that supports researchers and practitioners in making sense of their roles, challenges, and insights across diverse contexts.

This approach aligns with recent calls for more collaborative, learning-oriented approaches to sustainability knowledge production (Caniglia et al., 2020; Norström et al., 2020). It expands the scope of research practice beyond the production of scientific findings to include the creation of conditions for mutual learning–through shared reflection, contextual documentation, and dialogue across diverse communities of practice (Adler et al., 2017; Nagy et al., 2020).

Integrating research with educational practice

The design principles for transformative learning presented in Paper 4 build on the understanding that education is an integral part of scientific practice–especially in the context of transformative sustainability research (Barth et al., 2020; Weiser et al., 2023; Wiek et al., 2011). Traditional models of higher education often separate learning about research methods from engaging in research practice, particularly when it comes to more experimental or participatory approaches. The design principles challenge this divide by creating learning environments in which students engage directly in transdisciplinary research processes, developing both knowledge and the capacity to contribute to sustainability transformations.

The contribution of the framework lies in its intentional integration of educational and research goals within real-world laboratory settings. Grounded in contemporary understandings of sustainability learning and transdisciplinary research, it builds on the premise that learning and knowledge co-production are mutually reinforcing

processes and should not be treated as separate domains. The design principles provide a coherent set of guidelines that support this integration by helping to structure learning environments in which students can actively contribute to research while developing transformative capacities.

Working with students in RwL settings gave me firsthand insight into the potential of integrating education and research in transformative sustainability contexts (for an overview see Appendix B). While managing diverse perspectives can be challenging, student involvement brings fresh thinking and critical engagement into the research process. The design principles serve as a reflexive guiding tool in such situations and offer an entry point for designing transformative learning environments grounded in both research and educational discourses. They enable transformative sustainability researchers to support student learning while also gaining new perspectives and reorienting their own work. This shift toward experiential learning positions sustainability education and research as equally concerned with capacity-building and knowledge production, integrating transformative research and transformative learning (WBGU - German Advisory Council on Global Change, 2011, p. 23).

RwLs as spaces for practice innovation

The practice innovations discussed above emerged in RwL settings where conventional boundaries between research, learning, and societal engagement became more integrated. This integration created conditions for developing practices that move beyond traditional divisions between knowledge production, dissemination, and application.

Several characteristics of RwLs enable this kind of practice innovation. They involve diverse participants with different forms of expertise, interests, and roles–requiring new practices to bridge across these differences. Their focus on real-world problem solving fosters approaches that integrate knowledge, learning, and action. And through their longer-term engagement with local contexts, RwLs create opportunities for practices to evolve through iterative cycles of experimentation and reflection (Parodi, 2019; Schäpke et al., 2018; Wanner et al., 2018).

Due to these characteristics, RwLs function as incubators for practice innovation in transformative sustainability science. They provide environments where conventional research practices can be questioned and reimagined in response to the complex challenges of sustainability transformations. In doing so, they foster transgressive forms of research practice that reshape what counts as valid, relevant, and effective in the emerging field of transformative sustainability science (Caniglia & Vogel, 2023; Lotz-Sisitka et al., 2016).

5.3 Ontological transformations in scientific understanding

Two of the papers included in this dissertation–on emergent impacts (Paper 3) and modular evaluation (Paper 5)–propose new ways of understanding key concepts in transformative research, particularly in relation to impact and evaluation. These papers show how engagement in RwLs can shift underlying scientific assumptions, moving away from linear, cause-effect thinking toward more relational and emergent understandings. Such shifts reflect ontological transformations in how change, knowledge, and agency are conceptualised within transformative sustainability science.

Reconceptualising scientific impact

The concept of emergent impacts introduced in Paper 3 represents a significant ontological shift in how scientific impact is understood. While conventional approaches in sustainability science often focus on the direct effects of specific interventions, some scholars have already begun to question this linear, indicator-driven model (e.g. Luederitz et al., 2017; Walter et al., 2007; Wiek, 2007). The emergent impact concept builds on and extends these efforts by focusing on effects that unfold through long-term, collaborative processes rather than discrete interventions.

The concept of emergent impacts complements linear models by recognising effects that arise from the cumulative, long-term processes of collaboration in RwLs, rather than from isolated experiments or interventions. These impacts are not attributable to specific actions but unfold through ongoing interactions, relationships, and evolving contexts. As noted in Paper 3, they "while not accidental, were not planned for at the beginning of the process and were not achieved due to a specific experiment or intervention. Instead, they emerged from a continuous, collaborative process between the city administration, the civil society, and Leuphana University Lüneburg."

The development of the emergent impacts concept was grounded in my experience of working within RwL settings, where much of what we recognised as transformational could not be traced to individual actions or specific interventions. These changes were clearly visible, yet unfolded through relationships, evolving contexts, and sustained collaboration. This challenged conventional notions of scientific impact and underscored the need for frameworks that reflect the processual and relational nature of transformation. The concept resonated with practitioners and researchers involved in similar settings, suggesting that a broader understanding of impact–one that includes emergent and co-evolving effects–is not only theoretically important, but practically necessary for advancing transformative sustainability research.

Rethinking evaluation in complex systems

The modular evaluation approach presented in Paper 5 contributes to ontological transformation by rethinking how evaluation is understood in scientific research. Traditional models often assume linear relationships between inputs, activities, outputs, and outcomes, with evaluation focused on whether predefined objectives have been achieved through specified actions (Walter et al., 2007).

The modular evaluation approach presented in Paper 5 contributes to this deeper shift in how evaluation is understood within transformative research. Rather than treating evaluation as a neutral tool for measuring predefined objectives, it repositions evaluation as a process embedded in complex, evolving systems–responsive to change and oriented toward learning.

While strongly oriented towards societal impact, evaluating RwLs is particularly challenging due to the delayed, emergent, and often indirect nature of transformative outcomes (Fazey et al., 2018; Luederitz et al., 2017; Schäpke et al., 2018). These processes unfold across multiple layers–such as institutional change, capacity building, or shifts in discourse–and rarely align with short-term, quantifiable indicators. The multifaceted nature of RwLs, involving diverse actors and overlapping goals, further complicates evaluation. The modular evaluation approach addresses these challenges by proposing differentiated strategies for distinct components–such as context, lab processes, and experiments–allowing for more nuanced and situated assessments that reflect the complexity of real-world transformation processes.

RwLs as catalysts for ontological transformation

The ontological shifts discussed above emerged through engagement with the complex, emergent dynamics encountered in RwL research. These experiences challenged conventional scientific assumptions and opened space for new ways of understanding concepts such as impact, evaluation, and change–ones that better reflect the realities of transformative research practice.

Several features of RwL reserach help enable this kind of ontological transformation. Its extended engagement with complex, real-world challenges resists simplified, linear models and calls for more situated and relational conceptualisations. Their collaborative design brings together diverse perspectives and knowledge systems, opening space to question and expand dominant scientific assumptions. Finally, their normative commitment to sustainability transformation fosters critical reflection on how scientific concepts and practices must evolve to support systemic change.

In this way, RwL research acts as a catalyst for rethinking the foundations of sustainability science. By confronting researchers with the complexity, uncertainty, and relational nature of real-world change processes, it invites the development of

scientific concepts and practices that are better suited to transformative goals. Rather than simply applying existing frameworks, RwLs foster the conditions for reimagining what science is–and what it is for–in the context of sustainability transformations.

5.4 RwL research: advancing transformative sustainability science

Drawing together insights from the three dimensions analysed above, I argue that RwLs function as incubators for advancing transformative sustainability science. Through their unique characteristics and position at the boundaries of conventional scientific practice, RwLs create conditions for the emergence of novel methodological, practical, and ontological innovations that can transform how sustainability science is conducted.

Boundary spaces for scientific innovation

The innovations documented across the five papers emerged from the position of RwLs as boundary spaces or *fringe zones* between scientific and societal domains. This positioning creates productive tensions between different knowledge systems, demands for both rigour and relevance, and evolving roles for researchers and participants. Rather than attempting to resolve these tensions through compromise or simplification, RwLs create environments where they can be navigated creatively, generating innovations that might not emerge in more conventional research settings.

The case reporting approach (Paper 1), for example, emerged from navigating the tensions between the contextual specificity of transdisciplinary knowledge and the need for broader learning across contexts. The concept of emergent impacts (Paper 3) arose from the tensions between conventional impact frameworks and the complex, interactive processes observed in long-term RwL engagement. These innovations did not simply adapt existing approaches, but created new frameworks that reflect the distinctive nature of transformative research.

This boundary-spanning function resonates with what Cash et al. (2003) describe as the creation of "boundary objects"–concepts, tools, or practices that are meaningful across different domains and can facilitate communication between them. The innovations presented in this dissertation function as boundary objects that bridge the gap between conventional scientific approaches and the unique demands of transformative sustainability research.

Creating conditions for scientific evolution

Beyond specific innovations, RwLs create broader conditions for the evolution of scientific practice. Through their sustained engagement with complex sustainability challenges in real-world contexts, they provide environments where new approaches can be tested, refined, and institutionalised over time. This creates a cycle of innovation and learning that extends beyond individual research projects to influence the broader field of transformative sustainability science.

This evolutionary process is reflected in how the innovations developed in this dissertation build upon one another. The case reporting approach emerged from efforts to understand the GLOCULL cases disaggregated into context, lab, and experiment–an analytical structure that also underpins the modular evaluation approach. The concept of emergent impacts, in turn, deepens previous understandings of impact by capturing the indirect and co-evolving effects observed in long-term engagement. These interconnections illustrate how RwL research can generate cumulative innovation over time, with new insights emerging through iterative cycles of conceptual development, practical testing, and critical reflection. As such, RwLs offer not only a space for individual innovation, but a model for how scientific practices might evolve more broadly through embedded, reflexive research.

Balancing rigour and relevance

A crucial aspect of the incubator function of RwLs is their capacity to support innovations that balance scientific rigour with practical relevance. Traditional scientific approaches often prioritise rigour at the expense of real-world applicability, whereas practice-oriented approaches may prioritise societal impact but lack methodological robustness. The innovations documented in this dissertation illustrate how RwLs can foster research that maintains both qualities.

The dual-setting research design and conceptual replication approach (Paper 2) combines contextually embedded transdisciplinary research with more controlled studies to achieve both ecological validity and scientific rigour. The design principles for transformative learning (Paper 4) integrate educational best practices with principles from transformative research to create learning experiences that are both pedagogically sound and practically relevant. These innovations show how RwLs can serve as settings where traditional trade-offs–between rigour and relevance, and between research and education–can be navigated in new ways.

Implications for transformative sustainability science

The conceptualisation of RwLs as incubators for advancing transformative sustainability science has important implications for research practice and the broader

field. It suggests that attention should extend beyond the substantive outcomes of RwL research–such as sustainability solutions or interventions–to include the methodological, practical, and ontological innovations that emerge through these processes. These innovations may ultimately have wider relevance by influencing how transformative research is conceptualised and conducted across different contexts.

This perspective also underscores the importance of establishing RwLs as long-term research infrastructures rather than short-term projects. As Parodi et al. (2024) argue, RwLs realise their full potential when conceived as enduring institutional and epistemological frameworks for experimentation–not as isolated projects or single interventions. This long-term perspective is essential to their role as incubators for scientific innovation, which depends on sustained engagement, iterative learning, and space for reflection.

The design and governance of RwLs should therefore actively cultivate conditions that enable scientific innovation alongside substantive experimentation. This includes fostering spaces for methodological reflection and experimentation (Wahl, 2023), building on dialogue across diverse knowledge systems and perspectives, and supporting the systematic documentation and re-integration of methodological insights alongside empirical results (Jahn et al., 2012).

Through these implications, the conceptualisation of RwLs as incubators for transformative sustainability science contributes to a broader understanding of their role in sustainability transformations–not only as settings for applying established approaches, but as spaces where the practice of science itself can evolve. By enabling reflexive and transgressive forms of research, RwLs help advance the emerging field of transformative sustainability science in ways that are responsive to the complexity of real-world change.

5.5 Limitations and future research

While this dissertation offers valuable insights into how RwL research can inform and advance transformative sustainability science, it is important to acknowledge its limitations and outline areas for future research.

The empirical foundation of this dissertation is based primarily on three interconnected RwL settings, all located within the German and European context. While these cases provided rich opportunities to explore different dimensions of RwL research, they represent only a small subset of the diverse approaches being developed globally. The innovations presented here emerged from specific cultural, institutional, and thematic settings, and their relevance or transferability to other contexts may be limited.

My position as a transdisciplinary researcher embedded in the RwL processes

drawn from in this dissertation has shaped both the strengths and limitations of this work. It offered a unique vantage point on how transformative research approaches emerge and evolve in practice, while also situating my perspective within the academic dimension of these processes.

The field of transformative sustainability science is rapidly evolving, with new approaches and understandings emerging continuously. The innovations presented in this dissertation represent a snapshot of this evolution at a particular moment in time, and may already be subject to expansion, adaptation, or critique as the field develops further. This openness to revision aligns with the very nature of transformative research, where concepts are not static but are expected to evolve through application, challenge, and ongoing critical reflection.

These limitations point to several promising directions for future research. Adopting the idea of RwLs as incubators for advancing transformative sustainability science calls for more comparative studies that examine how similar innovations emerge–or fail to emerge–across diverse global contexts. There is also a need to better understand the processes through which scientific innovations develop within RwL practice, including the roles of collaboration, context, and reflexivity. This should be complemented by longitudinal research that investigates how such innovations influence the broader field of transformative sustainability science over time. Further work could explore the interconnections between the methodological, practical, and ontological dimensions of innovation identified in this dissertation–and extend this analysis to additional dimensions of scientific transformation.

These future directions, however, should not overlook the elephant in the room: while RwLs–as illustrated in this thesis–should be settings to explore what science could and should be, their primary purposes of enabling collaboration for sustainability transformations and generating actionable knowledge must not be compromised by an inward turn toward methodological refinement or theoretical abstraction that lacks practical relevance and risks detaching science from societal needs.

By balancing these ambitions through reflexivity and a transformative orientation, we can continue to develop a richer understanding of how research in RwLs can inform and foster an emergent transformative sustainability science–advancing not only our responses to specific sustainability challenges, but also our collective capacity to conduct transformative research itself.

Chapter 6

Conclusion

This dissertation has examined how research in real-world laboratories (RwLs) can inform and foster an emergent transformative sustainability science. Through five papers addressing different aspects of RwL research, I have shown how RwLs function both as incubators and as enabling research environments that advance the field across methodological, practical, and ontological dimensions. While each paper responds to specific challenges encountered in RwL settings, they collectively form a coherent body of work–not merely through shared empirical contexts, but through a common orientation toward shaping the methodological foundations, practical approaches, and conceptual understandings of transformative sustainability science.

The methodological innovations presented in this dissertation–including case reporting, conceptual replication, and modular evaluation–demonstrate how RwL research can address key challenges in knowledge transfer, generalisability, and evaluation by developing methods grounded in real-world engagement. The practice innovations–such as conceptualising case reporting as a collaborative learning practice and integrating educational goals into research through design principles–show how RwLs expand the role of research beyond knowledge production to include capacity-building and experiential learning. Finally, the ontological shifts–particularly in how scientific impact and evaluation are conceptualised–highlight how sustained engagement in RwLs can reshape foundational assumptions about change, complexity, and scientific agency.

These innovations emerged through direct engagement with challenges encountered in RwL practice, underscoring the value of RwLs as boundary spaces–or *fringe zones*–where tensions between knowledge systems, competing demands for rigour and relevance, and evolving researcher roles can drive scientific innovation. By creating conditions where such tensions are not resolved but creatively navigated, RwLs foster methodological, practical, and ontological developments that advance transformative sustainability science.

Transformative sustainability science should be understood as an emergent

field–not in the sense of accidental development, but as an intentional process shaped by reflexive researchers drawing on grounded, experiential, and contestable contributions. RwLs offer critical settings for this work, providing the conditions where researchers can develop the insights and capacities needed to rethink not just sustainability solutions, but the scientific practices used to address them. This conceptualisation of RwLs as incubators has important implications: for researchers, it highlights the importance of advancing methodological, practical, and conceptual innovation alongside empirical findings; for practitioners and policymakers, it underscores the need to support RwLs as long-term infrastructures that foster scientific and societal transformation in tandem. As this dissertation has shown, RwLs do not simply apply transformative approaches–they help generate them. Situated at the boundaries of conventional science, they create spaces where knowledge production, collaboration, and reflexivity converge–and where science itself can be reimagined for a world in need of sustainability transformations.

References

Abson, D. J., Fischer, J., Leventon, J., Newig, J., Schomerus, T., Vilsmaier, U., von Wehrden, H., Abernethy, P., Ives, C. D., Jager, N. W., & Lang, D. J. (2017). Leverage points for sustainability transformation. *Ambio*, *46*(1), 30–39. https://doi.org/10.1007/s13280-016-0800-y

Adler, C., Hirsch Hadorn, G., Breu, T., Wiesmann, U., & Pohl, C. (2017). Conceptualizing the transfer of knowledge across cases in transdisciplinary research. *Sustainability Science*, *13*(1), 179–190. https://doi.org/10.1007/s11625-017-0444-2

Augenstein, K., Lam, D. P., Horcea-Milcu, A.-I., Bernert, P., Charli-Joseph, L., Cockburn, J., Kampfmann, T., Pereira, L. M., & Sellberg, M. M. (2024). Five priorities to advance transformative transdisciplinary research. *Current Opinion in Environmental Sustainability*, *68*, 101438. https://doi.org/10.1016/j.cosust.2024.101438

Bartels, K. P., & Wittmayer, J. M. (Eds.). (2018, June 27). *Action research in policy analysis: Critical and relational approaches to sustainability transitions* (1st ed.). Routledge. https://doi.org/10.4324/9781315148724

Barth, M., Bruhn, A., Lam, D. P., Bergmann, M., & Lang, D. J. (2020). Capacity building for transformational leadership and transdisciplinarity. *GAIA - Ecological Perspectives for Science and Society*, *29*(3), 195–197. https://doi.org/10.14512/gaia.29.3.12

Beecroft, R. (2018). Embedding higher education into a real-world lab: A process-oriented analysis of six transdisciplinary project courses. *Sustainability (Switzerland)*, *10*(10). https://doi.org/10.3390/su10103798

Belcher, B., & Claus, R. (2025). A quality assessment framework for transdisciplinary research design, monitoring, and evaluation: Guidance for application. *MethodsX*, *14*, 103264. https://doi.org/10.1016/j.mex.2025.103264

Belcher, B. M., Davel, R., & Claus, R. (2020). A refined method for theory-based evaluation of the societal impacts of research. *MethodsX*, *7*, 100788. https://doi.org/10.1016/j.mex.2020.100788

Bergmann, M., Schäpke, N., Marg, O., Stelzer, F., Lang, D. J., Bossert, M., Gantert, M., Häußler, E., Marquardt, E., Piontek, F. M., Potthast, T., Rhodius, R.,

Rudolph, M., Ruddat, M., Seebacher, A., & Sußmann, N. (2021). Transdisciplinary sustainability research in real-world labs: Success factors and methods for change. *Sustainability Science*, *16*(2), 541–564. https://doi.org/10.1007/s11625-020-00886-8

Bernert, P., Haaser, A., Kühl, L., & Schaal, T. (2016). Towards a real-world laboratory: A transdisciplinary case study from lüneburg. *GAIA - Ecological Perspectives for Science and Society*, *25*(4), 253–259. https://doi.org/10.14512/gaia.25.4.7

Brandt, P., Ernst, A., Gralla, F., Luederitz, C., Lang, D. J., Newig, J., Reinert, F., Abson, D. J., & von Wehrden, H. (2013). A review of transdisciplinary research in sustainability science. *Ecological Economics*, *92*, 1–15. https://doi.org/10.1016/j.ecolecon.2013.04.008

Caniglia, G., Freeth, R., Luederitz, C., Leventon, J., West, S. P., John, B., Peukert, D., Lang, D. J., Von Wehrden, H., Martín-López, B., Fazey, I., Russo, F., Von Wirth, T., Schlüter, M., & Vogel, C. (2023). Practical wisdom and virtue ethics for knowledge co-production in sustainability science. *Nature Sustainability*, *6*(5), 493–501. https://doi.org/10.1038/s41893-022-01040-1

Caniglia, G., Luederitz, C., Von Wirth, T., Fazey, I., Martín-López, B., Hondrila, K., König, A., Von Wehrden, H., Schäpke, N. A., Laubichler, M. D., & Lang, D. J. (2020). A pluralistic and integrated approach to action-oriented knowledge for sustainability. *Nature Sustainability*, *4*(2), 93–100. https://doi.org/10.1038/s41893-020-00616-z

Caniglia, G., Schäpke, N., Lang, D. J., Abson, D. J., Luederitz, C., Wiek, A., Laubichler, M. D., Gralla, F., & Von Wehrden, H. (2017). Experiments and evidence in sustainability science: A typology. *Journal of Cleaner Production*, *169*, 39–47. https://doi.org/10.1016/j.jclepro.2017.05.164

Caniglia, G., & Vogel, C. (2023). On being oriented: Strengthening transgressive orientations in transdisciplinary sustainability research through queer theory. *GAIA - Ecological Perspectives for Science and Society*, *32*(1), 167–171. https://doi.org/10.14512/gaia.32.1.15

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., Jäger, J., & Mitchell, R. B. (2003). Knowledge systems for sustainable development. *Proceedings of the National Academy of Sciences*, *100*(14), 8086–8091. https://doi.org/10.1073/pnas.1231332100

Chambers, J. M., Wyborn, C., Klenk, N. L., Ryan, M., Serban, A., Bennett, N. J., Brennan, R., Charli-Joseph, L., Fernández-Giménez, M. E., Galvin, K. A., Goldstein, B. E., Haller, T., Hill, R., Munera, C., Nel, J. L., Österblom, H., Reid, R. S., Riechers, M., Spierenburg, M., … Rondeau, R. (2022). Co-productive agility and four collaborative pathways to sustainability trans-

formations. *Global Environmental Change*, *72*, 102422. https://doi.org/10.1016/j.gloenvcha.2021.102422

Charli-Joseph, L., Siqueiros-Garcia, J. M., Eakin, H., Manuel-Navarrete, D., & Shelton, R. (2018). Promoting agency for social-ecological transformation: A transformation-lab in the xochimilco social-ecological system. *Ecology and Society*, *23*(2), art46. https://doi.org/10.5751/ES-10214-230246

Clark, W. C., & Harley, A. G. (2020). Sustainability science: Toward a synthesis. *Annual Review of Environment and Resources*, *45*(1), 331–386. https://doi.org/10.1146/annurev-environ-012420-043621

Clark, W. C., Van Kerkhoff, L., Lebel, L., & Gallopin, G. C. (2016). Crafting usable knowledge for sustainable development. *Proceedings of the National Academy of Sciences*, *113*(17), 4570–4578. https://doi.org/10.1073/pnas.1601266113

Cornell, S., Berkhout, F., Tuinstra, W., Tàbara, J. D., Jäger, J., Chabay, I., De Wit, B., Langlais, R., Mills, D., Moll, P., Otto, I. M., Petersen, A., Pohl, C., & Van Kerkhoff, L. (2013). Opening up knowledge systems for better responses to global environmental change. *Environmental Science & Policy*, *28*, 60–70. https://doi.org/10.1016/j.envsci.2012.11.008

Dalla Fontana, M., Moreira, F. d. A., Di Giulio, G. M., & Malheiros, T. F. (2020). The water-energy-food nexus research in the brazilian context: What are we missing? *Environmental Science & Policy*, *112*, 172–180. https://doi.org/10.1016/j.envsci.2020.06.021

Derksen, M., & Morawski, J. (2022). Kinds of replication: Examining the meanings of "conceptual replication" and "direct replication". *Perspectives on Psychological Science*, *17*(5), 1490–1505. https://doi.org/10.1177/17456916211041116

Fazey, I., Schäpke, N., Caniglia, G., Hodgson, A., Kendrick, I., Lyon, C., Page, G., Patterson, J., Riedy, C., Strasser, T., Verveen, S., Adams, D., Goldstein, B., Klaes, M., Leicester, G., Linyard, A., McCurdy, A., Ryan, P., Sharpe, B., … Young, H. R. (2020). Transforming knowledge systems for life on earth: Visions of future systems and how to get there. *Energy Research & Social Science*, *70*, 101724. https://doi.org/10.1016/j.erss.2020.101724

Fazey, I., Schäpke, N., Caniglia, G., Patterson, J., Hultman, J., Van Mierlo, B., Säwe, F., Wiek, A., Wittmayer, J., Aldunce, P., Al Waer, H., Battacharya, N., Bradbury, H., Carmen, E., Colvin, J., Cvitanovic, C., D'Souza, M., Gopel, M., Goldstein, B., … Wyborn, C. (2018). Ten essentials for action-oriented and second order energy transitions, transformations and climate change research. *Energy Research & Social Science*, *40*, 54–70. https://doi.org/10.1016/j.erss.2017.11.026

Ferraro, P. J., & Agrawal, A. (2021). Synthesizing evidence in sustainability science through harmonized experiments: Community monitoring in common

pool resources. *Proceedings of the National Academy of Sciences*, *118*(29), e2106489118. https://doi.org/10.1073/pnas.2106489118

Frantzeskaki, N., Van Steenbergen, F., & Stedman, R. C. (2018). Sense of place and experimentation in urban sustainability transitions: The resilience lab in carnisse, rotterdam, the netherlands. *Sustainability Science*, *13*(4), 1045–1059. https://doi.org/10.1007/s11625-018-0562-5

Funtowicz, S. O., & Ravetz, J. R. (1993). Science for the post-normal age. *Futures*, *25*(7), 739–755. https://doi.org/10.1016/0016-3287(93)90022-L

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Peter, S., & Trow, M. (1994). *The new production of knowledge: The dynamics of science and research in contemporary societies*. Sage.

Heiskanen, E., Laakso, S., Matschoss, K., Backhaus, J., Goggins, G., & Vadovics, E. (2018). Designing real-world laboratories for the reduction of residential energy use: Articulating theories of change. *GAIA - Ecological Perspectives for Science and Society*, *27*(1), 60–67. https://doi.org/10.14512/gaia.27.S1.13

Hilger, A., Rose, M., & Keil, A. (2021). Beyond practitioner and researcher: 15 roles adopted by actors in transdisciplinary and transformative research processes. *Sustainability Science*. https://doi.org/10/gnsnnh

Hirsch Hadorn, G., Bradley, D., Pohl, C., Rist, S., & Wiesmann, U. (2006). Implications of transdisciplinarity for sustainability research. *Ecological Economics*, *60*(1), 119–128. https://doi.org/10.1016/j.ecolecon.2005.12.002

Hirsch Hadorn, G., Hoffmann-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., Wiesmann, U., & Zemp, E. (2008). *Handbook of transdisciplinary research*. https://doi.org/10.1007/978-1-4020-6699-3

Horcea-Milcu, A.-I., Dorresteijn, I., Leventon, J., Stojanovic, M., Lam, D. P., Lang, D. J., Moriggi, A., Raymond, C. M., Stålhammar, S., Weiser, A., & Zimmermann, S. (2024). Transformative research for sustainability: Characteristics, tensions, and moving forward. *Global Sustainability*, *7*, e14. https://doi.org/10.1017/sus.2024.12

Hudson, R. (2023). Explicating exact versus conceptual replication. *Erkenntnis*, *88*(6), 2493–2514. https://doi.org/10.1007/s10670-021-00464-z

Jahn, T., Bergmann, M., & Keil, F. (2012). Transdisciplinarity: Between mainstreaming and marginalization. *Ecological Economics*, *79*, 1–10. https://doi.org/10.1016/j.ecolecon.2012.04.017

Jerneck, A., Olsson, L., Ness, B., Anderberg, S., Baier, M., Clark, E., Hickler, T., Hornborg, A., Kronsell, A., Lövbrand, E., & Persson, J. (2011). Structuring sustainability science. *Sustainability Science*, *6*(1), 69–82. https://doi.org/10.1007/s11625-010-0117-x

Kampfmann, T., Bernert, P., Lang, D. J., & Drautz, S. (2024). Governance for urban sustainability through real-world experimentation – introducing an evaluation framework for transformative research involving public actors. *Cities*, *153*, 105301. https://doi.org/10.1016/j.cities.2024.105301

Kates, R. W. (2011). What kind of a science is sustainability science? *Proceedings of the National Academy of Sciences*, *108*(49), 19449–19450. https://doi.org/10.1073/pnas.1116097108

Kates, R. W., Clark, W. C., Corell, R., Hall, J. M., Jaeger, C. C., Lowe, I., McCarthy, J. J., Schellnhuber, H. J., Bolin, B., Dickson, N. M., Faucheux, S., Gallopin, G. C., Grübler, A., Huntley, B., Jäger, J., Jodha, N. S., Kasperson, R. E., Mabogunje, A., Matson, P., … Svedin, U. (2001). Sustainability science. *Science*, *292*(5517), 641–642. https://doi.org/10.1126/science.1059386

Lam, D. P. M., Hinz, E., Lang, D. J., Tengö, M., Wehrden, H. V., & Martín-López, B. (2020). Indigenous and local knowledge in sustainability transformations research: A literature review. *Ecology and Society*, *25*(1), art3. https://doi.org/10.5751/ES-11305-250103

Lang, D. J., & Wiek, A. (2022). Structuring and advancing solution-oriented research for sustainability: This article belongs to ambio's 50th anniversary collection. theme: Solutions-oriented research. *Ambio*, *51*(1), 31–35. https://doi.org/10.1007/s13280-021-01537-7

Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., & Thomas, C. J. (2012). Transdisciplinary research in sustainability science: Practice, principles, and challenges. *Sustainability Science*, *7*, 25–43. https://doi.org/10.1007/s11625-011-0149-x

Lang, D. J., Wiek, A., & von Wehrden, H. (2017). Bridging divides in sustainability science. *Sustainability Science*. https://doi.org/10.1007/s11625-017-0497-2

Leach, M., Reyers, B., Bai, X., Brondizio, E. S., Cook, C., Díaz, S., Espindola, G., Scobie, M., Stafford-Smith, M., & Subramanian, S. M. (2018). Equity and sustainability in the anthropocene: A social–ecological systems perspective on their intertwined futures. *Global Sustainability*, *1*, e13. https://doi.org/10.1017/sus.2018.12

Levin, K., Cashore, B., Bernstein, S., & Auld, G. (2012). Overcoming the tragedy of super wicked problems: Constraining our future selves to ameliorate global climate change. *Policy Sciences*, *45*(2), 123–152. https://doi.org/10.1007/s11077-012-9151-0

Loorbach, D. (2010). Transition management for sustainable development: A prescriptive, complexity-based governance framework. *Governance*, *23*(1), 161–183. https://doi.org/10.1111/j.1468-0491.2009.01471.x

Loorbach, D., Frantzeskaki, N., & Avelino, F. (2017). Sustainability transitions research: Transforming science and practice for societal change. *Annual Review of Environment and Resources*, *42*(1), 599–626. https://doi.org/10.1146/annurev-environ-102014-021340

Lotz-Sisitka, H., Ali, M. B., Mphepo, G., Chaves, M., Macintyre, T., Pesanayi, T., Wals, A., Mukute, M., Kronlid, D., Tran, D. T., Joon, D., & McGarry, D. (2016). Co-designing research on transgressive learning in times of climate change. *Current Opinion in Environmental Sustainability*, *20*, 50–55. https://doi.org/10.1016/j.cosust.2016.04.004

Luederitz, C., Schäpke, N., Wiek, A., Lang, D. J., Bergmann, M., Bos, J. J., Burch, S., Davies, A., Evans, J., König, A., Farrelly, M. A., Forrest, N., Frantzeskaki, N., Gibson, R. B., Kay, B., Loorbach, D., McCormick, K., Parodi, O., Rauschmayer, F., ... Westley, F. R. (2017). Learning through evaluation – a tentative evaluative scheme for sustainability transition experiments. *Journal of Cleaner Production*, *169*, 61–76. https://doi.org/10.1016/j.jclepro.2016.09.005

McCrory, G., Schäpke, N., Holmén, J., & Holmberg, J. (2020). Sustainability-oriented labs in real-world contexts: An exploratory review. *Journal of Cleaner Production*, *277*, 123202. https://doi.org/10.1016/j.jclepro.2020.123202

Meadows, D. (1999). *Leverage points - places to intervene in a system*. The Sustainability Institute. Hartland, Vermont. Retrieved May 19, 2025, from https://www.donellameadows.org/wp-content/userfiles/Leverage_Points.pdf

Miller, C. A., & Wyborn, C. (2020). Co-production in global sustainability: Histories and theories. *Environmental Science & Policy*, *113*, 88–95. https://doi.org/10.1016/j.envsci.2018.01.016

Miller, T. R., Wiek, A., Sarewitz, D., Robinson, J., Olsson, L., Kriebel, D., & Loorbach, D. (2014). The future of sustainability science: A solutions-oriented research agenda [ISBN: 1862-4065]. *Sustainability Science*, *9*(2), 239–246. https://doi.org/10.1007/s11625-013-0224-6

Moser, S. C. (2016). Can science on transformation transform science? lessons from co-design. *Current Opinion in Environmental Sustainability*, *20*, 106–115. https://doi.org/10.1016/j.cosust.2016.10.007

Nagy, E., Ransiek, A., Schäfer, M., Lux, A., Bergmann, M., Jahn, T., Marg, O., & Theiler, L. (2020). Transfer as a reciprocal process: How to foster receptivity to results of transdisciplinary research [Publisher: Elsevier]. *Environmental Science and Policy*, *104*, 148–160. https://doi.org/10.1016/j.envsci.2019.11.007

Nevens, F., Frantzeskaki, N., Gorissen, L., & Loorbach, D. (2013). Urban transition labs: Co-creating transformative action for sustainable cities. *Journal of Cleaner Production*, *50*, 111–122. https://doi.org/10.1016/j.jclepro.2012.12.001

Norström, A. V., Cvitanovic, C., Löf, M. F., West, S., Wyborn, C., Balvanera, P., Bednarek, A. T., Bennett, E. M., Biggs, R., De Bremond, A., Campbell, B. M., Canadell, J. G., Carpenter, S. R., Folke, C., Fulton, E. A., Gaffney, O., Gelcich, S., Jouffray, J.-B., Leach, M., ... Österblom, H. (2020). Principles for knowledge co-production in sustainability research. *Nature Sustainability*, *3*(3), 182–190. https://doi.org/10.1038/s41893-019-0448-2

Nowotny, H., Scott, P., & Gibbons, M. (2001). *Re-thinking science: Knowledge and the public in an age of uncertainty* [OCLC: 555515426]. Polity Press.

O'Brien, K., & Sygna, L. (2013). Responding to climate change: The three spheres of transformation. [OCLC: 1120317168]. *Proceedings transformation in a changing climate: International Conference in Oslo 19-21 June 2013*, 16–23.

Parodi, O. (2019). Wider eine Engführung des Reallabor-Konzepts. *Ökologisches Wirtschaften - Fachzeitschrift*, (2), 8–9. https://doi.org/10.14512/OEW340208

Parodi, O., Ober, S., Lang, D. J., & Albiez, M. (2024). Reallabor versus realexperiment: Was macht den unterschied? *GAIA - Ecological Perspectives for Science and Society*, *33*(2), 216–221. https://doi.org/10.14512/gaia.33.2.4

Parodi, O., Waitz, C., Bachinger, M., Kuhn, R., Meyer-Soylu, S., Alcántara, S., & Rhodius, R. (2018). Insights into and recommendations from three real-world laboratories: An experience-based comparison. *GAIA - Ecological Perspectives for Science and Society*, *27*(1), 52–59. https://doi.org/10.14512/gaia.27.S1.12

Pereira, L., Frantzeskaki, N., Hebinck, A., Charli-Joseph, L., Drimie, S., Dyer, M., Eakin, H., Galafassi, D., Karpouzoglou, T., Marshall, F., Moore, M.-L., Olsson, P., Siqueiros-García, J. M., Van Zwanenberg, P., & Vervoort, J. M. (2020). Transformative spaces in the making: Key lessons from nine cases in the global south. *Sustainability Science*, *15*(1), 161–178. https://doi.org/10.1007/s11625-019-00749-x

Pohl, C., & Hirsch Hadorn, G. (2007, March 22). *Principles for designing transdisciplinary research*. oekom verlag. https://doi.org/10.14512/9783962388638

Pohl, C., Krütli, P., & Stauffacher, M. (2017). Ten reflective steps for rendering research societally relevant. *Gaia*, *26*(1), 43–51. https://doi.org/10.14512/gaia.26.1.10

Popa, F., Guillermin, M., & Dedeurwaerdere, T. (2015). A pragmatist approach to transdisciplinarity in sustainability research: From complex systems theory to reflexive science. *Futures*, *65*, 45–56. https://doi.org/10.1016/j.futures.2014.02.002

Raworth, K. (2017, February). *Doughnut economics: Seven ways to think like a 21st century economist*. Chelsea Green Publishing.

Raymond, C. M., Fazey, I., Reed, M. S., Stringer, L. C., Robinson, G. M., & Evely, A. C. (2010). Integrating local and scientific knowledge for environmental

management. *Journal of Environmental Management*, *91*(8), 1766–1777. https://doi.org/10.1016/j.jenvman.2010.03.023

Reason, P., & Bradbury, H. (2008). *The SAGE handbook of action research*. SAGE Publications Ltd. https://doi.org/10.4135/9781848607934

Reed, M. S., Vella, S., Challies, E., De Vente, J., Frewer, L., Hohenwallner-Ries, D., Huber, T., Neumann, R. K., Oughton, E. A., Sidoli Del Ceno, J., & Van Delden, H. (2018). A theory of participation: What makes stakeholder and public engagement in environmental management work? *Restoration Ecology*, *26*. https://doi.org/10.1111/rec.12541

Reed, M., Stringer, L., Fazey, I., Evely, A., & Kruijsen, J. (2014). Five principles for the practice of knowledge exchange in environmental management. *Journal of Environmental Management*, *146*, 337–345. https://doi.org/10.1016/j.jenvman.2014.07.021

Rodríguez Aboytes, J. G., & Barth, M. (2020). Transformative learning in the field of sustainability: A systematic literature review (1999-2019). *International Journal of Sustainability in Higher Education*, *21*(5), 993–1013. https://doi.org/10.1108/IJSHE-05-2019-0168

Schäfer, M., Bergmann, M., & Theiler, L. (2021). Systematizing societal effects of transdisciplinary research. *Research Evaluation*, rvab019. https://doi.org/10.1093/reseval/rvab019

Schäpke, N., Stelzer, F., Caniglia, G., Bergmann, M., Wanner, M., Singer-Brodowski, M., Loorbach, D., Olsson, P., Baedeker, C., & Lang, D. J. (2018). Jointly experimenting for transformation? shaping real-world laboratories by comparing them. *GAIA - Ecological Perspectives for Science and Society*, *27*(1), 85–96. https://doi.org/10.14512/gaia.27.S1.16

Schäpke, N., Wagner, F., Beecroft, R., Rhodius, R., Laborgne, P., Wanner, M., & Parodi, O. (2024). Impacts of real-world labs in sustainability transformations: Forms of impacts, creation strategies, challenges, and methodological advances. *GAIA - Ecological Perspectives for Science and Society*, *33*(1), 4–9. https://doi.org/10.14512/gaia.33.S1.2

Schneider, F., Giger, M., Harari, N., Moser, S., Oberlack, C., Providoli, I., Schmid, L., Tribaldos, T., & Zimmermann, A. (2019). Transdisciplinary co-production of knowledge and sustainability transformations: Three generic mechanisms of impact generation. *Environmental Science & Policy*, *102*, 26–35. https://doi.org/10.1016/j.envsci.2019.08.017

Schneidewind, U., Augenstein, K., Stelzer, F., & Wanner, M. (2018). Structure matters: Real-world laboratories as a new type of large-scale research infrastructure: A framework inspired by giddens' structuration theory. *GAIA -*

Ecological Perspectives for Science and Society, *27*(1), 12–17. https://doi.org/10.14512/gaia.27.S1.5

Schneidewind, U., Singer-Brodowski, M., Augenstein, K., & Stelzer, F. (2016). *Pledge for a transformative science: A conceptual framework*. Wuppertal papers. Retrieved May 20, 2025, from http://nbn-resolving.de/urn:nbn:de:bsz:wup4-opus-64142

Scholz, R. W., & Steiner, G. (2015). The real type and ideal type of transdisciplinary processes: Part i—theoretical foundations. *Sustainability Science*, *10*(4), 527–544. https://doi.org/10.1007/s11625-015-0326-4

Sellberg, M. M., Cockburn, J., Holden, P. B., & Lam, D. P. M. (2021). Towards a caring transdisciplinary research practice: Navigating science, society and self. *Ecosystems and People*, *17*(1), 292–305. https://doi.org/10.1080/26395916.2021.1931452

Sengers, F., Wieczorek, A. J., & Raven, R. (2016). Experimenting for sustainability transitions: A systematic literature review. *Technological Forecasting and Social Change*, *145*, 153–164. https://doi.org/10.1016/j.techfore.2016.08.031

Singer-Brodowski, M., Beecroft, R., & Parodi, O. (2018). Learning in real-world laboratories: A systematic impulse for discussion. *GAIA - Ecological Perspectives for Science and Society*, *27*(1), 23–27. https://doi.org/10.14512/gaia.27.S1.7

Temper, L., McGarry, D., & Weber, L. (2019). From academic to political rigour: Insights from the 'tarot' of transgressive research. *Ecological Economics*, *164*, 106379. https://doi.org/10.1016/j.ecolecon.2019.106379

Tengö, M., Hill, R., Malmer, P., Raymond, C. M., Spierenburg, M., Danielsen, F., Elmqvist, T., & Folke, C. (2017). Weaving knowledge systems in IPBES, CBD and beyond—lessons learned for sustainability. *Current Opinion in Environmental Sustainability*, *26-27*, 17–25. https://doi.org/10.1016/j.cosust.2016.12.005

Turnheim, B., Berkhout, F., Geels, F., Hof, A., McMeekin, A., Nykvist, B., & van Vuuren, D. (2015). Evaluating sustainability transitions pathways: Bridging analytical approaches to address governance challenges. *Global Environmental Change*. https://doi.org/10.1016/j.gloenvcha.2015.08.010

Turnhout, E., Metze, T., Wyborn, C., Klenk, N., & Louder, E. (2020). The politics of co-production: Participation, power, and transformation. *Current Opinion in Environmental Sustainability*, *42*, 15–21. https://doi.org/10.1016/j.cosust.2019.11.009

Van Der Hel, S. (2018). Science for change: A survey on the normative and political dimensions of global sustainability research. *Global Environmental Change*, *52*, 248–258. https://doi.org/10.1016/j.gloenvcha.2018.07.005

Von Wehrden, H. (2023). Methods in sustainability science. *GAIA - Ecological Perspectives for Science and Society*, *32*(4), 341–341. https://doi.org/10.14512/gaia.32.4.1

Von Wirth, T., Fuenfschilling, L., Frantzeskaki, N., & Coenen, L. (2019). Impacts of urban living labs on sustainability transitions: Mechanisms and strategies for systemic change through experimentation. *European Planning Studies*, *27*(2), 229–257. https://doi.org/10.1080/09654313.2018.1504895

Wahl, D. (2023). Experimenting with sustainability transformations: A study of urban living labs in the food, water and energy nexus [Publisher: Unpublished]. https://doi.org/10.13140/RG.2.2.29513.72809

Wahl, D., Ness, B., & Wamsler, C. (2021). Implementing the urban food–water–energy nexus through urban laboratories: A systematic literature review. *Sustainability Science*, *16*(2), 663–676. https://doi.org/10.1007/s11625-020-00893-9

Wall, T. U., Meadow, A. M., & Horganic, A. (2017). Developing evaluation indicators to improve the process of coproducing usable climate science. *Weather, Climate, and Society*, *9*(1), 95–107. https://doi.org/10.1175/WCAS-D-16-0008.1

Walter, A. I., Helgenberger, S., Wiek, A., & Scholz, R. W. (2007). Measuring societal effects of transdisciplinary research projects: Design and application of an evaluation method. *Evaluation and Program Planning*, *30*(4), 325–338. https://doi.org/10.1016/j.evalprogplan.2007.08.002

Wanner, M., Bernert, P., Fischer, N., & Schmitt, M. (2021). Creating learning and teaching spaces for transformative and transdisciplinary research: The transformative innovation lab. *DIDAC*, (78), 49–59. https://doi.org/10.48102/didac.2021..78_JUL-DIC.83

Wanner, M., Hilger, A., Westerkowski, J., Rose, M., Stelzer, F., & Schäpke, N. (2018). Towards a cyclical concept of real-world laboratories: A transdisciplinary research practice for sustainability transitions. *disP - The Planning Review*, *54*(2), 94–114. https://doi.org/10.1080/02513625.2018.1487651

Wanner, M., Schmitt, M., Fischer, N., & Bernert, P. (2020). *Transformative innovation lab. handbook to facilitate student's real-world laboratory projects to promote transformative and transdisciplinary competencies*. Wuppertal Institut. Wuppertal. Retrieved May 21, 2025, from https://epub.wupperinst.org/frontdoor/deliver/index/docId/7685/file/7685_TIL_Handbook.pdf

WBGU - German Advisory Council on Global Change. (2011). *World in transition – a social contract for sustainability*. Wiss. Beirat d. Bundesregierung Globale Umweltveränderungen. https://www.wbgu.de/en/publications/publication/world-in-transition-a-social-contract-for-sustainability

Weber, H., Loschelder, D. D., Lang, D. J., & Wiek, A. (2021). Connecting consumers to producers to foster sustainable consumption in international coffee supply

– a marketing intervention study. *Journal of Marketing Management*, *37*(11), 1148–1168. https://doi.org/10.1080/0267257X.2021.1897650

Weiser, A., Meyer, S., Bernert, P., & Lang, D. J. (2023). Problem- und projektorientierte lehre transdisziplinär gestalten. In M. Barth, D. Fischer, & G. Michelsen (Eds.), *Bildung für nachhaltige entwicklung in der hochschule - wege und wirkungen am beispiel der leuphana universität lüneburg*. Verlag Barbara Budrich.

West, S., Van Kerkhoff, L., & Wagenaar, H. (2019). Beyond "linking knowledge and action": Towards a practice-based approach to transdisciplinary sustainability interventions. *Policy Studies*, *40*(5), 534–555. https://doi.org/10.1080/01442872.2019.1618810

Westley, F. R., Tjornbo, O., Schultz, L., Olsson, P., Folke, C., Crona, B., & Bodin, Ö. (2013). A theory of transformative agency in linked social-ecological systems. *Ecology and Society*, *18*(3), art27. https://doi.org/10.5751/ES-05072-180327

Wiefek, J., Nagy, E., & Schäfer, M. (2024). Formative evaluation of transdisciplinary research for systematic impact orientation in real-world laboratories. *GAIA - Ecological Perspectives for Science and Society*, *33*(1), 94–101. https://doi.org/10.14512/gaia.33.S1.14

Wiek, A. (2007). Challenges of transdisciplinary research as interactive knowledge generation experiences from transdisciplinary case study research. *Gaia*, *16*(1), 52–57. https://doi.org/10.14512/gaia.16.1.14

Wiek, A., & Iwaniec, D. (2014). Quality criteria for visions and visioning in sustainability science. *Sustainability Science*, *9*(4), 497–512. https://doi.org/10.1007/s11625-013-0208-6

Wiek, A., & Lang, D. J. (2016). Transformational sustainability research methodology. In H. Heinrichs, P. Martens, G. Michelsen, & A. Wiek (Eds.), *Sustainability science* (pp. 31–41). Springer Netherlands. https://doi.org/10.1007/978-94-017-7242-6_3

Wiek, A., Withycombe, L., & Redman, C. L. (2011). Key competencies in sustainability: A reference framework for academic program development [Publisher: Springer]. *Sustainability science*, *6*(2), 203–218. https://doi.org/10/c6hkjf

Williams, S., & Robinson, J. (2020). Measuring sustainability: An evaluation framework for sustainability transition experiments. *Environmental Science & Policy*, *103*, 58–66. https://doi.org/10.1016/j.envsci.2019.10.012

Wittmayer, J. M., & Schäpke, N. (2014). Action, research and participation: Roles of researchers in sustainability transitions. *Sustainability Science*, *9*(4), 483–496. https://doi.org/10.1007/s11625-014-0258-4

Wuelser, G., Adler, C., Breu, T., Hirsch Hadorn, G., Wiesmann, U., & Pohl, C. (2021). On which common ground to build? transferable knowledge across

cases in transdisciplinary sustainability research. *Sustainability Science*, *16*(6), 1891–1905. https://doi.org/10.1007/s11625-021-01010-0

Appendix A

Overview of Articles Included in the Doctoral Thesis

In accordance with the Doctoral Regulations of 20 July 2023 § 8 Section 3 and the Guideline for Cumulative Dissertations enacted at the Faculty of Sustainability in January 2012.

Article No.	**Bibliography**	**Publication Status**	**Specific contribution**	**Weighing Factor**
1	Bernert, P., Wahl, D., von Wehrden, H., & Lang, D. J. (2023). Cross-case knowledge transfer in transformative research: enabling learning in and across sustainability-oriented labs through case reporting. *Urban Transformations*, 5(12).	Published	Co-author with equal contribution (shared first authorship)	1.0
2	Bernert, P., Weber, H., Tóth, T., Loschelder, D., & Lang, D. J.. Bridging the gap between local solution development and broader knowledge generation: Insights from a marketing intervention study on sustainable coffee supply.	Manuscript	Co-author with predominant contribution	1.0
3	Bernert, P., Weiser, A., Kampfmann, T., & Lang, D. J. (2024). Impacts beyond experimentation – Conceptualising emergent impacts from long-term real-world laboratory processes. *GAIA – Ecological Perspectives for Science and Society*.	Published	Co-author with predominant contribution	1.0
4	Bernert, P., Wanner, M., Fischer, N., & Barth, M. (2022). Design principles for advancing higher education sustainability learning through transformative research. *Environment, Development and Sustainability*.	Published	Co-author with predominant contribution	1.0
5	Kampfmann, T., Bernert, P., & Lang, D. J. (2022). Toward a modular evaluation approach of real-world laboratories: Findings from a literature review. *Research Evaluation*.	Published	Co-author with important contribution	0.5

Detailed Contribution Statements

1. **Paper 1:** Conceptual development of the case reporting scheme, coordination of the collaborative writing process, shared lead authoring of the manuscript with equal contribution from Darin Wahl.

2. **Paper 2:** Conceptual development of the dual-setting research design, co-coordination of the field experiment, and lead authoring of the manuscript.

3. **Paper 3:** Development of the concept of emergent impacts, coordination of the case analysis, and lead authoring of the manuscript.

4. **Paper 4:** Development of the design principles framework, coordination of the collaborative writing process and lead authoring of the manuscript.

5. **Paper 5:** Contribution to the conceptual framework, and manuscript review. Lead author was responsible for data collection and analysis of the literature review.

Declaration

According to § 16 of the guideline for cumulative dissertations:

I avouch that all information given in this appendix is true in each instance and overall.

Place, Date Signature

Explanatory Notes:

Articles included in a cumulative doctoral thesis can also be conference contributions or book chapters besides papers published in journals.

Bibliography: Author(s) – Title – Journal / Book / Conference contribution – Date of publication – DOI (if available)

Specific contribution of PhD candidate submitting the doctoral thesis / Author status according to § 12 of the guideline for cumulative dissertations:

- Single author = own contribution amounts to 100%.
- Co-author with predominant contribution = own contribution is greater than the individual share of all other co-authors and is at least 35%.
- Co-author with equal contribution = (1) own contribution is as high as the share of other co-authors, (2) no other co-author has a contribution higher than the own contribution, and (3) the own contribution is at least 25%.
- Co-author with important contribution = own contribution is at least 25%, but is insufficient to qualify as single authorship, predominant or equal contribution.
- Co-author with small contribution = own contribution is less than 20%.

Weighing Factor according to § 14 of the guideline for cumulative dissertations:

Single author	1.0
Co-author with predominant contribution	1.0
Co-author with equal contribution	1.0
Co-author with important contribution	0.5
Co-author with small contribution	0

Appendix B

Overview of Teaching Activities

This appendix provides an overview of relevant teaching activities at Leuphana University Lüneburg between 2014 and 2023. The teaching experiences are grouped by format type to demonstrate my engagement with different teaching approaches and my focus on transdisciplinary and sustainability-oriented education.

Lecture-Based Courses

- **Tutorials on Mathematics and Statistics**
  Summer Semester 2017 & Summer Semester 2018
- **Lecture on Basics of Inter- and Transdisciplinarity**
  Winter Semester 2022/2023
  (Substitute for Prof. Dr. Daniel J. Lang, co-taught with Teresa Kampfmann and Prof. Dr. Jens Newig)

Transdisciplinary Projects in Real-World Laboratories

- **Zukunftsfähig regional Wirtschaften: Eine Vision für den Lüneburger Einzelhandel 2030+**
  Winter Semester 2015/2016
- **Project Seminar: Transformation regional gestalten - Interventionen für einen nachhaltigen Einzelhandel**
  Summer Semester 2016 & Winter Semester 2016/2017
- **Major Environmental Sciences Project Seminar: Project: 2030+**
  Winter Semester 2017/2018
- **Local Living Economy - Innovationen im Kontext Lokales Wirtschaften**
  Summer Semester 2018 & Winter Semester 2018/2019

- **Zukunftsstadt Lüneburg 2030+ - Reallabor für ein nachhaltiges Lüneburg**
  Summer Semester 2019 & Winter Semester 2019/2020
- **Transformative Innovation Lab**
  Winter Semester 2018/2019 & Winter Semester 2019/2020
- **Forschen und Lernen für und mit der Zivilgesellschaft in Zeiten der Krise**
  Summer Semester 2020
- **Komplexe Systeme Transformieren: Kooperationen mit der Praxis - Nachhaltiger Konsum**
  Summer Semester 2021 & Winter Semester 2021/2022

Advanced Topics in Sustainability Research

- **PostDoc Academy for Transformational Leadership**
  Winter Semester 2019/2020 and Summer Semester 2021

The diverse engagement in academic and practical settings has allowed me to learn alongside students at both undergraduate and master's levels as we collectively explored transdisciplinary and transformative sustainability research in the context of Lüneburg. These collaborative learning experiences have shaped the research presented in my dissertation.

Appendix C

Eigenständigkeitserklärung

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

Ich versichere, dass die Dissertation *Advancing Transformative Science Through Research in Real-world Laboratories* in der gegenwärtigen oder einer anderen Fassung noch keiner anderen Hochschule zur Begutachtung vorgelegen hat.

Ich versichere, dass ich im Rahmen des Cotutelle-Verfahrens jeweils einen Arbeitsaufenthalt an den beteiligten Hochschulen von insgesamt mindestens sechs Monaten hatte.

Ich versichere an Eides statt, dass ich die eingereichte Dissertation *Advancing Transformative Science Through Research in Real-world Laboratories* selbstständig und ohne unzulässige 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.

C.1 Erklärung zur Nutzung künstlicher Intelligenz

Beim Verfassen dieser Dissertation (konkret: des Rahmenpapiers) wurden KI-basierte Anwendungen für verschiedene Aufgaben des Schreibprozesses eingesetzt. Gemäß den Empfehlungen der Leuphana Universität zur Dokumentation von KI-Tools erkläre ich hiermit transparent den Umfang und die Art der Nutzung.

Verwendete KI-Tools und Verwendungszweck

- **Claude AI (Anthropic):** Strukturierung von Gedanken und Verbesserung der Textklarheit, Organisation komplexer Ideen, Verbesserung der Übergänge zwischen Textabschnitten, Überarbeitung verschachtelter Formulierungen, Unterstützung bei der Strukturierung der drei analytischen Dimensionen, Unterstützung bei der LaTeX-Formatierung
- **ChatGPT (OpenAI):** Kleinere sprachliche Überarbeitungen

Eigenständigkeit und Verantwortung

Alle konzeptionellen Entwicklungen, theoretischen Rahmenwerke, Forschungsfragen und analytischen Erkenntnisse sind meine originären intellektuellen Beiträge. KI-Tools wurden nicht für Datenanalyse, Literaturrecherche oder Forschungsdesign eingesetzt – diese Arbeiten wurden vollständig eigenständig durchgeführt.

Während KI zur Unterstützung beim Verfassen und Überarbeiten von Textabschnitten basierend auf meinen eigenen Ideen und Argumenten verwendet wurde, repräsentiert der gesamte Inhalt mein eigenes Denken, meine Analyse und mein wissenschaftliches Urteil.

Gemäß guter wissenschaftlicher Praxis übernehme ich die volle Verantwortung für alle KI-unterstützten Inhalte und habe deren Qualität und Richtigkeit eigenständig geprüft und verifiziert.

Absprache und zusätzliche Bearbeitung

Diese Herangehensweise wurde im Vorfeld mit meinem Betreuer Prof. Dr. Daniel J. Lang besprochen. Die Dissertation erhielt zusätzlich ein professionelles Lektorat durch Katherine Penker. Alle wesentlichen Inhalte, Argumente und Schlussfolgerungen stellen meine eigene wissenschaftliche Arbeit und meinen originären Beitrag zur transformativen Nachhaltigkeitswissenschaft dar.