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PO Box 117
221 00 Lund
+46 46-222 00 00



Experimenting with sustainability transformations:

A study of Urban Living Labs in the food,
water and energy nexus

DARIN WAHL

LUCSUS | FACULTY OF SOCIAL SCIENCES | LUND UNIVERSITY



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Darin Wahl



LUND
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Abstract

Scholars and practitioners increasingly emphasize the importance of transdisciplinary and experimental approaches for understanding and addressing sustainability challenges. While there is widespread agreement that human society must undergo deep and radical changes, or so-called transformation, how transformation happens depends on multiple and dynamic factors in local contexts. In this thesis, I explore how to advance experimental transdisciplinary sustainability approaches to facilitate the collaborative development of solutions to sustainability problems and contribute to transformation. I use a transdisciplinary and real-world experimentation research approach called Urban Living Labs (ULL) that focuses on specific sustainability challenges in the food-water-energy nexus. I explore the intersection of these to understand how interdisciplinary and transdisciplinary research can contribute to the co-production of action and solution-oriented knowledge. Moreover, I use a combination of interdisciplinary, participatory, and reflexive methods to investigate the processes of transdisciplinary sustainability research and the roles of researchers in these processes.

In five papers, I address issues related to research design and planning, navigating the day-to-day conduct of transdisciplinary collaborations, knowledge transfer and sharing, and individual transformative capacity. In the first paper, I examine urban FWE nexus research to understand if and how solutions and their implementation are approached at a 'local' level, with implications for research design. The second paper considers FWE nexus research broadly to develop a heuristic for local-centered action- and solution-oriented research with key roles for inter- and transdisciplinary research and collaborations. The third paper focuses on navigating long-term transdisciplinary collaborations by applying the ULL approach in the context of local work with craft breweries. The fourth paper reconsiders transdisciplinary case-study evaluation and tackles the issues of knowledge transfer and sharing between cases. The fifth paper explores the development of transformative capacity in researchers who engage in transdisciplinary experimentation. Overall, this thesis advances transdisciplinary experimentation research toward developing and inhabiting spaces that both generate and employ transformative potential to address complex sustainability problems.

Based on the outcomes of the papers, I discuss and challenge the position of the transdisciplinary academic by prioritizing not just what they know but who they are and how they act and interact. I argue that transdisciplinary sustainability research is an embodied practice, where it is more than just a methodological approach but akin to an identity with associated values and practices. The relevance of this work reaches into spaces of collaboration and negotiation for small or broad sustainability change, where sustainability requires us not only to do differently but also to be different.

List of Papers

1. **Wahl, Darin**, Barry Ness, and Christine Wamsler. “Implementing the Urban Food–Water–Energy Nexus through Urban Laboratories: A Systematic Literature Review.” *Sustainability Science* 16 (2021): 663–676.
2. Dalla Fontana, Michele, **Darin Wahl**, Fabiano de Araujo Moreira, Astrid Offermans, Barry Ness, Tadeu Fabrício Malheiros, and Gabriela Marques Di Giulio. “The Five Ws of the Water-Energy-Food Nexus: A Reflexive Approach to Enable the Production of Actionable Knowledge.” *Frontiers in Water* 3 (2021).
3. Ness, Barry, and **Darin Wahl**. “Getting Personal with Collaborative Sustainability Experimentation: Reflections and Recommendations from a Transdisciplinary Partnership with the Swedish Craft Beer Sector.” *Ambio* 51 (2022): 2544–56.
4. Bernert, Philip, **Darin Wahl***, Daniel Lang, Henrik van Wherden. “Cross-case knowledge transfer in transformative research: Enabling learning in and across sustainability-oriented labs through case reporting.” *Urban Transformations*, Accepted.
5. **Wahl, Darin**, Lauren Withycombe-Keeler, Philip Bernert. “Transformative capacity building through collaborative urban living lab research: Lessons from an international network of ULLs at the Food Water Energy Nexus.” *Sustainability Science*, In review.

*Co-first authorship equally shared by Philip and Darin

Author's contribution to the papers

1. I am the first author for this paper, leading the analysis and writing of all drafts. I designed the paper, chose the topic, and co-developed the conceptualization, methodology and led data collection and analysis. BN and CW supported the development of the conceptualization, methodology, data collection and analysis. They also reviewed all drafts and contributed edits and feedback.
2. MDF proposed the paper's 5Ws concept. MDF, FM, and I shared development of concept and associated literature review. Initial draft was divided amongst MDF, FM and me, and final edits were made by MDF and me with support and feedback from FM. Other co-authors provided edits and comments on all drafts. Visualization was created by me with support from MDF and FM.
3. This paper was conceptualized in a collaborative effort between the two authors, with initial drafting led by BN. Data collection and analysis were conducted jointly between BN and me. During the review process, the paper was extensively re-written and edited by both authors equally.
4. PB and I are co-first authors for this paper, working together to develop the research approach, and forming, testing and refining the reporting/ evaluation scheme and co-writing all sections of the paper. DJL and HvW provided feedback and edits for all drafts and provided valuable insights in the direction of the research at several stages.
5. I am first author on this paper and led conceptualization with input from LWK and PB. All authors developed the methodology and jointly collected and analyzed the data. I wrote the first draft and developed subsequent drafts with the feedback and comments from the other authors. LWK and PB provided feedback and commentary at several stages and contributed with comments and edits on all drafts.

Abbreviations

FWE Food water and energy

ULL Urban Living Lab

TTSR Transformative transdisciplinary sustainability research

Introduction

Experimenting with sustainability transformations

Sustainability transformations have been widely discussed in academic and non-academic circles as a necessary means of moving toward a sustainable future with thriving social-ecological and earth systems (Fazey et al., 2020; Raworth, 2017; Rockstrom et al., 2009). Impacts of climate change, habitat loss, and waste, along with the exploitation of resources, are causing irreparable (and unequal) loss and damage across the world (Boyd et al., 2017; IPCC, 2023; Lade et al., 2019; Raworth, 2017) and radical change is needed including cognitive, behavioral, and cultural shifts (McPhearson et al., 2021). Yet, we are only beginning to understand how deliberate transformations for sustainability happen (Abson et al., 2017; Bennett et al., 2019; Linnér & Wibeck, 2021; Loorbach et al., 2017; O'Brien, 2012).

A key aspect of addressing this gap is connecting agents of transformation (who are individual or collectives) with the knowledge and capacity for transformation, as well as the agency to act (Lam et al., 2020; O'Brien, 2012; Schneider et al., 2019; Wijsman & Feagan, 2019). Scoones and colleagues considered other questions (also in O'Brien 2012), stating, "It is often not clear what should be transformed, by and for whom, and through what processes" (Scoones et al., 2020, p. 65). They continue, "We see a crucial need to consider reflexively how knowledge about transformation can inform efforts towards intentional change in line with social-environmental challenges" (p.65).

This uncertain space provides the opportunity for novel approaches to enable and facilitate societal transformations that are both ethical and sustainable (Kenter et al., 2019). Sustainability transformations are intentional and fundamental shifts in human activities, including social, political, and economic systems (Caniglia et al., 2020; Fazey et al., 2018; MCPhearson et al., 2021; Meadows, 1999; O'Brien, 2012). Transformations, therefore, engage multiple interacting and dynamic complex systems. 'Intentional' suggests that they will require direct interventions to initiate. Yet, knowing how, when, where, why, who, and when to intervene will require much more unpacking. By transformation, I mean moving away from a future where we are sure of detrimental outcomes for planet and people (IPCC, 2023; IPBES, 2019) and toward a future for which we are uncertain of nearly everything – including the government and politics of nations, ecosystem health and management, economic system(s), and food systems. In other words, by

transformations, I mean that each of these aspects must undergo radical change (McPhearson et al., 2021), but we do not know which, if, or where any of the many alternative ideas we have today will work (Wright, 2010). Meanwhile, there is much to preserve and elevate: species and cultural diversity, human creativity and dignity, and uncounted built and natural environments that give richness and history for current and future generations, to name a few.

To engage in this research, there are many new and adapted methods and methodologies, e.g., multi-stakeholder scenarios, future visioning, forecasting and backcasting, along with different levels of inclusion of non-academic actors in research (Berbés-Blázquez et al., 2021; Fazey et al., 2020; Felt et al., 2016; Holmberg & Robert, 2000; Jahn et al., 2012). The inclusion and participation of non-academics is a cornerstone of transdisciplinary research, often in collaborative processes (Jahn et al., 2012; Lang et al., 2012). Enabling societal transformations requires a transdisciplinary approach to bridge gaps in knowledge systems and to integrate change processes into local society and culture (Fazey et al., 2018; Horcea-Milcu et al., 2020; Pereira et al., 2020; Scoones et al., 2020; Vogel & O'Brien, 2021). Within and among these are approaches that center around sustainability experimentation. Transdisciplinary experimentation places the researcher centrally in the messiness, where new roles, skills, and capacities are necessary to navigate collaborative processes. It also brings societal actors into the science and (re)considers new roles that science and society actors play in sustainability transformations. Therefore, experimental applies to the potential novel solutions developed in these collaborations and the forms and practices of transformative research approaches. One group of approaches to structure and conduct sustainability experimentation are *sustainability-oriented labs in real-world contexts*, of which Urban Living Labs is one and the specific approach used in this thesis (McCrory et al., 2020; Schöpke et al., 2018).

Experimentation is necessary when intervening in complex systems that are both uncertain and unpredictable (Sengers et al., 2019). Through experimentation, transdisciplinary researchers seek empirical evidence for sustainability solutions and their implementation pathways in specific contexts (Caniglia et al., 2017; Sengers et al., 2019). We try and understand how a system will react to a specific approach and intervention because intervening in complex systems can have unintended consequences (Chapin et al., 2010) in nested, coupled, and tele-coupled regions and systems (D'Odorico et al., 2018; Liu et al., 2007; 2013). Ideally, pathways to transformative change are established and revealed through understanding how innovations for sustainability are developed and managed as they gain traction outside of their development space and become adopted by society (Loorbach et al. 2017). The new knowledge gained then opens the potential for amplification for more and deeper change and transformations (Lam et al., 2020).

However, experimenting for sustainability is not an established formulaic practice; it is adaptive and dynamic, and as often developing new processes as finding

uncertainties in established methods. The outcomes and outputs from current transdisciplinary experimental approaches are not easily transferable or scalable, hindering their intended contribution to system transformations (Fuenfschilling et al., 2019; von Wirth et al., 2019; Withycombe Keeler et al., 2018). This problem is partly due to a lack of understanding of the dynamic processes that underlie the activities, relationships, structures, and organization of experiments that can facilitate, encumber, delay, or otherwise determine their "success" (Bergmann et al., 2021). Drawing on work from Bergmann and colleagues (2021), we know what the success factors are; however, we do not know how to achieve, embed, teach, or train them while experimenting for sustainability or the capacities and competencies in ourselves and others if they are not already present (Wiek et al., 2011). Furthermore, plurality and co-production, two key elements of 'success', have a variety of skills and knowledge associated with their practice, yet how they play out during transdisciplinary experimentation processes and their influences on the outcomes is not well understood (Caniglia et al., 2023; Chambers et al., 2022; Norström et al., 2020).

Aim and Research Questions

For this thesis, key target outcomes are the practices, learning, and action-oriented knowledge developed while experimenting with sustainability transformations. Yet, they are emergent from the spaces created (*where*), processes fostered and reflected upon (*how*), the researchers and participant-stakeholders (*who*), and the topics addressed (*what*). Against this background, this thesis aims to explore the practice of experimenting with sustainability transformation by conducting a local Urban Living Lab and comparing and synthesizing learning from six other ULLs. I will address the following overarching research question:

How can the experimental practices and processes within sustainability-oriented labs advance transformative transdisciplinary sustainability research?

Three sub-questions contribute to answering this question and target three key research areas of transdisciplinary case studies – research design, the conducting of experimental processes, and case-study evaluation:

- How can the design and planning of transdisciplinary and experimental sustainability research enable the development of action-oriented knowledge?
- How can collaborations in sustainability experimentation be better navigated to enable intentional and emergent outcomes?
- How can transdisciplinary sustainability experiments be evaluated to allow for knowledge sharing and transfer?

This thesis aims to better understand the *processes and approaches* within experimenting with sustainability transformations rather than the outcomes of sustainability experiments themselves. In this introduction, therefore, I present the aspects of my thesis as they contribute to this aim (see Figure 1¹). I will explain *how* I research experimentation; *where* this experimentation takes place; *what* I/we are experimenting for and with; and *who* is experimenting. After this, I present a discussion about knowledge and the role(s) it plays in experimenting with sustainability transformations. I end with a statement of positionality, an exercise encouraged in co-production settings, and this thesis (Darwin Holmes, 2020; Klenk & Meehan, 2017; Rose, 1997).

Key assumptions in the thesis

Several assumptions implicit in this thesis and elaborated on in the framing below provide context for this thesis and its research questions. I assume that transformative societal change requires the participation and collaboration of diverse knowledge spaces and perspectives (Caniglia et al., 2020). I assume that achieving such change requires awareness of unsustainability and knowledge of potential pathways and processes for sustainability action (e.g., Loorbach et al., 2017). I assume my research is part of a dynamic and unpredictable human-environment or social-ecological-technological, multi- and cross-scalar complex system (Geels & Schot, 2007; Ostrom, 2009). I assume an uncertain future and that people in general and sustainability transformation researchers specifically will need to develop skills, competencies, and capacities to navigate uncertainty-in-complexity while striving for transformative change (Brundiers et al., 2021; Wiek et al., 2011; Withycombe-Keeler et al., 2019). Finally, I assume that learning in uncertainty and complexity requires experimentation to develop solutions and gauge their impacts and reach. Consequently, the thesis is biased towards learning and reflexivity, as transformations in uncertainty require new knowledge and practices, and awareness of the processes in which these are developed (Fazey et al., 2020).

¹ Inspired by a heuristic developed during this thesis and included in Paper 2: The five Ws of the water-energy-food nexus.

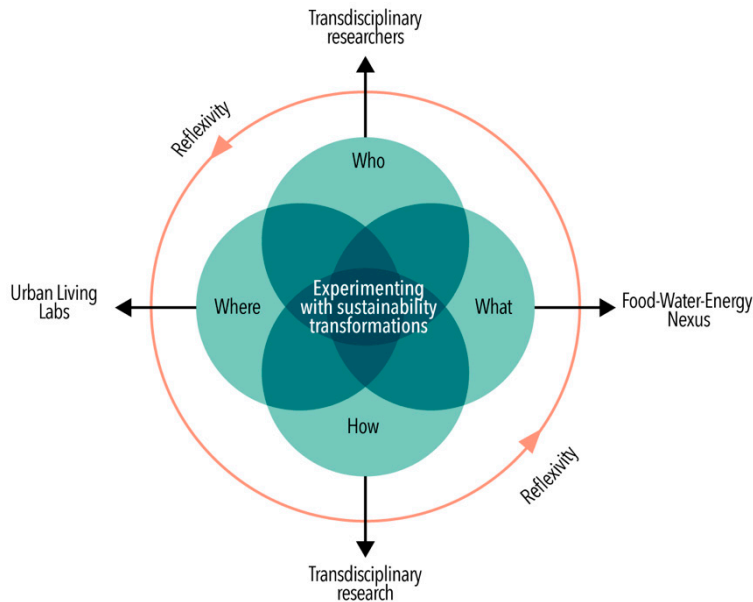


Figure 1. The positioning of experimenting with sustainability transformations in this chapter and thesis as the intersection of ULLs, the FWE nexus, transdisciplinary researchers, and transdisciplinary research. Connecting all is reflexivity, which is a central method and practice in this thesis and in transdisciplinary research more broadly.

How: Transformational transdisciplinary sustainability research

In this thesis, experimenting with sustainability transformations is positioned within the context of "transformational sustainability science," as outlined by Wiek and Lang (2016). They suggest that 'transformational,' as different from descriptive-analytical, sustainability science considers how a future based on normatively sustainable value systems would look and function and what viable pathways and solutions are toward that future (Wiek & Lang, 2012; Feola, 2015). However, currently, several pathways toward transformation have developed that are not explicitly or primarily transdisciplinary as is presented here (e.g., Abson et al., 2017; Bennett et al., 2019; Elmqvist et al., 2019; Pelling et al., 2015). For clarity's sake, I discuss the relevant context of this thesis as transformational transdisciplinary sustainability research (TTSR). Within this context sit sustainability experimentation approaches, of which I use one in particular – Urban Living Labs, itself a type of sustainability-oriented lab – to inform and reflect on sustainability experimentation, the labs that 'house' them, and TTSR in general.

Transformational transdisciplinary sustainability research is an action-oriented collaborative approach used to understand and address unsustainability and facilitate sustainability transformations (Karvonen et al., 2021; Marshall et al., 2018; Wiek & Lang, 2016). Transdisciplinary experimentation acknowledges that sustainable pathways are novel in context, and therefore ideas and strategies to achieve sustainability should be collaboratively trialed to understand how interventions will impact local systems and contexts. As a collaborative process, transdisciplinarity relies on the inclusion of multiple stakeholders and a diversity of knowledge systems (Jahn et al., 2012). Due to this complexity, transdisciplinary sustainability research is mainly exploratory, working with uncertainties in the present to influence uncertain pathways in the future (Phelan, 1999; Walby, 2007).

Transformative transdisciplinary sustainability research, as is presented here, is a bottom-up approach to engaging transformative change and, as such, is embedded in a local context. Context is a central aspect of this research as it is the broader object within which we aim to intervene and is a target of transformation. Therefore, transdisciplinary sustainability research aims for local relevance, credibility, and legitimacy (Cash et al., 2003). Ideally, the outcomes of transdisciplinary research can move within science and society in multiple ways to inspire and contribute to transformative processes in other contexts in either domain (Lang et al., 2012). However, transdisciplinary sustainability research is dynamic and adaptive to local contexts, and therefore moving knowledge and other innovations developed in transdisciplinary case studies to other contexts/cases is challenging (Adler et al., 2018). Furthermore, generalizing from specific transdisciplinary cases is problematic as the relevant context is lost (Adler et al., 2018). Missing from the field are studies that target the processes involved in transdisciplinary sustainability case study research that provide for comparability and learning without abandoning the context, providing the backdrop for the problem, solution, activities, and processes that may have occurred during the research.

Urban Living Labs

Urban Living Labs are the particular experimentation approach used in this thesis to inform the larger spaces of sustainability-oriented labs and TTSR.

Urban Living Labs (ULL) have grown from the Living Lab concept, which primarily focused on product innovations (Niitamo et al., 2006), and the socio-technical transitions tradition (Neuens et al., 2013). ULLs generally involve the development and governance, through experimentation, of new technologies and infrastructures as part of a sustainability transition (Bulkeley et al., 2016). They are participatory approaches to sustainability research, which integrate societal actors into the research process from beginning to end with multiple purposes, most importantly learning, innovation, and knowledge co-production targeting actionable solutions to sustainability problems. Therefore, they often comprise a

transdisciplinary team that coalesces around an innovation experiment(s) in a geographically defined location (Schäpke et al., 2018; Voytenko et al., 2016). The ULL construct creates opportunities/spaces for participants to ask questions about what needs to change to enable action toward sustainability, both looking externally at society as well as internally at the individuals within the group and the traditional positions they represent (local authority, NGOs, business, academia) (Wiek et al., 2012). To answer these questions, labs experiment with novelty of various stripes: technological, policy, management, adaptations, practices, behaviors, etc., in a safe-to-fail space that still exists in and interacts with society (see Figure 1) (Bulkeley et al., 2016, 2018).

The ULL approach has several characteristics including a solutions-orientation, practical methodological and process knowledge, working within the system to be intervened, normative, innovative, multi-faceted, an experimentation focus, multiple roles for researchers, and reflexivity (Bulkeley et al., 2016; Fuenfschilling et al., 2019; McCrory et al., 2020; Schäpke et al., 2018; Sengers et al., 2019), all of which are elements identified by Fazey et al. (2018) as *essential* for transformations, and are discussed through this Introduction and Chapter 2. These elements co-exist in the in-built processes of ULLs, which are inherently collaborative, sharing the responsibility for the functioning of the lab, its experiments, and outcomes, including learning and capacity development between participants.

Sustainability-oriented labs

Sustainability-oriented labs² are a growing set of local, bottom-up approaches for experimenting with sustainability transformations (McCrory et al., 2020). While there are some differences between, for example, Urban Living Labs, Transformation Labs, Real-world Labs, and others, there are many similarities including the characteristics listed above (McCrory et al., 2020; Schäpke et al., 2018). They are often years-long, action- and solution-oriented, and aim at system intervention through the co-development of sustainability innovations (Caniglia et al., 2017; McCrory et al., 2020). They engage in sustainability experimentation to develop and test ways to address co-defined unsustainability in local contexts (Bulkeley & Castán Broto, 2013; McCrory et al., 2020).

Most importantly for this thesis, they are intended to be pluralistic and engage in knowledge integration for the purposes of knowledge co-production and mutual learning for application and use in both science and society (Bulkeley et al., 2016; Lang et al., 2012; McCrory et al., 2020, 2022; Voytenko et al., 2016; Westberg & Polk, 2016). As pluralistic, labs aim to include diverse perspectives, worldviews, cultural and social backgrounds, and knowledge and value systems. By taking this democratic position, labs can challenge participants' positions, while they find connections to address shared societal issues and problems through collaboration. In

² Will often be referred to as simply 'labs' in this thesis.

other words, labs integrate researchers and practitioners and, therefore research and practice, shifting roles and expanding perspectives in support of societal transformation. Through experiment and innovation, participants co-create spaces in which potential sustainability governance is practiced (Bulkeley et al., 2016; Bulkeley & Castán Broto, 2013; Frantzeskaki et al., 2018), as Bulkeley and colleagues suggest that in some contexts, "what it means to govern well...is subject not only to uncertainty but also to contestation, [then] experimentation provides a means by which diverse actors seek to navigate and make sense of the present whilst also giving concrete form to particular visions of the future," (Bulkeley et al., 2018, p. 2).

Where: the spaces of research on experimentation

The research presented in this thesis takes place in two primary spaces: the GLOCULL project – an international consortium of seven ULLs, and the local case study called the SustBeerLab – an ULL in Skåne, Sweden.

The GLOCULL project

My PhD position was project-funded, and therefore this thesis is largely influenced by the structure and design of the project and its participants. The Globally and LOcally-sustainable food-water-energy innovation in Urban Living Labs (GLOCULL) project was granted by JPI-Urban Europe and Belmont Forum. The three-year project aimed to employ the ULL approach for FWE nexus innovations that are potentially scalable or impactful from the local to the global, along with developing a participatory toolkit that could identify nexus interconnections and potentially measure the impact of innovations through nexus resource systems. It consisted of a research consortium of city-university teams in seven countries in Europe, North and South America, and Africa. The project relied on interdisciplinary collaboration between researchers and transdisciplinary collaboration between researchers and their local society partners in their local ULL. The consortium provided a crucial space of disciplinary and interdisciplinary collaboration, from which researchers could share and build understandings, knowledge, and challenges.

The SustBeerLab

The SustBeerLab is the local ULL associated with the GLOCULL project and within which I was a participant-researcher. The lab partnered with craft brewers in Skåne, Sweden, to explore sustainability potentials through experimentation in the regional craft brewing sector. The lab is currently in its sixth year, predating and

outlasting GLOCULL. The lab conducted two main experiments within the GLOCULL project: the co-development of sustainability principles and hop trials to determine the viability and sustainability gains of on-site hop production for the breweries. The co-development of the sustainability principles created a general conceptual understanding of the sustainability challenges craft brewers face, including efficient resource use, ingredient sourcing, and transport, as well as social issues such as a generally more gender-inclusive brewer and consumer base. This broad experiment set the stage for the more specific co-determined hop trials.

Who: Transdisciplinary researchers as stakeholder-participants

Thus far, I have described transdisciplinary sustainability research as real-world interventionist, inclusive and collaborative, and action- and solution-oriented (Jahn et al., 2012; Marshall et al., 2018; Wiek & Lang, 2016). Through the research process, the collaborative work will hopefully gain the relevance, legitimacy, and credibility required for the implementation and integration of novelty into society (Cash et al., 2003). Ideally, they are achieved through the inclusion of diverse stakeholders in the research³. However, they can also depend on how the transdisciplinary sustainability researcher navigates these processes, and therefore the role of the researcher is a central theme of this thesis. Indeed, it is useful to consider the researcher as a stakeholder-participant that may often hold power as a convener, expert, or facilitator (Avelino, 2017).

The researcher in collaborative transdisciplinary and experimental settings may play several roles throughout the process and potentially at the same time while navigating between spaces of academia and society, observation, and participation (Bulten et al., 2021; Fazey et al., 2018; Pohl et al., 2010; Wittmayer & Schöpke, 2014). Moreover, while a traditional perspective on research would attempt to, e.g., prioritize the objectivity of the data, an experimental perspective will consider the character of relationships and trust that enables effective knowledge co-production and experimentation, inclusive of diverse and potentially conflicting positions. Therefore, there is a 'shifting target' of priorities in interactions during these processes, foregrounding the researcher's knowledge, skills, and personality characteristics. Developing the capacities to experiment with sustainability transformations should go beyond a 'learning by doing' approach (Van Poeck et al., 2020) to intentionally enable desired outcomes to emerge.

³ The significance and complications of stakeholder inclusion is discussed in several chapters.

What: Sustainability experiments in the food, water, and energy nexus

The food, water, and energy (FWE)⁴ nexus serves as the target of impact and innovation for the ULLs in the GLOCULL project and in this thesis. Therefore, the experiments we developed and implemented were influenced by the nexus. While the outcomes of the experiments are not a focus, the processes of developing TTSR in the context of the nexus are a focus and are discussed in later chapters and several papers.

The FWE nexus is a conceptual and analytical approach for the integrative management of these large, interconnected, and interdependent resource systems to reduce trade-offs and maximize synergies for sustainability (Hoff, 2011)⁵. The sustainability of food, water, and energy resources is essential for human society. However, current practices in, and the management and arrangements of the production and consumption of these resources do not ensure their security and sustainability (Liu et al., 2018).

Although the nexus concept is far from clearly defined (Wichelns, 2017), it has gained significant momentum. The FWE nexus aims to identify and understand the complex interconnections among the three critical resource systems (Albrecht et al., 2018). Methods in nexus research are often employed at regional or national levels, but there is a gap in putting the nexus approach into practice at local levels (Albrecht et al., 2018; Romero-Lankao et al., 2017). This gap exists in part due to the complexities of managing and coordinating the multiple, yet often mismatched, interacting scales and levels inherent in food, water, and energy systems (Pahl-Wostl, 2019; Pahl-Wostl et al., 2020). Importantly, action-orientation and implementation in nexus research is nascent, requiring a shift that Simpson and Jewitt (2019) referred to as moving from "nexus thinking" to "nexus action." The FWE nexus approach is transformative, as it ultimately aims to reshape the governance systems of globe-spanning resource systems. Getting there, however, will require significant changes in how FWE nexus research is conducted. Several nexus scholars point out the many complex factors that would be relevant in engaging nexus action, many of which are social or social-ecological, especially power and inequalities (cf. Allouche et al., 2015; Foran, 2015; Romero-Lankao et al., 2017). Transdisciplinary approaches are suggested to engage in this shift in inclusive and locally relevant ways (e.g., Albrecht et al., 2018; Allouche et al., 2018; Ghodsvali et al., 2019; Kurian, 2017; Stirling, 2015). It is in this transdisciplinary space where this thesis purposefully intersects ULLs and the FWE nexus.

⁴ Throughout this document, the FWE Nexus may be referred to as FWE or simply the 'nexus'.

⁵ See papers 1 and 2 for a richer description and review of the FWE nexus literature.

Actionable knowledge and action-oriented research

Transdisciplinary sustainability research arises from the understanding that addressing unsustainability will require knowledge that is both scientifically grounded, locally and practically relevant, accessible, and usable, i.e., actionable, especially if it aims to be transformational (Wiek & Lang, 2016). Experimenting with sustainability, as presented in this thesis, adopts co-production and uses a variety of participatory research methods during a long-term collaboration to produce actionable knowledge and are thus considered action-oriented research. Mach et al. (2020) offer an excellent discussion of the many meanings and ways of actionable knowledge, including where it is (co-)produced, by whom, and for what (and whom). TTSR aligns more with the idea that actionable knowledge is “not only relevant to the world of practice, [but] it is the knowledge that people use to create the world” (Argyris, 1993 in Mach et al., 2020, p. 31). Beyond seeking policy relevance, then, actionable knowledge can carry the potential of the creatively innovative.

In this thesis, actionable knowledge is an outcome of co-production. Co-production for actionable knowledge in sustainability is nothing new. Indeed, it is a well-trodden pathway, yet there is much uncertainty surrounding the *how* of co-production and its outcomes (Chambers et al., 2021; Jagannathan et al., 2020, 2023). In this thesis, the *how* of co-production is examined through transdisciplinary collaborative experimentation. Mach and colleagues explain: "The more collaborative forms of engagement aim towards co-creation of knowledge with the people who are most likely to use the knowledge in making changes in their organizations, communities, or environments. Knowledge making and decision-making can thereby continually reshape one another" (2020, p. 33). This relationship between knowledge and action mirrors ideas by West and colleagues (2019) about knowledge and practice as co-producing each other.

However, long-term collaborations for actionable knowledge draw on more than the co-production literature. Action research is a field in which practical solutions are sought to problems identified by stakeholders in localities (Brydon-Miller et al., 2003) and contributes much to the science of actionable knowledge (Arnott et al., 2020). Action research often involves the long-term embedding of the researcher within a specific context doing research to impact that context in a particular way. Action research is not a methodology, “but rather the creation of a context in which knowledge development and change might occur” (Kidd & Kral, 2005, p187). It has values such as democracy, collaboration, and plurality, which are central to the approach in that action research is inherently participatory (Brydon-Miller et al., 2003; Jefferson, 2014; Reason & Bradbury, 2008). As participatory, researcher-participants own and are accountable for the learning, knowledge produced, and their application to specific lives in specific real-world contexts (McTaggart, 1991).

The necessary learning to engage in this type of research is a topic area to which action researchers have contributed much (Brydon-Miller et al., 2003; Jefferson, 2014; Lewin, 1946; McTaggart, 1991). For purposes here, it is important to recognize that science for action, actionable knowledge, and solution development and implementation requires knowledge, skills, capacities, and even values and ethics specific to generating, navigating, and participating in experimental, transformative, collaborative processes (Brydon-Miller et al., 2003; Caniglia et al., 2023; Kemmis et al., 2014) and different from those gained in more traditional observer roles of researchers. Reflecting on the above, it leads me to ask, as others have in sustainability science, what space/s can and should be made for inter- and transdisciplinary researchers in academia (Felt et al., 2016; Haider et al., 2018).

Knowledge used and produced in TTSR

Knowledge is central to TTSR and experimentation and is therefore a central object in this research: a plurality of it is used, (co)created, integrated, (co)produced, shared, and transferred. Knowledge developed and used in these processes is also ideally actionable – which for this thesis means usable in practice: i.e., in society by and through participating non-academics and in academia in the 'practice' of TTSR and experimentation (Bergmann et al., 2021; Fazey et al., 2020; Lang et al., 2012; Withycombe Keeler et al., 2018).

Fazey et al. (2020) discuss the need for transforming knowledge systems, which determine how knowledge is produced, used, processed, evaluated, and copyrighted in ways that support and reinforce an unsustainable status quo, including the institutions such as universities, who greatly influence, privilege, and preference kinds of knowledge and the value that such knowledges hold. Future knowledge systems, called 'envisioned knowledge systems,' have several properties to which this research contributes: among other things, collaborative and learning-oriented, diverse, inclusive, action-oriented, holistic, and reflexive (Fazey et al., 2020).

For my research, ideally, knowledges are both shared and co-produced by the collaborators amongst each other and during experimentation. Then these are interrogated individually and as a group and integrated into what each individual 'knows,' as well as into what the group 'knows' as a collective. Knowledge integration can be both a process and an outcome of this research. However, this assumes that integrating a plurality of knowledge is both necessary and possible (Caniglia et al., 2020; Olsson & Jerneck, 2018; Olsson & Ness, 2019), which is an assumption this research will not challenge.

The processes of collaboratively developed and co-produced knowledge of and for sustainability solutions are discussed in the literature, often in generalizations. Norström and colleagues (2020) highlight four general principles for knowledge

co-production echoed throughout this thesis: context-based, pluralistic, goal-oriented, and interactive. Caniglia et al. (2020) identify nine more specific kinds of knowledge that support sustainability action categorized into three dimensions of purpose and application: knowledge for intentional design, shared agency, and contextual realization, all of which play some part in this research.

It is also relevant to consider what ‘knowledge integration’ involves in this context: what does the process of integration entail; what is actually being integrated; who is doing the integrating; for what purpose; toward what outcomes? (Klenk & Meehan, 2015). Furthermore, we can consider: do different kinds of knowledge require different processes of integration? And yet further, if integration is tied to learning, are we then differentiating for each individual learner and their learning style? One more step could then be, what kind of capacities are necessary for individuals and groups to enable them to collaboratively share, use, generate and integrate knowledge in these ways? What is the role of educational institutions in training/producing these types of learners, participants, and change agents (Bernert et al., 2022)? Or, as Fazey and colleagues might ask, where does the transformation of knowledge systems begin (2020)? These questions are both externally and internally aimed, which brings us to another central characteristic of this research: reflexivity, to be discussed in the methodology chapter. Suffice it to say here that reflexivity is both a research method and an individual practice, which carries with it skills and capacities (Fook, 1999; Knaggård et al., 2018; Sultana, 2007).

In sum, the goal of producing actionable knowledge for sustainability is diverse and layered, and when I suggest that knowledge for sustainability action processes can be integrated, shared and transferred, these aspects, types/kinds and purposes are embedded within.

Learning is an important outcome of transdisciplinary sustainability research (Westberg & Polk, 2016). Learning is a complex process, often requiring reflection on multiple elements, e.g., actions, reactions, intentions, and expectations, how oneself and others have changed, and in comparison, from what the group was when it began, what it has overcome, and ultimately become. In transdisciplinary settings, learning is often uncovered through evaluation (Luederitz et al., 2017). Learning, in this context, is not synonymous with exposure to new knowledge, skills, or capacities, but it is a process of co-producing and integrating new knowledge into one's understanding and capabilities (Bernert et al., 2022). Learning then has an experiential and practice element.

Here, pluralism is a crucial element in the process of co-producing actionable knowledge, as it is positioned as key to establishing the relevance, legitimacy, and credibility of the group and its efforts (Cash et al., 2003). A pluralistic position desires an inclusive process with a diversity of perspectives. Yet, with a consciousness that all perspectives could not feasibly be included. But then, what knowledge is included and excluded? This cannot but be an exercise of power

regarding who convenes, how processes are determined, who participates, and in what ways (Avelino, 2017; Turnhout et al., 2020). This framing of inclusion and exclusion suggests it is the responsibility of the process conveners to take appropriate steps to be inclusive and diverse as possible while still functional while addressing power in constructive ways (Stirling, 2008). However, society and cultures have built-in processes of inclusion and exclusion and imbalances of participation through time, class, gender, race, age, etc. Therefore, it should also be considered how spaces privilege particular knowledge/perspectives over others (Avelino, 2017; Wittmayer et al., 2017). From there, we could question how those privileges (have) define(d) what is possible within society and in our research processes (van Steenbergen and Frantzeskaki, 2018 Chapter 13). Yet, this understanding could open doors to sustainability innovation through new local configurations of knowledge inclusion and integration.

Ideally, pluralistic co-production processes are intentional and therefore require design and deft navigation, even if outcomes like knowledge and learning are emergent. Here, again, the knowledge 'how' becomes central. Some general frameworks have been instrumental in this regard, principally Lang and colleagues' paper on design principles for transdisciplinary research in sustainability science (2012) and Wiek and colleagues' (2011) paper on sustainability competences. Much has been built on this work, including general ideas of success factors for real-world labs (Bergmann et al., 2021). Yet while such works create a foundation for design, knowledge regarding the unfolding and managing of these processes is often buried in the cases themselves or not disclosed as academic publishing culture often preferences novelty and success over process.

Papers included in the thesis

To address the overarching and sub-research questions, this thesis considers several areas related to the conduct of TTSR, including research design and coordination, intrapersonal and interpersonal interactions, evaluation and comparison, and researcher capacity. Essentially, the papers in this thesis provide insights into: a) how to design and conduct TTSR research (papers 1 and 2), b) how to navigate interactions in TTSR research (paper 3), c) how to share knowledge and learnings from TTSR research (paper 4), and d) the transformative capacities developed through TTSR research (paper 5).

This thesis includes five papers that contribute to answering these main and sub-research questions, and while each paper has its specific focus, papers often have relevance to more than one of the above sub-research questions seen in Table 1.

Paper 1 examines the urban FWE nexus literature, which was assessed for opportunities in which Urban Living Labs and participatory research, in general,

could contribute. This systematic review aims to understand the potential for ULLs in nexus research and to address nexus problems. The authors analyze the intended impacts, policy considerations, framing of the nexus, experimentation, and participation of stakeholders.

Paper 2 examines the FWE nexus literature organized into *who, what, when, why, and where* and then discusses the interconnections between them to align and coordinate nexus research design for developing actionable knowledge. The authors provide a simple iterative heuristic of 5Ws with general key questions and connections aimed to provide guidance for new nexus researchers or those interested in shifting from 'nexus thinking' to 'nexus action' (Simpson & Jewitt, 2019).

Paper 3 examines the process of ULL experimentation, focusing on the personal interactions that are the core of collaborative sustainability experimentation. The paper considers three perspectives for analysis: intra-personal, inter-personal, and organizational, and develops recommendations for reflexive practice and long-term research collaborations. The authors examine their experiences of transdisciplinary collaboration over the previous three years through a series of reflections, dialogues, and note reviews.

Paper 4 reimagines sustainability-oriented lab evaluation into case reporting for cross-case comparison and transferability of learning. The aim is to develop a coherent scheme useful for sustainability-oriented labs, in general, to enable comparison across labs regardless of their local contexts. The authors iteratively test the scheme on seven ULLs. The research draws on current lab and experiment evaluation literature and queries the processes, structures, and organization of labs to foster a rich description of labs, their contexts, and experiments for knowledge transfer.

Paper 5 examines the development of transformative capacity by researchers using the ULL approach combined with the FWE nexus. The paper begins from the perspective that TTSR processes are carried out, at least in part, by researchers and other actors who exercise their agency and capacities for transformations - therefore, they develop and use actor-centric transformative capacity. The research analyses data gathered from a workshop and survey to understand actor-centric transformative capacity development.

Table 1: Research sub-questions in relation to the papers. A darker shade indicates a direct focus, and a lighter shade an indirect focus.

Research question	Paper				
	1	2	3	4	5
1. How can the design and planning of transdisciplinary and experimental sustainability research enable the development of action-oriented knowledge?					
2. How can collaborations in sustainability experimentation be better navigated to enable intentional and emergent outcomes?					
3. How can transdisciplinary sustainability experiments be evaluated to allow for knowledge sharing and transfer?					

Positionality statement

For this type of work, understanding and awareness of the perspective from which reflections are generated can lead to more ethical and contextualized knowledge (Sultana, 2007). This statement is to make more transparent my position in relation to the work, my academic colleagues, and non-academic participants in the lab. During this research, we have concluded that both positionality and personality matter when actively collaborating (Ness & Wahl, 2022). Therefore, I will briefly describe my positionality and personality⁶ as it relates to this research (Darwin Holmes, 2020; Moser, 2008; Rose, 1997).

I am a mixed-race Chinese and northern European cis-male from San Francisco, California, and Brooklyn, New York. I identify as being from Brooklyn, even though I spent only some of my childhood and adulthood there. I identify as non-white, though I am as often perceived as white as not. I am politically progressive and would be considered far-left in the USA. I grew up in cities but had several experiences that embedded in me a deep love of natural and wild places, which drives my work in sustainability. Also, race and race relations are strongly present in my day-to-day life and are part of how I understand and analyse my experiences in the world. My gender or racial identity did not seem to be a barrier, and my gender perhaps did facilitate acceptance into the brewer community, as most are male.

I have lived in six US states, China, Thailand, and Sweden, and have spent considerable time in Central and South America (2+ years). I say this in part to suggest that I am very used to being in places that are not 'my' places and adapting to local custom and culture. I am driven by curiosity of people and places, in work and personally, seeking to understand and connect regardless of differences; this is my passion. I am outgoing and tend to ask questions, though I try not to interrogate but rather to find commonality. I have a versatile humor that I employ naturally yet often intentionally.

In many ways, I am both an insider and outsider in Sweden and specifically in the context of my case study. I do not speak Swedish well, but that has not impeded interactions, though, of course, they would have been different if I had – even though not all participants were Swedish speakers (native or otherwise). I am not a beer enthusiast, which has impeded some connection and commonality as many of our participants are. Politically, there did not seem to be any conflict between myself and participants. However, I deeply value collaboration and teamwork as a method of change and a way of being, which is a main driver of pursuing this area of research. My interest and experience in collaborations facilitated learning and engagement during interactions and experimentation processes. Yet, culturally, Swedes tend to be conflict avoidant, which is not my instinctive response to

⁶ While this position was not announced to non-academic partners, our project ran a positionality and inclusivity awareness workshop in which we shared some aspects similar to the following.

relational uncertainty or tension. Engaging in indirect and passive ways can be complicated for this New Yorker and, at times, may inadvertently further tensions rather than diffuse them.

My experience of privilege in the case study research has been high but relatively flat, as all but 1 of our core participants.⁷ (10+/-) have been white men between the ages of 27 and 60 (or so), mostly all from Sweden, other northern Europe, or the USA. The one woman was a project coordinator brought in by the academic team midway through the project. Within our project consortium (+/- 18-30), there was a mix of genders (+/- 75-25% m-f) and professional positions with their associated power and privileges, though only three of us identified as non-white. My position and job as a PhD researcher in Sweden afforded enough privilege that most power differentials, when exerted, had only short-term or situational influence over me or my work. The power and privilege of a researcher in social contexts did not seem to overly influence non-academic partners, as this is not a generally exalted position in Swedish society, however respected, as is other professions. Some of the above specifics are reflected on throughout the discussion chapter.

Ethical considerations

Research in this thesis was conducted in collaboration with societal actors as well as other academics in several countries from various contexts and backgrounds. Each local research team, including my own, conducted its own ethical assessment, and effort was taken to ensure that while learning was shared between teams, locals remained anonymous, and any identifying information was not included in any publications without direct permission. Furthermore, all political, religious, or other personally sensitive information was neither requested nor recorded in any data used for this thesis.

However, during the research, people's values may have been indirectly challenged, specifically regarding understandings and interpretations of sustainability. For example, in our sustainability principles, we included considerations of gender inclusion in both production and consumption of craft beverages. For some, the idea that gender exclusion is unsustainable, however it happens, may be challenging to their values and understandings. The ethics of challenging people in this way seems central to sustainability and often unavoidable, yet it should be done with awareness and intentionality.

⁷ There were many other participants (50+/-) at different times that were more or less peripheral – for example, there were 20+ participants at each of the sustainability principles workshops.

Conceptual and philosophical groundings of experimentation in TTSR

This chapter discusses the positioning of this PhD thesis under sustainability science and presents the conceptual and philosophical groundings of TTSR. I begin by giving an overview of sustainability science, focusing on transformational sustainability. Next, I discuss the philosophical groundings of TTSR, focusing on integrative pluralism and pragmatism, tying together ideas of inclusive and diverse knowledge systems in transdisciplinarity with real-world applicability of action and solutions. I then present the 'doing' of TTSR research by considering the many potential roles of the researcher in these processes. Figure 2 below shows how these areas of research connect in this thesis.

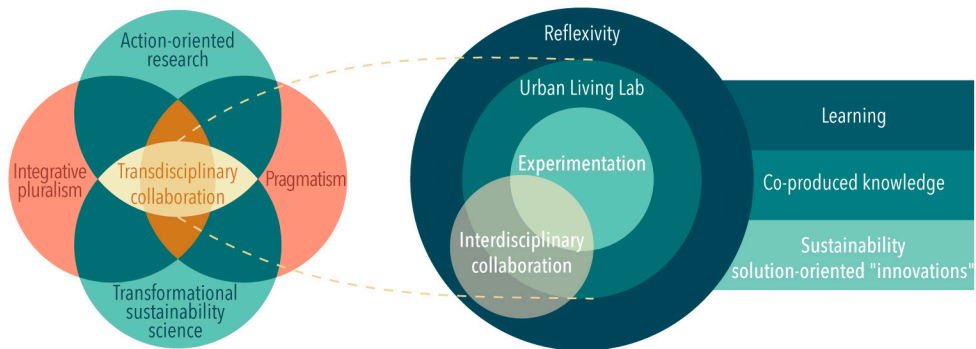


Figure 2. This diagram encapsulates this entire chapter and the connections between the sections. The left sections are philosophical, action-oriented, and sustainability science research areas this thesis draws upon. Their intersection creates the transdisciplinary collaboration space in which this research sits. Looking into that section are the specific areas of this thesis research. Reflexivity underlies much of this work and therefore frames Urban Living Labs, which in turn houses experimentation. Interdisciplinary collaboration intersects through this space as a key process. The outcomes of these are innovations, co-produced knowledge, and learning.

Sustainability science

Sustainability science is a field of research that aims to both understand the complexities of human-nature interactions and to intervene in human-environment systems to shift from unsustainable to sustainable development pathways (Bettencourt & Kaur, 2011; Clark & Harley, 2020; Kates et al., 2001). In this way, sustainability science is both problem-driven and solution-oriented (Clark & Dickson, 2003). The complexity of coupled social and ecological systems (SESs) includes myriad interconnections across scales and levels. SESs function in such a way that outcomes are dominantly trade-offs, e.g., where human systems benefit at the detriment of environmental systems and where some humans benefit at the detriment of others, currently or in the future (Cash et al., 2006; Clark & Harley, 2020; Gibson et al., 2000). Sustainability science, then, aims to work toward or find solutions with synergistic benefits for both human and environment systems. This thesis aims to contribute to developing sustainability solutions that minimize trade-offs in other linked social-ecological systems. Particular attention is focused on how solutions and associated knowledge and learnings can be developed and the role of the sustainability scientist in these processes.

Transformational sustainability science

Sustainability science can be argued to have two main branches: one that is mainly disciplinary, descriptive, and analytical and considered 'normal,' traditional, mode 1, or science for sustainability (Spangenberg, 2011); and the other is transdisciplinary, working with complex and adaptive systems that are unpredictable and uncertain, which can be called post-normal, mode 2, or the science of sustainability (Funtowicz & Ravetz, 1993; Gibbons, 1994; Spangenberg, 2011). Unsustainability problems are often 'wicked problems' that are outcomes of complex systems, with known and unknown interconnections with current and historical socio-cultural drivers and influences, and therefore exhibit high uncertainty and high urgency (Jerneck et al., 2011). Partially in response to the need for science to address real-world problems (versus problems in a particular discipline), Gibbons (1994) and colleagues introduced the idea of mode 2 science and argued for research processes that produce knowledge in and from dynamic complex contexts. They suggest that science and society are part of an ongoing co-evolution and call for a shift in the relationship between science and society from the 'traditional' separation of roles and spaces, as is the premise behind mode 1 science, to one that recognizes that the two spheres have indeed already merged (1994, 1999).

Transformational sustainability science research has evolved in response to a growing urgency for new knowledge on sustainability problems and the recognition to provide solutions to those problems (Fazey et al., 2018, 2020; Lang et al., 2012;

Wiek & Lang, 2016). Transformational sustainability science research asserts that science can and should intervene in society to develop evidence-supported sustainable solutions to complex, uncertain, urgent problems (Wiek et al., 2012). It is transformational because it aims for systemic change, in that the desired solutions are meant to trigger, facilitate, or otherwise contribute to sweeping, radical change in human society (Loorbach et al., 2017; O'Brien, 2012; Patterson et al., 2016; Rockstrom et al., 2009). How and where these changes should be made are central questions, spawning many branches of inquiry and debate within the field (Brandt et al., 2013; Clark & Harley, 2020; Folke et al., 2019; Olsson et al., 2015; Tengö & Andersson, 2021).

Transdisciplinary sustainability research opens avenues of inquiry and knowledge that can effectively develop bespoke strategies to address local problems. Intervening in a complex system for a desirable sustainability impact is rife with difficulties, including avoiding unintentional consequences, co-optation, concerns of fairness, equality and justice, short-term and long-term impacts, and management. Yet, with appropriate stakeholder inclusion and participation, ideally, problem understandings can be more robust, and strategies can be action-oriented, salient, legitimate, and credible (Cash et al., 2003). This is not an automatic outcome as transdisciplinary processes are complex, where appropriate stakeholder inclusion is just one piece of many (and indeed a process in itself) (e.g., Pohl et al., 2017)). Therefore, the use of transdisciplinary methods by sustainability researchers has expanded to include developing and testing experimental solutions to sustainability problems, which may take the form of, e.g., policies, management and governance arrangements, or technical and technological innovations (Sengers et al., 2019). These are alongside less tangible but equally important outcomes from the transdisciplinary process, such as learning, knowledge integration, and co-production, and the development of trusted networks of sustainability-minded local stakeholders who have shown to be motivated and committed enough in these issues to take part in often long-term research partnerships (Marshall et al., 2018).

Philosophical groundings

The philosophical groundings of this thesis center around that which enables and supports transdisciplinary and action-oriented transformational sustainability science research. The need for new knowledge for transformation has led to a boom in transdisciplinary co-production processes in several fields driven by a recognition that integrating stakeholder knowledge is crucial for sustainability (Turnhout et al., 2020). This turn toward transdisciplinary co-production rests on the idea that transdisciplinary research has long been associated with addressing real-world sustainability problems and transformation (Brandt et al., 2013; Lang et al., 2012; Mauser et al., 2013; Polk, 2014). Transdisciplinary sustainability research partners

science directly with non-academic societal actors to inform and address complex societal issues (Pohl et al., 2017). Along with knowledge co-production, other outcomes are possible such as innovations of various types, including organizational, policy, cultural, institutional, and technological. The co-produced knowledge aims to be action-oriented in that it influences the development and deployment of change for sustainability. The knowledge, therefore, should be salient, legitimate, and credible (Cash et al., 2003) or 'usable' by both society and science (Clark et al., 2016). Transdisciplinary processes can create trust and buy-in through multiple and mutual ownership in these often long-term systemic change processes (Hirsch Hadorn et al., 2006).

Yet, in practice, there are functional limits to inclusion, making transdisciplinary sustainability research not without contestation and questions of power and co-optation (Kok et al., 2021). Transdisciplinary processes are methodologically messy and have a diversity of known and often unknown dynamic elements at play at any given time, invoking a healthy amount of uncertainty in the processes (Pohl & Hirsch Hadorn, 2008). This uncertainty is, in a way, a parallel to the uncertainty evident in society and is one of the central benefits of transdisciplinary research in that it is meant for such contexts (West et al., 2019).

Transdisciplinary research rests on the notion that more and multiple perspectives are necessary to understand complex social phenomena. Moreover, these perspectives must be integrated for a rich understanding to develop (Hirsch Hadorn et al., 2006). In this sense, this thesis aligns with integrative pluralism (Mitchell, 2002; Mitchell, 2007), which suggests that in complex systems, a plurality of perspectives is necessary to gain insights: "Complex phenomenon harbor multiple interacting causal processes and multiple levels of organization which all may be involved in the generation of the feature to be explained" (Mitchell, 2002, p. 57). Regardless of whether the intention is to understand the current system's functioning or how to intervene in the system, it is impossible to comprehensively understand or explain the system from a single position. For addressing complex sustainability problems, it is essential to negotiate spaces of commonality, to work synergistically rather than in trade-offs. Moreover, these pluralistic processes are intentionally spaces of learning. What can be learned and innovated from processes of tension-collaboration-action? An integrated pluralist approach not only welcomes diversity but also seeks perspectives that together co-create new pathways, building on existing knowledge to co-produce new knowledge for sustainability action.

Co-production can happen in various ways and contexts, and it is helpful to consider some aspects related to co-production in this thesis (Chambers et al., 2021). "The promise [of co-production] is compelling: developing solutions through legitimate processes that draw on diverse and credible expertise with, by, and for those best placed to use them" (Chambers et al., 2021, p. 983). While this quote paints an idyllic picture, co-production does not only come through consensus but also through the tension created through different perspectives. Integration seen as

consensus can be problematic because it can silence contestation and preference dominant positions, which can often be the 'expert' voice of the researcher (Klenk & Meehan, 2015; Mach et al., 2020). While contestation can create stagnation, reflexively considering "who participates and what values, perspectives and interests do these participants represent, and deliberation; how can all voices be voiced and included in a legitimate way" (Turnhout et al., 2020, p. 17) can create opportunities for new knowledge, learning, and expanded inclusive understandings and solution options. Therefore, Turnhout and colleagues continue, "it will be vital to allow for pluralism, create scope to highlight differences and enable the contestation of interests, views, and knowledge claims." (2020, p. 18).

Importantly, pluralism applies not only to knowledge but also to values and norms. Recent research on the importance of values for sustainability transformations is growing (e.g., Horcea-Milcu, 2022; Rosenberg, 2021; West et al., 2020). In experimental and co-production contexts, values can be instrumental in change processes, yet should be considered intentionally and transparently when possible (Horcea-Milcu, 2022). During these collaborative processes, values can be revealed, confronted, and changed. Revealing participants' values creates a foundation from which tensions and the collaboration itself can be better navigated (Kenter et al., 2019). Values can also be confronted through dialogue and self-reflection by individuals and between participants. The researcher especially can reflect on the values present, e.g., the different roles they play, the research design, the stakeholders included, and the knowledge used and sought (Horcea-Milcu, 2022). For example, Staffa and colleagues present a 'feminist ethos of care' leading to three modes of knowledge co-production: thinking with, dissenting within, and thinking for (Staffa et al., 2022). These, they find, can lead to relating to the 'other-than-human,' cultivating caring academic spaces, and including and building upon marginalized knowledge amongst others. Experimentation and co-production in value plural contexts can lead to the changing of values, the change of behaviors to better align with core values, and the co-creation of values that better align with sustainability, social justice, collaboration, inclusion, and transformative change (Horcea-Milcu, 2022; Isacs et al., 2023; Rosenberg, 2021; Woiwode et al., 2021).

At this point, integrative pluralism in co-production, as presented here, is aspirational and perhaps ideal. How these contexts play out in real life will differ as these are complex processes functioning within limited resources and time (Isacs et al., 2023).

In addition to integrative pluralism, this research also assumes a pragmatist philosophy. In pragmatism, the central purpose of knowledge is practice, whether it supports, derives from, or enables – "action and knowledge cannot be separated either conceptually or in practice" (Caniglia et al., 2020, p. 2). In this combination of knowledge-practice-action, pragmatism aligns with the purposes and approaches of TTSR as defined in this thesis, considering broadly what could be done in a particular context within the realm of what should be done. Pragmatism is "rooted

in a collaborative process of concrete problem-solving in which participants are led to question and jointly reframe their values and understandings" (Popa et al., 2015, p.48) and is "motivated by a desire to enhance individual and collective learning about how to tackle real-world challenges," (Caniglia et al., 2020, p. 5).

Ansell and Bartengerger discuss pragmatism in connection with experimentalism, seen broadly as a strategic approach to problem-solving (2016). Pragmatism in this context, they argue, draws much on John Dewey. For Dewey, an experiment "operates to change the customary state of things, and thereby to present challenges to thought, seeming discrepancies, unexpected phenomena, that require explanation" (Dewey, 1911, p. 554 in Ansell & Bartenberger, 2016, p. 65). From the assumption of uncertainty, pragmatic experimentation requires action (or intervention) from which responses to the action can be observed and experienced. At this point, hypotheses can be made and then tested in further experimentation. Furthermore, pragmatism embeds meaning in purpose and situation (or context), suggesting that different purposes should be met with different experiments (Ansell & Bartenberger, 2016). This positioning of experiments as place-embedded, defined by purpose yet change-oriented, problem-solving, and exploratory (in uncertainty) is seen throughout this thesis and in experimenting with transformations more broadly.

Pragmatism aligns with evolutionary learning in that "pragmatists emphasize that learning is an ongoing process of problem-solving, deliberation, experimentation, sedimented over time as experience, identity, habit, skill, and knowledge" (Ansell & Geyer, 2016, p.151). In sustainability labs and experimentation, the conditions that enable evolutionary learning are built-in to activities and processes: problem-driven, reflexivity, and deliberation (Ansell, 2011). Further, evolutionary learning can happen when diverse and contested positions are brought together (Ansell, 2011). The link between pragmatism and transdisciplinarity is also described by West and colleagues (2019) through a practice-based approach that shifts from using knowledge to inform action to developing knowledge and action iteratively and collaboratively.

In this thesis, then, linking integrative pluralism and pragmatism creates a space of collaborative action-oriented learning, knowledge integration, and co-creation in an ongoing process that is both reflexive and iterative as knowledge and action perpetuate and influence each other and grounded in experience, dialogue, and developed skills and capacities.

The framing of transdisciplinary processes and action research as integrative and pragmatic has been described as, among other things, complex, exploratory, and uncertain thus far in this thesis. It is not surprising, then, that there is an omnipresent idea of 'learning by doing' when considering how these processes should be conducted and managed (e.g., Brydon-Miller et al., 2003; Pohl et al., 2010; Popa et al., 2015). Thus, this thesis does not necessarily represent or promote a single

epistemological or ontological stance; instead, a purpose of this research is to develop within the researcher an ability to work with greater fluency in multi-, inter-, and transdisciplinary contexts (Caniglia et al., 2023; Norström et al., 2020; Rosenberg, 2021). In other words, I aim for an "epistemological agility" with which I can better "interface with whatever group" to facilitate and participate in collaboration, knowledge sharing, and learning in the development of actionable sustainability knowledge and solutions (Bulten et al., 2021; Chambers et al., 2022; Haider et al., 2018; Mach et al., 2020). This purpose challenges the 'learning by doing' idea and suggests that learnings from transdisciplinary case studies can and should be transferred to researchers and practitioners in other contexts. Thus, other types of knowledge are necessary and valuable in these contexts beyond experiential knowledge, especially knowledge of the "how" of transdisciplinary research.

The roles of the researcher

Transdisciplinary sustainability research is complex and dynamic, as instead of being isolated from society, it is embedded in society and, therefore, subject to its shifts. In short-term collaborations, these shifts may be less impactful, but in long-term collaborations, they are expected, e.g., turnover within positions, funding shifts, parental responsibilities within the partnership, or even global level pressures as was relevant for this thesis, such as COVID-19. This factor makes the design of transdisciplinary research a moving target and is best based on principles or ideals. Lang et al. (2012) suggest a set of principles as an iterative process composed of three phases: (A) collaborative problem framing and team building, (B) knowledge co-creation, and (C) the (re)integration of that co-created knowledge into the science and societal domains (see Figure 3). This ideal-typical framing illustrates transdisciplinary sustainability research as a coming together of science and society, yet separation between the two spheres exists. This conceptualization still maintains an illusion of the separation of academia from society. While this is a valuable dichotomy for clarity of description, which I have also adopted in this thesis, it should be questioned in practice, especially when understanding the many and changing roles a transdisciplinary sustainability researcher must assume.

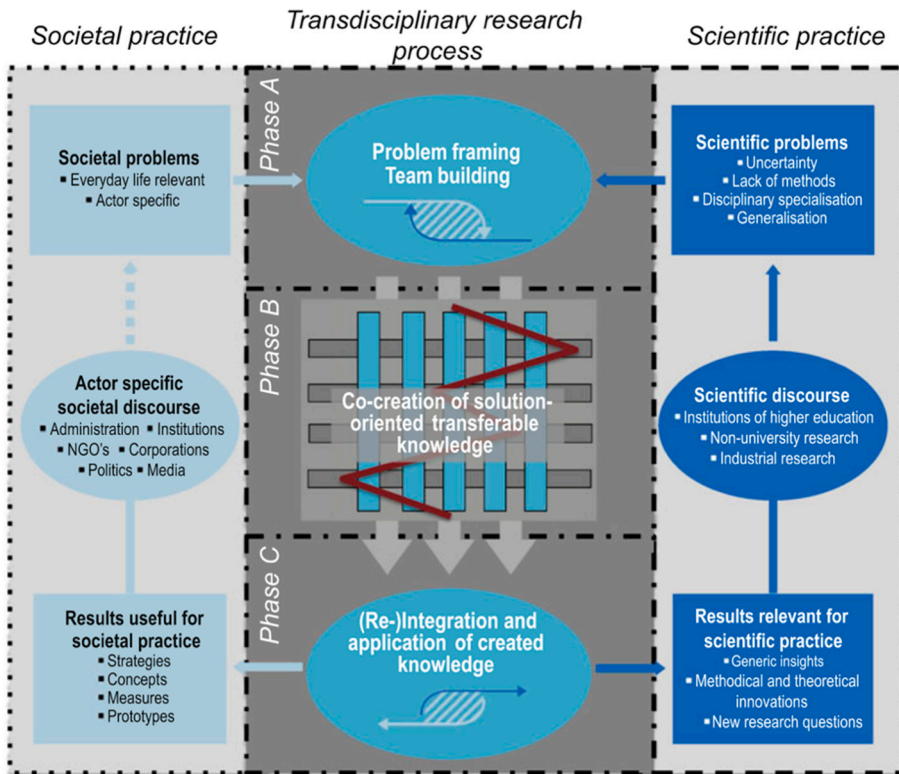


Figure 3. The ideal-typical diagram showing a transdisciplinary research process in sustainability, where science and society collaborate, which proceeds through phases, that leads to a reintegration of knowledge back into the respective spaces (Lang et al. 2012).

More helpful for this thesis is to consider transdisciplinary sustainability research as practice and the transdisciplinary researcher as also a practitioner, stakeholder, and participant (Hilger et al., 2018; Pohl et al., 2010; Wittmayer & Schöpke, 2014). This argument aligns with West and colleagues (2019), who conceptualize knowledge and action as co-producing each other.

In this context, the role of the transdisciplinary sustainability scientist expands, and new competencies and skillsets are required (Bergmann et al., 2021; Brundiers et al., 2021; Wiek et al., 2011). The question of how to intervene in society involves taking the normative sustainability position and, while looking forward, must actively engage in processes as they happen in order to gather the evidence of, among other things, what works, what does not, and what obstacles and resistance to change may exist (Jahn et al., 2012). Intervening is in stark contrast with traditional-normal research, where the scientist is a passive observer - uninfluenced and uninfluencing the processes, relationships, and systems under study (Funtowicz

& Ravetz, 1993). The transdisciplinary sustainability scientist and their research are conducted as part of the system under study, which impacts and is impacted by the work toward a sustainability intervention in the system (West et al., 2019). This approach implies that the researcher is changed by the research conducted. Therefore, their role is not the passive reporting of findings and results but the active and open engagement with the system and stakeholders, making the outcomes of the research in part embodied within the researcher themselves (Brydon-Miller et al., 2003). With this logic, the transformational sustainability scientist is both a researcher in active observation (and data gatherer) and a practitioner in that they are putting into practice novelties with the intention of (co)creating actionable knowledge. Once this bridge is formed, the transformational sustainability scientist assumes new roles, shifting from formal to informal roles as fitting the research approach and processes within, such as change agent, facilitator, knowledge broker, project manager, and reflective scientist, among others and yet underneath, consistently 'doing' science (Fazey et al., 2018; Pohl et al., 2010; Wittmayer & Schöpke, 2014).

The move into new spaces and roles for the researcher is not arbitrary; instead, it assumes that a solutions orientation requires new and potentially new types of knowledge. The new knowledge is necessary to move from thinking, ways, patterns, and pathways that have proved unsustainable to a great degree and move to new thinking, ways, patterns, and pathways that will prove sustainable (Fazey et al., 2020). New knowledge happens in two general ways relevant to this thesis: by integrating knowledge from different perspectives, positions, and disciplines and by intentionally co-creating knowledge from novel arrangements of purpose-driven (e.g., problem-solving) research and working partnerships (Caniglia et al., 2020). Integration and co-creation are not mutually exclusive, and both require the active engagement of the researcher in processes, often long-term, in close collaboration with people and experiences outside their spheres of expertise, influence, or comfort.

The scientist's responsibility is not only to the project, case-study, or society, but also to the larger field/s their work inhabits. For the transdisciplinary researcher, this responsibility is not clear-cut, as it is often considered an approach to research rather than a research field in itself. Yet, there is much that can be contributed to the understanding of the practice of transdisciplinary research. In a recent paper on the topic, authors Sellberg et al. (2021) describe this aspect of their work as a collaborative auto-ethnography, where a group of transdisciplinary researchers entered a series of intentional group reflections on the practice of engaging research. They discuss the difficult balance, familiar to many in action-oriented fields, between societal impact, scientific rigor, and self-care (Sellberg et al., 2021). Indeed, this notion of caring, as part and representative of personal values brought into transdisciplinary research, can be an essential part of sustainability transformation processes (Care et al., 2021; Rosenberg, 2021). However, the near

absence of this in the transdisciplinary sustainability literature lends a transactional feel to something that is much more relational (Walsh et al., 2021; West et al., 2020) in that the how of transdisciplinary research largely involves (an awareness of) how researchers themselves think about, value, and engage with others (Caniglia et al., 2023). Therefore, processes of transdisciplinary research are also part of the self-reflexive scientist and a space in which this thesis aims to contribute.

Transformations in this thesis

For this thesis, awareness of underlying values and their influence on actions is important, and then understanding how participation in labs and experiments may have shifted those values. Transformation involves integrated changes across individual, collective, and system levels (O'Brien, 2018; Wamsler et al., 2021). In this context, individual and collective paradigms are central in the construction and understanding of reality (an ontology), and they set boundaries for what is perceived as possible now and in the future, and have implications for agency and leadership (O'Brien, 2018). Furthermore, Wamsler and colleagues identify individual and collective qualities and capacities that impact learning and decision-making and can facilitate paradigm shifts toward sustainability (Wamsler et al., 2021). This aligns with Donella Meadows's hierarchy of leverage points for change, with paradigms and worldviews as the pinnacle (Meadows, 1999). One way of linking this individual and collective 'sphere' with action is learning, or as has been described as transformational learning (Fazey et al., 2018; Pahl-Wostl, 2009; Pahl-Wostl et al., 2013). Pahl-Wostl describes transforming structural contexts or regulatory frameworks, or in their words, "one starts to reconsider underlying values and beliefs, world views if assumptions within a world view do not hold anymore" (Pahl-Wostl, 2009, p. 359).

The organizational level can be considered another, yet interconnected, level on which transformations can occur that is relevant to this thesis. The definition of an organization is challenging to pin down as organizations are not clearly defined in organizational studies, being, among other things, aggregations of individuals, social network nodes, or members of a population (King et al., 2010). Yet there are two definitions that provide useful grounding for this thesis. King et al. describe an organization as a type of social actor "capable of behaving in a purposeful, intentional manner... with emergent, path-dependent personalities and enduring qualities" (2010, p.291). They assert that "organizations are actors that can exert influence on individuals, shape communities, and transform their environments. Organizations are bona fide mechanisms for societal change" (p. 292). A second understanding of organizations that function dynamically in a changing and uncertain environment is as a "system that 'processes' information or 'solves' problems," and further, "one that create[s] information and knowledge" (Nonaka,

1994, p.14). It is in the context of engaged social actor and knowledge creator that this thesis considers the potential of small and medium-sized enterprises as research partners in sustainability change processes. Transformations at this level consider the role and integration of small and medium-sized enterprises into their local contexts, how business values and practices can shift internally, and what that shift might mean for the larger system in which they are embedded.

A note about socio-technical transitions

Socio-technical transitions research contributes much to the approaches represented in this thesis, specifically Urban Living Labs. Therefore, I will present a brief introduction of this literature here. This thesis however, will adopt the language of transformations as discussed in the sections above.

Socio-technical transitions is a growing field of sustainability research in which society 'transitions' through processes of structural change occurring within and or without a socio-technical system (Geels, 2002; Loorbach, 2010; Rotmans & Loorbach, 2009). Building from socio-technical studies and evolutionary economics, transitions research aims to understand how to intervene in society to facilitate sustainability transitions that span societal and technical systems such as water or energy (Frantzeskaki et al., 2012; Geels, 2010; Geels & Schot, 2007; Loorbach & Rotmans, 2010). Socio-technical transitions and the associated multi-level perspective have themselves become a mid-level theory, arguing that transitions can be conceived of and governed (navigated, led) through a process encompassing a diversity of actors, e.g., academics and societal stakeholders, over several years and several stages/phases, with planning that includes the relevant levels of society from the niche (where the innovation is developed) to the landscape (where culture and societal norms shape society, economy, politics, and the built environment) (Geels, 2010; Geels & Schot, 2007; Loorbach, 2010).

Socio-technical transitions have also connected the spaces of, among other things, action-oriented research, innovation research, urban governance, and sustainability (Geels, 2010; Geels & Schot, 2007; Frantzeskaki, 2022). Importantly, transitions research introduces urban transition experiments as essential parts of societal transitions to sustainability, in which new potentially sustainable pathways are collaboratively developed and trialed with societal actors (Nevens et al., 2013; Sengers et al., 2019). As the name suggests, these experiments are convened in urban laboratories, which use urban space as the laboratory to engage with societal complexity. Urban Transition Labs have a normative sustainability goal and employ the transition management and multi-level perspective approach, which uses a variety of participatory methods to foster the development of innovations from the niche into mainstream society (regime and landscape), which in turn should

transition society onto a more sustainable pathway (Nevens et al., 2013). As research in transitions has evolved, sustainability transitions have become established as its own branch, moving sustainability as an outcome of a socio-technical transition to where it is normatively embedded in the processes, activities, and structures of transitions (McCrorry et al., 2022). McCrorry and colleagues provide an excellent review of this evolution (2022).

Distinguishing transitions and transformations within sustainability literature is no easy task, as they can be defined interchangeably (Hölscher et al., 2018) and often contribute to each other (Loorbach et al., 2017). Nevertheless, they have distinct roots: transitions come from a socio-technical space, and transformations come from a social-ecological one (Loorbach et al., 2017; Olsson et al., 2004). These lines are functionally blurred with recent research in sustainability transitions and the increasing inclusion of technical systems into social-ecological research (Loorbach et al., 2017; McPhearson et al., 2016).

Methodology

The core of the methodology is transdisciplinary and interdisciplinary collaboration to advance co-production in lab and experiment contexts (Chambers et al., 2022; Norström et al., 2020; Pohl et al., 2017; von Wirth et al., 2019). The main research question of the thesis revolves around participating in an Urban Living Lab, which is itself a methodological approach. ULLs are each tailored to their contexts and purposes, therefore, no two ULLs are ever the same. This Chapter presents a description of how ULLs work by describing the process of the SustBeerLab - our local case study⁸. I take a multi-methods approach, supported by inductive and qualitative empirics: i) to understand ULL processes as they unfold, ii) to collaborate with societal actors, iii) to collaborate with academic colleagues, and iv) to understand and develop recommendations, heuristics, and tools for research design, the conduct of sustainability-oriented labs, and to understand, share, transfer, and compare sustainability-oriented lab research and their experiments.

Notably, the peculiarities of this type of research have methodological implications, where being responsive and adaptive are crucial elements (Felt et al., 2016). Collaboratively experimenting through, with, and on transformative processes navigates layers of uncertainty and complexity. While research aims for knowledge and action that leads to beneficial-for-sustainability outcomes, determining what those specifically are in a local context is complex. For example, determining who and what benefits from a particular intervention may not be clear, nor are, e.g., stakeholders easily identified, as complex interconnections can mean they are not within the study area. Yet these normative complexities are key justifications for transdisciplinary experimentation (Brandt et al., 2013; Caniglia et al., 2017) and part of the many uncertainties surrounding the 'doing' of this research.

Thus, to better understand these implications, I have approached this research both *from within* and *from without*, while often moving inside and outside and back throughout the process (Fazey et al., 2018). By this, I mean that I study/observe the research approaches of transdisciplinary experimentation (without) by *participating* in research approaches doing transdisciplinary experimentation (within). In essence, I observe myself and others as we jointly participate. As such, reflexivity plays a

⁸ Case study refers to the ULL as a whole – the context, lab, and experiments.

central role as a method for providing data to analyze the research approach (described below).

The in-out navigation occurred throughout my interdisciplinary and transdisciplinary collaborations. At the case study level, activities were planned with our societal partners, but most often, interactions and learning were discussed between the academic team members. At the international consortium level, tools and activities were developed for trial in local cases. These tools and activities were deployed in local cases, reflected upon locally, and then discussed, processed, and refined by the consortium.

The methods employed while participating in the ULLs include semi-structured interviews, a survey, participatory mapping, and participatory workshops. To observe ULL processes, reflexive methods are used in several contexts, both individually and collectively. Methods for tool and framework development are also used to better conduct action-oriented research, ULLs, and their experiments. The design of research is not pre-determined but instead follows the development of the ULL and its purpose and therefore evolves and adapts over time. For example, determining the experiments has several factors with different amounts of uncertainty *inter alia*: what are the interests/motivations/agendas of participants; what are the time and funding limitations for the group/participants; who is responsible for the experiment, its maintenance, and outcomes?

This Chapter is divided into several subsections: First, I describe reflexivity and its role as a method in the thesis. Next, I discuss the transdisciplinary collaboration process by describing my local case, the SustBeerLab. Then, I discuss the interdisciplinary process as structured through project collaborations. Then, I describe the specific methods used to examine ULLs in the FWE nexus that led to the included publications in this thesis. Finally, I describe the specific methods/activities used to conduct the ULL.

Reflexivity as method

Reflexivity is a core principle underlying the methodologies utilized in this research, as it is in transdisciplinary and action research.

Reflexivity is the intentional act of critical reflection on interactions, events, or other happenings from one's own perspective as well as from projecting empathetically and compassionately from other's perspectives (Knaggård et al., 2018; Ness & Wahl, 2022). TTSR takes place in dynamic complex systems; therefore, as research processes unfold, understanding 'how' the unfolding took place is largely a reflexive exercise that will lead to understanding why specific outcomes were achieved and not others (Arkesteijn et al., 2015; Beers & van Mierlo, 2017). In transdisciplinary

sustainability contexts, reflexivity is deeply connected to the processes of learning and integration, both within individuals and in the collaborative group (Fook, 1999; Popa et al., 2015; Schmidt et al., 2020). The self-reflexive scientist is a key role of transdisciplinary sustainability researchers, with a purpose described by Fazey et al. (2020): "to critically evaluate their role in shaping the research, action and learning, including how their epistemological, ontological positions, norms, values, concepts, methods and paradigms influence understanding about change and how they are part of, reinforce and influence the systems they seek to change," (p64). Self-reflexivity is, therefore, a central part of the knowledge contributions of this research, as the understanding of why decisions or actions were taken is dependent in part on the ideas, values, experiences, personality, creativity, culture, and previous understandings of the individuals in the group, as well as their receptivity to ideas that are 'outside the box' to create opportunity for novel and innovative options.

Reflexivity is a critical component of transdisciplinary and interdisciplinary research (Jahn et al., 2012; Knaggård et al., 2018) and is relied on for methods in three of the papers included in the thesis, each in different ways (Alvesson, 2018; Fook, 1999). Reflexivity is broadly used as a way for researchers to make sense of the approaches they use, for example, to individually learn, evaluate a process, or reveal assumptions (e.g., bias) (Knaggård et al., 2018).

I have distinguished three areas of reflexivity relevant for this thesis: the self, the process, and the group. Reflexivity for the self includes questions such as: who am I during the research process (roles); what do I contribute to the group, to the process; why do/did I act/respond in certain ways; how may I have imposed bias on the formulation of questions and analysis of responses; what do I want to get out of this; how can I facilitate my own learning and understandings? Reflexivity in the process involves questions such as: Why is the group doing what it is doing; How were decisions taken; Who enacted the decisions; How are we establishing legitimacy? Reflexivity in the group involves questions such as: How do group members learn; What is motivating each member and the group; How can the group use existing and developing knowledge; What and who is this research for – and are they participating? Who is taking action, based on what knowledge, and with what intentions? This thinking can most clearly be found in Paper 3, where these were reflected on under the categories of intra-personal, inter-personal, and organizational. Yet, some questions similar to these appear in Paper 4, embedded into the case reporting scheme. And in Paper 5, reflexivity is used individually and collectively to understand capacity development.

Transdisciplinary collaboration in the SustBeerLab

The specific conduct of the SustBeerLab follows a generic ULL methodological approach, both of which will be described here (see Figure 4). Participating in and conducting a ULL is as much adaptive as it is prescriptive. The structure, organization, actor-participants, activities, and experiments are determined within each ULL. The ULL is embedded within a local context which sets the socio-cultural, political, economic, custom, and infrastructural framing with which any innovations will interact and or disrupt. Lab partners determine the understanding of the sustainability problem, the structure and organization of the lab, along with the experiment/s that may address that problem. Outcomes and outputs from experiments cycle back to the lab, where they inform the next steps.

Broadly, I contributed to or participated in all the activities of the SustBeerLab. In early workshops, I played more of a support role, while in later workshops, I was a co-designer and co-lead. For the design of the hops experiments, I was a support collaborator, as my expertise is not in plant science or greenhouse design. For the maintenance of the hops experiment, I was a regular participant for some time, which waned during the COVID years. Other roles I played are as described in the context below and in upcoming sections. Paper 3 comes directly from this work.

Purpose-setting and trust building

Some things can and should be negotiated and discussed between core Lab partners, such as the purpose of the Lab, including intentions and expectations, responsibilities of individuals and positions (e.g., academic as sustainability 'expert'), the structure of Lab and its activities, and importantly, a common understanding of the problem and pathways to address that problem through experimentation. In the SustBeerLab, much of this was part of early dialogues between project partners but was adapted and renegotiated over time. Early dialogues also establish a rapport, common ground, and the foundations of a working collaboration, e.g., trust. I entered the SustBeerLab in 2019, two years after the original dialogues began. At this point, the general purpose of the lab was laid, the organization of the lab and partners had been negotiated, and the first experiment had already begun (see Sustainability Principles description below) – though there had already been significant changes as one core industry partner had dropped out⁹. To enter these dialogues and to establish myself in the 'circle of trust,' I thought to reveal a lab narrative through a podcast (described more fully below) (Harris & Lyon, 2013). Therefore, the approach to the podcast was intentionally layered: 1) to reveal the shared and individual understandings and motivations of participants (purpose), 2) to co-create a narrative of the lab as it existed at the time, and 3) to

⁹ Due to leadership changes that came with accompanying priority shifts which did not include this partnership.

begin to establish myself as an insider into the group (develop trust). All of which are central to a long-term collaborative process (Norström et al., 2020).

Establishing the Lab – general collaboration and system understanding

The negotiations around the shape of and methods to progress the SustBeerLab and its experiments were regular over many months. An adaptive meet-and-talk-it-through strategy largely dominated the conduct of our ULL. Major events were planned well ahead of time, such as the capacity and principles workshops, but many were more casual, especially as Lab participants became more familiar with each other and relational groundwork had been laid (through repeated interactions, informal and formal conversations, observations, etc.). Many other meetings were set as time and need dictated, over email most often, *though much of the interaction in the Lab and experiment occurred in person at the brewery in an ad hoc manner* – yet this is a core aspect of ULL collaborations and central to Paper 3, highlighting the critical role of reflexivity to these processes.

Developing a mutual system understanding is an important step in the conduct of a ULL. Sometimes 'systems thinking' is a skill that needs to be developed or adapted by participants. In the SustBeerLab, academics did not understand the craft beer production systems, and the industry partners had not previously communicated their understandings using academic tools. Neither fully understood the specific embedding of the brewery process and supply chain in the local context. For this, we ran several participatory mapping sessions (see below for details) that included Causal Loop Diagramming (Richardson, 1997; Schulerbrandt Gragg et al., 2018) and flow diagrams (e.g., Soundararajan et al., 2014).

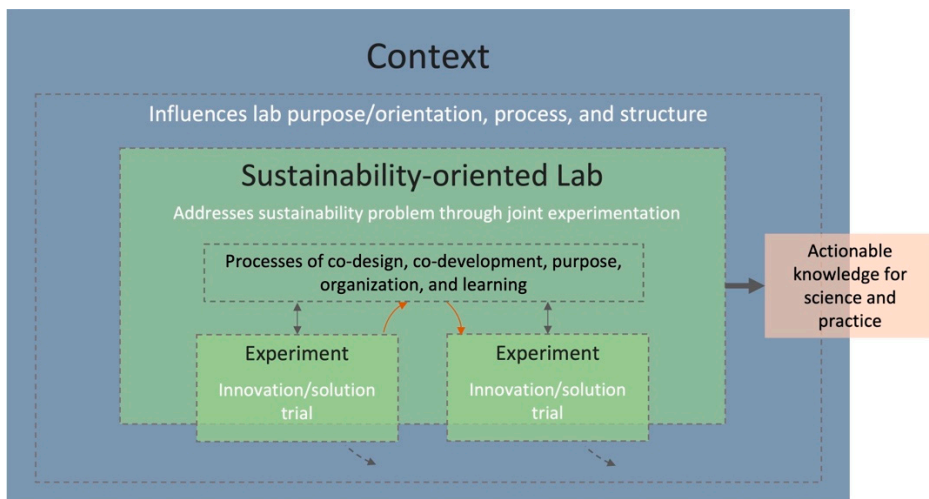


Figure 4. This diagram shows the function of and the connections between the sustainability-oriented lab, the local context, and the sustainability experiments. The dotted lines refer to the interactive nature and influence between the different spaces. This is taken directly from Paper 4 (Bernert et al. 2023 in review).

Experimentation

Experimentation co-develops and tests innovative sustainability solutions to co-defined problems (Voytenko et al., 2016; Caniglia et al., 2017). ULL experiments are meant to take place in a semi-sheltered, safe-to-fail space to promote learning, yet they are still exposed to some complexities of society and the environment (Sengers et al., 2019). If time and funding allow, through the experimentation, obstacles, and challenges to societal adoption of the novelty can be identified, and then the Lab can restructure around these new problems to develop inclusive strategies to create an enabling environment within the local context for the novelty to survive and thrive (Sengers et al., 2019, von Wirth et al., 2019). This can lead to further experimentation in these strategies (see the experiment boxes in Figure 4). Beyond this, and more relevant for my context in this thesis, experimentation creates new configurations of work contexts, for ourselves and our societal partners, along with new purposes for work (Frantzeskaki et al., 2018). The collaboration process that occurs in the space of new configuration and purpose is a key focus of my investigation, along with the associated knowledge development and learning.

In the SustBeerLab, we primarily conducted two experiments: one developing sustainability principles and the other testing the viability of multi-harvest greenhouse-grown hydroponic hops. The purpose of the experiments is co-defined by all partners as well as the general roles and responsibilities of participants – all of which can be (and was) renegotiated over time. Once the experiments were determined and began in earnest, each experiment required a shift in collaboration away from organizational and structural aspects to conducting the experiment. In the SustBeerLab, both experiments were designed and negotiated to have a strong academic presence with societal partner participation, support, input, and dialogue. The paths of the two experiments can be seen in Figure 5 below.

In the SustBeerLab, we have partnered with two organizations, a local craft brewery, and the regional craft alcohol producer's association. Together we entered sustainability experiments to address co-identified sustainability problems in which all partners have some stake and interest. When does transformational change occur within the organization – i.e., at what point can we consider a transformation process to be active? For ourselves, we looked at business models that began to shift to reflect sustainability values. The idea is that the values will direct priority setting, decision-making, and practices in a way that sustainability (broadly) is a driving force pushing against a profit-dominated model.

Sustainability Principles

While the development and web launch of the sustainability principles seems to be the end of this experiment, it was not designed to be. Initially, the development of principles was meant as a first step toward an experiment, which was meant to inspire a set of tested practices for engaging the sustainability principles in craft

breweries in Skåne. The tested practices were to be shared in narrative and detailed forms through the network of breweries part of the brewery association. This was to establish a sustainability network amongst Scanian brewers. Innovative practices may have included, e.g., equipment and transport sharing to reduce costs and emissions. Unfortunately, our main collaborator, the president of the Scanian craft alcoholic beverage producers' association, could no longer participate in our Lab. This occurred early in COVID, and with little opportunity to make new collaborators, this experiment and this part of the lab diminished.

Therefore, the development of sustainability principles was not an experiment in a traditional sense; rather, it was more in the co-creation, co-production space where stakeholders developed locally and regionally relevant principles that can be shared more broadly.

Hydroponic Hops

This central experiment of the lab came about from discussions around the potential reuse of production 'wastes' combined with intentions to intervene in the ingredient supply system of the brewery. The hydroponic hops experiment aimed to test whether and how it could be possible to grow brewable hops hyper-locally and hydroponically, which in our case meant on-site at the brewery (see Photos 1+2). This experiment coalesced around reflections from a drought in Sweden in the summer of 2018 that had some impact on the ingredient supply chain of local breweries and the realization of emissions related to long transport distances. The hop growing trials continue to this day (as of summer 2023), with activities continuing to evolve, for example, CO₂ augmented growing, which has led to a surge of interest within the brewery to better understand their CO₂ levels and health risks to employees due to high CO₂ exposure; meanwhile, the energy price surges (2022-23) have opened up more circular thinking around waste heat capture and reuse – which lead back to Lab type discussions around planning future sustainability experiments. The methods for running the hop trials are many but not relevant to this thesis as they venture well into plant science and greenhouse management. Yet the trials served as a convener and topic of conversation and growing interest over the several years of trials (and tribulations). Paper 3 discusses these as *sustainability knock-on effects*, which, while these are results and will be addressed in the next Chapter, come about accidentally yet intentionally, in that there is no specific causal link that produces them, yet they (as learnings and knowledge integration) are intended outcomes of the ULL and of TTSR processes.



Photos 1+2. Images show the hydroponic system developed for the hop trials with different varieties of hops plants at an early stage (1) and then at a late stage (2) with hops ready for harvest. Photos by Darin Wahl.

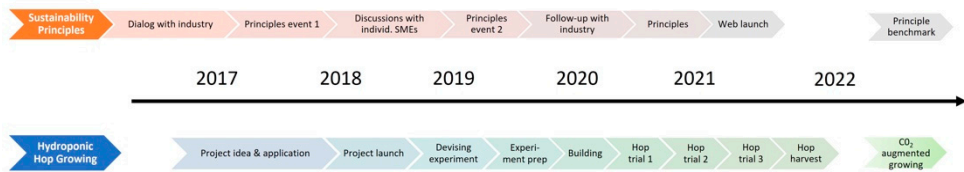


Figure 5. A timeline of the experiments and their activities conducted in the SustBeerLab – taken from Paper 3 (Ness & Wahl, 2022)

Interdisciplinary collaboration in the project consortium

A large portion of the work done in this thesis was interdisciplinary, working collaboratively with other researchers in the GLOCULL project, many with different backgrounds, expertise, training, and interests. The project set the terms of collaboration between project teams through shared responsibility of work packages and by having biannual project in-person¹⁰ meetings for consortium building and workshops. Supplementing these, the early career researchers decided to have once per three-week Zoom meetings, as the early career researchers were most regularly engaged with project responsibilities (if not in their local case-studies as well). The research collaborations originally formed during these sessions resulted in spin-off teams working on specific project-based tasks that were then turned into relevant publications for participating researchers and the project.

¹⁰ Which moved online during COVID.



Photo 3: Sketch of ideas for how change happens in the GLOCULL project. Cape Town, South Africa, 2018. **Photo 4:** GLOCULL team viewing local projects in Tempe, Arizona, USA. Photo 3 by Darin Wahl, photo 4 by Tadeu Malheiros used with permission.

My role in the consortium was to fulfil the responsibilities of the Lund University team by contributing our due to each work package. In the project, I was the lead contributor with support from my supervisor Barry Ness (whereas in the SustBeerLab, it was the opposite). I was the lead on one work package -FWE nexus interactions- and was the main support for two other work packages -case evaluation and case comparison- while also working as part of the tool development team. Papers 1,2,4 and 5 have their roots in the project work and collaborations developed during work packages.

There were seven ULLs in the international consortium, though no two were similar in context or purpose (see Box 1). Early in the project and during an all-hands workshop, we held several sessions to collaboratively develop project language – a ‘GLOCabulary’ – to ensure a foundation for inter-team communication. The collaboration in the consortium was not always seamless, yet it was coordinated and managed adaptively. In response to tension experienced by some early career researchers, we held a positionality awareness workshop designed to make aware to the project team the positions and identities held by individual members and the conflicts they experience in their lives and research spaces within and without the project. Further, in our first online workshop, our teambuilding exercises included a session for collaborative poetry writing where project researchers shared and expressed their pandemic experience. All these sessions combined to create, at least for me, a rich, creative, trusting, and rewarding collegial space where collaboration was encouraged, and I was able to learn from and engage with others readily.

Box 1: GLOCULL ULLs, briefly described below, are diverse in terms of their context, lab design, sustainability orientation and experiments.

Lüneberg, Germany - as part of the 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.

Applying the food-water-energy nexus in ULLs

The FWE nexus concept provides a particular systems perspective for the work done in the GLOCULL project and the associated ULLs, including the SustBeerLab. In a practical sense, the nexus framing imparted a *nexus thinking* in which participants in transdisciplinary processes consider resource system interactions across scales (Kurian, 2017).

In using Urban Living Labs as an approach to the food, water, and energy nexus, this thesis reconsiders the usual regional-to-local flow of the nexus. The ULL approach is inherently bottom-up (or out) and therefore forces a likewise perspective of the FWE nexus system from the local to the beyond or from waste to use to source, shifting the direction of understanding that is normal to nexus research. Furthermore, this thesis exists in the mostly uncharted space of solutions implementation in the FWE nexus. Broadly speaking, the nexus is itself transformative by the depth and breadth of changes necessary to institute integrated resource management (Pahl-Wostl, 2019; Urbinatti et al., 2020). Further, it has transformative potential in conceptualizing a complex system, as the focus is on synergies potentially across geographies and sectors (see Kurian et al., 2019;

Vanham et al., 2019). However, while this potential exists, much of the work in the nexus follows a descriptive-analytical purpose, a mode 1 sustainability research agenda, targeting what the nexus is, how it works, and the complexities inherent (Albrecht et al., 2018; Bazilian et al., 2011; Schulterbrandt Gragg et al., 2018; Simpson & Jewitt, 2019; Spangenberg, 2011).

At the local level, the ULL approach moves the nexus from a descriptive-analytical research agenda to a transformative and solution-oriented agenda (Wahl et al., 2021). From the ULL side, these factors together push the co-development of ULLs and their experiments and the associated co-production of knowledge to have inherent synergistic sustainability benefits both in local and beyond-local contexts (Engström et al., 2018). These have implications for how research was conceived in the ULLs and led to a reflexive rethinking of how to develop actionable knowledge in transdisciplinary research. The impacts of this shift of framings are discussed in the results chapter and seen in Papers 2 and 5.

Methods to examine the ULL+FWE nexus approach

I used multiple methods to study ULLs, which were varied and spanned from straightforward, such as literature reviews and surveys, to multi-phase iterative collaborations to reflexivity. The methods in this section correspond to the papers included in the thesis. Each paper's methods are summarized in Table 2 and discussed in the sections below.

Table 2. The papers included in this thesis, their methods, and relevant TTSR process.

Paper	Type	Research Question	Methods and analysis	Topic/Case	Relevant TTSR process aspect
1	Conceptual	What opportunities exist in the urban food, water, and energy nexus research for the Urban Living Lab approach to enable action and solutions development?	Systematic literature review Content analysis - for operationalization of nexus, methods used, and intended real-world relevance.	Topic: FWE Nexus and ULLs	Research design and coordination
2	Conceptual - Perspective	How can food, water, and energy nexus research be designed to enable an action and solutions orientation?	Literature review Collaborative concept/framework development	Topic: Actionable knowledge in nexus research	Research design and coordination
3	Empirical - perspective	How can we better navigate long-term transdisciplinary collaborative sustainability research and experimentation?	Reflexive methods: collected reflections, dialogue; co-writing. Thematic analysis: Intra-, inter-personal, and organizational frame for understanding reflections	Case: SustBeerLab	Navigating day-to-day interactions in long-term collaborations
4	Conceptual w/test empirics	How can Urban Living (and similar) Lab research be evaluated to enable cross-case comparison and transferability?	Multi-stage co-development process: workshops, group discussion, testing and trials; co-writing. Iterative scheme development and testing on GLOCULL ULLs	Topic: Comparative evaluation and reporting	Transfer, sharing, and other amplification through Lab and experiment reporting and comparison
5	Empirical	How is actor-centric transformative capacity developed and used by Urban Living (and similar) Lab researchers?	Project-wide co-development workshop with reflexive exercises and discussion; follow-up survey. Thematic and content analyses	Case: Seven GLOCULL ULLs	Capacity to engage and conduct TTSR research

Literature Reviews – Papers 1+2

A systematic literature review was done to link the FWE nexus and ULLs, which led to Paper 1 (Xiao & Watson, 2019). The motivation for this paper was to understand how the nexus is being operationalized and/or 'implemented' at local levels and to reveal opportunities for ULL-type (e.g., transdisciplinary, participatory, collaborative) research approaches. I selected the *urban* FWE nexus literature to match ULL's general operating area. Then using content analysis (Krippendorff, 2004), I considered the conceptualization of the nexus, methods, and proposed future steps of each reviewed paper. This was done to understand how the nexus was understood in the context, what was done to develop any action-related knowledge, and what the research was hoping to contribute or lead to, e.g., papers that aimed for policy relevance – and then, if so, the paper's methods were examined to see if any policy actors were included in the research methods.

The first paper's systematic literature review laid a foundation for a broader literature review to understand 'key interactions' in the FWE nexus. This framing proved a challenge that led to considering the nexus from a bottom-up perspective instead of the usual top-down. Still, the idea of 'key interactions' remained elusive. However, the ideas generated in the discussions within this mini-project team led to Paper 2.

A qualitative literature review was performed for Paper 2 and spanned the FWE nexus literature broadly, seeking to gain insights around a question we were struggling with within our project: How can we help researchers new to the nexus design and plan research that follows an action-oriented agenda? Drawing on nexus literature and using simplicity as our guide, we developed the 5Ws heuristic. For our literature review, the nexus literature was classified thematically into the one of the Ws to synthesize how research has presented each (Fereday & Muir-Cochrane, 2006). To develop the heuristic, the overlaps between the Ws were considered. Sustainability research on how action-oriented research is organized was also consulted.

Reflections and reflexive dialogue – Paper 3

Collaborative experimentation in sustainability-oriented labs can require a significant commitment from academics that can stretch far beyond the coarse methodological guidelines of TTSR. Although there is work mapping the ideal-typical process and research on the relevant success factors and competencies involved (Bergmann et al., 2021; Brundiens et al., 2021; Lang et al., 2012; Wiek et al., 2011), little research has been conducted on the day-to-day management, conducting, and participation in these processes.

We used reflexivity as a method to better understand this gap on two levels, individual reflections and reflexive dialogues (Fook, 1999). Reflexivity, in this way, is more akin to ethnographic research in which researchers find meaning in the juxtaposition of themselves and the other (see Lichterman, 2017; Roberts & Sanders, 2005). Our reflexive approach sees Roberts and Sanders work not only at the study level but also at the interactions, where we reflect before, during, and after, centering interaction dynamics in co-production.

During our (at the time of paper writing) 3-year collaboration with our SustBeerLab societal collaborators, we intentionally and unintentionally used a combination of oral and written reflections to better understand how to navigate our collaboration and the relationships embedded within. These reflections were then used as data for the paper. Yet to write the paper, we used reflexive dialogue to consider the reflections of the other and to create a more complex understanding of experiences as recorded in memory, emails, and conversations, and then shared our impressions, understandings, actions and reactions, intentions, emotions, and expectations surrounding them. We determined three domains for reflexivity: intra-personal, inter-personal, and organizational, and reconsidered our reflections from these perspectives. The framing of our analysis emerged through the reflexive dialogues and therefore is also an important result. We found this process so beneficial to the understanding of ourselves as part of this collaboration and the collaboration process itself that we embedded several aspects of it into our recommendations in the article.

Case reporting scheme development – Paper 4

The ability to compare ULLs and other transdisciplinary case studies is crucial to share and learn from other cases and their processes. To accomplish this, we developed a case reporting scheme for our GLOCULL ULLs. The scheme was designed to accomplish two key tasks: an evaluation of the ULLs and their activities and a coherent basis for cross-case comparison. To achieve these purposes, the scheme needed to be comprehensive yet broad and general to capture the diversity of ULLs in the project.

A first and important breakthrough came with the first introduction of the Logic Model that separated the Lab into three dimensions (Kampfmann et al., 2022)¹¹. Following the general path shown in Figure 6, the development of the case reporting scheme involved a small core team of 2 researchers, a larger group for ideas and feedback (8, with at least one member from each team), and the entire project team for insights and critical elements for inclusion in the scheme.

¹¹ The modular aspect of this paper uses this idea provided by a co-author of that paper, who is a core member of this project team and co-lead author of Paper 4.

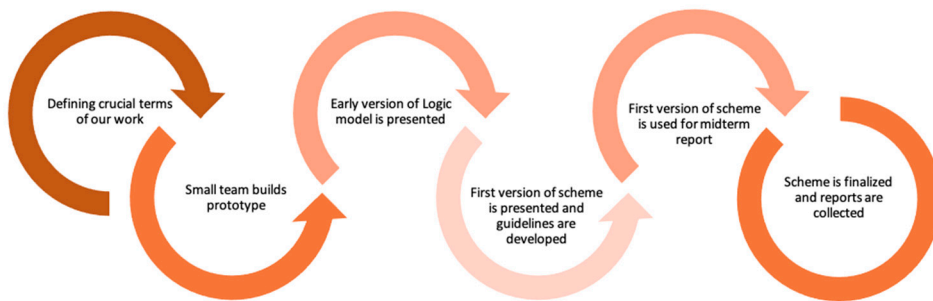


Figure 6. The process of development of the case reporting scheme. The circular-ness of each step is meant to represent an internally iterative process.

The whole project group listed all the questions they would want answered for an evaluation of their case during an in-person workshop. These were collected, categorized, synthesized, generalized, and then compared and combined with existing literature. Literature on experiment evaluation formed the backbone of our scheme, drawing heavily on the work of Luederitz et al. (2017) for experiment questions.

Two rounds of testing with the GLOCULL ULLs refined the case reporting scheme and led to the inclusion of a brief set of instructions. It was then used within the team to collect case data and then compare and synthesize experiences, processes, and learnings. The paper where we present the case reporting scheme evolved through a co-writing process between the co-lead authors (Richardson & St. Pierre, 2005).

Project workshop and structured reflections – Paper 5

Finally, I consider how researchers use and build transformative capacity for TTSR. The later GLOCULL project workshops included sessions for reflection and evaluation. These workshops were necessarily held online. To understand this, we took an actor-centric approach to transformative capacity (as opposed to a social-ecological system perspective (cf. Westley et al., 2013; Wolfram, 2016; Wolfram et al., 2019)) in which we consider the confidence, competence, commitment, and power dimensions of project researchers¹². The questions for the sessions were created with these categories in mind. Individuals answered questions on an online

¹² Not all project researchers would identify as transdisciplinary sustainability researchers.

idea-mapping ‘board’¹³ then discussed in breakout rooms and then again in the main group, all of which were recorded. Four rounds of this were done to match the four dimensions. These structured reflections were again an example of reflexivity as a method for data collection, as well as a test of a reflexive practice for the project, in that this session is also an evaluation of the project and the time and investment of researchers and funders. We conducted a follow-up survey to provide the opportunity for individual, deeper or more detailed reflections. The data collected was categorized into four dimensions, and then the authors performed three rounds of content analysis (Biggs et al., 2021; Krippendorff, 2004; Neuendorf, 2017) to reveal the general topics and themes, which were later refined into findings.



Screen capture 1. A section of the data collected on a digital board used for Paper 5.

A note on writing as method

The execution of much of the work in this thesis is collaborative, by design, including the writing. There are no single-author papers in this thesis, and while that is not unique, or perhaps even unusual, the process of paper writing explored collaborative academic writing in several ways (Richardson & St. Pierre, 2005). Papers 3 and 4 were my most collaborative, and I will briefly discuss those here. It could be said that papers 3 and 4 evolved out of the writing process in that ideas were initiated by individuals, but the development and expression of those ideas were further developed through dialogue; therefore, there is no real ability to distinguish individual insights (Ritchie & Rigano, 2007). In paper 3, which focused on reflexivity, it can be argued that the process was “writing as research” (Ritchie & Rigano, 2007) in that during the writing, we revisited our reflections on our collaborative experiences and jointly developed ideas for collaborative processes; one of which at least was quite similar to the process we were at the moment practicing.

¹³ We used Mural at www.mural.co.

The most exciting and rewarding paper for me to write was paper 4, as it was the most collaborative, with writing often happening in time during dialogue and discussions. The idea explorations during these discussions spawned several versions, drafts, and directions, resulting in more than a dozen paper drafts stashed in an archive and other paper ideas bullet-pointed but unexplored over a three-year writing period (Colyar, 2009; Ritchie & Rigano, 2007). The difficulty (and reward) with this process is the shared ownership, founded in a deep trust-based reliance on the other. This put findings from Paper 3 into practice, as this is a profoundly intra- and interpersonal process, balancing progress delays with understanding, patience, and compassion – which necessitate reflexivity, self-awareness, and other-awareness.

Paper 2 was my most interdisciplinary paper, with the three main authors coming from different research spaces, one an FWE nexus researcher, another a climate scientist, and myself a transdisciplinary sustainability scientist. Yet our collaboration, founded through work together on the GLOCULL project, was rather smooth and open, building on the strengths of each other's fields and the trust we had previously established.

Participatory methods in the SustBeerLab

There were various methods employed in the course of work for this thesis that did not directly link with the papers, but are relevant to the larger research question of this thesis and represent the *researching from within*/participatory aspect of this thesis. Within the ULL there were many activities that employed research methods to establish a functioning collaboration and to pursue Lab experiments.

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Podcast – trust building and narrative building

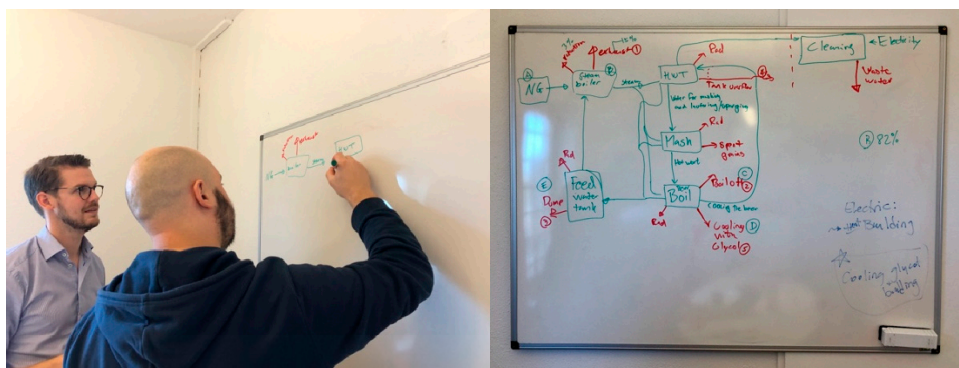
It is foundational for long-term collaborations to establish a common understanding along with building rapport and trust between participants. To do this, I created a narrative of the SustBeerLab as it was in 2019 by developing a podcast. To develop a podcast, I conducted interviews with ULL partners and edited, produced, and published the episode¹⁴. I conducted four interviews, three individual and one group, to capture the perspectives of the collaboration, their participation, personal interest,

¹⁴ <http://bit.ly/3HfWduc>

and overall understanding of a sustainability position. This also included their understanding of the FWE nexus in relation to their roles in the collaboration. Interviews were carefully recorded for the podcast with radio-quality equipment, and used the Apple app *Garage Band* to edit and create the podcast.

Participatory mapping – system understanding

We also ran a series of four participatory system mapping exercises in three sessions with our ULL local partners to better understand the systems in which we planned on intervening, the potential impacts of intervening, along with the relevant system interconnections (these maps will appear in the Results Chapter) (Saija & Pappalardo, 2018). Two exercises focused on developing a causal loop diagram of the brewing operations and their linkages, locally and beyond (cf. Inam et al., 2015). Another exercise focused on understanding and mapping the internal processes of the brewery and what interventions could increase the efficiency of resource use. The final exercise combined a resource flow diagram and the causal loop diagram to understand how resource flows matched the causal linkages of the SME, the FWE nexus, and the intended interventions with their impacts.



Photos 5+6. Our brewery partners draw the brewing process and reveal potential points of intervention for sustainability. Photos by Darin Wahl

Participatory workshops – capacity building and experimentation

For the development of sustainability principles for the craft brewing industry (experiment 1), we held a series of 2 evening participatory workshops with stakeholders in the local craft brewery industry, including our ULL partners, followed by several rounds of edits with our ULL partners¹⁵. The purpose of these workshops was to first co-create sustainability principles for the craft brewing industry in southern Sweden through dialogue and small group discussions.

¹⁵ <https://www.skandesdryckesproducenter.com/en>

However, progress on this experiment was slowed to a near standstill due to the pandemic and the shifting priorities of the brewer's association with whom we collaborated. Ultimately, the principles were translated into Swedish, and both versions were uploaded onto the association's website, but further progress has yet to be made. Though the next step in the process was to develop indicators for each of the principles and then measure them at selected breweries.

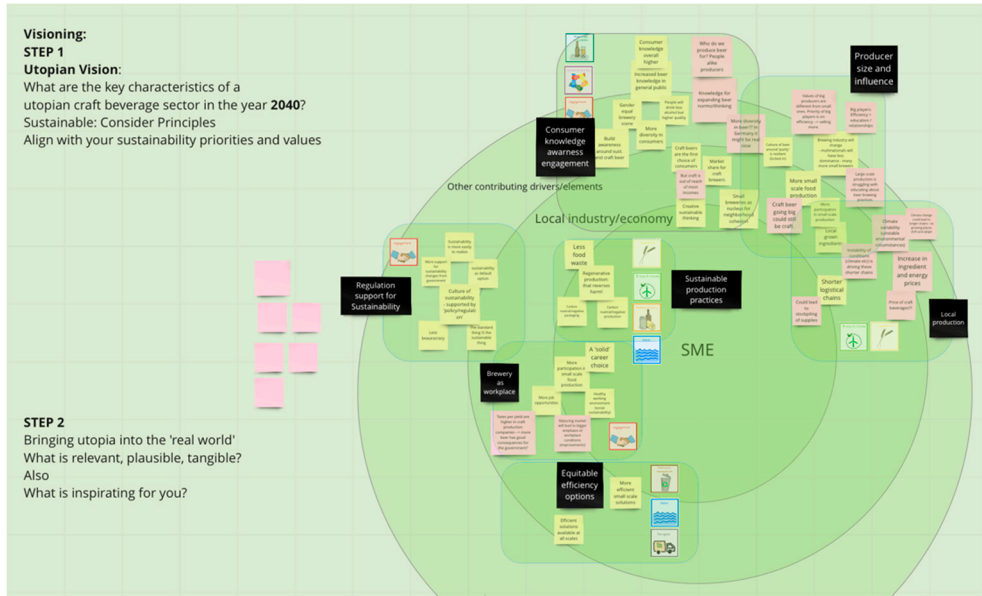


Photos 7+8. Local craft brewing stakeholders consider the sustainability principles and provide insights and feedback. Photo 7 by Darin Wahl; Photo 8 by Barry Ness, used with permission.

The second workshop was to gather feedback and comments on the sustainability principles and their descriptions and guiding questions. Each participant provided written feedback, followed by a small group discussion and then a whole group discussion. Both sessions were well attended, with between 16-24 participants.

We held three workshops with ULL partners from the Sweden and German hubs to understand their capacity needs now and in the future, including sessions on visioning, backcasting, and networking. These capacity-building workshops were held two years after the principles workshops and involved participants who had expressed interest in sustainability experimentation or were already partners in experimentation from the Swedish and German ULL hubs; all non-academic participants were craft brewers. The visioning session asked each participant to consider what they realistically hoped their business would evolve into by 2040, including how they interact with their supply chains and local communities (cf. Wiek & Iwaniec, 2014). Then we used a backcasting exercise for them to consider how to get from current conditions to their 2040 visions (Robinson, 2003; Robinson, 1982; Holmberg & Robert, 2000). Discussions were then structured for all participants to consider their businesses and the associated "ecosystem" for capacity gaps, points of change, and potential sustainability experimentation. Conversations between brewers were encouraged to establish relationships for potential future

international collaborations. These sessions were held online due to pandemic precautions using a Miro board¹⁶ as a workshop share space.



Screen capture 2: This shows a portion of the digital Miro board used for collecting, discussing, and categorizing ideas from participants in a 2040 visioning workshop.

¹⁶ Miro is another online mind-mapping tool similar to Mural: www.miro.com

Results

This chapter presents the main findings of the thesis and is structured in two main sections. The first presents findings relevant to the three research sub-questions. These are the main findings of this thesis and form the basis upon which I contribute to the field and answer my overarching research question: *How can the experimental practices and processes within sustainability-oriented labs advance transformative transdisciplinary sustainability research?* The first section also represents the *research from without* aspects of this thesis. The second section presents the results of the participatory methods and activities done as part of the SustBeerLab. These represent a portion of the *research from within* aspects of this work and show the variety of activities and their findings. Experimenting can be seen in this section on several levels: in the design and conduct of the designated experiments, but also as a response to the novelty of the project space (ULL + FWE), which prompted new method configurations such as combining causal loop and flow diagrams.

Research design and planning

How can the design and planning of transdisciplinary and experimental sustainability research enable the development of action-oriented knowledge?

The findings relevant to the first question come primarily from papers 1 and 2, but also from 3, 4, and 5. Papers 1 and 2 start from the FWE nexus and consider how to frame nexus research toward developing actionable knowledge. Papers 3, 4, and 5 are from the ULL and experimentation perspective and offer insights into design and planning to facilitate the navigation of these processes for desirable outcomes such as actionable knowledge and learning.

Paper 1 revealed that while progress is being made in FWE research, there is a lack of adaptation to the complexity of urban contexts. Most solutions proposed in the literature focus on local production of FWE resources, such as urban gardens and rain capture, but do not directly address larger systemic issues, e.g., fair and equal access to and distribution of resources.

The results of paper 1 shows that the nexus requires a re-conceptualizing at the urban level as thinking shifts from production and processing to use and waste, taking into account social complexities that affect the distribution and use of resources. Another

consideration is that intervening for impact/change in the nexus will require understanding how the social-ecological system might respond to interventions. This is a directional conceptual shift from considering "nexus interactions not only as incoming flows, but also as outgoing impacts" (Wahl et al. 2021 p7). This shift in directional thinking was not clearly recognized in the literature reviewed for the paper; instead, local solutions were more simply proposed to be mathematically scaled up without suggesting how this might be accomplished nor how changes might be received or resisted (cf. Gondhalekar & Ramsauer, 2017; Villarroel Walker et al., 2017).

Based on the results, paper 1 suggests that the Urban Living Lab approach has the potential to address this gap in urban FWE nexus research by enabling participatory solution development. The findings suggest that the Urban Living Lab approach could fill the gaps in the literature and help to develop long-term sustainability solutions for urban FWE systems.

Among other things, we¹⁷ recommend the following considerations in research planning based on the results: "(1) knowledge development should extend to implementation; (2) stakeholders should be engaged, and be able to align solutions with the agency to implement; (3) research should move beyond material flows, and focus on the behaviors, habits, and social patterns that underpin urban complexity" (Wahl et al., 2019, p. 1). These recommendations require breaking disciplinary siloes and long-term coordination of research for actionable knowledge. For example, research can be considered in phases, as Daher et al. (2019) suggested, with quantitative modeling for descriptive-analytical understanding as the first phase, followed by stakeholder outreach and dialogue to understand on-the-ground realities as the next steps.

More broadly, this paper establishes an understanding of the gap between nexus research and TTSR. Nexus research leans heavily toward the technical and quantitative, even when aiming for action or solutions. Therefore, the space for participatory methods and transdisciplinary research is broad in the nexus, especially with intentions aligning with sustainability (cf. Allouche et al., 2018; Bergendahl et al., 2018; Hoolohan et al., 2018). There were few papers that showed interdisciplinary collaboration or even identified an inter-sector collaboration, which seems implicit to the FWE nexus. Furthermore, article 1 found that the tested solutions rarely involved local actors or other relevant actors like policymakers, even when suggesting the research was "policy relevant." Drawing on Cash et al. (2003), this lack of participation or inclusion does very little to establish the legitimacy, credibility, or salience of the work. These absences made it clear that the contribution of participatory transdisciplinary research in the nexus could be considerable as it moves into an action and implementation space.

¹⁷ As the papers are all co-authored, 'we' is used in these contexts.

Paper 2 contributes to operationalizing the findings from paper 1, broadening to the FWE nexus in general (not just the urban). The literature review also revealed that nexus research tends toward siloed approaches to the research, in which only specific aspects of nexus research and understandings are explored. However, the spaces of connection between nexus aspects still need to be explored. The paper synthesizes arguments from the literature to support research design that explores each of the 5Ws - who, what, where, why, and when - as well as the interconnections and dependencies between them.

Building on the arguments of Paper 1, which suggest that integrating social complexity is necessary for the nexus to create action- and solutions-oriented knowledge, we present a simple heuristic (Figure 7) that can guide the design of action-oriented nexus research.

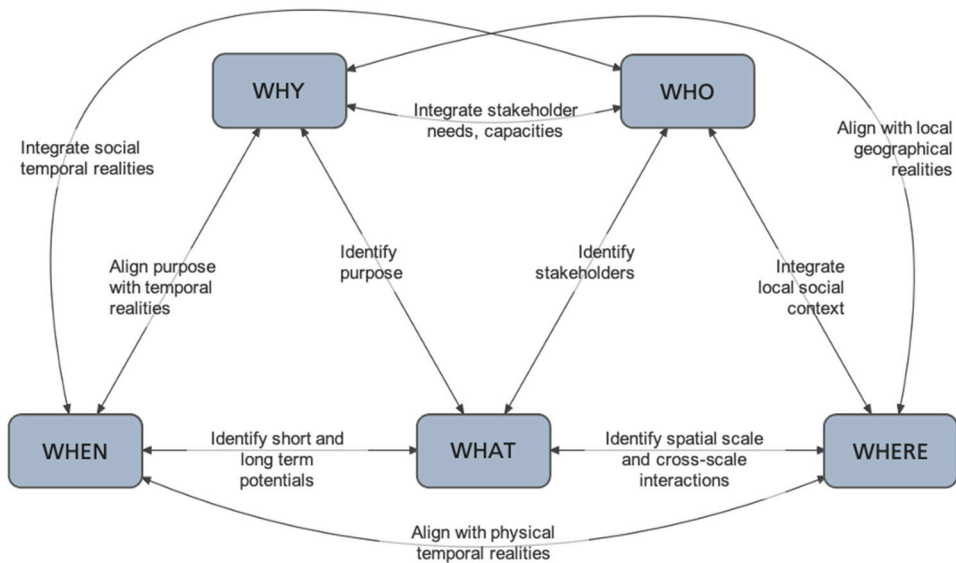


Figure 7. A heuristic guide for designing FWE nexus research for developing actionable knowledge for sustainability. The figure can be entered at any point depending on, e.g. priorities of one's current research (Dalla Fontana et al., 2021).

In the paper, we encourage researchers to develop reflexivity in their practice and "to build interdisciplinary or transdisciplinary networks" to align purposes and share knowledge (Dalla Fontana et al., 2021, p.9). This approach asks for no small understanding of one's systems, and we acknowledge that only some research projects can or should develop a comprehensive understanding of the systems alone. Instead, understanding and addressing the complex and diverse nexus problems will require interconnections and coordination through knowledge sharing and expanded

participation with other ongoing research and local stakeholders. We argue that action- and solution-oriented nexus research should take an integrated approach rather than a siloed one to ensure legitimacy, salience, and credibility (Cash et al., 2003).

This approach suggests a bridge from the conceptual, descriptive-analytical space that much nexus research targets and moving into problem-driven research, then solutions and innovation development, and finally implementation. Coinciding with the theme of this thesis, inter- and transdisciplinary collaborations are critical for this bridging, along with the knowledge, skills, and capacities necessary to engage in them.

Papers 3 and 5 have much to say about navigating these collaborations in the next section, yet they also have implications for design. Research projects of this type can have capacity, reflexivity and positionality, and other competences intentionally and strategically designed to develop for academic and non-academic participants. Findings from these papers reveal that while there is much learning while doing, more can be done with intentionality. This can shift the emergent outcomes beyond learning skills and capacities and further into new knowledge creation and its real-world applications. This is true in TTSR and experimentation contexts but especially true in nexus research, which is ironically quite disciplinary in execution. Therefore, we recommend intentional space-making for personal and group development to develop the interpersonal and to be aware of the intrapersonal.

Navigating collaborations in experimentation contexts

How can collaborations in sustainability experimentation be better navigated to enable intentional and emergent outcomes?

This question is primarily answered by paper 3, which reflects on conducting our local ULL case study. Paper 5 is also very relevant here, focusing on transformative capacity development in this research. Together these papers consider what can be done during participatory and collaborative experimental research and the abilities one needs as a transdisciplinary researcher to engage in the 'doing.'

Paper 3 is the outcome of several years of collaboration with local partners in the SustBeerLab. Our purpose with this paper is to understand the collaborative process as we have experienced it and to provide recommendations on how it might be improved from the TTSR researcher's perspective. Yet, through our reflections, we identified missed opportunities for group reflection and dialogue. Recognizing missed opportunities and seeing the value that could have been was a strong impetus for some of our recommendations. For example, our recommendation to conduct regular collaborative reflection sessions with partners comes directly from our

reflections on experiences that were not discussed with other participants but were significant in small yet meaningful ways in the conduct of the experiment and the relationships within.

Writing this paper was essential for the understanding of what is at the heart of my thesis research: the detailed processes of TTSR. In it, we developed an analytical framing for our reflections, which includes the intra-personal, inter-personal, and organizational levels, as defined in the paper: "The organizational level encompasses the SME and lab structure and governance, in which the purpose and functioning of the lab are determined. The reflections for this level refer to discrepancies between how the lab is imagined running at conception and how it actually progresses. The interpersonal level encompasses the space of interaction between lab actors. The intrapersonal level refers to the individuals themselves from an 'I' perspective," (Ness & Wahl, 2022, p. 2). Thinking in these terms allowed us to reflect on these spaces from a perspective of understanding why events and interactions unfolded in the way they did and what could/should be done differently in the future (see Table 3).

Table 3. Recommendations for navigating collaborations in experimenting with transformations (Ness and Wahl, 2022).

Recommendations and Considerations
Reflect on the influence of one's own positionality and personality
Develop skills and capacity to practice patience, compassion and empathy
Learn the intentions & expectations of other participants
Practice situational self-awareness and adaptability
Integrate collaborative reflections to regular lab/experiment meetings
Designate organizational champion(s)
Strategically embed flexibility in proposal to anticipate change

We argue that understanding these three spaces helps to create and maintain functioning and effective collaborations that actively co-produce knowledge, deepen trust, and facilitate sharing and learning, which are our core outputs from this work. The outcomes should be mutually desirable and sustainable. Therefore, we must intentionally enter lab processes to make connections and create safe and inspiring spaces where ideas, innovations, and creativity can be openly explored and experimented with. "As a result of this reflective process, we have learned that a willingness to learn to collaborate and co-create with others goes hand in hand with the need to reflect on oneself and what we, as researchers, bring to the partnerships beyond mere expertise in science," (Ness & Wahl, 2022, p. 10).

In this exploration of experimenting with transformations, I have presented recommendations in papers regarding the design and conduct of such processes. I

also suggest that there is a blurred line between how recommendations can be applied and who the person is that applies them (e.g., see positionality and personality in Table 3). The idea for paper 5 arose from discussions with colleagues about who has, builds, and needs capacities during participatory research and transdisciplinary settings. Paper 5, therefore, examines transformative capacity (transformative capacity) from the position that TTSR researchers aim to both co-design and participate in societal change processes, coupled with at least the agency granted by their academic position and funding (this link between knowledge with the agency was also made in papers 1 and 2).

Transformative capacity can be a characteristic of complex systems like SESs or one of individuals or groups of individuals. The transformative capacity of SESs considers the ability of systems to dramatically, radically, fundamentally change in response to shifting conditions (Folke et al., 2010; Wolfram, 2016). Building from this scholarship is actor-centric transformative capacity, which suggests that if a human system has transformative capacity, the individual humans must need to play a role and, therefore, can have, develop, and employ transformative capacity (Withycombe-Keeler et al., 2019).

Findings from this study can be divided into two spaces: transformative capacity and the FWE nexus and transformative capacity and ULLs, to help understand the influence of the different research areas on the researchers' capacities. Considering the FWE nexus first, it is important to remember that the nexus is predominantly used as a concept and not as an analytical framework or a resource governance transformation (e.g., from siloed to integrated). As a concept, then, the FWE nexus had several avenues of influence over transformative capacity, especially in regards to competence. To take the nexus into account, researchers had to develop 'nexus thinking' in which the three resource systems and their elements are integrated into a system understanding; there is a focus on interactions between resource systems, and systems are expanded to include other locations with which the nexus resources are entangled – the 'beyond local.'

However, while working with the nexus had some transformative capacity benefits, it also had several drawbacks. There was difficulty working with local participants on the nexus as it was neither a local governance reality nor a familiar concept. In this way, while some researchers gained confidence in their system-understanding skills, they were both less confident in the concept and less committed to it in the future as a functional conceptual tool in transdisciplinary sustainability research¹⁸.

Transformative capacity in ULLs considers the impact of conducting the ULL on project researchers. The most impactful aspect is the experience gained in the planning and conduct of transdisciplinary sustainability research, which intersects four categories of actor-centric transformative capacity: competence, commitment,

¹⁸ Important to note here that only one researcher on the project identified as a nexus scholar.

confidence, and power (Withycombe-Keeler et al., 2019). Competence was gained through experience and the support of consortium colleagues, which helped build confidence in ongoing work and planning future activities in the labs and experiments. The consortium was vital in this aspect, as ideas were generated by many researchers from various disciplines and experience bases and then interrogated, leading to the development of concepts such as the logic model, which helped gain an understanding of the labs and roles and functions within. Other ideas were developed into approaches such as combining CLD and flow diagrams. Furthermore, the consortium created a network of colleagues with established familiarity and trust, enabling problems to be presented and options explored. This development combined to form a commitment to the approach, supported by on-the-ground validation through collaboration with local partners and the learning and other outcomes achieved. It should be noted that not all outcomes were positive, and not all experiments were successful; however, researchers found benefits in the process. For some research teams, there were also power-based impacts within and outside the project case study. Power dynamics between researchers and Lab participants were revealed in the course of the research, and in some cases, access and exchange with local politics improved.

This research has implications for the design and conduct of TTSR. To develop transformative capacity in researchers, projects should intentionally create space for interdisciplinary collaboration, build reflexivity into research spaces, and dedicate time and personnel for coordination. Researchers have shared that there is often little time for cross-hub collaborations on international projects unless it is purposefully carved out. Similarly, time should be allocated not only for sharing research progress but also for individual and group reflections on processes and outcomes, including inter-researcher conflicts. Effective and consistent coordination was a critical facilitator of capacity development, opening spaces, responding to needs, and matching tasks and skills with people (Brink et al., 2018).

Enabling knowledge transfer, comparison, and sharing through evaluation

How can transdisciplinary sustainability experiments be evaluated to allow for knowledge sharing and transfer?

A central goal of this thesis was to break the case embeddedness of sustainability-oriented labs and transdisciplinary experiments and enable knowledge sharing, comparison, and process facilitation, which was directly addressed by paper 4. Deeply context-embedded research, such as TTSR and sustainability-oriented lab research, cannot be replicated, and therefore, detailed process reporting has not been a focal point of case-study and Lab publications (Adler et al., 2018). We consider

this as a significant loss of learning potential. We argue that what could be learned by sharing and comparing lab and experiment processes could elevate this research beyond contexts and further influence the sustainability transformations in which they are intended to contribute (Loorbach et al., 2017; von Wirth et al., 2019).

The logic model we developed (see Figure 4) was critical to the development of the case reporting scheme for paper 4. The separation of the lab into three dimensions - context, lab, and experiment - enabled a clearer understanding of sustainability-oriented labs and what they do beyond conducting sustainability experiments. This is itself a result of the process of developing the case reporting scheme¹⁹. This understanding provided the foundation for the structure of the case reporting scheme and, ultimately, the logic with which cases can be compared and process knowledge shared.

This separation, especially of the lab from the experiment, allowed for evaluation/reporting questions on the conduct and processes in the lab, which we found to be primarily about governance, including structure, organization, activities, actor involvement, plurality, knowledge integration, and learning. All aspects that are central to managing experimentation and its associated outcomes but not part of the experiments themselves.

Separating out the context from the other lab processes establishes a basis for comparison. The practice and outcomes occur within and because of the context, so the disambiguation of the spaces can make the interconnections more visible and the lab more understandable to itself and others. The shared and compared elements are not meant to establish replicability of results but to inform on processes, outcomes, and possible reasons for those outcomes.

The case reporting scheme can also be useful in research design, collaborative planning, and synthesis of results, as well as used as a reflexive exercise. Its comprehensive scope can help consider how the lab and experiments are structured and organized, and if used iteratively, can help develop and adjust research as the lab changes and evolves. While the language of the case reporting scheme is academic, it can be used collaboratively with non-academic participants to plan activities, reflect on accomplishments, and map new directions and opportunities as they arise.

¹⁹ Kampfmann et al. (2022) present a ‘modular’ separation in Real-world labs – the idea for which was developed during this case reporting scheme process and brought to the Kampfmann paper through PB – a co-lead on our case reporting scheme development paper and contributing author to the Kampfmann paper.

Results from SustBeerLab activities and methods

This section presents the results of participatory activities carried out in my local ULL. They are presented here as a backdrop and context for the papers presented above. While the results from the papers largely represent the researching without or the observing (while doing) aspect of this research, this section presents the research from within or the participating aspect. While these results are not directly part of the included papers, these results, the associated activities, and the planning, coordinating, and enacting of them are central to this research. Indirectly, the results of these methods are used across research questions, e.g., to form the basis of reflection and dialogue for paper 3 (all below), or as foundational system insights that helped inspire and guide paper 2 (CLD and Flow diagrams), or as experience with which capacities were developed for paper 5 (all below).

Understanding context and system

The mapping exercises produced several noteworthy results. Firstly, we arrived at a shared understanding of the system within which we were operating among the lab's partners/participants. This exploration of the system also helped us identify various spaces that intersect with different aspects of food, water, or energy systems. In addition, we placed the potential interventions being considered by the lab at the time on the map and pinpointed where they could have impacts. Lastly, we found that our Causal Loop Diagram (CLD) (see Figure 8) extended beyond our local geographical context, which is atypical for CLDs as they are not usually spatially explicit, but was necessary to capture the FWE aspects moving in and out of the local system.

The project required us to identify local-to-global linkages in our case studies, but several GLOCULL ULLs found this conceptually challenging and practically meaningless due to the small impact of our respective case studies and experiments. However, this tension between the cases and the project led to a reframing of local-to-global to “beyond local” that opened new possibilities for thinking and understanding. This slight shift in framing directed the conversation towards considering impacts in interlinked locales in the supply chain of our SME. For example, we explored how locally-grown hops could affect suppliers in Germany in terms of livelihoods, chemical use, and other factors.

A second participatory mapping result emerged from our creation of a flow diagram (Figure 9) that illustrated the brewery's resource flows, which we then integrated into the CLD (Figure 10). After conducting a quick literature review, we did not find any other successful examples of this type of mapping process. Thus, as a project, we designed the process ourselves. This type of mapping revealed other elements in the local system that could be significant but were not present in the

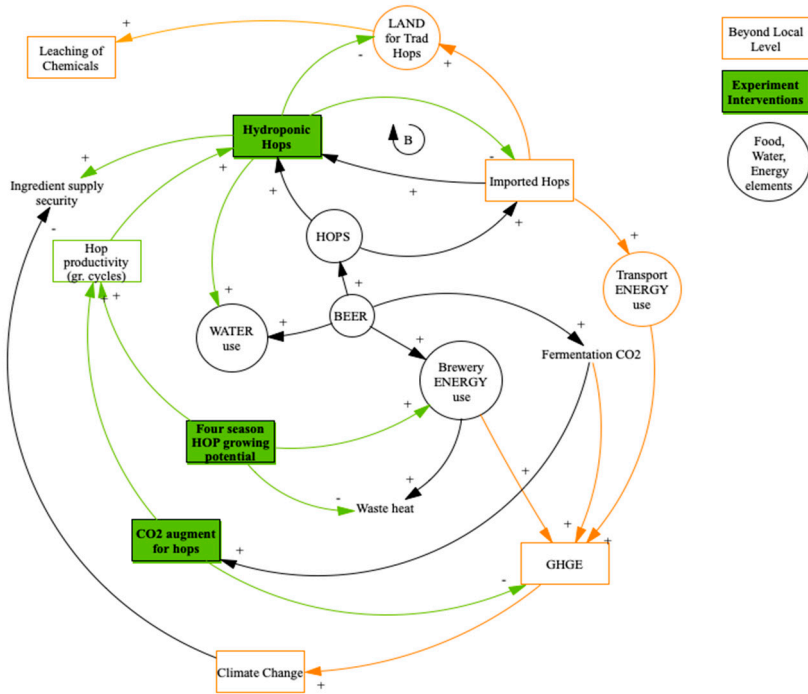


Figure 8. The causal loop diagram collaboratively developed by SustBeerLab participants to better understand system thinking, our local system, and the potential impacts of future interventions. The CLD also aimed to position FWE elements and reveal the interconnections between them.

CLD exercises, such as malt production and spent grains. This exercise generated greater interest from our practice partners, as they could more clearly understand the value of this mapping by seeing how it measured actual resource use to reveal impact. Although we discussed converting this map into a model that would allow for measuring and monitoring, this task fell outside the scope of our research.

It is important to note that these diagrams/maps are both methods and results. As methods, they are used to better understand the context and limits of the system in which we are working. Yet they are also results of participatory processes that reveal a shared understanding in our science-society collaboration, which we then built upon for later work. As a result, one can assume some learning has taken place by all participants, as none could have produced these maps with their knowledge alone. Furthermore, they represent part of the co-production process – they are the work of many hours of discussion and dialogue, sketching on notebooks and whiteboards, reflection, revision, and 'talking through.' Here we continue to build the narrative of our Lab, as well we build the relationships through trust, familiarity, and shared experience.

Main Flows without Onsite Hydroponic Hop Production

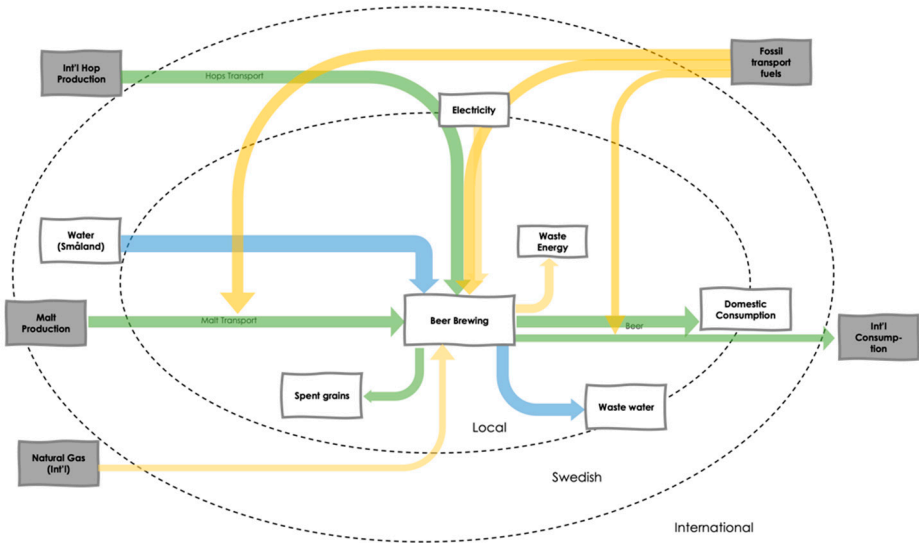


Figure 9. The original flow diagram mapping resource contributions and their general source locations for beer production.

Main FWE Flows and CLD with Onsite Hydroponic Hop Production

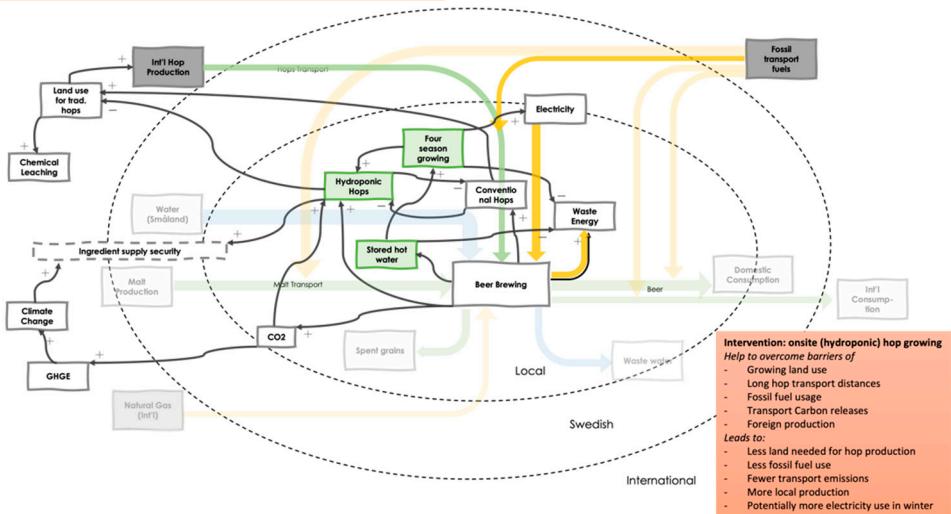


Figure 10. The flow diagram overlaid with the CLD highlighting the resource flows, their system interactions, and the potential resource impacts for the planned interventions.

Sustainability Principles

While progress on the principles experiment stopped after the web launch, the workshops did yield two important results. They formed a foundation for building relationships with a broad range of stakeholders, expanding our networks and hopefully theirs. Attendees were, among others, brewers from the region, representatives from the brewer's association, students, a journalist, other researchers, associates from a local consultancy, and a regional water supplier²⁰. We were able to gain a clearer understanding of what the stakeholders saw as important in sustainability terms – a strong focus on brewing process efficiency measures. The co-production process was meant to be as inclusive as possible and participatory – in order to create a mutuality and trust between us (academics) and the participants. We then made a bridge to our own sustainability ideas and ideals, broadening the discussions to include gender, responsibility, and community thinking. We were also able to establish ourselves in the group/network, which contributed to foundations for future work together.

Capacity building workshops

The capacity-building workshops were fruitful and led to a deeper understanding for both researchers and brewers, as reported through reflexive conversations. The visioning and backcasting exercises provided several insights, especially concerning the limited amount of time and resources that the brewers have to pursue sustainability measures that do not support their bottom lines. Additionally, there is little support from outside the business, whether from customers or the public sector, which could create a broader context where sustainability is more achievable. However, it was exciting to see that the breweries hoped to be more interactive and engaged with their local communities in 2040. Several ideas for future experimentation arose from the backcasting and visioning exercises. For researchers, the workshops highlighted the limits of change and transformation that breweries were capable of and, therefore, the need to broaden the scope of the labs and their activities, potentially shifting how and where they engage with whom to enable more systemic changes if the labs can continue. Furthermore, the conversations between brewers in Sweden and Germany seemed to create a mutuality and inspiration for brewers as they discussed their visions, hopes, ideas, and intentions.

²⁰ Representatives of Sweden's alcohol monopoly Systembolaget were invited, but declined.

Discussion

With this thesis, I am pushing into the uncertain and experimental space of how inter- and transdisciplinary interactions and collaborations might be intentionally conducted to contribute to a sustainable future. I focus on researchers as active participants and stakeholders in their research places, highlighting their conduct and capacities. This chapter discusses the research results through broad and specific reflections on the research question that guides this thesis: *How can the experimental practices and processes within sustainability-oriented labs advance transformative transdisciplinary sustainability research?* The sub-research questions regarding research design and planning, navigating collaborations, and knowledge sharing through evaluation are also addressed. The research primarily targets transdisciplinary researchers while also having some relevance for FWE nexus researchers.

I begin the discussion with reflections on a question that had plagued me and my colleagues as we conducted our labs: where is the transformation? From these considerations, I discuss implications for the researcher moving between research and practice and observer and agent. I discuss TTSR as an embodied practice in that the work relies heavily on *who* researchers are, their values and ethics, not just their skills and knowledge. I consider the implications of this research for collaborative practice, sustainability experiments, and labs, and then discuss the complexities of power in this work. I end the chapter with relevant considerations for research design for actionable knowledge and researcher development.

Where is the transformation?

This thesis has assumed that the work we are doing in TTSR is transformative, yet how are we able to suggest that is so? On one level it is obvious that there have, as yet been no system transformations due to this work. In our project, we had a running joke regarding the idea of ‘local to global’ impacts that relied on fictitious if-then multipliers to justify innovations: *If every household in Europe had one of these devices, then impacts would be high. Oh, just like that ey?* Yet, these jokes forced us to consider where exactly we were finding impact from our work – because in that context, the widespread adoption of any innovation in our ULLs was

fairly impossible. So, what then were we doing? Where would a transformation happen? What was transforming? Why are we doing this work?

Bottom-up system change can be an agonizingly slow and often frustrating process, especially in sustainability science, which is often looking generations into the future. This is in direct conflict with the nature and speed of the changes that must be undertaken to secure a thriving future for those future generations (IPCC, 2023). Kates et al. highlight the urgency with which we must problem-solve, and so there may not be time for incremental change, especially as many issues continue to worsen (Kates et al., 2012). Yet if we accept that it is a slow process, then we cannot look for what has transformed now as measures or evidence that our efforts are successful. Instead, we have small changes that we can point at, sometimes as simple as a new thought or understanding that a participant gained through the research process. But then, how can we call that transformative?

We can romanticize learning and the power of knowledge and networks to justify this research, as we often do, yet we must confront the potential that this is not very sturdy ground to inhabit. It is easy to get stuck in the space where we compare what actual change our efforts produced and the enormity of the changes necessary to move humanity onto a sustainable pathway. This is the difficulty in working in complex systems with multiple interacting scales, levels, sectors, domains, and disciplines. To be fair, it is difficult know what impact our work has or will have or where significant sustainability impact will occur (Salomaa & Juhola, 2020; Schneider et al., 2019). This uncertainty is part and parcel of our research. And while it can weigh heavy at times, it is also an exciting space to work. While no major revolutions will likely be triggered by my work, there are many ways in which we could have future impact. Could I even make it worse? Yes, I could, but I try quite hard not to.

From the experiments in our projects, I propose that looking for transformative change in society from this work is largely the wrong perspective, a mismatch of time-scales at the least. What we should be discussing is *transformative potential* (individual and collective) (Romero-Lankao et al., 2018). How has our work impacted the transformative potential of this system and/or the actors within (Wolfram et al. 2019; Withycombe-Keeler et al., 2019)? Considering TTSR in the context of transformative potential rather than actual change may have an impact on how we approach this work. There can be learning and knowledge and other perceivable changes on the local levels that transdisciplinary research normally functions. These can increase the transformative potential of the larger system it is embedded in, because there are more actors with knowledge, intention, and agency to work toward sustainability within the system (Schäpke et al., 2018). Change at higher system levels often appears much more slowly, so while some local level impacts have already happened, the larger system may respond in time or not at all (Walker et al., 2012). Meanwhile, larger system level changes and processes are also occurring, necessitating local levels to adapt or transform in response, if

necessary, which it often is not (Walker et al., 2012). For example, the Russian invasion and subsequent war has not had a large impact on my life, my PhD, or the city I live in as far as I have experienced it. Yet, there are intense global political, economic, and military implications of this ongoing conflict that are potentially rewriting global power structures and reshaping demographics across Europe and beyond (Flockhart & Korosteleva, 2022).

A transformative potential perspective, then, considers the process of transformative change as larger than the particular case study or project we might be in. This allows us to think more expansively about our work, to make connections, to consider the cooperation, coordination, and collaborative perspectives I put forth in this thesis as both activating and building potential for future transformative change. In this way, I do not position my research in competition with other change approaches, but in alliance with them. We need them all.

Furthermore, a transformative potential perspective creates a framing which gives a more purposive understanding of the individual's place in transformation processes. For example, a transformative potential framing allows space to suggest that while an individual does not necessarily trigger a transformation, they can contribute to and facilitate a transformation process. Therefore, in the following discussion sections runs an undercurrent of understanding and increasing the transformative potential of individuals and systems.

Research as practice, researcher as agent

This thesis explores several aspects of how to conduct TTSR. While deeply considering this how-to context, there was an inevitable connection to the idea of who the TTSR researcher is, and the TTSR researcher as a transformation agent. There is an easy connection made between what a TTSR researcher does and how they do it, i.e., their chosen methods and what skills and capacities they possess. If we start from a position of integrative pluralism, then, to some extent, the individual researcher must be willing and capable of engaging in the practice of integrative pluralism. This does not mean that we can assimilate into other cultures and backgrounds, or that we can change our positionality as it suits us; rather, it implies how we, as individuals, enable it as a practice. Indeed, I present the idea that TTSR is an embodied practice indicating that this work is not just external, but rather, something that we internalize and become. Reflecting on the overall research question – by placing these arguments at the beginning, I am suggesting that advancing TTSR begins with researchers themselves, which then frames their practices, processes, and research design.

Practice-knowledge co-production

Before delving into ‘embodied practice’, it is crucial to reflect on the connections between practice and knowledge. Although this research primarily presents the academic's perspective, there is certainly potential for societal actors to be researchers, as has long been the case in Participatory Action Research (McTaggart, 1991), as well as in citizen science contexts among others, which we witnessed in our ULL with several brewer participants. This thesis focuses on practice as the application of knowledge, in both research and society. Part of the foundation of transdisciplinary research is that we strive to learn and understand the collaborative application of this knowledge in practice settings. In this model, the academic is a disciplinary knowledge "expert," and the societal actors are practice knowledge "experts." Together, we produce new knowledge co-created during collaborative processes. However, the dynamics of this are not as simple. Experience in this thesis also shows that knowledge and practice are complex and intertwined aligning with work by West et al. (2019) who describe an iterative co-production relationship between knowledge and practice, as was presented in previous chapters.

This view is central to our conception of the Case Reporting Scheme (paper 4). We suggest building from the experiment and using it as a boundary setter, but also as the grounding for reporting. The experiment is a co-production of knowledge and action, and the lab is a structure for this process. The case reporting scheme is then part of the learning and reflection, documenting and sharing both the outcomes of this co-production, as well as and importantly, the processes that led to these outcomes. In a way, it is a structured narrative that shares how the knowledge \leftrightarrow practice co-production occurred in a place. We take a process focus because we are pragmatists, interested not only in what worked and what did not, but also in how activities were done, planned, and supported.

TTSR as an embodied practice

"It follows that in the face of the complexity of the systems we seek to understand and manage for sustainability, the ultimate requirement for researchers seeking to produce usable knowledge may simply be humility" (Clark et al., 2016, p. 4572).

Here I return to considering the person/s doing the practice and the idea of TTSR as an embodied practice. There is a tension that is present in this thesis between implementing the research approach and researching the research approach. If we begin with the traditional view of the scientist as the observer and then add the roles associated with transdisciplinary and co-production research - reflexive scientist, facilitator, knowledge broker, or change agent (Caniglia et al., 2023; Pohl et al., 2010; Wittmayer & Schöpke, 2014) – then what an academic must learn (and unlearn) to play these roles must be considered. I am both the observer-scientist and the participant-scientist at the same time. Yet, I would argue that this duality is part

of what a self-reflexive scientist is and does (Fazey et al., 2018; Wittmayer & Schöpke, 2014). The idea that transformative research is an embodied practice is not new, Augsburg (2014), for example, discusses becoming the transdisciplinary individual; West et al. (2020) discuss embodied experience in relational sustainability; Thambinathan & Kinsella (2021) discuss decolonization as embodying a transformative praxis; and Rigolot (2020) proposes transdisciplinarity as its own discipline and ‘way of being’. Indeed, Klein (2004) presents transdisciplinary research as a “human science”, where researchers have a “transdisciplinary attitude” and a “transdisciplinary ethos” for developing a “culture of cooperation” (p.521).

Paper 3 on reflexivity was the first foray into this for this thesis, based on the reflections of my colleague/supervisor and my experiences in the SustBeerLab where we assumed many roles. We tried to identify how and where these learning processes were happening, and it was rare that any of our reflections were not in some way connected to what we called the intra-personal, or the individual and their associated positionality, personality, and understandings. The intra-personal we found underpins the inter-personal, suggesting rather obviously that who we are strongly influences how we interact with others. Interpersonal processes have been discussed recently, e.g., Ayers and colleagues (2023) identify eight interpersonal capacities including ‘deeply value others’ and ‘persist with lightness’, linking education for sustainable development research to inner dimensions of sustainability and transformation research (Wamsler and Brink, 2018).

Collaborative processes in transformative sustainability contexts are complex and rely heavily on participants' interpersonal skills. Inclusive and plural processes involve awareness of privileges and how they impact our understanding of the world and our own positions. Self-reflexive practice is value-laden and must challenge dominant positions while including voices that are less heard (Caniglia et al., 2023). Therefore, it must be asked, not only of our approaches to TTSR but also of ourselves, whether we have a compatible personal value system with the processes we facilitate, and indeed of the values of those we collaborate with as well. Diversity, including diverse perspectives and knowledge systems, is desirable as long as it is not incommensurable. Kenter et al. (2019) suggest navigating through the tensions in diversity by "loving" the mess of value exploration in collaborations for sustainability transformations. In the SustBeerLab, the biggest source of tension between participants was the difference in sustainability values, and how values translated into business practices. Our reflections for Paper 3 highlighted this often-internal tension as we struggled to make sense of particular actions, lack of action, or perceived annoyances from our collaborators. Much of the discussion from the brewers in our network centered on efficiency as sustainable, and therefore the new practices they hoped to experiment with targeted more efficient use of resources. While efficiency is certainly better, it is better in a less-bad sense. Understandably, the success of the business remained the top priority for the brewers we worked

with, which aligns with the standard brewing industry position on sustainability as efficient use of resources. Such thinking parallels findings from paper 1 and the FWE nexus, leading to the recommendation to move past material flows and focus on the behaviors, habits, and social patterns. This efficiency focus was the topic of much debate between academics and led, in part, to a shift from our work being aware of practices to being aware of the thinking behind and beyond practices. Drawing on O'Brien and others (Caniglia et al., 2023; O'Brien, 2018; Vogel & O'Brien, 2021; Wamsler et al., 2021; West et al., 2019; 2020), we began to consider the connections between values, practices, and knowledge for sustainability-oriented labs. With this grounding, we challenged our collaborators to consider what else might sustainability mean, and what possible agency they may have or develop to make change. Important to note that the previous sentence may seem nice and neat, but it represents years of messy collaborative work, the associated interactions, and subsequent reflections.

Other scholars describe this “mess” and offer further insights into navigating through. Augsburg (2014) describes the ‘transdisciplinary individual’ through a dynamic interplay of virtues, practices, skills, and traits. Augsburg argues that transdisciplinary research is relational in that at its core are relationships for collaboration, and therefore one must be *inter alia* trans-paradigmatic, practice inter-perspectivity, and both foster and give trust, mutuality, and humility. Haider et al. (2018) describe the *undisciplinatory journey*, and propose "epistemological agility" as a desirable characteristic for recognizing and valuing epistemological and ontological differences in co-production and collaborative contexts. Chambers and colleagues describe “co-productive agility” as “the willingness and ability of diverse actors to iteratively engage in reflexive dialogues to grow shared ideas and actions that would not have been possible from the outset” (p. 102422). Caniglia et al. (2023) suggest developing *virtue ethics*, including courage to transgress disciplinary academia, a sense of justice for inclusion and equal opportunities, and agility in managing complexities, tension, and conflicts. These uses of *agile* resonates with me and this thesis. Having the openness and ability to move between, to adapt, to work with, to accept a diversity of perspectives, ideas, beliefs, values, and knowledges seems indispensable for TTSR.

Caniglia et al. (2023) further suggest that these aspects are expressed in thoughtful deliberation and skillful action. “Thoughtful deliberation relies on the capacity to reason through the many complexities of decision-making and action, so-called practical reason, by giving arguments as well as by mobilizing intuitions and emotions. Skillful action refers to the capacity to put such considerations to work in specific contexts, whether individually or collectively” (p. 7). TTSR interactions are purposive for transformation and sustainability, and therefore our actions must be intentional. Thoughtful and skillful represent this intentionality in that the complexities of managing long-term collaborations demand a bigger-picture

awareness even during the everyday management and small frustrations, especially for trust management, which is central for collaborative work for all parties.

Transformative Capacity

Transformative capacity in the context of TTSR considers the capacities of researchers to engage in this work and the many roles and processes it entails. Part of the transformative capacity is its connection to transformative agency. Agency is often seen as a capacity, but it has much to do with power, politics, economics, and culture (Avelino, 2017; Loorbach et al., 2017). If we assume that stakeholders have the agency to impact their systems, the question of whether they have the capacity to engage in or facilitate transformative processes becomes quite central. Transformation requires specific capacities that stakeholders may or may not possess or know how or when to exercise, or indeed have the agency to mobilize those capacities (Westley et al., 2013). The assumption that participants in the ULLs have agency to act and influence change has been made in this thesis, at least to some minimum. This then, assumes a variety of other things, including aspects of the positionality of participants in the research.

TTSR researchers often aim to build capacity with their societal partners. However, we must also ask if researchers have transformative capacities themselves and in what ways they build and use them in their transformative sustainability research. Paper 5 refers to capacities as transformative when employed in settings with transformative potential or the capacity, agency, and intention to transform. However, does the employment of capacities create the transformative potential or enhance it? Or conversely, do the settings of transformative sustainability research create both the potential and the building of transformative capacity?

Paper 5 concerns TTSR researchers, functioning on an assumption of a baseline agency of academics to influence their respective communities. This perhaps speaks to the potential of academics to work as transformative agents. What are the roles that academics can assume outside of the traditional ones? For those roles, what capacities and competences do they need? Research in monitoring and evaluation showed that researchers would benefit from technical, relational, and transformational competences, aligning with recommendations in this thesis (Rosenberg & Kotschy, 2020). Klenk suggests that transdisciplinary co-production research requires attuning to difference, paying attention, and grounding experience in context through story (2018), differences that we saw as brewers shared different future visions in our workshops inspiring each other to curious conversation at least.

Collaborative Practice

In previous sections, I have discussed the relationship between knowledge and action following logic by Clark et al., (2016) and West et al., (2019) that they iteratively co-produce each other. I have also argued that this is an intentional process. Therefore, the centralizing of in-time awareness of the process through reflexive activities before interactions, as preparation, and after as learning and processing are well represented in recommendations throughout the included papers. Intentional reflexivity is positioned as potentially the most important aspect of this work for several reasons, all of which are grounded in the co-production of transformative sustainability potential through action, knowledge, learning, and practical innovations. The intentionality of collaborations suggests that it is important to not leave significant aspects to chance or ‘wing it’ processes, but rather to create structure for collaborative spaces and relationships that engender trust, safety, and establish equal footing for participants as much as is possible within the socio-cultural context. This ties to the values that underpin the processes and aim for specific outcomes – and here we refer to ideals that will be discussed below, e.g., value ethics, trans-paradigmatic thinking, and plurality (Caniglia et al., 2023; Augsberg, 2014).

Approaching collaborative processes with humility is not a new idea (Jasanoff, 2003; Clark et al. 2016; Urbinatti et al., 2020), but it is important to reflect on how one develops and exercises humility. In paper 3 we suggest an intra- and inter-personal approach to collaboration, where individuals understand their positionality, personality, response tendencies, and triggers. This was born out of interactions with our partners that sometimes left us baffled, even with feelings of rejection: for example, on one occasion, years into the partnership, I was aggressively approached by a collaborator, asking what I was doing inside the brewery – a place I had been inside dozens of times by that point. I almost felt I had to reintroduce myself and our years-long collaboration (as if I was not recognized) to somehow try and justify my presence. To better process interactions like these, an awareness of personality factors and potential triggers (mine²¹ and others’), can allow individuals to better align their interpersonal approach and communication style with their goals and intentions (Turnhout et al., 2020). Transparency dialogues may reveal some positions to the lab group, and adaptations to conflict and tension can be planned individually or collaboratively.

It may be necessary, therefore, to work on the self and links to arguments around an embodied practice. It is easy to suggest that values, qualities, characteristics and practices matter and that we should have and develop these in ourselves and in collaboration. Yet, the how to achieve these is likely not straightforward for most.

²¹ Am I over-thinking (again), overly sensitive (as usual), or not confident in my role or participation (or as an academic)?

And of course, our positionality is not something that can be easily changed. My gender, class, and race did not noticeably negatively impact my research. Nor did my political leanings or those of our participants interfere with progress in the research. This is perhaps both good and bad, as tensions in these areas could have broadened learning and challenged thinking, bringing more political dimensions into the research.

Research that addresses individuals' role in sustainability transformations is growing, and suggests that transformations will likely require individuals to undergo deep change to spur collective and system change (cf. Leichenko et al., 2022; Vogel & O'Brien, 2021; Wamsler et al., 2021), including researchers that work toward sustainability transformations (Caniglia et al., 2023). Knowledge co-production and learning are not external tangible objects, yet we describe them outside of the context of the individual who has learned, who has new knowledge. I argue here that collaborations can and perhaps should facilitate change in the participants.

Advancing sustainability-oriented labs and experiments

I have examined the processes of sustainability experiments from within and without sustainability-oriented labs, as well as through participating in long-term academic international collaborations with others conducting similar labs and sustainability experiments. I also reflect on ideas surrounding debates on the change potential of labs and sustainability experiments (cf. von Wirth et al., 2019).

The design of the GLOCULL project created a lab management construct that could be a starting point for a 'global lab'. While this idea is not quite formed, the potential of coordinated labs across multiple contexts is an appealing idea. Funding constructs like the Belmont Forum, which established the call through which GLOCULL and similar projects were funded (cf. Laborgne et al., 2021), can be a starting point for exploring the potential here. The labs in GLOCULL were connected through the project and, therefore, conceptually through the ULL and FWE nexus approaches. By jointly developing methods and tools and testing them in each of the case studies, we were able to consider what might work in what contexts. However, a Global Lab would reach beyond this space and could find several points of connection or intersection, potentially using the case reporting scheme as a guide for comparison and collaborative 'global' knowledge development around specific topics, innovations, strategies, or other lines of inquiry in labs or experiments.

In this way, one aspect of amplification is superseded in a sense because the structure of multiple connected and overarching-governed labs and experiments have a transfer and share amplification built in. While there are many coordination challenges in this idea, the project itself is an example that it is possible. While the case reporting scheme is meant as an amplification tool for labs and experiments for

transfer, knowledge sharing, and comparison, in this context, it can also be a research design guide. Linking this idea with others above, a structured ‘knowledge-creating’ organization of a Global Lab can synthesize learning and knowledge from multiple contexts and generate broader hypotheses that address larger level issues (beyond the local contexts of labs and experiments).

This suggests that sustainability experiments, in themselves, are not often transformative, but require the processing capacity available in labs to turn the empirical understanding gained in the experiment into applicable learnings and knowledge in local and broader contexts. This argumentation links the transformative potential of an experiment to the amplifiability of the outcomes (Lam et al., 2020; Westley et al., 2014). Thus, experiments without the engaged stakeholder participatory networks of labs, as described above, have limited potential to amplify their outcomes or design next stage/phase experiments that might build on the experiment or test amplification strategies. These arguments assume that experiments do not have the embedded capacity to manage these processes themselves, which is an assumption, as experiments vary widely. Yet, as I argue in the thesis, the intentional space for these processes is significant, as there is already much that is ad hoc in labs and experiments (Kenter et al., 2019).

In the ideal-typical transition experiment process, experiments feed into local society (regime) and then generate subsequent, yet connected, experiments (Smith & Raven 2012). The addition of the lab removes the passive processing done in the regime and replaces it with intentional processing done in the lab, which then potentially generates subsequent experiments (as seen in the logic model in Chapter Methods).

The Global lab configuration of experiments and labs positions this original as one of many labs and experiments running in multiple locations, potentially in very different contexts (e.g. North-South or East-West), that are interacting not only with their regime, but also with the other labs that can inform non-context-bound sustainability problems – in the GLOCULL project, this was the FWE nexus both broadly and in each locality. This is not meant to criticize the transitions process, but rather to suggest that there are more ways in which labs and experiments can contribute to change processes.

This thesis provided several recommendations for the planning and conducting of sustainability-oriented labs. One of these recommendations concerns the role of coordination in labs and clusters of labs. If we consider the case reporting scheme of Paper 4 and the multitude of activities and governance processes amongst various actors with multiple and often conflicting responsibilities, then coordination can make all the difference, as was the case in GLOCULL (Cummings & Kiesler, 2007). Furthermore, when we add the recommendations from Paper 3 regarding the conduct of labs and experiments, the roles and responsibilities of the researcher can seem cumbersome. Our recommendation for an organizational champion in paper 3

is aimed at directly addressing this issue and sharing responsibility with our local partners for coordination.

The coordination aspect, more than any other, shows the value of the sustainability-oriented lab. However, the question of whether labs are important and necessary for transformative sustainability experiments arises. Colleagues and I have had this discussion several times recently, as I have recently joined a project²² designed for experimentation, but not the broader lab approach. In comparing the two approaches, the lab seems essential for creating, driving, and maintaining the purpose of the experiment and other activities. Beyond determining the planning, organization, and structure of activities, the lab is also where learning and knowledge integration occur. In fact, the lab more broadly convenes multiple and diverse actors for this very purpose, while the experiment draws those with a particular stake and interest in the experiment processes. For instance, there may be more participants in the lab than those conducting one experiment, or different participants running different experiments. The lab is a place of synthesis and coordination between participants, activities, experiments, and learnings, findings, and other outcomes. Without the lab space, we have personally experienced much more confusion, less shared understanding of larger purposes, and a more fragmented understanding and experience of the experiments.

During the research and drafting of the case reporting scheme paper, we reflected on the role and function of sustainability-oriented labs. While Urban Living Labs and experiments have been discussed as alternative forms of sustainability governance (Bulkeley et al., 2016, 2018; Bulkeley & Castán Broto, 2013; Frantzeskaki et al., 2018), our case reporting scheme is the first to distinguish between the lab and the experiment and to request documentation of the details of lab processes as separate from experiment processes. Moreover, building on the reasoning above regarding knowledge synthesis and integration, and learning, the Lab can be considered a knowledge-creating organization, as discussed by Nonaka (Nonaka, 1994; Nonaka & Toyama, 2003). If we view the lab as a knowledge-creating organization, it may provide more structure to how lab participants think about their purpose and co-create their roles and relations. Although there is no universal blueprint on how labs should be structured and organized, drawing on the overall purpose of creating knowledge, and then more specific types of knowledge, can guide the roles and relations within the lab. Nonaka suggests that organizational knowledge is created through a "continuous dialogue" between tacit and explicit knowledge, where explicit knowledge is that which can be documented and shared, and tacit knowledge is that which comes from experience and action (Nonaka, 1994). He describes a knowledge-creating organization as organic and

²² The TRANSFORM project: <https://transformcities.ca>

"conceptualized as a shared context in motion, [that] can transcend time, space, and organizational boundaries to create knowledge" (Nonaka & Toyama, 2003, p. 3).

This preliminary exploration of organizational theory has already shaped our understanding of sustainability-oriented labs. Viewing the lab as a knowledge-creating organization allows us to reposition the experiment's centrality, which has practical real-world innovations as targets. Instead, the experiment would share its purpose with intentional knowledge creation (rather than only as an emergent outcome of activities and experiments), potentially targeting specific types of knowledge, such as those supporting actions for sustainability in three dimensions as outlined by Caniglia et al. (2020): intentional design, shared agency, and contextual realization, or knowledge for guiding action-oriented transformations as outlined by Fazey and colleagues (Fazey et al., 2018). However, there is much more to consider in the future, as this is well established in organizational theory with much debate and development.

In the context of knowledge creating organizations, I will briefly reflect on the international consortium of the GLOCULL project. Most of the research conducted for this thesis took place in connection with the Urban Living Labs (ULLs) of the GLOCULL project. While it is not accurate to say that the consortium formed a "Global Lab"²³, it is possible to consider it as an overarching governance construct for the individual labs. This framing might re-consider the role of the project consortium as a space for support, inter- and transdisciplinary collaborative development, and agenda setting.

Brief reflections on the SustBeerLab

Transdisciplinary sustainability experimentation is necessarily a long process. The SustBeerLab ULL that this thesis is, in part, based began in 2017 and is still ongoing. Experimentation has progressed, but still is in the proof-of-concept phase. After six years, what differences can we see? This is a layered question. And one in which other questions are embedded, e.g.: How long does it take to embed a new practice into people or organizations – especially one that is based on values that they have only recently, through this process, came to be aware of explicitly?

In long-term collaborations, adaptability is necessary for nearly all aspects of the work. Some participants stay, others leave – and they take their learnings, knowledge, and intentions with them. Can they be replaced? In the SustBeerLab, the original partnership involved a battery factory and proposed experiments involved using their space and waste heat from their production to support an

²³ As far as I know, this is not established in sustainability research, though it does exist in e.g., the medical sciences. In our case, it is a term tossed around in our conversations regarding what is next for ULLs.

aquaculture, that would then feed hydroponic hops growing all year long. Then the battery company got new management who were uninterested. They were not replaceable. Years later, the brewery association partner basically stopped their participation. The goals and activities, the legitimacy, the network connections that they represented had to be reconceived. But this does not mean that the lab lost its purpose. It needed to adapt. And it did, with new ideas developing, and eventually added new partners exploring new directions.

Beyond the direct learning and knowledge developed in our lab and experiment, there were other ‘outcomes’ that we observed that were unexpected, potentially emergent. In Paper 3 we call these *sustainability knock-on effects*, e.g., other breweries growing interest in sustainability and experimentation, so far as to now run several on their own; or a close collaborator joining a brewer’s association and creatively pushing a sustainability agenda nationwide. Neither of these are direct or planned results from our lab or experiments. This has led us to question what the sustainability objectives of labs and experimentation are and perhaps should be. While we pursued practical innovations in hop growing, other more interesting and arguably more impactful outcomes occurred. Our interests shifted from the innovation target to a more human-centered target for where and how change will happen through the lab. This, we suspect, is where the actual transformative potential of our lab lies.

However, the amplification of these types of outcomes is less tangible. If the impact is within the participants, then different but intentional processes are needed for amplification (Vogel & O’Brien, 2021). Can and should TTSR processes influence what people do and how people are in the future? Yet, if the focus splits between innovation development and these other more personal shifts, the purpose and therefore processes of sustainability-oriented labs and the experiments and collaborations within them may also change, from practical solutions development and knowledge co-production to e.g., sustainability translators and transmitters, where through the collaborative practice people become aware of and can challenge unsustainable values with sustainable alternatives.

How does TTSR deal with power?

A key difference between TTSR and e.g., Action Research, is that Action Research is centrally emancipatory in that it aims to directly and critically address inequality, justice, and power imbalances in society (Kemmis, 2006; Kemmis et al., 2014). In TTSR, sustainability is at the center and these aspects are entangled, but not always the direct target. In this shift however, addressing these imbalances can effectively disappear from the agenda.

“Researchers seeking to craft usable knowledge need to accept the political character of their work and to be aware that their science may impinge on power structures conditioning the opportunities of various actors. This means thinking through whose interests and agendas are likely to be supported, and whose threatened, by the problems we choose to address or ignore.” (Clark et al., 2016 p. 4573).

That phrase *the problems we choose to address or ignore* lay heavily with me during the course of this thesis. Being able to choose the problems we engage in is an extremely privileged position that many academics enjoy (Sultana, 2007). In choosing the problems we address, we are exercising power. What are the opportunity costs for the research we choose to do? By these choices, are we/am I reinforcing existing power structures instead of challenging them? Necessary reflections, even if unanswerable to a large degree.

Unequal power dynamics existed within the project that was invisible to many until several early career researchers became aware of unrealized interdisciplinary collaborative potentials. With the inclusion of two global south partners in the project, the consortium had the opportunity to dig into the decolonial space, and for researchers across contexts to build diversity of understanding and approach – for training, in other words, in the individual (researchers) and collective (the consortium) capacity for pluralism. Exchange with Stellenbosch University was not explored, primarily due to time and opportunities for funding which were minimal for the South African team. Even from the beginning there was not sufficient funding for the South African team to travel to the biannual project meetings/workshops. The absence of this from leadership priorities is at best a reflection of who gets funded to do what, and at worst the continuation of centralizing and normalizing of Western and Northern research and perspectives (Chilisa, 2017).

There are also the dangers of co-optation of the lab and process by academia, due to their knowledge on certain topics, the lack of knowledge from other participants, and the perception of academics by other participants (McTaggart, 1991). In our case, there was tensions between what experiments we should run at what time: the brewers were interested in experiments that trialed improved efficiencies, while academics were interested in local ingredient production. Ultimately, the academics’ experiment was run for a variety of reasons that appeared logical to us and were fully discussed with partners, but perhaps they perceive that we co-opted the experiment process. Furthermore, time for research was a big factor, as the academics had more time to plan and contribute to activities, including the monitoring of experiments than other partners.

Yet, the closest to home so to speak display of power and politics is brought up by Mach and colleagues: “conceptualizations of co-production as intrinsically collaborative may obfuscate the role of co-production as a governance mechanism

that defines who participates and who does not, what voices matter, and how decision-making may be changed as a result,” (2020 p. 31). Going further Turnhout and colleagues suggest that the “co-production literature has not paid sufficient attention to the role of power and politics in shaping processes and outcomes” (Turnhout et al., 2020 p. 15). This is a critique that is indeed relevant to my thesis, and I must admit that beyond what I have already discussed here there was little discussion of power and politics in our case study. Perhaps because the diversity in our case was not strongly of power or societal position, but more of values and their expression in practice and business. However, in developing the case reporting scheme for paper 4, we aim to include this concern by giving space for case study participants to be transparent not just about who participated, but who did not, why, and how those conditions were determined and decided.

When considering how plurality happens or is represented in the lab, there are many factors that determine who participate. The topic can determine central stakeholders and the diversity within them. In the SustBeerLab, there was little variety in knowledge systems, though some key differences in perspective. Tension was personality and preference vs positionality and power. Yet, participation rests also on who can participate. People self-select through their ability to participate in this research to a certain degree – at least that they have the time and flexibility in their work and home lives. Was my lab a collection of the privileged-interested? Is this on some level necessary to make progress in the lab? Said in another way, how many, how different, and how contentious can knowledge systems and perspectives be and still have a functioning collaboration? While my own ULL did not reach this threshold, reports from one of our connected labs suggested that their lab collapsed because egos, control, and exploitation became prominent issues between core participants, and were insurmountable. This is perhaps part of a transdisciplinary paradox, where heterogeneity is limiting, yet necessary (Augsburg, 2014).

Does TTSR address drivers of unsustainability?

The transformative potential discussion above feels quite positive and optimistic to me. Yet, I think it pertinent to again consider how TTSR hopes to address the drivers of unsustainability. For many of my colleagues, this is perhaps a moment to address the elephant in the room: global neo-liberal capitalism. This is a difficult question to consider, yet important as I claim societal transformation. An answer for this is that I believe changing the capitalist hegemony and its associated unsustainability will take a multiple interacting change pathway approach (e.g. Leach et al. 2007). By that I recognize that unsustainability and neo-liberal capitalism are insidious and chimeric, and therefore addressing them will take a concerted approach that is as diverse as possible. TTSR is a bottom-up and people centered approach, in that it aims for emergent change through a collaborative process that also aims for

individuals to become more self-aware and intentional (Caniglia et al., 2023; Chambers et al., 2022; Klenk 2018; Mach et al., 2020). Therefore, and in line with TTSR values, work should be done on many fronts, with different tools, by different people in multiple locations combining bottom-up and top-down work in multiple theaters. A TTSR approach would suggest that these are as aligned and coordinated as possible, while recognizing that coordination is itself a significant challenge.

A more difficult answer is to say that I am not sure if this approach can directly address root causes of unsustainability. But then again, I would push back to say that I am not sure it is intended to. TTSR builds from a particular idea of how change for sustainability should happen: by building bridges, collaboration, connection, self-reflexivity, values-knowledge-action feedbacks, co-production, trust, empathy, and experimentation. In this sense, it does not directly confront or contest, rather it asks us to intentionally make space for the other, to include, to learn and think together (Gardiner, 2020). This runs contrary to many spaces that currently exist built on competition and individual achievement, including academia itself. In this way, it seeks change by shifting the ways that we are with ourselves, the ways we are with each other, and therefore the ways in which we inhabit space and co-exist²⁴. Caniglia et al. (2023) raise these ideas quite well in discussing virtue ethics as qualities, characteristics, or traits that TTSR researchers perhaps should embody. Through these processes, system level change could be facilitated, as people intentionally aim to remake systems that match their values.

This perspective however, has many and significant challenges, one being that causes and drivers of unsustainability are deeply embedded in global systems, which are more than the values and understandings of individuals, yet not unconnected. This, I argue with hope, is a coordination problem.

Designing for actionable-knowledge and researcher development

In light of the reflections and discussion presented thus far, it is fitting then to consider the implications for designing TTSR. The papers in this collection have much to say about research design, largely suggesting that coordination and collaboration should be more intentional. The need for coordination between fields to address complex sustainability problems is not new (Bennett et al., 2015; Reid et al., 2010; Volkery et al., 2006), yet it remains often unfulfilled in practice. It could be an exciting development for sustainability science if it could be practically accomplished, where e.g., quantitative nexus researchers align their work with

²⁴ 'Inhabit' and 'co-exist' are taken from a presentation at the International Transdisciplinarity Conference 2021 given by Guido Caniglia.

qualitative transdisciplinary sustainability researchers to develop evidence-based potential pathways toward action and implementation. Another potential key role of labs (Culwick et al., 2019).

Yet, collaboration is not always beneficial to researchers, as their individual fields, measures for success, and funding schemes are powerful determinants of how research happens, and the coordinating costs for navigating among these differences can be high (Cummings & Kiesler, 2007). Moreover, action-oriented novel collaborations are not proven to drive academic careers forward, especially as they can often deprioritize publications, use exploratory methods, and are often theoretically ambiguous as they move into uncharted academic territory (Caniglia et al., 2023; Haider et al., 2018). Despite these obstacles, the work in this thesis suggests that there could be heightened potential for action and solutions if even modest coordination and collaboration could be achieved by design.

Two papers in this thesis are literature reviews that draw conclusions regarding how to shape and direct research in the context of sustainability-oriented labs and the FWE nexus. In Paper 1, the focus is on coordination and interdisciplinary inclusivity. The important questions are who possesses the necessary knowledge and when is that knowledge prudent? The planning and timing of research then depends on the answers to these two questions. If the ULL aims, as our project determined, to have an impact in the FWE nexus, then an understanding of the FWE nexus needs to be gained, as well as the intended impact. For example, are you intending a governance or a use-based impact on the nexus? For either, an assessment of potential participants with the agency to affect the desired impact must be done. However, what is the FWE nexus in the local space? How is that determined? Is the local nexus actual, aspirational, or fictional? What are its boundaries? Key questions for this space include whether, how, and when to include actors in the food, water, and energy sectors, and local researchers in the FWE nexus. An eye-opening finding for me, especially in the first year of my PhD, was that the FWE nexus papers I reviewed largely intended "policy impact" for their research. However, nowhere in their research design was a policy actor included or mentioned, nor were urban or regional planners or other indications that the research was specifically targeting policy. Furthermore, there was very little in the nexus research about how to engage with nexus change, intervention, or implementation on the ground.

In the literature on the FWE nexus, coordination is emphasized as crucial because the implementation of the nexus will involve multiple sectors and interact with "power constellations and political economy issues" (Pahl-Wostl, 2019, p.357). While Papers 1 and 2 promote a solutions/action-oriented perspective that shifts the nexus from a top-down to a bottom-up approach, coordination remains crucial. The papers emphasize that coordination is a necessary challenge for research to address sustainability issues in the nexus, which can have cross-sectoral, socio-cultural,

political, and economic causes and manifestations (Allouche et al., 2015; Foran, 2015).

Lastly, I return to the potential of the case reporting scheme as a tool for considering lab research design and planning. Lab and experimental sustainability processes often rely on iterative reflexive governance, as each learning in the lab or experiment might shift the direction of inquiry (Bulkeley et al., 2018; Van Der Jagt et al., 2021). The case reporting scheme can be helpful in several ways: as a general and comprehensive guide, the guiding questions themselves can suggest aspects that need to be considered and planned. If comparability is important, relevant and interconnected elements can be pre-determined as baselines, and deeper consideration can be given to those aspects. Using the scheme iteratively as a reflection exercise can reveal shifts, biases, expectations, surprises, and obstacles that can then be integrated into future activities or actor arrangements.

However, I have not yet integrated the idea of TTSR as an embodied practice; I will turn now to consider TTSR as part of a long-term learning process within and without formal education.

Designing TTSR as a learning process

Understanding learning in TTSR could pursue questions such as: what could be gained by a process of integration of different knowledge systems to address a co-defined problem; how are the people who participated different; were they open to be influenced by the other? Scholars are moving into this space, recognizing the need for learning skills, capacities, and competences for intersectionality and decolonization (Maina-Okori et al., 2018), learning across disciplines (Ely et al., 2020), and thinking together to develop an epistemic position grounded in ‘inclusive collaboration’ and ‘emergent creativity’ (Gardiner, 2020).

This perspective also prompts a reconsideration of how to teach and train sustainability and transdisciplinary practitioners and the capacities and skills necessary to engage in this work (Ayers et al., 2023; Bergmann et al., 2021; Bernert et al., 2022; Brundiars et al., 2021; Leichenko et al., 2022; Maina-Okori et al., 2018; McGregor, 2022). Given that this work is personal and relies on interactions with others, it is important to foster empathy, care, and supported self-care among researchers. Some recent papers argue that there needs to be ongoing dialogue about care. Care et al. (2021)²⁵ argue for care which “involves the mutual recognition of an individual’s situation, active listening, the development of trust, and ongoing expressions of solidarity” (Ey et al. 2020 in Care et al. 2021, p. 1). Care in the *Careoperative* is for people and planet, and explicitly for each other as transformative sustainability researchers. They recognize that this work is difficult

²⁵ Care is not an individual but represents the Careoperative which is a collective.

and draining. Sellberg et al. (2021), similarly argue for supported self-care, where researchers in a collective support each other in the work. Interestingly, these two papers, as well as the Caniglia et al. (2023) make these suggestions reflecting on the often difficulties transdisciplinary researchers have in navigating academia: “Current dominant academic structures, cultures and metrics of success are not supporting a balanced and flourishing transdisciplinary research practice, but rather creating and exacerbating the tradeoffs between [science, society, and self]” (Sellberg et al. 2021 p. 292).

Making space for TTSR

This leads to the idea of intentionally creating space for TTSR. This builds on the purpose of the sustainability-oriented lab as a created space for transdisciplinary collaboration and experimentation. A key function of the sustainability-oriented lab is space-making, or in transitions language, niche creation or a transition arena, where a protected space is created by agreement between participating actors to actively and collaboratively pursue sustainability within a local context (Loorbach, 2010; Smith & Raven, 2012). Wittmeyer and Schöpke (2014) describe various ways different fields have described space making for their research: an agora, a communicative space, arena for dialogue, or a participatory space – which the authors categorize as *spaces for societal learning*.

However, space making is relevant beyond the lab context. Scholars from the preceding section paragraph seek an accepted space within their academic institutions that supports the way they do sustainability research, while others are asking for learning spaces where the transdisciplinary individual can be explored and competencies developed (e.g. Bernert et al., 2022; Brundiens et al., 2021). Taking this idea of a safe space and expanding it to these contexts seems crucial for progressing TTSR. In many cases, this is both figurative and literal, as the existence of physical safe spaces where people can gather, build and share ideas, or otherwise commune can be considered community capital for building resilience and sustainability (Fraude et al., 2021; Callaghan & Colton, 2008). Figuratively, intentionally making space can also be important for building understanding between perspectives or ontologies, i.e., for integrative plurality (Wamsler & Brink, 2018). In this, intentionally making space in one’s worldview for differing knowledge-value-practice systems is more than accepting that they exist; it is taking steps toward connection and understanding that are necessary to collaboratively move toward sustainability while honoring diversity. This space-making is something that I hope to explore further in future work.

Finally, I would like to turn briefly to the roles of the researcher in TTSR. I have presented TTSR roles such as change agent, facilitator, knowledge broker, project manager, and reflective scientist. In conducting the work, a researcher moves back and forth through these roles quite regularly (Wittmeyer & Schöpke 2014). But how

can we assume that an individual can manage all of this? In practice, navigating roles can become easier through experience, though this is not necessarily the case. Each role carries skills and capacities, and the reflexive awareness to know when to change roles and shift approaches. The project manager has different problem-solving approaches than a facilitator – when is each approach best; what outcomes (learning, co-production, experiment results) should be prioritized? This suggests that we will make and have made mistakes. Yet, how have we allowed for them; how can we learn from them? Here is another reason reflexivity is important in these processes, and potentially paired with transparent communication between collaborators. However, it is exactly this sort of question, on a larger level, that is the impetus for transdisciplinary experimentation: we must create a safe-to-fail space and bring novel configurations of people (with representative societal roles) together around a specific purpose/question/problem – where we collaboratively, yet with tension and disagreement, build transformative potential.

Conclusion

In this chapter I synthesize the key findings and contributions of this thesis research to the current body of knowledge on the FWE nexus and transformative transdisciplinary sustainability research. I then present potential areas of future research.

Findings and contributions

This research began by identifying specific gaps in the FWE nexus and how an ULL approach could contribute to this space. The broad idea for this overlap originated in the specific call for projects by the Belmont Forum and JPI Urban Europe. The role that grant/funding bodies play in enabling new configurations of transdisciplinary research is critical, especially as sustainability-based academia moves into a more project by project model. In my context, this is relevant in that my thesis addresses how transdisciplinary sustainability research is conducted, and by extension, the roles and capacities of the researcher.

Findings relevant to the FWE Nexus

The idea of the FWE nexus, the integrative management of key resource systems for security and sustainability, is easy to support. However, practically it is a cumbersome space to explore as these systems are large and complex, with interconnections between the resources on many levels. My findings show that: implementation of solutions and the development of actionable knowledge at local levels in the nexus is nascent; more specifically, I show that there is a dearth of methodologies in nexus research for action or solution-oriented research. While the nexus is meant to break silos, research tends to be disciplinary and predominantly quantitative. I found that therefore, the solutions developed in nexus research are often technical and do not include people who are meant to use or adopt the solutions be they households or policymakers. Meanwhile, there were very few inclusive and participatory approaches, but those few showed potential to tackle to the complexities of the nexus even at local levels.

These findings set the stage for further research, and for my contributions to developing “nexus action”. This I addressed through suggested research design and method recommendations for bottom-up and top-down research in the nexus to develop action and solution-oriented knowledge. To do this we used a literature review to consider the nexus from the 5Ws: who, what, when, why, and where. In this way, we contribute a heuristic for nexus researchers to interrogate the purpose of their research in connection with social-geographical-temporal realities. In researching both papers, the near absence of these connections revealed a clear need for transdisciplinary and participatory research approaches in the nexus, e.g., to establish credibility, salience, and legitimacy of research to local contexts.

At the same time, this work is relevant for transdisciplinary and interdisciplinary sustainability researchers working in the nexus or other disciplinary contexts. My research revealed the need not only for interdisciplinary collaboration, but also quite acutely for interdisciplinary coordination. Understanding the nexus in any local-regional context is no small task. Coordinating research between teams could be of huge benefit to sustainability research processes, yet this is not a reality in many projects. Instead, researchers continue in their silos and have little time, incentive, or funding opportunities to break them.

Findings relevant for TTSR

This thesis has several direct implications for transformative transdisciplinary sustainability research. Transformative transdisciplinary sustainability research involves not only the development of new knowledge and innovations but also the cultivation of new attitudes, capacities, values, and practices that can support sustainability transformations. This applies in and out of academia. As pragmatic, TTSR should be functional, action oriented, and move toward implementation of ‘solutions’ in society. As pluralistic, TTSR should be inclusive, should integrate knowledge systems and perspectives to co-produce knowledge. Through examining sustainability-oriented labs, this thesis contributes to how to conduct TTSR as pragmatic and pluralistic, while developing *transformative potential* in their respective systems in four key ways regarding how to: design and plan research for actionable knowledge; navigate long-term transdisciplinary collaborations; share, transfer, and compare learnings between experimentation-based case studies; and build and use the transformative capacity of researchers to better engage in these TTSR processes.

At the core of these contributions is reflexivity. While this is by no means new for transdisciplinary research, this thesis makes advances toward how to become both a reflexive and self-reflexive scientist. If we place personal and mutual learning and development as a central goal of these processes along with the innovations from experimentation, then intentional reflexivity is critical. For interactions with participants/collaborators, we found that ex-ante and ex-post reflexive time can

bring intentions and expectations in line with one's daily mood, attitude, and stressors – and can enable empathetic connections with others after tension or conflict. Furthermore, there is value in conducting reflexive activities with participants over a variety of topics and issues.

To fully realize the potential of TTSR, my thesis indicates that researchers should continue to explore new ways of working together across disciplines and sectors, while also investing in the development of the transformative capacities of both researchers and stakeholders. To support the development of transformative capacities in researchers, TTSR projects should intentionally create spaces for interdisciplinary collaboration, build reflexivity into research spaces, and allocate time and personnel for coordination. Adequate time should be available for researchers for cross-hub collaborations on international projects and for individual and group reflections on processes and outcomes, including inter-researcher conflicts. Effective and consistent coordination is also essential for building capacity in TTSR, as it enables the matching of tasks and skills with people, opens spaces for exploration and experimentation, and responds to the needs of researchers and local partners.

As argued throughout this thesis, facilitating sustainability transformations requires bottom-up processes that place people in contextually novel societal configurations with collaborative intentions. Such a transformation pathway suggests that we model the future we intend to create (inclusive, collaborative and cooperative), and through the modelling we develop the skills, capacities, awareness, and knowledge to spread learnings and expand existing configurations into other connected spaces. Ideally, people's positions are challenged, and participants have found new ways to learn from, honor, and integrate diverse perspectives and knowledge systems. Meanwhile, innovations are trialed and system interventions are developed and tested. My thesis research suggests that sustainability experimentation intentionally target both the 'soft' and the 'technical' to develop transformative potential.

Further research

Further research is necessary in several areas directly connected to this thesis research. The case reporting scheme needs broader testing and then cases should be compared in different ways to establish a stronger evidence base for the scheme's value and functionality. To do this, better ways of sharing data need be established. Currently, the scheme is being shared through networks with projects and cases considering if and how to use the scheme. This rather organic spread is quite encouraging.

The development of action-oriented research in the nexus must also proceed. Linking local or urban nexus research with complex social issues needs both quantitative and qualitative methods to progress (Albrecht et al., 2018; Allouche et al., 2018). Furthermore, the need for inter- and transdisciplinary coordination across scales and levels, as well as between sectors is crucial for nexus ‘action’ research (Pahl-Wostl, 2021).

Research is also necessary in this broader idea of space-making for TTSR. What potential spaces exist in academic institutions and educational programs? How can research or education integrate capacity development including inner qualities/capacities that go beyond the professional into experimental spaces? How are researchers gaining experience in these processes? This is both an assessment and experimental in that answering these questions are an exploration of what is possible in specific settings (e.g., classrooms, fieldwork sites, project teams). At the same time, TTSR should be employed in more contexts, coordinated if possible. The idea of a Global Lab or a lab of labs should be explored. This thesis suggests it is possible by design.

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Experimenting with sustainability transformations

The many complex challenges society faces today call for science-society, or transdisciplinary, collaborations to develop sustainable pathways forward. Yet, future pathways are uncertain and can require experimentation to determine what solution options exist and how to implement those options. This thesis explores small-scale transdisciplinary collaborations and experimentation through participation in an Urban Living Lab (ULL), which is a formalized science-society collaboration to develop and experiment with solutions to locally defined sustainability problems. The thesis includes a ULL case-study in Sweden in collaboration with six others in Europe, the United States, Brazil, and South Africa. Each Lab experiments with innovations in the local food, water, and energy nexus. By focusing on how experimentation processes unfold, they can be better designed, conducted, and navigated to produce actionable knowledge useful for implementing change for sustainability.



DARIN WAHL is an interdisciplinary and transdisciplinary scientist interested in the intersections of science and society, knowledge and action, and the dynamics of collaborative change processes. He has a background in intercultural relations, education, social-ecological resilience, climate change impacts, and disaster risk reduction.