Designing Sustainable and Resilient Cities

Small Interventions for Stronger Urban Food-Water-Energy Management

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Chapter 2

The urban living lab as an adaptive governance mechanism for the transdisciplinary Food-Water-Energy nexus

Lessons learned from six local contexts

Maryam Ghodsvali, Gamze Dane, and Bauke de Vries

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1. Introduction

As many cities worldwide try to restore the balance in trade-offs between the food, water, and energy sectors (i.e. the FWE nexus), it has gradually been discerned that, beyond the adoption of new technologies and infrastructure, changes are required in how practices and policies shift (Gorddard et al., 2016; Colloff et al., 2019). Projections prove that the upward global trend in urbanisation combined with the overall growth of the world's population could boost human demand for FWE in excess of nature's regeneration capacity. By 2030, humans will require 50% more food, 30% more water, and 50% more energy (Cairns, Wilsdon, & O'Donovan, 2017) at a rate of 100% faster than their regeneration by nature (European Commission, 2017). Human behaviour regarding resource consumption is of central importance in ecosystems' integrity and the implementation of integrated nexus solutions for the FWE sectors (Ghodsvali, Krishnamurthy, & de Vries, 2019). However, urban communities will not modify their consumption behaviour while gaps exist regarding the awareness of the severity of the issue and the role of stakeholders at human scales (Yan & Roggema, 2019).

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In response to these challenges, a new governance mechanism that shifts policies and practices towards communication, experimentation, and learning is emerging in the form of the Urban Living Lab (ULL). ULLs constitute a form of innovative governance mechanism whereby stakeholders that are in a value chain co-create ideas, plans, and service propositions and experiment with solutions to urban sustainability challenges in a real-life environment (Bulkeley et al., 2016). The co-creation process, with its reliance on iterative consultation, suggests stakeholder involvement at multiple stages throughout the FWE nexus process (Davis & Andrew, 2017). The experimentation process, consisting of various participatory approaches, establishes new forms of collaboration among stakeholders, guides urban policies, and navigates the dynamics of urban transformation (Nevens et al., 2013; Frantzeskaki et al., 2018). For cities trying to maintain an ecological balance, ULLs appeal as an open form of collective urban experimentation towards transformative improvements.

However, policymakers and other FWE nexus actors are struggling with the implementation of ULLs and are seeking guidance on their further development (de Kraker, Scholl, & van Wanroij, 2016). This operational weakness is mainly due to a lack of evidence-based guidelines concerning how a ULL can best be organised and integrated into the local governance structure of nexus-emphasised cities. This practical shortcoming calls for a critical reflection on the experience of FWE nexus projects in implementing ULLs, to help guide others towards an effective route into collaborative innovations that meet local socio-ecological challenges.

This study aims to frame the understanding of how ULLs are being operationalised in urban governance for the nexus linking food, water, and energy in cities. After a thorough review of the literature on the characteristics of ULLs and their recent contribution to the transdisciplinary FWE nexus (section 2), we selected six local case studies of nexus ULLs for further analysis (sub-section 3.1). The empirical cases are part of an ongoing FWE-nexus ULL project called Climate Resilient Urban Nexus CHoices (CRUNCH), which aims to create an interconnected knowledge platform in support of the increasing challenges of food, water, and energy management. The selection of multiple case studies is supposed to broaden the potential rigor of the study by improving the validity and robustness of the results (Yin, 2009). We assessed key operational characteristics of the selected ULLs and the likelihood of advancing their performance in terms of the transdisciplinary FWE nexus. Our findings lay down guiding principles for the development of ULLs for the practical challenges of the transdisciplinary FWE nexus (sub-section 3.2 and section 4).

2. The ULL through the lens of the transdisciplinary FWE nexus

The essence of the transdisciplinary FWE nexus is about building capacity to inclusively gain more from less, in the context of the natural food, water, and energy sectors (Scott, Kurian, & Wescoat, 2015; Ghodsvali, Krishnamurthy, & de Vries, 2019). Acting upon this concept requires *cooperative interactions*, *localised interventions*, a *resilient alliance*, *efficient resolutions*, and *adaptive capacity* (Ghodsvali, Krishnamurthy, & de Vries, 2019). The ULL approach is a way to put these theoretical propositions into practice (Baccarne et al., 2016; Ghodsvali, Dane, & de Vries, 2022).

From the transdisciplinary FWE nexus perspective, ULLs perform beyond simply promoting learning and innovation. They undergo a structured process in which a wide range of nexus actors (i.e. civil society, academia, government, and industry), through implementing a combination of diverse participatory methodologies (e.g. co-creation workshops and focus groups), give shape to socio-ecological interventions and govern development resolutions in real time (Bulkeley et al., 2016; Ghodsvali, Dane, & de Vries, 2022).

Empirical research on the transdisciplinary FWE nexus underlined four key peculiarities shared by ULLs (see, e.g., Almirall, Lee, & Wareham, 2012; Mulder, 2012; Nesti, 2017). First, ULLs are founded on a network of relationships among their *actors and users* inspired by the quintuple helix model – i.e. collective interaction and exchange of knowledge between the political system, civil society, the natural environment, the economic system, and the education system (Carayannis, Barth, & Campbell, 2012). Along with the transdisciplinary nature of nexus practices, ULLs forge an effective public-private-people partnership, placing people at the very centre of the innovation process (Molinari, 2011). This relational structure in turn facilitates *cooperative interactions* as part of the transdisciplinary nexus requirements through which different actors, organisations, and ecosystems are able to collaborate.

Second, ULLs enable the adoption of *co-creation approaches* for socio-ecological problems that are designed, prototyped, evaluated, and refined with participants in real-world settings (Pierson & Lievens, 2005). Through comprising of co-creation, a form of collaborative innovation, ULLs represent a remarkable shift from passive user engagement to a more active approach based on the dominant paradigm of iterative consultation and participatory knowledge production. They develop a knowledge-driven society, thereby potentially leveraging the knowledge circulating in the urban environment (Baccarne et al., 2016; Cardullo, Kitchin, & Di Feliciantonio, 2018). From the transdisciplinary FWE nexus perspective, the ULL approach, including experimentation and learning, explores the possibility of directing societal behaviour change and optimising the overall ecological impact of a ULL's development (Davis & Andrew, 2017; Lund, 2018). More specifically, it contributes towards the requirement of the transdisciplinary FWE nexus to characterise paradigms of *localised interventions* based on the collaborative knowledge of society.

Third, at the core of ULLs lies the concept of collective responsibility, from which stakeholders can form the basis for a concerted *governance structure* (Halbe et al., 2015; Voytenko et al., 2016). The basic idea is that instead of delegating responsibilities to specific stakeholders, such as politicians or certain businesses, ULLs make an effort to remain inclusive to all different stakeholders and to foster joint innovations (Chesbrough, 2003; Nesti, 2018). Within ULLs, participants are encouraged to brainstorm and discuss ideas for which the operational knowledge is diffused across society, and in turn practical solutions to FWE nexus challenges are offered by governments, scholars, and industrial coordinators together with communities. Hence a *resilient alliance*, in terms of concerted action across multiple actors (i.e. the FWE nexus quintuple helix system), is promoted through a continuous process of knowledge diffusion and the division of responsibilities. This concept of a coordination role is significant for a ULL to be effective within the transdisciplinary FWE nexus process, since it underpins the ability of ULLs to build the *adaptive capacity* of the nexus social system to meet mutual challenges. It facilitates explicit learning among nexus participants and allows for the refinement of developmental visions and how to better align them with the needs of the end-users (Voytenko et al., 2016).

Fourth, ULLs are characterised by their concern for *socio-technical system design* utilising Information and Communication Technologies (ICT) (Nesti, 2017). Active collaboration with citizens often necessitates generating new content, instant sharing with others, and testing the outcomes of decisions. ICT provides great opportunities for active collaboration, since it enables interactions at all times with lower costs of connection, and facilitates the transformation of thorough knowledge (Meijer, 2012). Communities utilising ICT for inclusive and active collaborations benefit from empowerment and social progress. From a transdisciplinary FWE nexus perspective, ICT infrastructure supports ULLs with social progress through enabling mutual interactions, a continuous exchange of knowledge, and the transformation of expert knowledge into information that is comprehensible to all participants. This interlinked socio-technical systems design in turn particularly contributes to the nexus' goal for an *efficient resolution* of socio-ecological transformations which meet environmental changes with social progress.

Notwithstanding commonalities, there are apparent differences in the way that ULLs have been implemented in the practice of the transdisciplinary FWE nexus. The urban contexts of FWE nexus practices vary in their social, institutional, and environmental aspects, and the ULL approach is implemented differently in accordance with this (Ghodsvali, Krishnamurthy, & de Vries, 2019). Transdisciplinary FWE nexus practices need to modify the ULL approach with regard to context-based specifications and complexities. Research often depicts practical experiences as versatile guidelines which development operations can learn from and, if applicable, can adapt. Hence cities need to obtain adequate evidence in order to draw up operational guidelines for adopting the ULL approach in the context of the transdisciplinary FWE nexus.

This study aimed to collect sufficient evidence of the use of ULLs in transdisciplinary FWE nexus actions across the world, in order to provide cities with empirical knowledge and operational guidelines. In doing so, we first developed a framework of the key components of a ULL for operationalising the transdisciplinary FWE nexus (sub-section 2.1). The components are derived from the above-described peculiarities shared by ULLs in the practice of the transdisciplinary FWE nexus (i.e. actors and users, co-creation approaches, governance structure, and socio-technical system design). The framework developed proposes relevant variables through which cities can characterise, appraise, and test a ULL's performance in terms of the transdisciplinary FWE nexus. Next, in order to draw out further nexus developments on practical experiences, this study investigated the performance of six nexus ULLs citing the proposed framework. The understanding of various ways through which nexus ULLs are implemented in different socio-political contexts with varying ecological complexities can guide cities towards an adaptive governance mechanism for more inclusive environmental management protocols.

2.1. Key operational components for employing ULLs in the transdisciplinary FWE nexus

This sub-section addresses the defining characteristics of the ULL approach in operationalising the transdisciplinary FWE nexus. Drawing conclusions from the insights from theoretical and empirical research (section 2), four key operational components for implementing the ULL approach in the transdisciplinary FWE nexus can be identified: actors and users, co-creation approaches, governance structure, and socio-technical system design (Figure 2.1). Each of these is comprehensively explored below.

- **Actors and users** provide the ULL's community with their specific wealth of knowledge and expertise, assisting in boundary-spanning knowledge transfer results (Bergvall-Kåreborn et al., 2009). The actors, whose participation in a nexus ULL's activities is required, are at a minimum: end-users of the FWE sectors; in many cases citizens, knowledge institutes, private actors (e.g. companies, industry, and businesses), and public actors (e.g. governments and public organisations). These actors, in addition to their need for active and continuous participation in ULL activities, need to have the power to influence the process (Prahalad & Ramaswamy, 2004). The balance of power among all ULL actors enables their active partnership in innovations and development.
- **Co-creation approaches** represent methodologies and tools aimed at experimentation and learning (e.g. workshops, design thinking, and group discussions) that emerge as best practices within a ULL's processes (Mulder, 2012). To qualify as co-creation, a transdisciplinary FWE nexus process that is highly dependent on stakeholder engagement needs the targeted actors and users of the ULL to be involved in all sorts of development phases and activities. In addition to being asked for their opinions, actors within nexus ULLs should have power in decision-making processes (Steen & van Bueren, 2017). The development mechanism of ULLs is iterative, which implies that after being created and designed the prototypes of solutions to FWE nexus challenges are validated and tested by stakeholders. The evaluation and refinement gathered from these phases are employed in further developments and improvements.
- The **governance structure** stands for a collaboration setting that handles the way in which ULLs are organised on different operational or strategic levels in their FWE nexus activities (Molinari & Schumacher, 2011). The strategic level addresses several issues, such as the way in which ULL actors and users are involved concerning their responsibility and influence, the ownership of the ULL, and the way in which the management structure handles the delicate balance between leading and controlling. The operational level comprises aspects such as a road map to empirical practices, progress monitoring, and the way that

development strategies are validated and refined. It is crucial for nexus ULLs that ultimate responsibility for decisions and strategies lies with all of its actors. For this to happen, governance models and the allocation of resources are of vital importance.

- Finally, the **socio-technical system design** component outlines the role of technology in facilitating new ways of co-creating innovations among ULL actors. A ULL is a context-based experience which is complicated to replicate in exactly the same way elsewhere. A combination of the ICT-based collaborative context, open innovation platforms, user-centred development methods, and public-private-people partnerships proposes potentially transformational effects on socio-ecological systems (Molinari, 2011).

The framework developed not only signifies the most crucial components of a ULL in operationalising the transdisciplinary FWE nexus but also enables the determining of bridges between existing nexus ULLs. The multiplicity of aspects explained by this framework drives the design and development of future nexus ULLs to learn from each other, benchmark the validation of actors' attitudes, adopt best practices, and interconnect similar ULLs in environment and approach.

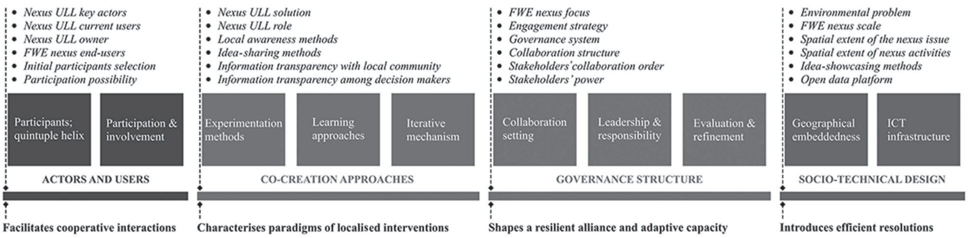


Figure 2.1: The assessment framework for defining characteristics of Urban Living Labs (ULLs) in operationalising the transdisciplinary Food-Water-Energy (FWE) nexus

Actors and users, co-creation approaches, governance structure, and socio-technical system design are the four key components that significantly contribute to practical innovations in the transdisciplinary FWE nexus. Each component, relying on multiple factors (coloured text boxes), contributes towards a specific requirement for operationalising the transdisciplinary FWE nexus concept in a real-life environment (linked via dashed lines). Nexus ULLs foster social, administrative, and technological innovations through supporting community-focused/led participation, running various sorts of experimental and learning methods, governing active involvements and shared responsibilities, and identifying a distinct spatial form of governance associated with desired digital platforms that support nexus ULL activities. This framework offers a set of categorical variables (bullet points) based on an online survey that was conducted for the assessment of the characteristics of the selected ULLs in this study.

Source: Adapted from Molinari (2011); Nevens et al. (2013); Baccarne et al. (2016); Voytenko et al. (2016); Steen & Van Bueren (2017); Chronéer, Ståhlbröst, & Habibipour (2019); Ghodsvali, Krishnamurthy, & de Vries (2019).

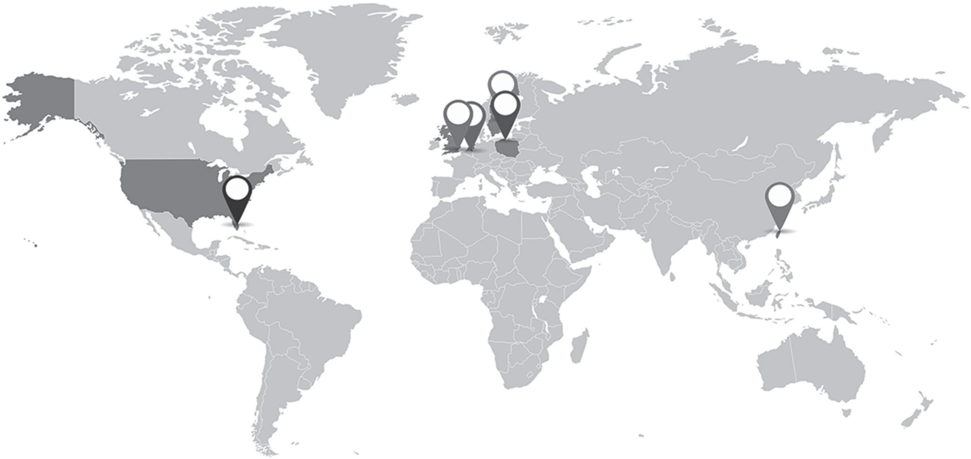
Hence, a real-life-practices assessment was conducted for a set of selected FWE nexus ULLs investigating the components defined in Figure 2.1. (Given that this study, due to time and resources availability limitation, involved a small number of ULL actors for data collection, the framework should also be further validated on a larger scale.)

3. ULLs in the practice of the transdisciplinary FWE nexus: insights from six local experiences

3.1. Case selection and research methods

This research employed a qualitative multiple case-study method to obtain empirical evidence of six nexus-emphasised cities, namely Miami Beach, USA; Southend-on-Sea, UK; Eindhoven region, the Netherlands; Gdańsk, Poland; Uppsala, Sweden; and Taipei, Taiwan, for organising and integrating the ULL approach into their local governance structure. The case selection criteria required that the ULLs must have links to the FWE nexus, innovate in a real-life environment, engage multiple stakeholders including people, and emphasise the role of actors and users in innovation. Moreover, the chosen cases reflect the diversity in FWE nexus ULLs, as they were driven by diverse types of actors. Figure 2.2 presents an overview of the cases in general.

It can be seen from the data in Figure 2.2 that many variations on FWE nexus themes can be put into practice. Carbon neutrality and circularity are instances of the studied nexus ULLs themes linked to the concept of the transdisciplinary FWE nexus. Developing a carbon-neutral city, on closer inspection of the Miami Beach nexus ULL, refers to nature-based, coastal blue-green infrastructures that support a mix of renewable energy-harnessing and storage systems, organic food waste for biomass, hydroponics, and wastewater treatment strategies. Moreover, the circularity in Brainport Smart District (BSD) in Helmond – i.e. the Eindhoven region ULL – will be realised in conjunction with collaboration between humans and nature and its resources combined with existing and future technology. In BSD, smart technologies for mobility, a strong social foundation, and clean energy generation (organic urban agriculture, and a circular water system for becoming hydrologically neutral) are the means to support circularity and, in turn, the transdisciplinary FWE nexus.



Urban Living Lab	Geographical location	Main theme	Operational scale	Running time
Miami	Miami, USA	Carbon neutrality	City level	2017 – present
Southend High Street	Southend-on-Sea, UK	Green infrastructure	Street level	2018 – present
Brainport Smart District	Eindhoven, the Netherlands	Circularity	District level	2018 – present
Olivia Business Centre	Gdańsk, Poland	Local microclimate	Building level	2010 – present
Rosendal	Uppsala, Sweden	Socio-eco-techno integration	District level	2016 – present
Fudeken Envi. Restoration Park	Taipei, Taiwan	Ecosystems integrity	Neighbourhood level	2016 – present

Figure 2.2: An overview of the selected ULLs operating in the practice of the transdisciplinary FWE nexus process

Data collection

Research data on the characteristics of the selected nexus ULLs were collected through an online survey and an in-person focus group discussion. Thirty stakeholders in the case studies, including governmental authorities, scholars, industrial coordinators, technical specialists, and users provided research information. Participant selection was based on the purposive sampling technique in order to reliably characterise and criticise the selected nexus ULLs from the perspective of their key, well-informed actors. To ensure confidentiality, the identities of participants have been withheld. During the data collection, the participants were first asked to complete an online survey (Appendix A: Table A.1) and then to participate in a face-to-face focus group discussion.

Through the online survey, we explored the association between the actors which a nexus ULL may involve, mechanisms that best support their interactions, and the technical infrastructure that may facilitate a consensus of opinions on nexus solutions. Multiple categorical variables, following the proposed framework (Figure 2.1), formed survey questions encompassing 25 scaling and multiple-choice questions. The contribution of the research participants to the survey resulted in a set of qualitative data.

Through the face-to-face focus group discussion, we linked the likely challenges of practical nexus experiences to the variant ULL approaches and environments across the case studies. In the face-to-face group discussion, the research participants were first asked to define the core problem that their ULL faces in implementing the transdisciplinary FWE nexus in practice, and then to elaborate on the immediate and secondary causes and effects of the problem raised. This manner of issue mapping – i.e. problem tree – guides the activities for the effective development of the nexus ULLs concerning context specifications and the available capabilities of the political, social, ecological, economic, and education systems. Afterwards, the qualitative data collected were cross-checked with the participants to verify the key findings.

Data analysis

For analysing the data collected, this study followed a multi-phased, analytical process, including Multiple Correspondence Analysis (MCA) for the survey data, and the Logical Framework Approach (LFA) for the group discussion data.

MCA is a multivariate statistical technique designed to explore underlying structures in a categorical dataset and is a particularly useful method for dealing with survey data (Abdi & Valentin, 2007). The general strategy of MCA is to look for the principal dimension explaining the variability of individuals (i.e. survey respondents), and to closely examine the links between variables (i.e. categorical variables forming the survey questions, see Figure 2.1). Given that the data collected for this research is categorical, and we aim to analyse it for discovering variabilities of the selected nexus ULLs, the MCA technique should prove useful to this research. Having J variables (i.e. the categorical variables that form our survey questions) each comprising of K categories (i.e. the response options to the questions), and I individuals (i.e. the 30 survey respondents in this study), MCA generates a Complete Disjunctive Table (CDT). The CDT represents individuals as rows and categories as columns, with binary values illustrating whether each category belongs to each individual or not (Zárraga & Goitisolo, 2011). Relying on the CDT, MCA creates a low-dimensional point cloud to explore relations between individuals and categories. The MCA dimensions separate individuals based on the categories that differentiate them extremely from the average. MCA uses the frequency distribution to distribute all of the categories across each of the computed dimensions, with categories with the lowest distance being considered those with the highest degree of similarity in the corresponding dimension (Rodriguez-Sabate et al., 2017). In MCA, the individuals are located in a *K-J* dimensional space, which gets bigger and bigger as the number of categories per variable increases. Therefore, even if the variables are firmly linked, the maximal percentage of inertia there can be in a given dimension (i.e. the percentage of each dimension's contribution towards defining the main subject of the analysis) is $J/(K\text{-}J)*100$, which for this study is 14%. Based on the inertia value and Cronbach's alpha greater than 0.7, a measure of dimensions' reliability (Field, 2013), this study extracted the first two MCA dimensions yielding a total variance of 13.5% to interpret the results (see Appendix A: Table A.2). Interpreting the MCA point cloud, individuals with a significant number of categories in common are located close to the origin of the point cloud, and those of which have rare common categories are located at the periphery of the point cloud. This interpretation applies to the categories as well. Rare categories are located away from the point cloud origin. Accordingly, the MCA technique enables the detection of relationships among the ULLs' actors, approaches, governance structures, and socio-technical design factors. Subsequently, the MCA result investigates the possibilities of adopting the ULL approach and the best way in which it can be organised for the transdisciplinary FWE nexus. In this study, the MCA method was performed using the "FactoMineR" package R.

LFA is a systematic and participatory technique of mapping out core problems, as well as their contributing causes-effects and means-ends relationships. This technique supports ULL actors to set clear and achievable goals, and strategies for the best ways to attain them. An open brainstorming session is the first step in employing this participatory technique. In consultation with participants, employing visual methods, namely flipcharts or colour cards, a core problem and a hierarchy of its immediate and secondary causes and effects (i.e. the problem tree) are established. These arrangements can be useful in building a community's awareness of a nexus problem, the way that they contribute to the problem, and how the problem affects their living conditions. The second step is to reformulate the negative situations of the problem tree into positive solutions, presenting means-ends relationships (i.e. the objective tree). It is of central importance that all ULL actors are involved in the discussions, giving their feedback. The objective tree created provides an outline of the desired future situation, including effective means by which ends can be achieved. After creating the desired future situation, the third step is to form possible interventions. This step requires a balance to deal with different stakeholder interests. Through a group discussion session, this research analysed six problem trees, each created by representative actors of the selected nexus ULLs. Subsequently, it developed a Logical Framework Matrix (LFM) as the main result of the LFA technique for possible operational guidelines for the nexus ULLs.

3.2. Current status of the CRUNCH ULLs in operationalising the transdisciplinary FWE nexus

This research aims at obtaining two main pieces of information about the nexus ULLs examined: 1) the defining operational characteristics of a FWE nexus ULL, and 2) the likelihood of advanced implementation levels of the transdisciplinary FWE nexus employing the ULL approach.

3.2.1. The defining operational characteristics of the FWE nexus ULL

The MCA determined the defining characteristics upon which the nexus ULL approach has been employed in the different studied socio-ecological contexts. From the MCA dimensions obtained, there were clear differentiating values among the FWE nexus cases studied in employing the ULL approach (Appendix A: Table A.2 and Figure 2.3). The variables stakeholder power, idea-showcasing methods, and local awareness methods, which presented similar discrimination measures in both dimensions, contribute significantly to the variant performance of the selected nexus ULLs.

On closer inspection of the power balance among the stakeholders of the nexus ULLs studied, there are various kinds of operational commonality. A top-down governance system enabling collaboration among key nexus stakeholders is the defining operational commonality across the studied nexus ULLs (Figure 2.3, A). In Taipei, local government, in cooperation with academics, has significant power over the decisions that affect nexus-related actions in Futekeng Rehabilitation Park (FRP). Likewise, the Olivia Business Centre (OBC) ULL in Poland operates under the great power of the municipality and academics. In both the FRP and OBC

ULLs, the ultimate responsibility for nexus-based decisions lies with the public actors. People and local communities are solely considered as end-users of services that the ULL sites offer and are not automatically involved in the process of the ULL's development.

In comparison, BSD ULL of Helmond, Eindhoven region and Uppsala were the more promising of the six nexus ULLs in terms of a public-private-people partnership. The BSD ULL in Helmond, Eindhoven region and the Södra District (SD) ULL in Uppsala possess various characteristics of an effective FWE nexus ULL working towards transdisciplinarity. Although they have different approaches in co-creating the scope of the nexus ULL and setting up the technical communication infrastructure, their main merit is the level of openness for cooperative interactions. By broadening the collaboration to the entire community (who are either directly or indirectly influenced by nexus-related problems, decisions, and development plans), the BSD and SD ULLs ascertained how transdisciplinarity boosts the effectiveness of FWE nexus practices. They both engage stakeholders from multiple disciplines, though by adopting different techniques and infrastructure. Opting for an ad-hoc infrastructure, as in BSD, stakeholders feel less restricted in testing out innovations that are linked to the thematic focus of the ULL. It is of vital importance that new ideas and solutions can be created and shared amongst every stakeholder when joining the ULL initiative. If SD had a mixed set of experimentation and learning tools, the possibility for seizing new opportunities for innovative ideas would have been higher.

Despite all the nexus ULLs studied having various commonalities in practice, Miami and Southend-on-Sea formed a distinct group. This difference may be due to the missing links in their value chains and the unequal contribution of stakeholders. For instance, the Southend Central Highstreet (SCH) ULL in Southend-on-Sea focused on green infrastructure though there was no thematic expert involved in executive decisions. This gap brought about missed opportunities for building more innovative services in that domain. A good variety of stakeholders is what Southend-on-Sea missed while setting up its nexus ULL. Regarding Miami Beach (MB), a clear narrowed-down thematic focus will lead to complementary motives for collaboration within the ULL, which, in turn, will benefit the community aspect and creation of new partnerships. Carbon neutrality includes various thematic focuses (e.g. renewable energy, hydroponics, wastewater treatment) that perform more accurately and comprehensively at the micro level.

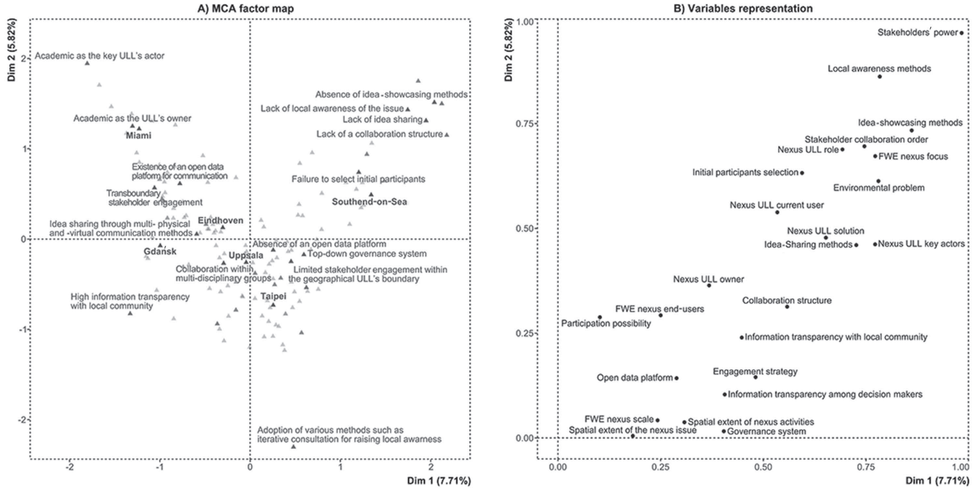


Figure 2.3: Multiple Correspondence Analysis (MCA) plots showing A) how differently the ULLs studied operate in terms of the transdisciplinary FWE nexus, and B) what variables significantly contribute towards the effective operation of the transdisciplinary FWE nexus across the nexus ULLs examined

In plot (A), red triangles, along with their descriptive statements, represent MCA categories with the largest contribution in characterising the ULLs examined, which are visualised in green. The distance between two triangles shows how different or similar they are. The closer the categories are located to each other, the more similar their categorisation pattern. The centre of the plot represents the average characteristics of the nexus ULLs examined. Unique categorisation patterns result in a triangle's location being further away from the centre. Therefore, categories that are located close to the centre represent the most common characteristics of the nexus ULLs studied. Plot (B) illustrates MCA variables (given in Figure 2.1) along the two extracted principal dimensions. The further a variable is placed from the centre point of the plot, the greater the contribution it has for understanding the distinguishing characteristics of the nexus ULLs studied.

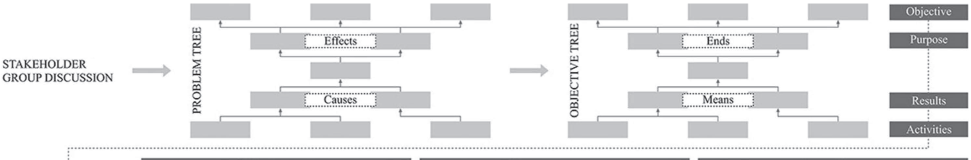
The balance of stakeholder power and responsibilities is what the nexus ULLs studied should emphasise most while developing their FWE nexus strategies (Figure 2.3, B), although each should consider other conditions that need to exist for advanced performance (see sub-section 3.2.2 and Figure 2.4).

3.2.2. The likelihood of advancing the FWE nexus ULL implementation

The LFA, based on the structures of the problem and objective trees, identified logical linkages between the strategic intent of the ULLs studied for operationalising the transdisciplinary FWE nexus and the prerequisite activities and conditions for such development. The findings from the group discussion session (i.e. problem trees, see Appendix B: Figure B.1), identifying negative aspects of the current nexus ULL situations, established positive achievements that can contribute towards eliminating the problems which were subsequently used for the projects' strategy description in the Logical Framework Matrix (LFM). The LFM contains three items of information in this research: *project strategies* elaborating the strategic intent and alignment of each nexus ULL project, *success measures* appraising the performance and signs of the nexus ULL projects' improvement, and *assumptions* highlighting potential risks to functional prerequisites. Figure 2.4 provides the sequential steps leading to the LFM development, which describes activities to be undertaken in order to reduce the impacts of barriers to the transdisciplinary FWE nexus through the ULL approach.

The structures of the problem trees show how the barriers identified impact the realisation of transdisciplinarity in FWE nexus projects. Lack of community capacity and governance practices have directly affected people's inability to participate in FWE nexus projects. In addition, a lack of professional and technical competence in transdisciplinary engagement and the absence of adequate security caused the affected people to be unwilling to participate. Furthermore, scientific and technical knowledge issues limit the opportunity for nexus end-users and other indirectly affected people to participate in the development of the project, since the nexus ULLs have been mostly founded on thorough expertise and ICT-based communication infrastructure. Therefore, inability, unwillingness, and a limited opportunity to participate can be considered as the main reasons for the lack of community participation in FWE nexus ULLs, and accordingly, the failure of the transdisciplinarity perspective.

Following the establishment of a means-ends relationship among a nexus ULL's objectives, it becomes clear that to realise the transdisciplinary FWE nexus in practice, the affected community needs to be enabled to participate. For this to happen, the structure of the nexus community needs to be re-established, community ownership of the ULL ownership should be encouraged, and management for transition support, as well as social accountability opportunities, must be provided. From our findings, a multimodal communication platform, relying on a common language supporting real-time collaboration in both physical and virtual spheres, is the potential benefit of the ULL approach for FWE nexus practices, in order to overcome a disconnection between the general public and the concerns of politicians.



	Project strategy	Success measure	Assumptions
Objective	Bottom-up governance	Power equity among stakeholders	
Purpose	Iterative stakeholder interaction	Number of physical/virtual group discussions	A sense of joint ownership among local actors
Results	Local awareness	Voluntary participation rate	Communities' desire to boost ecological recovery
Activities	Provision of open source information	Availability of an open data platform	Sufficient knowledge of actors to use the platform
Objective	Strong governance structure	Continuity of multidisciplinary consensus	
Purpose	Innovative resource-efficient intervention	Approval of ecological optimisation rules	Concerted effort to avoid overlaps and conflicts
Results	Responsibilities distribution	Equality of stakeholder responsibility and power	Appropriate context for consensus and cooperation
Activities	Institutional capacity development	A well-articulated mandate for management	Sufficient human, financial, and time resources
Objective	Convergent cross-sectoral policies	The ratio of cross- to solo- sectoral policies	
Purpose	Sense of ownership and responsibility	The ratio of active actors to all stakeholders	Iterative co-creation with all stakeholders
Results	Clarity of thoughts and vision	Continuation of idea-sharing sessions	A sense of belonging and acceptance
Activities	Mutli-physical and-virtual communication	Availability of an ICT-based platform	Basic knowledge of actors to use the platform
Objective	An open governance structure	Voluntary participation rate	
Purpose	Reduction of long-term mistrust costs	Continuity of multidisciplinary consensus	High stakeholder interest and power
Results	Inclusive and constant collaboration	The ratio of active actors to all stakeholders	A sense of belonging, acceptance, and trust
Activities	Real-time collaborative technologies	Availability of an ICT-based platform	Communities' desire to collaborate
Objective	Resource efficiency	Economic values as health expenditures	
Purpose	Interconnected socio-ecological system	Balance of resource supply and demand	Adherence to regulations and decisions
Results	New innovative regulations on ecological recovery	Individual's investment (time) in nature	Concerted effort to avoid overlaps and conflicts
Activities	Consensus on ecological-recovery protocols	Presence of internal collective choice rules	Commitment of community to ecological recovery
Objective	Strong governance structure	Continuity of multidisciplinary consensus	
Purpose	Mutual public-private-people trust	Voluntary (citizens) participation rate	Stability of social accountability policies
Results	Policy alignment with end-user needs	End-users' satisfaction with nexus practices	Unbiased implementation of nexus policies
Activities	Citizen involvement in FWE nexus activities	The ratio of active actors to all stakeholders	Transparency and openness in local governance

Figure 2.4: The Logical Framework Matrix (LFM) of the CRUNCH nexus ULLs

LFM is the placement of activities into an ordered hierarchy of purposes and results, systematically culminating in the principal objective each project has. "Activities" refers to tasks and resources that along with the existence of some other conditions (i.e. "assumptions") bring about some noticeable "results". The "results", referring to potential deliverables of activities along with associated assumptions, lead to the project "purpose". The project "purpose", referring to expected project changes along with the existence of some other conditions, fulfils the project's "Objective". In general, the objective, purpose, result, and activities target the strategic intent of the project and answer the question of *what the project is trying to accomplish and how*. This matrix gives the nexus ULLs coherence across the various aspects of their main problem at hand and serves as a guideline for a nexus ULL's governance structure and activities. The logical framework analysis has been done for all of the six selected nexus ULLs in this study, distinguished by coloured outlines in the matrix. The colours are assigned to the case studies as in Figure 2.1. The LFM presented was developed based on the defining characteristics of the nexus ULLs presented in Figure 2.1 and Figure 2.2 and on the problem trees that were developed (see Appendix B: Figure B.1).

4. Knowledge requirements for implementing transdisciplinary FWE nexus ULLs

FWE nexus stakeholders require a platform and structure to communicate, negotiate, and integrate their perspectives. Such a structure is complicated to develop and manage, since the FWE nexus challenges extend over multiple scales and dimensions. The ecological dimension of the FWE nexus is closely interwoven with the social, political, and economic dimensions. Consequently, FWE nexus projects are surrounded by various uncertainties and involve several interdependent stakeholders, often with diverging interests and perspectives on the actual nature of the problem as well as on possible ways to solve it. To acquire knowledge relevant to the management of such complex challenges, scientists need a structure of integrated approaches that involves multiple perspectives and various types of expertise (de Kraker, Kroeze, & Kirschner, 2011). Participatory modelling in nexus ULL applications is a structured process conducted with stakeholders to evaluate the social, ecological, and economic dimensions of the complex FWE nexus problem and the impacts of policy choices.

Investigations into the role of ICT-based participatory modelling methods and tools suggest that they are advantageous for the multiplicity of spatial and temporal scales of environmental challenges, the complexity of interactions between the social and ecological systems, and the uncertainties around stakeholders' understanding of the system and its related challenges (de Kraker, Kroeze, & Kirschner, 2011). A higher degree of local stakeholder involvement in the development of participatory models can raise the effectiveness of the process in the form of transdisciplinary tools, although this is resource- and time- intensive, and complicated to scale up.

A range of factors are of vital importance in identifying actionable policy options and instruments for engaging the transdisciplinary FWE nexus concept, ULL approach, and computer-supported participatory platform. Regarding the strategy for such engagement in the socio-ecological transition, the nexus ULLs examined in this research have experienced multiple obstacles, including lack of transparency and complexity of participatory tools, which often made direct stakeholder interactions impossible, with a low degree of user-friendliness and a lack of support for aligning feasible policy options with stakeholders' interests (either spatially or temporally) (Figure 2.3). To surmount these obstacles, the use of participatory-supported models should be made using innovative geographical, semi-quantitative methods and tools that translate conceptual models to stakeholder perspectives and to simulation models. In addition, the tools and methods should be flexible in terms of the diversity of stakeholder interests and values; in other words, in terms of the alignment of different goal definitions. Moreover, the models should be more efficient in terms of iterative stakeholder interactions, which are often restricted due to limited time availability.

Various innovative tools and methods are offered to help with the likely instrumental obstacles to a governance mechanism with people at the very centre of the process; they are potentially applicable to the ULL approach for the transdisciplinary FWE nexus (Ghodsvali, Krishnamurthy, & de Vries, 2019). Instances include multi-player gaming experiments in a face-to-face or virtual reality setting (Mochizuki, Magnuszewski, & Linnerooth-Bayer, 2018; Agusdinata & Lukosch, 2019), creating interfaces between participants and computer models through participatory scenario development for exploration through alternative future storylines (Johnson & Karlberg, 2017; Colloff et al., 2019), and participatory geographic information systems potentially open to the multi-dimensional visualisation of ecological changes for interactive decision-support experiences (Karpouzoglou, Pereira, & Doshi, 2017; Kraftl et al., 2019).

An intensive participatory modelling approach may consequently increase the effectiveness and efficiency of the ULL approach in supporting an adaptive governance mechanism for the transdisciplinary FWE nexus. The following statements explore how the strategy of such an engagement between the transdisciplinary FWE nexus concept, the ULL approach, and a computer-supported participatory platform promotes requisites for a sustainable socio-ecological transition (see Figure 2.1). The use of participatory modelling methods and tools, specific to contextual complexities, supports:

- **Sociability to facilitate cooperative interactions**
  Through the FWE nexus projects, direct and indirect stakeholders should regularly collaborate in order to cope with the uncertain challenges of socio-ecological transitions. Working as a team can support participants in learning from each other and exchanging useful information. Thus, the structure of nexus social networks and the capacity of individuals to interact with each other are of primary importance in constructing knowledge. In addition, a greater number of stakeholders of potential benefit for progressing opportunities as it maximises corrections and improvements, although it also raises additional concerns over the management of a more extensive collaboration. Virtual collaboration, along with face-to-face discussion, serves as a practical solution to extensive nexus collaborations. As an advantage, virtual collaboration operates across space, time, and organisational boundaries. Moreover, virtual collaboration overcomes the likely emotional states within face-to-face meetings and minimises the risk of impeding the negotiation process.

- **Knowledge co-production to characterise paradigms of localised interventions**
  In FWE nexus projects where all stakeholders have to collaborate as a team on new socio-ecological solutions, every stakeholder should have a chance to propose their experiences and democratically take the initiative. It means an all-together-decision-making that is a requisite for the transdisciplinary FWE nexus. Such decisions entail potential risks associated with the uncertainties of stakeholder engagement, consensus, and the future, which can be part of the creative process. Exploration of new ideas and experimentation with new solutions through participatory modelling tools involving local stakeholders may potentially contribute to a reduction in the nexus transdisciplinarity attendant risks.
- **Corporate governance to shape a resilient alliance and adaptive capacity**
  Accountability, fairness, transparency, assurance, leadership, and stakeholder management are of primary importance in empowering a community for ecological-conservation purposes. The contextual design embedded in the participatory-supported ULL mechanisms attaches great importance to power dynamics in multi-stakeholder nexus processes (Ghodsvali, Krishnamurthy, & de Vries, 2019). The contextual inquiry captures detailed information about how stakeholders affected by a nexus project interact with the environment in their normal life. In addition to the support for participatory modelling methods in distributing an equitable balance of power, it supports nexus stakeholders to understand others' interests, and in turn adjusts and prioritises their ideas and tasks.
- **Socio-eco-techno integration to introduce efficient resolutions** Exploring innovative ideas, experimenting with different future scenarios, and learning adaptable responses to ecological changes are the collection of participatory-supported ULL mechanisms through which FWE nexus resolutions are controlled and operated. Best practice is to seek this through the integration of computer-supported participatory techniques into socio-ecological concerns. Although experiments vary significantly in objective and scale, they always rely on an iterative procedure and logical exploration. FWE nexus experimentation provides insight into cause and effect relationships by indicating which outcome occurs when a specific factor is manipulated. Experimenting with social innovation, including new technology, strategies, ideas, and institutions, enhances

the capacity of social and ecological systems to help steer away from multiple FWE resource thresholds. The trial-and-error logic promotes the need of FWE nexus projects to experiment through iterative consultation and the subsequent mutual understanding among participants. Moreover, experimentation may provide nexus actors with a sense of joint ownership and raise opportunities for accountability.

By integrating the above-described potential benefits of participatory modelling methods into the nexus ULL approach, FWE nexus projects might be able to end up with new context-specified solutions and operational concepts.

5. Concluding remarks

A ULL can potentially support the accomplishment of the transdisciplinary FWE nexus if there is a well-balanced social-ecological-technological integration. From the literature and existing empirical evidence, there appear to be many requisites for making the ULL approach more effective and efficient as an adaptive governance mechanism for the transdisciplinary FWE nexus. However, a critical evaluation of these requisites and the best way to satisfy them has not been conducted so far, and no operational guidelines are available on how to adopt the ULL approach to effectively and efficiently support the transdisciplinary FWE nexus, emphasising inclusive, active, and direct stakeholder engagement. This knowledge gap requires thorough studies of the interactions between the ULL approach and the varying related participatory settings and the transdisciplinary process in the FWE nexus. Thus far, evaluations of participatory techniques in nexus ULLs have been characterised by limited attention to socio-technical design and the development of innovation processes (e.g. Molinari & Schumacher, 2011). We suggest that such evaluations could greatly benefit from the fields of corporate governance, sociability, knowledge co-production, and, in particular, from the rapidly expanding area of ICT-supported participatory modelling methods and tools. Studies show how the insights from ICT-supported participatory modelling are supportive in designing collaboration support tools, facilitating negotiation and learning processes, building consensus, and evaluating the effectiveness of jointly made decisions. We expect, therefore, that integrating the fields of participatory modelling via ICT tools, the ULL approach, and the FWE nexus will considerably advance our capabilities in accomplishing the concept of transdisciplinarity for more sustainable environmental and natural resource management.

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Appendix A. Methodological details

Table A.1: Questions of the online survey conducted on the design, processes, and practices of the selected ULLs

1- What are the environmental problems your city deals with?

€ Densification	€ Biodiversity loss	€ Pollution	€ Heat stress	€ Water scarcity	€ Flooding	€ Lax food security	€ Other:

2- What is the focus of the nexus project in your city? (one or more choice)

€ Strategic planning	€ Policy interventions	€ Analytical approach	€ Development actions	€ Other:

Please explain your choice in detail.

3- What is the scale of the nexus project in your city?

€ City scale	€ Neighborhood scale	€ Building scale

4- What is the relevance of the designed Urban Living Lab in relation to the aim of the nexus project in your city?

€ Studying existing governance structure and processes	€ Assessing existing state of the challenges in your city	€ Increasing co-creation and participation	€ Testing the usefulness of the ULL approach	€ Other:

5- What are the solutions that proposed ULL explores?

€ Repurposing existing areas	€ Densification of existing urban areas	€ Development of innovative solutions on green/blue infrastructure
€ Creation of mixed-use areas	€ Increasing awareness through participation	€ Other:

Please explain your choice in detail.

6- To what degree following stakeholders are involved in the proposed ULL?

	1 (Low)	2	3	4	5 (High)
Academic/University					
Municipality					
Industry/Professional					
Local community					

7- Who are defined as current users in the proposed location of the ULL?

8- Who are defined as end-users in the nexus project of your city?

€ Existing group of users € Future users € Proxy (through a representative)

9- Who are the key actors in the proposed ULL?

€ Governmental actors € Industry € Financial actors € Local community € Academic € Other:

10- Please select the collaboration order of stakeholders within proposed ULL.

	Government	Industry	Academic	Local community	Financial actors
1 (First) – 5 (Last)					

11- Does the issue go beyond the administrative borders of your city/municipality?

€ Yes € No € Maybe

12- At which level of administrative boundary are the nexus activities of the proposed ULL managed?

€ National € Regional € Local

13- How was the ULL's engagement strategy identified geographically?

€ Within the ULL area € Beyond the ULL area

If "beyond the ULL area", please identify the extent.

(*Continued*)

Table A.1: (Continued)

14- What is the governance system of the proposed ULL?

€ Top-down € Bottom-up € Top-down and bottom-up

15- How was the selection of initial participants from the community made?

€ Open to everyone (self-selection)	€ Stakeholder representative	€ Demographically representative	€ Specific individuals	€ Other:

16- Is it possible for all community members to participate in the ULL?

€ Yes, within the ULL boundary	€ Yes, from outside the ULL boundary	€ No

17- How do different actors collaborate in the ULL?

€ Working individually	€ Within multi-disciplinary groups	€ In groups of similar backgrounds	€ Other

18- How does the ULL approach raise local awareness about the nexus concerns?

€ Information sharing	€ Consultation	€ Collaboration	€ Empowerment	€ Other:

19- How do the ULL actors share ideas?

€ One-way physical communication (e.g., post)	€ One-way virtual communication (e.g., media, advertising)	€ Two-way physical communication (e.g., workshops, booths)	€ Two-way virtual communication (e.g., apps, remote attendance)	€ Multi-model sharing (combination of physical and virtual methods)

20- Is there an open data platform that all different actors of the ULL have access to?

€ Yes € No

If yes, please add the link.

21- How transparent is the knowledge sharing within the proposed ULL?

	1 (Low)	2	3	4	5 (High)
Between decision makers and local community					
Between decision makers					

22- Please identify methods used to showcase ideas between decision makers and community through the proposed ULL.

€ Gamification	€ 3D model	€ Rendering and images	€ Discussing examples of current studies	€ Other:

23- Who is the owner of the proposed ULL in your city?

€ Local government	€ The Municipality	€ Industry	€ Local community	€ Other:

24- Please identify policy barriers your city faces that prevent the integrated resource management in your city?

Please explain your answer.

25- How aligned are current political interests to the interest of local community in the context of nexus challenges in your city?

Please explain your answer.

Table A.2: MCA dimensions discrimination measures

Categorical variables	*MCA dimensions*	
	Dimension 1	*Dimension 2*
Stakeholders' power	0.983	0.966
Idea-showcasing methods	0.861	0.734
Local awareness methods	0.791	0.862
Nexus ULL key actors	0.783	0.462
Environmental problem	0.780	0.613
FWE nexus focus	0.772	0.672
Stakeholder collaboration order	0.746	0.696
Idea-sharing methods	0.726	0.460
Nexus ULL role	0.693	0.688
Nexus ULL solution	0.652	0.478
Initial participants selection	0.594	0.632
Collaboration structure	0.558	0.313

(*Continued*)

Table A.2: (Continued)

Categorical variables	*MCA dimensions*	
	Dimension 1	*Dimension 2*
Nexus ULL current user	0.534	0.538
Information transparency with local community	0.448	0.240
Information transparency among decision makers	0.406	0.104
Governance system	0.404	0.016
Nexus ULL owner	0.368	0.364
Spatial extent of nexus activities	0.308	0.033
Open data platform	0.289	0.143
FWE nexus end-users	0.250	0.293
FWE nexus scale	0.243	0.028
Spatial extent of the nexus issue	0.182	0.005
Participation possibility	0.102	0.288
Active total	12.955	9.773
Percentage of variance	7.712	5.817

Appendix B. Analytical details

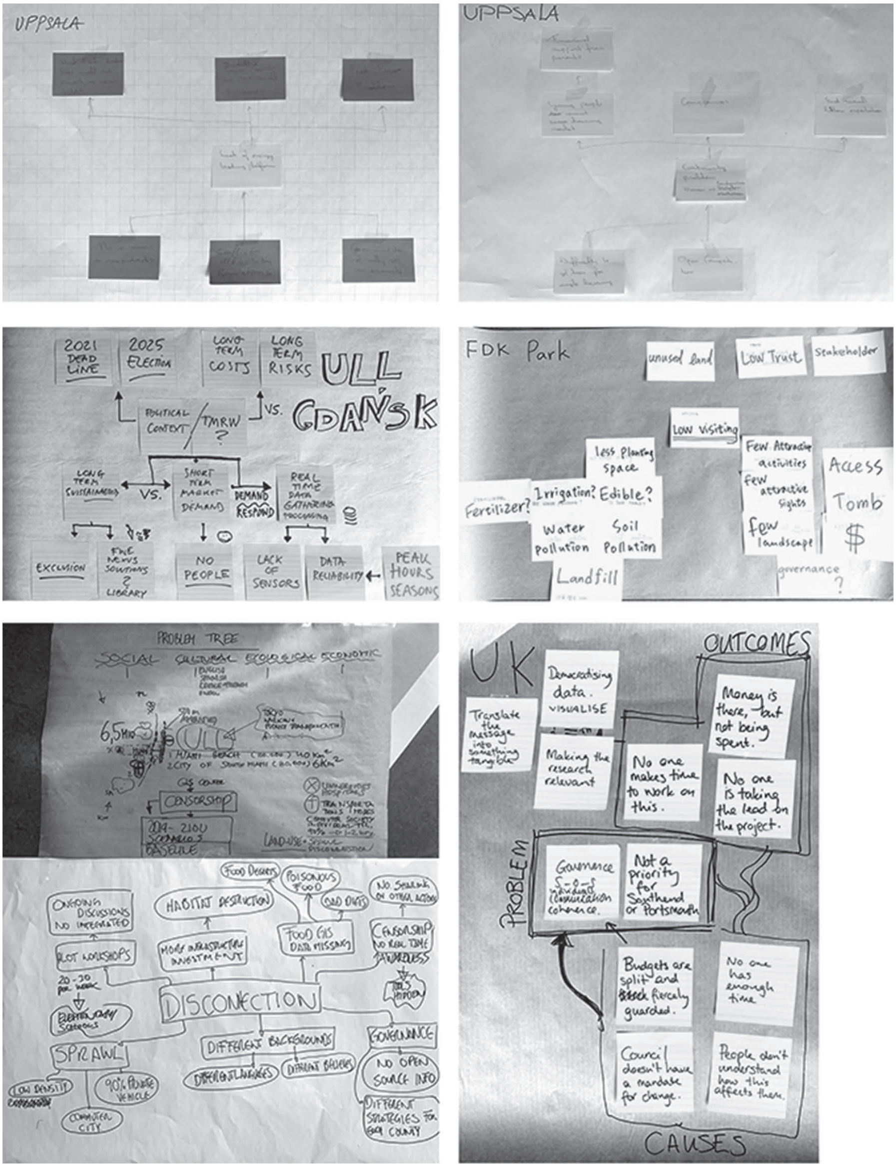

Figure B.1: Problem trees of the nexus ULLs selected for this research

Teams of multiple stakeholders from each ULL, through a focus group discussion, debated the main problem of their nexus ULL and defined its associated causes and effects. The problem trees were analysed for a logical strategic guideline (see Figure 2.4).