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Positive energy districts and energy communities: how living labs create value

SPECIAL COLLECTION: LIVING LABS: AGENTS FOR CHANGE

RESEARCH

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ABSTRACT

Urban living labs (ULLs) are experimental governance mechanisms accelerating sustainability transitions in the built environment, yet their governance implications and systemic impact are often under-examined. A comparative analysis of six ULLs is presented with a focus on positive energy districts (PEDs) and energy communities (ECs) in Austria, Germany, Sweden and the Netherlands. Stakeholder configurations, governance models and value creation processes are analysed using structured case documentation and a multitheoretical lens combining the multi-level perspective (MLP), ULL frameworks, innovation ecosystem theory and the Cambridge Value Mapping Tool (CVMT). Substantial variation is revealed in governance, ranging from centralised, municipality-led models to distributed, cooperative or academic leadership. Mapping stakeholder networks across MLP levels uncovers critical tensions between regime incumbents and niche actors. CVMT analysis demonstrates that value creation is multidimensional (economic, environmental, social) but often uneven, with missed or destroyed value linked to governance misalignment or limited stakeholder engagement. It is argued that ULLs function as infrastructures for transition governance, not merely technical testbeds. Their success relies on their capacity to align multi-actor systems, mediate institutional frictions and co-produce shared value. Findings offer actionable insights for designing ULLs that are technically effective and socially embedded for just and sustainable urban energy transitions.

PRACTICE RELEVANCE

This study provides practical insights for stakeholders involved in the development of PEDs and ECs through ULLs. First, the analysis highlights that governance models play a critical role – distributed and inclusive structures tend to foster trust, legitimacy and sustained innovation, while centralised, siloed models often lead to missed or destroyed

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value. Second, successful ULLs rely on strong stakeholder alignment across different institutional levels, enabling systemic change and the embedding of new practices. Third, value creation in ULLs is multidimensional – economic, social and environmental – and tools like the CVMT are essential for identifying opportunities and avoiding value loss. Fourth, co-creation processes that involve citizens meaningfully improve acceptance, adaptability and long-term impact. Finally, ULLs should be understood not merely as project testbeds but as infrastructures for transition, capable of bridging the gap between innovation and policy to support just and sustainable energy futures.

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1. INTRODUCTION

Urban living labs (ULLs) are increasingly positioned as critical instruments for accelerating sustainability transitions in the built environment. Promoted by European policy frameworks such as the SET Plan and Horizon Europe (Voytenko *et al.* 2016), ULLs are intended to bring together public authorities, researchers, businesses and citizens in real-life settings to co-create, test and scale sociotechnical innovations. In the context of energy transition, ULLs are now central to the development of positive energy districts (PEDs) and energy communities (ECs), aiming to combine decentralised energy systems with digital tools, social engagement and novel governance models. However, despite their proliferation, there is a growing recognition that ULLs are not inherently transformative. Their success depends on how they are institutionally embedded, how they manage diverse stakeholder relationships and how they generate and distribute value. Existing research often focusses on individual projects or technological outcomes, with less attention to the broader governance dynamics, value constellations and institutional tensions that shape ULL trajectories. There is a need for more systematic and comparative approaches that interrogate how ULLs function as governance infrastructures within multi-level sociotechnical systems.

This paper addresses this gap by conducting a comparative, multitheoretical analysis of six ULLs involved in PED and EC development across Austria, Germany, Sweden and the Netherlands. Structured case study data and a combination of the multi-level perspective (MLP), ULL theory, innovation ecosystem thinking and value mapping are used to understand the governance configurations, stakeholder constellations and value dynamics that underpin experimental energy transitions and identify the factors that influence their transformative potential and long-term institutionalisation.

The research question addressed is: 'how do urban living labs for positive energy districts and energy communities govern sociotechnical experimentation, coordinate stakeholder networks and co-create value within complex transition contexts?'

The objectives are:

1. To analyse and compare the governance models and stakeholder configurations across six ULLs in Europe.
2. To apply the MLP framework to structure and interpret stakeholder interactions within PED and EC initiatives.
3. To assess the value creation, capture and destruction processes using the Cambridge Value Mapping Tool (CVMT).
4. To identify enabling and constraining factors that influence the institutionalisation and transformative potential of ULLs in urban energy transitions.

This study contributes by offering a comparative, theoretically informed and methodologically plural perspective on ULL dynamics in energy transitions. Through integrating the MLP, ULL theory, innovation ecosystems and value mapping, an approach is created to capture both the structural positioning and internal processes of labs.

There are limitations. The comparative method relied on structured expert templates rather than full ethnographic immersion, limiting insights into informal practices and affective dimensions of participation.

The geographic scope is confined to the European policy context. The findings may not fully translate to other policy or cultural settings. Nonetheless, the comparative design and theoretically grounded analysis offer insights into the systemic features and governance dimensions of experimental urban energy transitions.

It is important to clarify the positionality of the authors. The research was conducted by a team of researchers who were closely observing the ULLs as part of a larger, EU-funded projects on sustainable urban transitions. This situated perspective provides a nuanced understanding of the ULLs' internal processes and stakeholder dynamics but this also means that the analysis is based on structured data templates rather than full ethnographic immersion, a limitation acknowledged by the authors.

2. THEORETICAL FRAMEWORK

2.1 CONCEPTS OF PED AND EC

The concepts of PEDs and ECs have emerged as paradigms in contemporary urban energy transitions, aiming to enhance local sustainability, energy self-sufficiency and decarbonisation. These concepts are deeply rooted in the broader discourse on distributed energy systems, smart cities and participatory governance, reflecting a shift from centralised (often) fossil-fuel-based energy infrastructures to decentralised, renewable-based solutions. Despite the increasing recognition of decentralisation, the European energy landscape remains highly diverse, with significant variations in national energy strategies and market structures. Some countries, such as Sweden, have successfully developed centralised energy systems that are both green and cost-effective, largely due to extensive investments in hydropower, nuclear energy and district heating networks. These centralised systems benefit from economies of scale, long-term energy security and stable electricity prices, making them attractive models for national and urban energy planning.

However, even in such well-established centralised energy markets, the issue of resilience remains a critical consideration, particularly in the context of increasing climate variability, geopolitical energy dependencies and grid vulnerabilities (Goldthau 2014). Large-scale energy infrastructure is susceptible to systemic risks, such as cyber threats, extreme weather events and energy supply disruptions, which can have cascading effects on national and regional energy security (Cherp & Jewell 2011).

The decentralisation of energy production through PEDs and ECs introduces a complementary model that enhances energy resilience by diversifying energy sources, reducing transmission losses and enabling local energy autonomy (Koirala *et al.* 2016). Additionally, decentralised energy governance fosters greater social inclusivity, allowing communities to actively participate in energy production and decision-making processes, which contributes to energy democracy and citizen empowerment. However, decentralised systems also present their own set of challenges, including potential downsides related to economic viability and operational complexity. These can include the high upfront costs for individual households and businesses, as well as the technical and administrative complexities of managing a distributed network.

PEDs are defined as urban areas that produce more energy than they consume on an annual basis through the integration of renewable energy generation, storage and efficiency measures (JPI Urban Europe 2019). The PED concept aligns with the European Union's climate goals and the Smart Cities and Communities agenda, which emphasise sustainable urban planning and energy-positive developments (European Commission 2020). PEDs leverage technological advancements such as photovoltaic (PV) systems, wind turbines, battery storage, demand-side management and digital twins to optimise energy flows and enhance resilience. A key characteristic of PEDs is their multi-actor governance model, where ideally municipalities, energy utilities, real estate developers and citizens collaboratively manage energy resources (Malakhatka *et al.* 2024; Sassenou *et al.* 2024).

The success of PEDs depends not only on technological innovations but also on effective regulatory frameworks and financial mechanisms that support decentralised energy production and trading. Despite their potential, PEDs face challenges related to grid integration, fluctuating energy demand, and policy fragmentation, necessitating adaptive governance approaches (Valkenburg & Cotella 2016).

ECs, on the other hand, focus on the collective ownership, management and distribution of renewable energy within local communities. ECs are often driven by principles of energy democracy, citizen participation and cooperative business models, aiming to empower local actors in energy governance (Bauwens *et al.* 2016). Unlike PEDs, which are typically planned as integrated urban districts, ECs emerge in diverse contexts, including rural cooperatives, neighbourhood-based solar communities and prosumer-led energy sharing networks (Chaudhry *et al.* 2022). ECs play a vital role in fostering social acceptance of renewable energy and reducing energy poverty by enabling local control over energy generation and consumption. However, they also encounter institutional barriers, particularly in regulatory environments that favour incumbent energy providers over community-led initiatives (Kooij *et al.* 2018).

Both PEDs and ECs contribute to energy transition by promoting decentralised, community-driven energy solutions, yet they differ in scale, governance structures and implementation strategies. While PEDs typically operate within a structured urban planning framework, ECs rely on grassroots participation and cooperative ownership models. The intersection of these two concepts presents opportunities for hybrid energy systems where urban PEDs integrate community-based energy solutions, fostering a more inclusive and resilient energy transition.

2.2 ULLS AS ENABLERS OF PED AND EC DEVELOPMENT

A defining characteristic of ULLs is their real-world experimental approach, which differentiates them from traditional laboratory-based research. Unlike controlled environments, ULLs operate within complex urban settings, where diverse social, economic and infrastructural dynamics influence innovation outcomes (Bulkeley *et al.* 2019). This situatedness enables ULLs to bridge the gap between abstract policy objectives and practical implementation by testing solutions in dynamic urban contexts (Kemp & Scholl 2016). Furthermore, ULLs emphasise iterative learning, enabling continuous feedback loops where stakeholders evaluate and adapt strategies based on empirical findings. Through this approach, ULLs contribute to the development of new/advanced governance frameworks that align municipal planning, regulatory policies and market incentives with local sustainability goals.

The role of ULLs in co-creation and stakeholder engagement has been widely documented in urban innovation literature (McCormick & Kiss 2015). Co-creation in ULLs extends beyond conventional public–private partnerships by actively involving citizens, local businesses, energy providers and policymakers in the innovation process. This participatory governance model fosters collective ownership of solutions and enhances social acceptance of emerging technologies (Hossain *et al.* 2019). ULLs, particularly in the European context, have evolved as spaces not only for co-design but also for the communing of knowledge and infrastructures (Petrescu *et al.* 2022), enabling deeper community embedding and mutual learning across cities. In the context of PEDs and ECs, co-creation within ULLs enables multiple stakeholders to participate in energy governance, influencing decisions related to renewable energy generation, demand-side management, and peer-to-peer energy trading (Frantzeskaki & Rok 2018).

Moreover, ULLs facilitate multistakeholder experimentation, wherein actors with divergent interests collaborate in defining common objectives, testing regulatory frameworks and exploring financial models. For PEDs and ECs, this means aligning the interests of municipalities, energy cooperatives and technology providers to create economically viable and socially inclusive energy solutions. The experimental function of ULLs is crucial for navigating regulatory uncertainties and assessing the feasibility of decentralised energy models in real-world conditions (van Bueren & de Jong 2007). By providing a shared infrastructure, ULLs help reduce innovation risks and accelerate the scaling of successful solutions, while at the same time increasing the complexity within decision-making and governance.

Finally, ULLs contribute to the institutional embedding of PEDs and ECs by influencing policy development and governance mechanisms. As living experiments, they generate empirical evidence that informs municipal decision-making, enabling cities to adapt regulatory frameworks in response to emerging challenges (Voytenko *et al.* 2016). Additionally, they play a key role in fostering knowledge diffusion, as insights from successful projects can be transferred to other urban contexts, facilitating the broader adoption of PED and EC initiatives.

2.3 MULTI-LEVEL PERSPECTIVE FOR SOCIOTECHNICAL TRANSITIONS

The MLP provides an established theoretical foundation for analysing sociotechnical transitions, particularly in understanding how emerging innovations disrupt and transform established systems. Originally developed by Geels (2002, 2011), the MLP framework conceptualises transitions as a dynamic interplay between three interdependent levels: niche innovations, sociotechnical regimes and sociotechnical landscapes (Figure 1).

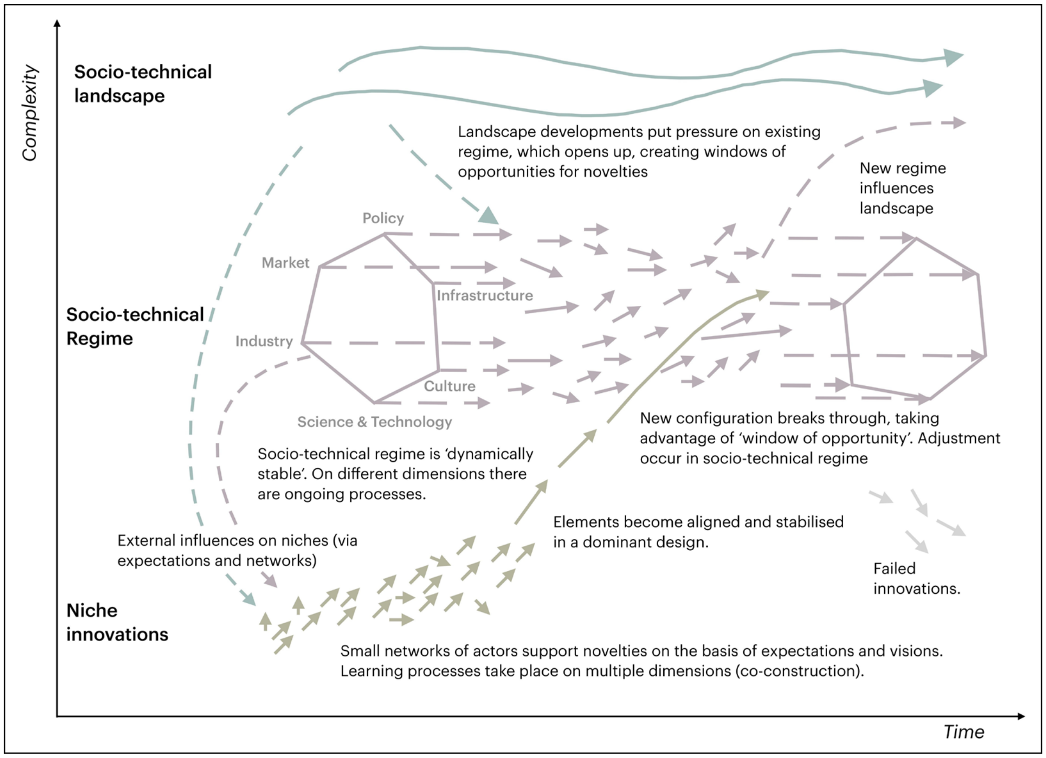

Figure 1: Multi-level perspective.

Source: Adapted from Geels (2002).

At the niche level, innovations emerge within protected spaces where actors, such as research institutions, start-ups and municipalities, collaborate to develop and refine novel technological, social and policy solutions. The concept of niches as 'incubation spaces' has been widely discussed in transition studies (Schot & Geels 2013), emphasising their role in enabling experimentation and learning that is essential for transformative change. In the context of PEDs and ECs, niche innovations manifest through pilot projects and ULLs, where local energy systems, smart grid solutions and advanced energy management systems are tested. These innovations often operate outside mainstream market and regulatory constraints, allowing for iterative adaptation and co-evolution with societal needs. However, niche development alone is insufficient for systemic transition; it requires alignment with or disruption of the existing sociotechnical regime.

The sociotechnical regime represents the dominant configurations of institutions, infrastructures, policies and market structures that govern a particular sector. These regimes are typically characterised by stability, path dependency and resistance to change owing to vested interests, sunk investments and regulatory lock-ins (Markard *et al.* 2012). The persistence of centralised energy generation, rigid regulatory frameworks and fossil fuel dependency exemplifies the entrenched nature of the energy system at the regime level. In the case of PEDs and ECs, regime resistance is evident in challenges such as the integration of decentralised energy production into

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existing grid infrastructure, the reluctance of utility companies to shift from traditional revenue models, and the complexity of navigating fragmented regulatory landscapes. The transition from a centralised to a decentralised energy paradigm necessitates institutional reconfiguration, policy adaptation and market innovations that enable local energy trading, performance-based contracts, new governance models and business opportunities.

The sociotechnical landscape represents the broader exogenous trends and macro-level developments that exert pressure on existing regimes and create windows of opportunity for transition (Smith *et al.* 2005). Landscape dynamics include climate change imperatives, economic fluctuations, geopolitical energy dependencies and advancements in digitalisation and artificial intelligence. These pressures can destabilise the sociotechnical regime, creating openings for niche innovations to scale up and gain broader acceptance. For instance, the European Union's Green Deal and national climate policies are reshaping energy markets by mandating carbon neutrality, increasing investments in renewable energy and fostering citizen participation in energy governance.

The MLP framework is instrumental in examining the evolution of PEDs and ECs, as it makes clear the mechanisms through which innovations emerge, interact with dominant sociotechnical structures and eventually reconfigure urban energy systems. Empirical studies on sustainability transitions have demonstrated that successful regime transformation often occurs through a combination of bottom-up niche innovations and top-down policy interventions (Kemp *et al.* 1998). However, transition pathways are contingent on context-specific conditions, such as governance structures, market readiness and stakeholder alignment, which necessitate adaptive strategies tailored to different sociopolitical and economic settings. By integrating insights from transition theory and empirical studies, the MLP framework offers a valuable perspective for analysing the complexities of PED and EC implementation. Thus, the MLP serves as a critical analytical tool for advancing both theoretical and practical knowledge on sociotechnical transitions within the domain of PEDs and ECs.

2.4 VALUE MAPPING

The value mapping framework used in this study is grounded in the CVMT, which was originally developed to support the design and evaluation of sustainable business models (Bocken *et al.* 2013). The CVMT has increasingly been adapted for use in sustainability transitions and living lab contexts, offering a structured approach to identifying and reflecting on multiple dimensions of value – including value captured, missed and destroyed and opportunities for value creation. In this study, the CVMT is used not only as a diagnostic tool but also to facilitate reflexive dialogue around stakeholder expectations, trade-offs and systemic constraints.

Theoretically, the CVMT aligns with the broader shift from linear value chains to value constellations in which multiple stakeholders co-produce, appropriate or block value (Normann & Ramirez 1993). Within ULLs, where experimentation involves diverse actors with varying interests and institutional logics, the ability to make value flows explicit is crucial to fostering mutual understanding and iterative learning. Value in this context is not only economic but also environmental, social and institutional – and may be interpreted differently by different actor groups. The CVMT approach enables a systemic unpacking of these plural value framings.

In our analysis, CVMT is applied across all six ULL case studies to identify patterns of value creation and capture, as well as gaps and frictions where value is missed or destroyed owing to governance misalignment, stakeholder exclusion or technical failures. This approach supports recent calls in the literature for integrating value-sensitive design and evaluation into the governance of sustainability transitions (Bocken *et al.* 2014; Farla *et al.* 2012). It complements the MLP and ULL frameworks by offering a fine-grained lens to assess the normative and experiential dimensions of innovation. It allows us to reflect on how governance models, actor constellations and sociotechnical configurations enable or hinder inclusive value outcomes within experimental urban settings.

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3. METHODS

This research employs a qualitative, comparative case study methodology to investigate how ULLs support the development and implementation of PEDs and ECs. The methodological approach integrates structured case documentation, stakeholder network analysis and value mapping across six ULLs located in Austria, Sweden, Germany and the Netherlands. The six case studies were selected based on their diversity in geographical context, institutional arrangements and experimental focus.

Primary data were collected using a structured case study template completed by researchers involved in or closely observing each ULL. The template included six major sections: a) general information; b) case study background; c) implementation and governance; d) technical and infrastructural aspects; e) stakeholder value exchange analysis; and f) outcomes and impacts. Each national PED/EC team completed the template based on their local documentation, expert knowledge and project insights. In addition, project documentation, workshop outputs and internal reports were reviewed to triangulate and deepen the empirical material.

Three analytical lenses were applied to interpret the data:

- The MLP was used to categorise stakeholder networks and identify actor positions across niche, regime and landscape levels.
- The ULL framework guided the analysis of co-creation processes, iterative learning and the embedding of experimentation in real-world settings.
- The CVMT was used to assess value creation, capture, destruction, and missed value in each ULL, providing a cross-case comparative perspective.

3.1 ULL OVERVIEW

The six ULL cases across four European countries were selected to empirically explore the dynamics of PED and EC development. The portfolio includes both top-down and bottom-up initiatives, spanning a diversity of socio-spatial scales, governance models and maturity levels. Three cases – Am Kempelenpark (Vienna, Austria), Atelier REPUBLICA (Amsterdam, Netherlands) and Jättesten (Gothenburg, Sweden) – represent PED-focussed developments embedded within broader urban transformation agendas, characterised by strong municipal involvement and integrated planning. The other three – WUNergy (Wunsiedel, Germany), University Campus (Gothenburg, Sweden) and Mariatrost (Graz, Austria) – focus on EC models grounded in cooperative ownership, institutional experimentation and local energy autonomy (see Figure 2). This selection enables comparative analysis across different national regulatory contexts, infrastructural legacies and stakeholder constellations. Each case contributes empirical insights into how PEDs and ECs are designed, governed and implemented in real-world settings, with attention to their sociotechnical

Figure 2: Positive energy districts (PEDs) and energy communities (ECs) case studies portfolio.

configurations, stakeholder collaborations and value creation mechanisms. The case-specific narratives presented in this section provide the foundation for the subsequent sociotechnical analysis and stakeholder assessment.

Am Kempelenpark (Vienna, Austria) is a large-scale PED initiative repurposing a former industrial area into a sustainable, mixed-use neighbourhood. The project is coordinated through a public–private partnership involving municipal authorities, planning consultancies and real estate developers. Key sociotechnical components include renewable energy integration (*e.g.* photovoltaics and heat pumps using a local renewable energy source), digital planning tools such as BIM, and participatory public space design. The project is embedded within Vienna's tradition of socially inclusive urban planning and is guided by a quality assurance board to ensure social, architectural and environmental standards.

Atelier REPUBLICA (Amsterdam, Netherlands) is a demonstration district, aimed at showcasing replicable PEDs. The local municipality leads a multistakeholder consortium involving academic institutions, technology providers, energy service companies (ESCOs) and residents. The district combines diverse energy technologies (*e.g.* solar PV, batteries, electric vehicle charging and heat pumps) with digital infrastructure such as energy management systems (EMSs), digital twins and a peer-to-peer trading platform. A defining feature is the formation of a local EC that engages residents as prosumers. Operating within a regulatory sandbox, the initiative supports governance experimentation and dynamic energy exchange, though some challenges remain in reaching marginalised groups and scaling beyond the pilot.

Jättesten (Gothenburg, Sweden) is a PED initiative embedded in a mixed-use district comprising residential buildings, schools and commercial infrastructure. The initiative is led by a technical university in collaboration with a publicly owned housing company, architects and other institutional stakeholders. The core experimental dimension centres on the development of a digital twin to simulate and optimise energy performance at building and district levels to achieve the municipal mandatory goal of 90% reduction of greenhouse gas emissions by 2030.

WUNergy (Wunsiedel, Germany) represents a cooperative energy sharing community in a semi-rural town in Bavaria. It brings together municipal actors, local energy system integrators, private businesses and prosumers under a shared governance framework. The community leverages digital tools for dynamic tariffs, smart metering and real-time tracking to facilitate local energy exchange. Governance is democratic and community-led, though hindered by regulatory uncertainties and limited expansion capacity. WUNergy showcases a socially embedded and economically viable EC model with strong potential for replication, especially if supported by national legal reform and technical infrastructure upgrades.

Campus Energy Community (Gothenburg, Sweden) focusses on creating an integrated EC across university-owned and student housing facilities. The initiative is anchored in a campus-wide EMS and involves real estate managers, energy researchers and infrastructure providers. Key components include renewable energy systems, a battery energy storage system and vehicle-to-grid infrastructure. While highly optimised from a technical perspective, the community aspect remains underdeveloped, with limited direct participation from students or building occupants.

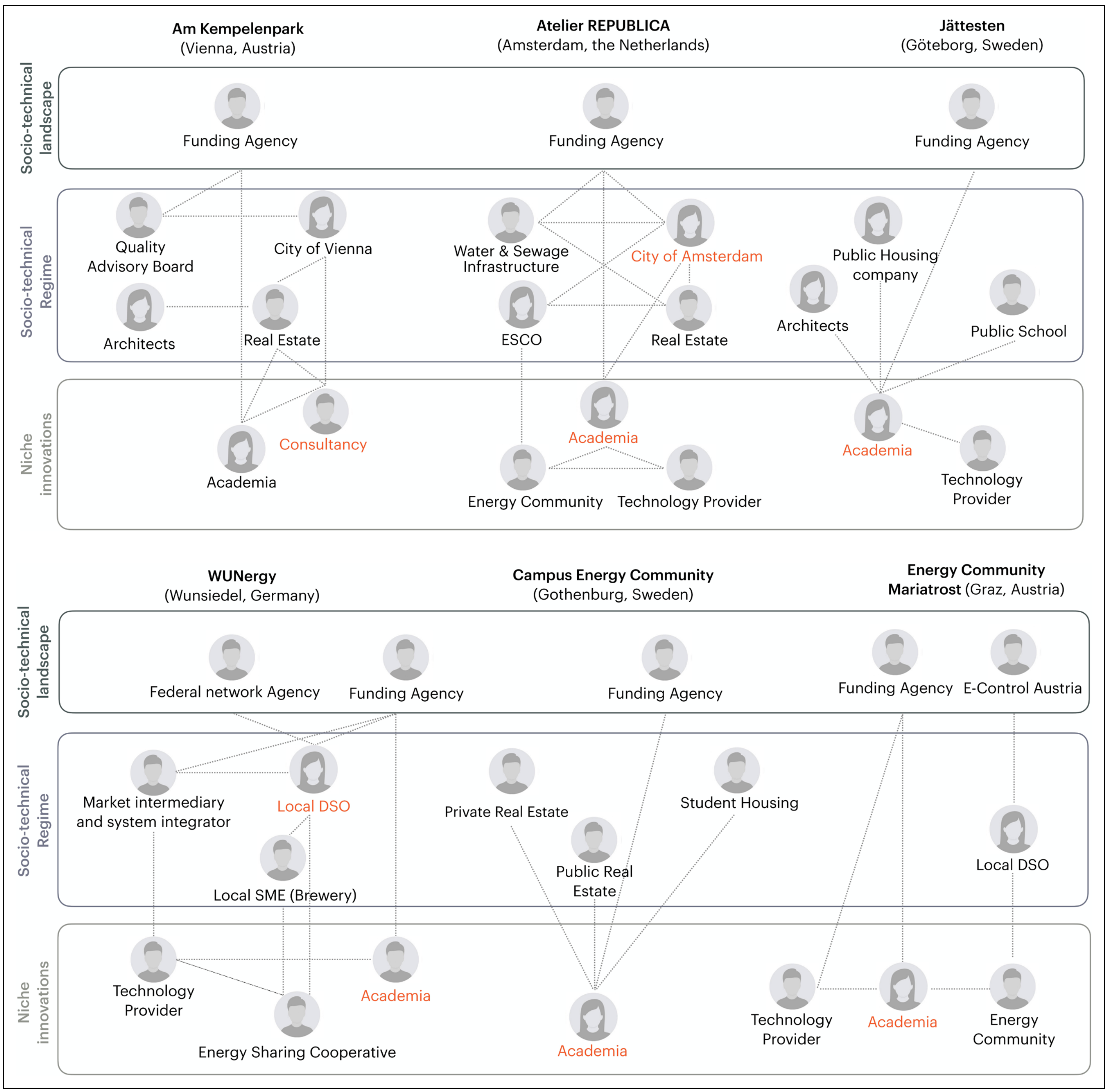
Renewable Energy Community Mariatrost (Graz, Austria) is a bottom-up, citizen-initiated EC supported by regional energy agencies. Structured as a legal association under Austria's Renewable Energy Expansion Act, it facilitates local PV generation, smart metering and long-term energy autonomy. The community includes households, prosumers, local institutions and technology providers, emphasising ecological motivation and social trust. Governance is democratic and volunteer-driven, though challenges arise from coordination fatigue and limited administrative capacity. Nevertheless, the initiative demonstrates a promising model for small-scale, replicable ECs grounded in local engagement and sustainability values.

3.2 STAKEHOLDER NETWORK ANALYSIS

The stakeholder network analysis was conducted across the six urban innovation cases and grounded in the MLP on sociotechnical transitions (Geels 2002) and conceptually enriched through the ULL approach (Frantzeskaki & Rok 2018; Voytenko *et al.* 2016). The MLP provides a structural lens to understand how actors interact across the niche, regime and landscape levels, while the ULL perspective operationalises this structure through place-based experimentation, co-creation and learning-by-doing. ULLs act as experimental arenas where stakeholder roles evolve through iterative co-creation, prototyping and reflexive governance (Evans & Karvonen 2014; von Wirth *et al.* 2019). Actors frequently move across levels, such as academic institutions acting both as innovation intermediaries within the niche and as advisers to regime-level policy bodies, thus functioning as 'transition intermediaries' (Frantzeskaki & Rok 2018). This fluidity highlights the importance of viewing stakeholder networks not only in terms of roles and institutional affiliations but also through their capacities for coordination, alignment and institutional entrepreneurship. The six cases also underscore the significance of identifying the 'driving force' actors – those initiating, coordinating or catalysing the ULLs. These actors are visualised in the diagrams (see Figure 3) through the orange-highlighted nodes, signifying their central role in mobilising networks and sustaining transition pathways. Each case illustrates distinct governance models, tensions and opportunities reflective of the broader sociotechnical and institutional context.

Figure 3: Stakeholder network analysis for Positive Energy Districts (PEDs) (top) and Energy Communities (ECs) (bottom).

Note: Orange nodes are key mobilizers.



Am Kempelenpark is embedded in Vienna's long-standing tradition of state-led planning and public housing development. The centrality of the city in the network illustrates a semi-centralised governance model, where steering remains top-down yet is increasingly open to external consultancy inputs. A sustainability consultant – marked as a key actor – bridges the regime with the niche innovation level, enabling dialogue between academic partners, real estate developers, and planners. However, the absence of direct citizen and resident engagement within the planning process limits the inclusive potential of the ULL. Experimentation is therefore controlled and formalised, with little room for iterative co-creation or adaptive learning. The innovation ecosystem remains orchestrated yet siloed, with clear functional roles but weak horizontal interaction, especially with digital solution providers and start-ups. Thus, while Kempelenpark represents a regulated and high-quality development, its stakeholder network reveals missed opportunities for deeper community-led innovation and feedback integration.

Atelier REPUBLICA in Amsterdam stands out for its mature and horizontally integrated ULL model. The Municipality of Amsterdam functions as the central node in a polycentric network that includes utilities (ESCOs, energy retailers), infrastructure managers, real estate developers, technology providers, academia and an operational EC. This dense and interactive stakeholder network facilitates both top-down coordination and bottom-up experimentation. Regulatory sandboxing enables temporary exemptions from energy market rules, fostering an agile governance model aligned with systemic innovation goals. Academia plays a dual role as both knowledge provider and community co-creator, helping test novel peer-to-peer trading models and EMS prototypes. The innovation ecosystem is diverse and interdependent, promoting cross-sector learning and systemic alignment. However, technological and operational complexity occasionally results in coordination bottlenecks. Despite this, Atelier REPUBLICA exemplifies a well-functioning ULL with hybrid governance, mutual accountability and strong potential for replication and scaling.

In the Jättesten PED, the network is more fragmented and emergent. Academic actors act as the principal driving force, engaging architects, technology providers and owners of public school buildings in experimentation with digital and sustainable solutions. However, regime actors such as the municipally owned housing company and the mother housing company and utility demonstrate limited integration. The central friction arises from a misalignment between the goals of PED decentralisation and the municipality-owned energy utility company, whose existing model is focussed on centralised, green and affordable district heating. This reflects the risk of 'institutional lock-in', where incumbent systems, though environmentally sound, resist decentralising innovations (Kern & Smith 2008). Additionally, the absence of meaningful engagement with tenants limits social learning and jeopardises broader acceptance, a gap echoed in sociotechnical transitions literature highlighting the role of user-driven change (Seyfang & Haxeltine 2012).

WUNergy represents a high-performing EC with a richly interconnected stakeholder network. At the centre is the local distribution system operator (DSO), which collaborates closely with a technical innovation and system integrator, a market intermediary and a community-led energy sharing cooperative. This configuration exemplifies a distributed governance model where experimentation is both technical (*e.g.* peer-to-peer trading platforms) and institutional (*e.g.* cooperative-led investment structures). Academia, prosumers and local businesses (*e.g.* a brewery) are also active participants, suggesting a socially embedded and functionally diverse innovation ecosystem. The regime-level actors – local government, cooperative associations and energy transition agencies – offer enabling support without dominating the governance process. WUNergy's stakeholder structure fosters trust, iterative co-creation and real-world testing. This ULL model reflects the power of community-centred innovation ecosystems when technical and social actors are aligned.

Campus EC is a university-led initiative characterised by centralised control and low levels of community participation. The university, along with its real estate subsidiaries, occupies a central position in the stakeholder network. Experimentation focusses on technical optimisation, digital infrastructure and campus-level energy management. However, students and tenants remain peripheral actors in both planning and implementation. Governance is strongly institutional, with limited transparency or horizontal accountability. The innovation ecosystem is internally coherent but externally isolated, with minimal involvement from digital solution providers, local government or sustainability educators. As a result, while the technical capacity and experimentation potential are high, societal integration is weak. This limits the ULL's potential as a socially inclusive testbed and raises questions about long-term replicability outside the academic environment.

Mariatrost is a grassroots-led EC grounded in strong local networks and democratic governance. The central actor is the EC itself, supported by academic partners, local prosumers, community members and technical providers. The governance structure is fully distributed, with decisions made collectively by community members and facilitated through transparent, voluntary processes. The local DSO and public institutions occupy a supportive, non-dominant role, enabling regulatory compliance and technical integration without undermining community autonomy. The innovation ecosystem is rich in social capital, with trust and local knowledge compensating for limited technical sophistication. Experimentation revolves around community ownership models, renewable energy self-consumption and behavioural change. This ULL exemplifies a socially grounded approach to energy transition, leveraging cooperation and place-based innovation. Despite some challenges around scale and administrative burden, Mariatrost presents a compelling model of inclusive energy governance with strong societal legitimacy.

3.3 VALUE MAPPING

The CVMT was applied to the six ULL case studies as a means of evaluating the actual and potential value outcomes of each initiative. Drawing on project documentation, stakeholder interviews and workshop insights, the multidimensional value flows and frictions that shape each ULL's trajectory were identified. The CVMT analysis serves as a diagnostic tool to highlight not only successes and missed opportunities but also areas of systemic tension or institutional inertia that may hinder long-term impact (see Table 1).

The Am Kempelenpark project captures value through high-quality urban design, public–private collaboration, and alignment with Vienna's social housing ethos. Economic value is realised through integrated planning and cost efficiencies. Environmental value is created via smart mobility and sustainable architecture. However, the rigid planning process lacks value in terms of community empowerment, participatory engagement and flexible energy experimentation. Potential value is destroyed through delays in integrating digital tools and lack of tenant co-ownership in energy systems. Opportunities lie in expanding digital participation platforms and experimenting with decentralised energy systems.

Atelier REPUBLICA creates substantial value across multiple domains. Social value emerges from participatory governance, co-creation workshops and community ownership. Environmental and economic value are driven by EMS trials, EC operations and peer-to-peer trading. Despite this, value is missed in the broader engagement of marginalised groups and scalability beyond the local context. Some technical pilots underperform or generate resistance, leading to partial value destruction. Opportunities include strengthening inclusivity, refining technology deployment and replicating successful governance formats.

Jättesten generates value through advanced digital twin experimentation and building retrofit strategies. Academic and technical institutions benefit from real-world learning environments. However, value is missed in the absence of community integration and resistance from incumbent energy providers. This mismatch creates governance inefficiencies and delays in implementation. Social value destruction occurs as a result of poor tenant engagement, reinforcing perceptions of top-down technocratic control. Future opportunities include participatory digital platforms, energy feedback loops and utility alignment.

WUNergy captures considerable economic and environmental value through community energy trading, cooperative investment models and smart metering. Social values are fostered by transparent governance and collective identity. Value is occasionally missed due to legal barriers restricting the expansion of services and membership. Instances of value destruction arise from data latency and technical incompatibilities. The project has clear potential for scale, particularly by integrating storage systems and enhancing regulatory adaptability.

This case generates strong institutional and technical value through energy efficiency, data collection and system optimisation. However, societal value is largely missed owing to minimal tenant participation and a lack of community-facing innovation. Governance is highly centralised, limiting the adaptive capacity of the system. Technocratic silos risk destroying relational and experiential value. Key opportunities include stakeholder diversification, interdisciplinary governance, and piloting participatory engagement mechanisms with residents.

Mariatrost captures value through local empowerment, ecological stewardship and democratic governance. Economic value is realised through cost-sharing and optimised energy self-consumption. Social value is high, driven by trust and local collaboration. However, financial return on investment (ROI) remains limited and administrative complexity discourages broader participation. Missed value includes underuse of surplus generation and lack of regional expansion. Destruction occurs through volunteer burnout and lack of professionalised coordination. Key opportunities lie in automating processes, developing storage, and building replication capacity.

Table 1: Capture Value Mapping Tool applied for the selected case studies

CASE STUDY	VALUE CAPTURED	VALUE MISSED	VALUE DESTROYED	OPPORTUNITIES
Am Kempelenpark	Urban regeneration, cross-sector planning, sustainability	Community participation, energy flexibility	Rigidity in governance, lack of digital adoption	Decentralised energy systems, participatory tools
Atelier REPUBLICA	EMS innovation, citizen ownership, P2P trading	Broader inclusivity, replicability	Underperforming pilots, operational resistance	Refinement, scalability, citizen inclusion
Jättesten	Digital twin, academic learning, retrofit gains	Tenant involvement, utility engagement	Governance friction, low legitimacy	Energy system alignment on different levels, participatory feedback loops
WUNergy	Cooperative trading, prosumer trust, energy saving	Legal scalability, wider membership	Data and tech integration issues	Regulatory sandbox, energy storage, regional expansion
Campus EC	Infrastructure, academic optimisation	Societal engagement, tenant participation	Technocratic silos, lack of social legitimacy	Student engagement, interdisciplinary governance
Mariatrost	Community resilience, low-carbon energy, trust	ROI, administrative simplicity	Volunteer fatigue, coordination challenges	Automation, storage, wider participation

The analysis reveals that ULLs with distributed governance and high stakeholder alignment are more likely to capture multidimensional value and minimise losses. Conversely, centralised and siloed projects risk alienating users and underutilising innovation potential. The CVMT thus offers a strategic framework for aligning ULL objectives with inclusive and sustainable outcomes.

4. COMPARATIVE ANALYSIS OF SIX ULLS

The insights from the six ULLs case studies are synthesised in this section, comparing their stakeholder networks, governance configurations, innovation ecosystems and value generation strategies. By positioning these cases within the broader scholarly discourse on sociotechnical transitions, innovation ecosystems and ULL governance, the aim is to uncover both shared patterns and context-specific divergences that influence the development of PEDs and ECs.

The six case studies reveal varying degrees of centralisation and distributed governance. Am Kempelenpark (Vienna) and Atelier REPUBLICA (Amsterdam) exemplify hybrid governance models where public institutions lead while enabling co-creation through strategic partnerships. In contrast, Jättesten (Gothenburg) and Campus EC (Gothenburg) are more academically driven, with universities or research institutions functioning as key coordinators. Meanwhile, Mariatrost

(Graz) and WUNergy (Wunsiedel) exhibit community-led or cooperative governance structures. These differences affect project adaptability and resilience. For instance, Mariatrost's grassroots structure fosters high trust and inclusivity but is vulnerable to volunteer burnout and coordination gaps. Conversely, strong institutional oversight in Am Kempelenpark ensures regulatory alignment but limits bottom-up engagement.

Stakeholder constellations across the ULLs vary in terms of diversity and interconnectivity. REPUBLICA, with its expansive network including ESCOs, technology providers and citizens, showcases a robust multi-actor engagement. In contrast, Campus EC and Jättesten show more siloed networks, primarily involving academic and property management actors with limited tenant or public engagement. Such engagement asymmetries have implications for social learning and legitimacy. Seyfang and Haxeltine (2012) emphasise the role of community engagement in fostering sociotechnical change, and its relative absence in Jättesten could explain emerging frictions. Meanwhile, WUNergy demonstrates high stakeholder alignment and trust, one of the key ingredients for successful community energy models. The presence of transition intermediaries – especially in REPUBLICA and WUNergy – has been critical in maintaining collaboration, accelerating experimentation and translating learnings into policy feedback (Kivimaa *et al.* 2020).

The cases illustrate diverse innovation ecosystem dynamics, shaped by sectoral complementarities and actor interdependencies. In Am Kempelenpark, innovation is predominantly infrastructural and regulated, relying on district-wide planning frameworks and integrated sustainability standards. By contrast, Atelier REPUBLICA leverages a regulatory sandbox to enable experimentation with peer-to-peer energy markets and EMS innovations. WUNergy stands out as a mature ecosystem that blends technical innovation with cooperative governance, representing a replicable model for energy sharing. Mariatrost's ecosystem, while smaller in scale, exemplifies a values-driven innovation approach rooted in ecological and social objectives. Jättesten's strength lies in digital experimentation, particularly its use of digital twin technologies to inform retrofitting and energy simulations. However, its innovation trajectory risks becoming overly technocentric owing to limited user co-creation.

Application of the CVMT across the six cases highlights significant differences in how value is created, missed or destroyed. Atelier REPUBLICA and WUNergy capture multidimensional value by integrating environmental innovation, economic feasibility and strong social embedding. REPUBLICA's participatory mechanisms and WUNergy's cooperative trust systems result in fewer missed or destroyed values.

Overall, the comparative analysis reveals that successful ULLs balance institutional coordination with participatory experimentation. Projects with distributed governance and embedded value creation – like REPUBLICA and WUNergy – demonstrate higher adaptive capacity and legitimacy. Conversely, cases with centralised or siloed leadership face greater risks of value destruction and limited scalability.

5. GUIDING PRINCIPLES FOR ULL DESIGN

Based on the above comparative analysis, four key principles are presented for designing and implementing effective ULLs.

5.1 FOSTER HYBRID GOVERNANCE

Successful ULLs balance top-down institutional leadership with bottom-up, distributed governance. While centralised, municipality-led models like Am Kempelenpark ensure quality and regulatory alignment, they risk missing value from limited engagement. Conversely, grassroots initiatives like Mariatrost foster trust and social value but can be vulnerable to volunteer burnout and administrative gaps. The most resilient models, such as Atelier REPUBLICA and WUNergy, demonstrate a hybrid approach that allows for both oversight and multi-actor experimentation.

5.2 EMPOWER TRANSITION INTERMEDIARIES

The cases show that transition intermediaries – actors who bridge different institutional levels – are critical for success. Academic institutions and sustainability consultants, for example, can both produce niche innovations and influence regime-level policy. Local governments should actively support these brokers to translate project learnings into systemic change.

5.3 USE VALUE MAPPING STRATEGICALLY

Value is a multidimensional, not just economic, concept. Using tools like the CVMT from the start helps ULLs proactively identify opportunities and avoid value destruction. This approach ensures that the project's design is sensitive to the social, environmental and economic values of all stakeholders, preventing the loss of legitimacy that can result from exclusionary practices.

5.4 DESIGN FOR REPLICATION

A recurring challenge is the limited ability of ULLs to scale beyond a single project. To address this, ULLs should be designed as part of a continuous process of institutional learning, not as isolated experiments. Creating meta-governance platforms to systematically share knowledge and best practices across projects can help bridge the gap between niche experimentation and regime-wide adoption.

6. DISCUSSION AND CONCLUSIONS

This paper provides an exploration of how ULLs function as governance infrastructures in the development of PEDs and ECs. The comparative analysis of six European cases foregrounds the importance of actor configurations, governance modes, and value dynamics in shaping sociotechnical experimentation. Importantly, this research challenges dominant policy discourses that frame ULLs as universally replicable innovation templates. Instead, we argue for understanding ULLs as situated, path-dependent and institutionally co-produced arenas of urban transition.

One of the central contributions of this study lies in rethinking ULLs not as isolated pilots but as 'infrastructures for transition' (Petrescu *et al.* 2022; Scholl *et al.* 2022). This framing foregrounds their spatiotemporal embeddedness – how they articulate short-term experimentation with long-term transformation. ULLs that successfully integrate iterative co-creation, deliberative governance and reflexive learning – as exemplified by Atelier REPUBLICA and WUNergy – can mediate between niche innovation and regime adaptation (Frantzeskaki & Rok 2018). Conversely, cases such as Jättesten and Campus EC demonstrate that, when experimentation is siloed or overly technocratic, the potential for institutional embedding, social legitimacy and systemic scaling is diminished.

Drawing on the MLP, this study further explains how ULLs mediate interactions between niche actors, regime incumbents and landscape pressures. Our synthesis reveals that the success of ULLs is deeply influenced by the policy culture and institutional legacy of their host country. We observe that academic institutions frequently operate as transition intermediaries, simultaneously occupying multiple MLP levels – producing niche innovations while influencing regime discourse. This cross-level positioning (Kivimaa *et al.* 2020) is particularly potent in cities where universities act as conveners of municipal, industrial and civil society actors. However, such intermediaries must be embedded in governance architectures that promote reciprocity and transparency, rather than functioning as technocratic brokers disconnected from community agency (Bulkeley *et al.* 2019).

The integration of the CVMT allows for a granular understanding of how different ULLs generate, miss or destroy value. Our findings resonate with the conceptual shift from linear value chains to value constellations (Normann & Ramirez 1993), where multiple actors co-create, block or reframe value. In this sense, value is not a singular metric but a negotiated, context-dependent construct. Projects like Mariatrost demonstrate the power of commons-based value creation, grounded in ecological motivation and trust. By contrast, value destruction often results from governance misalignments – such as limited tenant inclusion or resistance from incumbent utilities – which prevent shared ownership and legitimacy.

The presented comparative synthesis shows that ULLs with mechanisms for deliberative governance – such as REPUBLICA's community feedback loops or Mariatrost's volunteer-led structures – are more likely to generate durable social and institutional value. Conversely, value destruction often results not from technical failure but from governance misalignment, legitimacy deficits or exclusionary design. ULLs therefore need to be assessed not only by what they innovate but by how they govern value processes and for whom.

A recurring challenge across our cases is the limited ability of ULLs to sustain momentum and scale beyond the demonstration phase. Even highly promising labs – such as Jättesten PED or WUNergy ESC – face barriers in translating niche experimentation into regime-wide adoption. This reflects both structural constraints (*e.g.* regulatory inertia, funding cycles) and a lack of institutional anchoring.

To overcome this, a shift is needed from viewing ULLs as isolated experiments towards seeing them as part of broader transition infrastructures (Voytenko *et al.* 2016). This aligns with recent calls for a meta-lab approach (Scholl *et al.* 2022), where institutional learning, cross-city knowledge exchange and reflexive governance are systematically integrated into the fabric of urban transformation strategies. This requires institutionalising learning processes, building meta-governance platforms and supporting transition intermediaries that can broker across niches, regimes and landscapes. It also entails designing ULLs with long-term governance capacity – not just technical novelty – as a central design criterion.

Future work should further explore the role of ULLs as long-term governance mechanisms, not only as project platforms. This includes tracing their institutional afterlives, evaluating their impact on regime change and understanding how they interact with different cultures of public administration. Moreover, comparative research should extend to diverse geographies, particularly in the global south, where the living lab model may intersect differently with informal governance and socio-ecological challenges.

Finally, there is a need to deepen the integration between qualitative process-tracing and participatory evaluation tools like the CVMT, to surface how different actors experience, contest and appropriate value in real time. Such approaches can help bridge the gap between innovation theory and lived urban governance, providing a more grounded understanding of how PEDs and ECs succeed or fail within complex institutional ecologies.

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COMPETING INTERESTS

The authors declare that they have no known competing financial or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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DATA AVAILABILITY

The primary data supporting the findings of this study – specifically the structured case documentation and expert templates – are not publicly available owing to intellectual property agreements within the consortium of the EU-funded project and the proprietary nature of some technical data provided by partner organisations. However, the data will be made available from the corresponding author upon reasonable request.

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