The Bioeconomy, Experimental Governance, and Spatial Planning

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Abstract
Spatial planning, deeply rooted in institutional contexts, is a key enabler of societal transitions towards sustainability. The governance structures that influence planning are shaped by institutional frameworks and regulations determining land-use and developmental decisions. While agendas like the bioeconomy offer pathways to sustainability, their implementation is often hindered by rigid governance, fragmented coordination, and slow processes stemming from divergent perspectives and institutional inertia. Sustainability-focused governance models can improve planning effectiveness. Experimental approaches such as testbeds and living labs encourage institutional learning and collaboration among stakeholders, enabling co-creation. However, they also introduce challenges related to stakeholder interests and power dynamics. This paper analyses the interplay between planning systems and sustainable transitions such as the bioeconomy, whilst exploring how experimental governance can address some these challenges.

Keywords: *the bioeconomy; spatial planning, sustainability transitions, experimental governance, living labs*

Introduction

"Deliberately steering societal change towards a desired future is an endeavor of tremendous size and complexity." (McCrory et al., 2018, p.3).

Sustainability transitions require profound shifts in socio-technical practices, behaviours, and governance to address complex challenges like climate change and inequality (Truffer et al., 2010). Contemporary research emphasises the need to navigate uncertainty, ambiguity, and non-linearity in these transitions, advocating for learning, reflexivity, and experimentation as adaptive strategies (McCrory et al., 2018).

A growing body of literature frames human settlements and natural environments as integrated socio-ecological systems (SES), characterised by dynamic, interconnected relationships across spatial and temporal scales (Martínez-Fernández et al., 2021). Spatial planning plays a crucial yet often underdeveloped role in managing these complexities, especially in emerging fields like the bioeconomy (Grossauer and Stoeglehner, 2020).

Urban experimentation has become a prominent approach, shifting from rigid planning to open, iterative exploration (Andersson et al., 2024). Urban experiments (UEs) are deliberate interventions designed to trigger sustainability transitions (Baatz et al., 2024), but their effectiveness is deeply shaped by the socio-ecological and spatial contexts in which they occur (Sauer et al., 2015). Researchers using socio-ecological systems frameworks realised that this approach didn't account for the role of technical infrastructure in urban areas (Andersson et al., 2024). This led to the development of 'social-ecological-technical systems' (SETs), which focus on interactions between ecological, social, and technological aspects (*ibid*). Current research uses this framework to analyse urban issues like risks, resilience, ecosystem services, justice, and nature-based solutions (*ibid*).

Urban experiments unfold within specific "sites" defined by unique socio-spatial configurations physical, cultural, and institutional which actively shape and are shaped by social actions (Baatz et al., 2024). These configurations influence both the outcomes of experiments and the potential for transformative change. Experiments can disrupt established routines, alter perceptions, and reshape regulatory or cultural aspects of space (Gaba and Bretagnolle, 2020; Ehnert, 2023).

Ultimately, effective sustainability transitions depend on the dynamic interplay between experimental governance, socio-ecological-techical systems, and spatial contexts. Recognising the embeddedness of agency within these configurations enables a more nuanced understanding of how transformative change can be facilitated or constrained (Gaba and Bretagnolle, 2020).

The Bioeconomy: Navigating Spatial Dynamics, Governance Challenges, and Inherent Tensions

The bioeconomy is widely recognised as a key strategy for providing essential goods, replacing non-renewable resources with renewables, and preserving natural resources (Wohlfahrt et al., 2019). It is central to current

sustainability transitions agendas, particularly within Europe (Halonen et al., 2022). The European Commission introduced the "knowledge-based bioeconomy" in 2005, emphasising the role of education, research, and collaboration in unlocking the value of biological resources across sectors (Birner, 2017; McCormick & Kautto, 2013). Since the early 2000s, the European Union (EU) has promoted bioeconomy policies at multiple levels, launching its bioeconomy strategy in 2012 and updating it in 2018 (Lühmann, 2020). This strategy aims to foster a low-carbon, sustainable growth model, focusing on food and energy security, biodiversity conservation, and effective resource management (Altoukhov et al., 2022; Ronzon et al., 2022).

Despite being touted as inherently sustainable, the bioeconomy faces criticism. Early emphasis on biotechnology led to a focus on innovation and technical fixes, often at the expense of interdisciplinary approaches and practical solutions (Priefer et al., 2017). Critics also highlight risks of commercialising nature, prioritising market interests over environmental and social well-being, and concerns about land grabbing and greenwashing (Birner, 2017). Thus, a comprehensive understanding of the bioeconomy must go beyond techno-economic perspectives, considering spatial and governance dimensions and inherent tensions (Wohlfahrt et al., 2019; Ahlqvist & Sirviö, 2019).

The bioeconomy's spatial dynamics are rooted in specific territories, relying on local biomass and value chains, and shaped by both local and global networks (Wohlfahrt et al., 2019). Its manifestations vary by scale: globally, it involves market-driven dynamics; nationally, it creates uneven development; regionally, it highlights tensions between industrial resource use and alternative land-uses (Ahlqvist & Sirviö, 2019). Strategic spatial planning is important in balancing environmental, social, and economic goals and addressing land-use conflicts (Grossauer & Stoeglehner, 2020).

While the bioeconomy offers potential for sustainable development, it is also subject to conflicts. Debates persist over whether it perpetuates capital accumulation within neo-liberal frameworks or can drive transformative change (Ahlqvist & Sirviö, 2019). Policy frameworks often favour corporate interests, risking continued resource exploitation and exceeding ecological limits (Ville, 2023). For instance, Finland's forest bioeconomy may reinforce resource extraction rather than rural revitalisation (ibid). Integrating sustainability and circularity principles is critical to avoid replicating traditional models (Holden et al., 2022). The "biosave regime," which prioritises reduced resource use based on ecological principles, has been proposed as an alternative to growth-oriented paradigms (Halonen et al., 2022). A comparative analysis of the "biosave regime" and other predominant regimes in bioeconomy development is provided in Figure 1.

	Biotech regime	Biomass regime	Biosave regime
Idea	Technical innovations resolve ecological problems with new 'less polluting' solutions	Renewing bioresources replace the 'more polluting/non-renewing' resources and thence resolve ecological problems. Requires more efficient use of the resources so the resource use does not increase	Degrowth and restricting the use of the resource to the minimum resolve socio-ecological problems. Techno-economic solutions have a minor role
Progress	Driven by markets - > R&D and investment support, and policies follows	Driven by normative policies and related R&D and investment support - > markets follow	Driven by normative policies and regulations - > markets follow
Role of institutions	Supporting of the markets	Guiding the markets and resource use	Restricting and restraining of the markets
Driving actors	Economic/market-oriented actors, e.g. companies, business organisations	Public organisations, NGOs	Public organisations, NGOs, citizens
Supporting/enabling actors	Public organisations, consumers	Companies, customers	Companies, customers

Figure 1: *Characteristics of bioeconomy regimes (Halonen et al., 2022, p.3).*

The bioeconomy faces a salient challenge of reconciling economic growth with finite biological resources and ecological boundaries (de Schutter et al.,2019). Current bioeconomy activities are often linked to environmental degradation (e.g. intensified agriculture and land conversion leading to habitat loss and disruption of local ecosystems) (*ibid*). While the bioeconomy can contribute to Sustainable Development Goals (SDGs), it can also undermine their achievement (*ibid*). A truly sustainable bioeconomy requires actively recognising the ecological foundation of all activities and the physical boundaries of social and economic systems (Pungas, 2023).

Moreover, the bioeconomy must grapple with questions of social justice and equity (Halonen et al., 2022). Ensuring an inclusive bioeconomy constitutes an active area of research. The concept of a 'just transition' is regarded as crucial for ensuring the sustainable transition to a bioeconomy that is equitable (Faulkner et al., 2024).

Therefore, while the bioeconomy presents prospective avenues for resource substitution and advancement towards sustainability, it embodies an intricate paradigm intrinsically linked to spatial considerations, governance frameworks, and the inherent discordance among economic expansion, ecological constraints, and equitable practices. The realisation of a sustainable bioeconomy mandates a comprehensive navigation of these multifaceted challenges via spatially nuanced regional integration, robust and harmonised governance mechanisms, and dedicated initiatives to confront fundamental contradictions and safeguard equity.

Theoretical Foundations

Institutional Frameworks in European Spatial Planning

Conventional spatial planning paradigms have been critiqued for their limited capacity to effectively address increasingly intricate and unpredictable challenges (Raynor et al., 2018). The complexity of these issues stems from their cross-sectoral nature, multi-scalar operation, and the involvement of diverse stakeholders with varying perspectives and values (*ibid*). Planning processes have often perpetuated existing inequalities and followed established trajectories, projecting current conditions onto future scenarios without critical evaluation (*ibid*). This reflects a broader issue of inflexibility and path dependency within socio-technical systems, which are understood as dynamically stable complexes shaped by the co-evolution of individuals, technology, and institutions (Jensen et al., 2019). These systems tend to evolve incrementally due to lock-in effects and path dependence, which impedes radical transformation (*ibid*). Furthermore, established administrative practices significantly influence the elasticity or rigidity of public administrations in response to reform initiatives (Polverari et al., 2024).

A further challenge lies in the sectoral nature of planning and governance (Hansen and Coenen, 2015). Governing sustainability transitions necessitates encompassing multiple policy areas (Polverari et al., 2024). However, planning systems often operate in silos, impeding policy integration (*ibid*). This can sometimes be linked to the different degrees of politicisation within the public sector (Kalogiannidis et al., 2024). Addressing complex interdependencies is difficult when governance functions are dispersed, especially within multi-level systems (*ibid*). While consensus-oriented approaches exist, the increasing complexity of governance implies that the ability of urban and regional authorities to control these processes may be diminishing, with some central regulatory functions transferred to national or supranational levels (Hansen and Coenen, 2015).

Importantly, transitions are inherently and deeply political (Jensen et al., 2019). They challenge existing relations of power and capital, involving trade-offs between competing visions of the future (*ibid*). Power asymmetries are central to the politics of transitions (*ibid*). Power dynamics can shape the organisation of knowledge and institutional arrangements, potentially emphasising particular aspects of urban systems while concealing others, thereby rendering some stakeholders and actions more significant than others (*ibid*). Unequal power relations can be masked by seemingly neutral concepts like 'sustainability' or 'best practices', which can be appropriated to legitimise particular agendas or practices (*ibid*). Different actors, such as policymakers, industry associations, social movements, technology manufacturers, and individual professionals, contribute to change, but their relationships, roles, and relative positions can shift as a transition unfolds (Farla et al., 2012). Incumbent actors with established networks are often expected to favour existing systems, while newcomers may push for alternatives (*ibid*). Understanding these power dynamics, the struggles between actors with competing interests, and the resources they mobilise is crucial for assessing the governing conditions under which sustainability transitions can materialise (*ibid*).

The convergence of systemic rigidity, fragmentation, and power imbalances poses substantial obstacles to achieving sustainability transformations. While urban sustainability experiments, defined as localised, intentional interventions designed to prototype alternative future scenarios are frequently undertaken, the translation of initial political support into effective governance mechanisms for systemic change remains limited (Jensen et al., 2019). These dynamics shape the persistence of established systems, the perpetuation of power inequalities, and the distribution of advantages and disadvantages. Advancing sustainability necessitates planning strategies that are more adaptable, resilient, and responsive, with a focus on inclusive stakeholder engagement and participatory processes (*ibid*). This entails a comprehensive understanding of systemic complexity and the inherent political dimensions of transformative change (Raynor et al., 2018). Future research should further investigate strategies for actors to effectively operate within existing systems and explore mechanisms for fostering collective action to catalyse sustainability transitions (Farla et al., 2012).

Introduction to Experimental Governance

The urgent need for a fundamental societal transformation toward sustainability presents major challenges for established governance and planning systems (Laakso et al., 2017). Traditional regulatory and bureaucratic frameworks often struggle to manage the complex, non-linear dynamics of sustainability transitions (ibid). These systems have also faced criticism for ambiguity and increasing commercial influence, particularly under neo-liberalisation and local financial constraints (Haderer, 2023).

Sustainability transitions research investigates how large-scale system change occurs and how actors can influence these processes (Laakso et al., 2017). A key concept is governing through experimentation defined as inclusive, practice-based, and challenge-led initiatives that promote system innovation and social learning amid uncertainty (Sengers et al., 2019). Experimentation is seen as a vital governance tool for fostering innovation and transformative change (Kivimaa et al., 2017).

Experimental governance, alongside approaches like Strategic Niche Management (SNM) and Transition Management (TM), offers alternatives to rigid, fragmented planning (Kok, 2022). Unlike hierarchical, command-and-control regulation, experimental governance supports adaptable, exploratory, and reflexive strategies that mobilise diverse actors, develop shared visions, scale innovations, and foster learning (Kivimaa et al., 2017; Kok, 2022). It emphasises stakeholder inclusion, deliberation, and co-creation, recognising that transformative change requires collaborative and multi-actor processes (Kok, 2022).

In urban and spatial planning, experimental governance is operationalised through testbeds, living labs, and innovation districts dedicated arenas for collaboration and real-world testing of solutions (Berglund-Snodgrass & Mukhtar-Landgren, 2020). These labs prioritise co-innovation and co-creation, with continuous feedback between users and innovators, enhancing participatory planning (Massuga et al., 2024; McCrory et al., 2018; Knickel et al., 2021). Intermediary actors, such as spatial planners, often facilitate stakeholder engagement and balance diverse interests (Berglund-Snodgrass & Mukhtar-Landgren, 2020; Kok, 2022).

However, integrating experimental governance within traditional systems is challenging, requiring policy changes and risking fragmented or short-term outcomes (Grönholm, 2022). There are concerns about neo-liberal co-optation, reduced accountability, and the sidelining of public authority (Haderer, 2023). Addressing these risks demands systemic changes, democratised co-production, and reconceptualised governance to align with experimental approaches (Kok, 2022; Haderer, 2023). Ultimately, successful experimental governance in spatial planning requires intentional, coordinated efforts to confront political dynamics and avoid reinforcing existing inequities (Kok, 2022).

Living Labs as a Mechanism of Experimental Governance: Conceptualisations, Open Innovation Ecosystems, and Their Role in Advancing Sustainable Regional Development

Experimental governance, characterised by "learning by doing" and adaptive objective-setting, provides a valuable framework for addressing the complexities of sustainability transitions (Van Poeck et al., 2020). It involves actively testing new forms of territorial governance and engaging diverse stakeholders to tackle multifaceted societal challenges (*ibid*). Within this context, Living Labs (LLs) have emerged as prominent mechanisms, functioning as "societal laboratories" that foster innovation and experimentation in real-world settings (Eneqvist, 2022).

LLs are closely related to "testbeds" and "real-world laboratories," representing an experimental, co-creative approach to innovation policy (Engels et al., 2019). They are defined as user-centred, open innovation ecosystems that integrate research and innovation processes in real-life communities (ibid). LLs aim to test, demonstrate, and advance new socio-technical arrangements and governance modes under real-world conditions (Lupp et al., 2021). A central feature is their emphasis on placing citizens at the heart of innovation, fostering collaborative partnerships among public, private, and community stakeholders (Engels et al., 2019; Lupp et al., 2021). These environments enable experimental and experiential learning, involving diverse users and stakeholders (Mbatha & Musango, 2022). However, not all initiatives labelled as LLs align with these core principles (ibid). LLs can also serve as sites where the meaning of sustainability is contested and negotiated (McCrory et al., 2022).

A typology of sustainability-oriented labs includes "empower and govern" labs, which are partnership-based and focus on understanding and responding to complex sustainability challenges, often at the urban level (Mbatha & Musango, 2022). These labs catalyse relational or institutional experimentation rather than solely technical or commercial innovation (McCrory et al., 2022). LLs are intrinsically linked to spatial contexts, frequently situated in cities, neighbourhoods, or regions (Lupp et al., 2021; Mbatha & Musango, 2022). They expedite co-creation and implementation across value chains, as seen in agricultural LLs (Lupp et al., 2021; Martins et al., 2025). Their key features include fostering innovation, openness, spontaneity, knowledge generation, and the development of sustainable solutions (Martins et al., 2025).

LL methodologies are iterative and phase-based, typically involving problem understanding, stakeholder engagement, solution development and testing, and outcome evaluation (Lupp et al., 2021). Evaluation often using theory-driven or developmental approaches is crucial for supporting generative experimentation and producing actionable knowledge (Dekker et al., 2021).

LLs are increasingly used to support urban planning, enabling transformative place-making and the shaping of socio-spatial identities (Eneqvist, 2022; von Wirth et al., 2018). They make experimentation tangible for landscape and nature-based solutions by functioning as both virtual and real spaces (Lupp et al., 2021). Urban LLs are experimental forms of governance designed to address urbanisation, climate change, and resilience (Mbatha & Musango, 2022), while regional LLs promote sustainable regional planning (ibid). Implementation can be challenging due to tensions with traditional planning practices, but regulatory flexibility within LLs can foster creativity and innovation (Lupp et al., 2021).

Experimental governance and LLs are increasingly seen as essential for advancing sustainability transitions, acting as real-world laboratories to test and refine solutions (von Wirth et al., 2018). Addressing sustainability challenges requires deep system-level innovation (McCrory et al., 2022). LLs enable regions to experiment with new ideas and engage with complex issues, aligning with the broader goals of sustainability transitions. They also serve as platforms for societal reflection and learning (ibid). Labs may pursue incremental or disruptive change, contributing to global sustainability transitions and supporting UN Sustainable Development Goals, such as protecting cultural and natural heritage (SDG 11.4) (Pastorelli, 2022). The regenerative development approach, which shares elements with LLs, further informs their potential to address root causes of unsustainable development and redesign humanity's relationship with the planet (ibid).

Living Labs and the Regional Advancement of the Bioeconomy

The shift towards a sustainable bioeconomy system is increasingly recognised as important, with regions playing a central role in driving this change (Szarka et al., 2023). While most strategies and policies have been formed at the national level, there is growing awareness of the need for regional bioeconomy strategies to capitalise on local strengths and priorities, because industrial activities tend to be concentrated regionally (Ayrapetyan et al., 2022).

Regional development is a multifaceted concept that extends beyond just economic growth (Medeiros, 2022). It should encompass a broader range of factors contributing to the overall well-being of a region, such as social equity, environmental sustainability, institutional strength, governance effectiveness, and spatial planning (*ibid*). Economic growth remains a component but should not be the sole focus.

Traditional regional development theories centred on economic growth fail to adequately capture the multi-dimensional nature of development and the importance of integrated, place-based approaches (*ibid*). This has led to the emergence of alternative paradigms like sustainable development, place-based development, and knowledge-based development, which adopt more holistic, location-specific perspectives (Barca, 2009).

LLs and experimental governance are being applied to study and promote the bioeconomy (Pinsky et al., 2024). Experimental governance using LLs can help shift stakeholders from conflicts based on different economic interests towards cooperative solutions (*ibid*).

However, advancing the regional bioeconomy through this approach faces challenges, including policy coordination issues, limited collective action among actors, and a lack of incentives for systematic experimentation and learning from local experiences (Pinsky et al., 2024). Key elements for unlocking the potential of experimental governance in this domain include political will, a long-term strategy based on metrics, and a system for peer review of local experiments to support policy decisions and joint learning (ibid). The experimental problem-solving approach can have a significant impact by demonstrating and replicating successful initiatives, fostering systematic learning, and promoting socio-economic opportunities alongside environmental conservation (ibid). LLs serve as a potential mechanism within the broader framework of experimental governance, providing real-world sites and methodologies for testing, learning, and co-creating solutions to complex challenges. As open innovation ecosystems, they bring together diverse actors, to develop place-based innovations. Their link to spatial contexts makes them relevant for urban and regional planning, while their focus on experimentation and multi-stakeholder involvement positions them as key enablers for sustainable transitions. Applied to the regional bioeconomy, experimental governance facilitated by LLs offers a valuable pathway towards fostering sustainable growth, collaboration, and systemic learning, despite challenges related to coordination and institutional capacity. Successful application depends on developing organisational capacity within public institutions, ensuring democratic legitimacy, and strategically embedding experimental practices. The conceptual diagram illustrates the interconnectedness of experimental governance, bioeconomy, strategic spatial planning, socio-ecological-technological systems (SETs), living labs, and urban experimentation (see Figure 2).

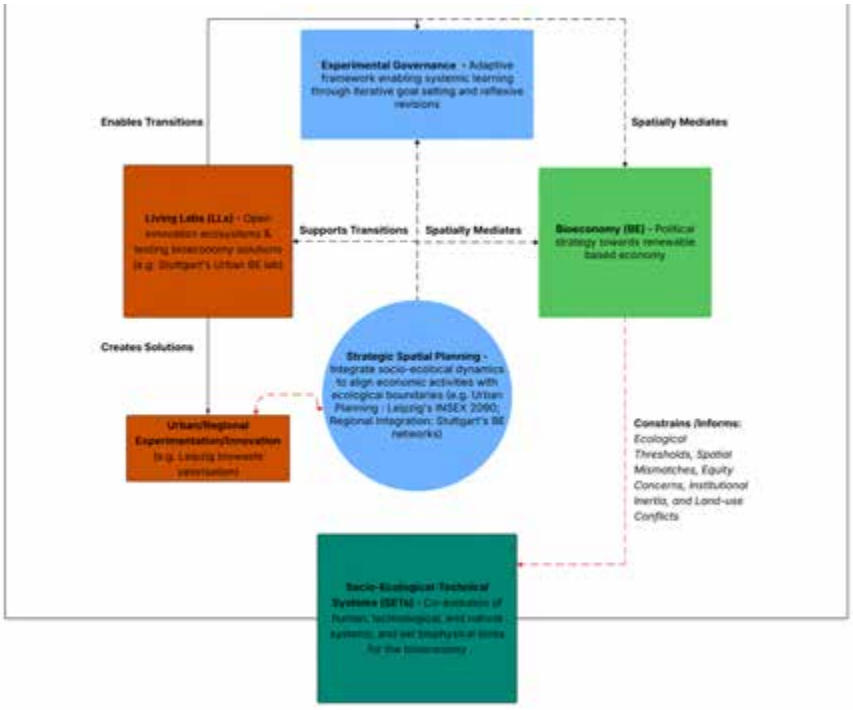

Figure 2: *Conceptual diagram showing the interconnectedness experimental governance, bioeconomy, strategic spatial planning, socio-ecological-technological systems (SETs), living labs, and urban experimentation (de Almeida, 2025)*

Methodology
This study adopts a qualitative, comparative case study design to investigate how experimental governance particularly through living labs and strategic spatial planning advances bioeconomy transitions in urban regions. The research focuses on two German cities, Stuttgart and Leipzig, selected for their contrasting yet complementary approaches to integrating innovation ecosystems and territorial coordination within Germany's national bioeconomy strategy.

Case study selection and rationale:
Stuttgart exemplifies a technical, living lab-driven model, operationalising experimental governance through the Circular Bioeconomy Strategy (ZirBioS) and the Urban Bioeconomy Lab, which integrate cascading biomass use and cross-sectoral stakeholder platforms into urban redevelopment. Leipzig, by contrast, is analysed for its policy-driven "bio-principled city" vision, embedding bioeconomy goals within the Integrated Urban Development Concept (INSEK) 2030 and piloting innovative public-private partnerships for biowaste valorisation and urban agriculture.

Data collections:
- Peer-reviewed journal articles with the broad fields of spatial planning and urban studies, urban governance, experimental governance, sustainability transition and socio-technical studies, bioeconomy and circular economy, political science and power dynamics, and environmental policy and justice.
- Policy document analysis of strategic plans (Stuttgart and Leipzig).

Analytical Framework:
A socio-ecological-technological systems (SETs) perspective is employed to assess institutional alignment, stakeholder power dynamics, spatial-material integration, and the outcomes of experimental governance. Comparative analysis highlights how multi-level governance, network structures, and spatial planning instruments mediate the effectiveness and equity of bioeconomy transitions.

Comprehensive Analysis of German Bioeconomy Transitions: Stuttgart and Leipzig Case Studies
This analysis examines experimental governance approaches to bioeconomy development in two German cities, revealing how spatial planning mediates sustainability transitions through institutional innovation and multi-stakeholder coordination. The contrasting experiences of Stuttgart and Leipzig demonstrate both the potential and limitations of experimental governance mechanisms in advancing urban bioeconomy strategies, highlighting critical factors that influence the effectiveness of spatially embedded policy integration within Germany's national bioeconomy framework.

Germany's Approach to Bioeconomy Transition: Comparative Case Studies
National Context and Urban Opportunities
The transition towards a sustainable bioeconomy represents a key strategic priority for Germany, supported by comprehensive national strategies implemented since 2010 (Wen, 2024). While rural areas have traditionally been prioritised for their biomass potential, urban regions increasingly offer significant opportunities, particularly through knowledge creation and innovation networks (Stöber et al., 2023). This analysis explores bioeconomy advancement in Stuttgart and Leipzig, two German cities that exemplify distinct approaches to experimental governance, strategic spatial planning, and institutional coordination within the broader context of national bioeconomy policy.

The involvement of diverse industries, including process and mechanical engineering, highlights the cross-sectoral nature and economic relevance of the bioeconomy beyond traditional bio-based sectors (Stöber et al., 2023). This approach demonstrates experimental governance through targeted research funding and network analysis designed to understand knowledge dynamics (ibid). However, the concentration of funding and projects among large, established actors suggests potential structural limitations, possibly hindering wider participation and network resilience across different stakeholder groups (ibid).

Stuttgart: Living Labs and Circular Bioeconomy Integration
Stuttgart's selection as a case study is anchored in its adoption of living lab methodologies to test bioeconomy solutions within urban-industrial systems. The city's Circular Bioeconomy Strategy (ZirBioS) operationalises experimental governance by prioritising cascading biomass use, carbon sink development, and cross-sectoral stakeholder platforms (Schuchardt et al., 2024). The Urban Bioeconomy Lab, a Fraunhofer Institute-led initiative, functions as a "transformation model" where municipal authorities, industries, and researchers co-design circular systems for wastewater, biowaste, and construction materials (*ibid*). This approach aligns with academic frameworks emphasising spatial experimentation as a tool for overcoming sectoral fragmentation in bioeconomy transitions (Stöber et al., 2023).

Stuttgart's strategic spatial planning further mediates these experimental initiatives through institutional coordination mechanisms. The Preparatory Land-Use Plan integrates bioeconomy objectives into urban redevelopment processes, ensuring that brownfield sites and industrial corridors are systematically repurposed for bio-based value chains (Dieckhoff et al., 2020). Academic analyses highlight how such spatial coordination enables Stuttgart to reconcile competing land-use demands while scaling pilot projects from experimental phases to broader implementation (Stöber et al., 2023). The city's governance model combines Baden-Württemberg's state bioeconomy strategy with municipal spatial planning, providing a replicable blueprint for multi-level experimentation across different administrative scales (Bioregions Facility, 2023).

Stuttgart's Network Dynamics and Institutional Challenges
Despite these innovative approaches, Stuttgart's bioeconomy innovation network exhibits concerning centralised characteristics that limit broader participation and systemic resilience (Stöber et al., 2023). The University of Hohenheim, the Fraunhofer Institute, and the University of Stuttgart have been identified as key gatekeeping institutions that control knowledge inflow and diffusion within the regional network (*ibid*). This concentration of institutional influence is mirrored in resource allocation patterns, where federal funding disproportionately benefits established research actors, allowing them to "soak up funding and relevant knowledge" while marginalising smaller stakeholders (*ibid*). Such dynamics can lead to "weak network failures," limiting collaboration and innovation among less-connected, peripheral actors and ultimately hindering the overall resilience and inclusivity of the regional innovation ecosystem (*ibid*).

Leipzig: Bio-Principled City Vision and Policy Coordination Challenges
In contrast to Stuttgart's technical focus, the Leipzig case study examines policy frameworks for transitioning towards a "bio-principled city," a comprehensive vision that integrates biological principles into urban life for enhanced sustainability and resilience (Boldt and Thrän,2023). Research indicates that Leipzig's current policy mix for this transition remains complex, uncoordinated, and lacks definitive implementation actions (*ibid*). The bioeconomy is explicitly addressed mainly at supra-national and national levels, with limited focus at state or municipal levels, despite local initiatives such as Leipzig's bioeconomy working group (*ibid*). This situation highlights significant flaws in vertical policy coordination and reveals the limited autonomy of German local governments, which remain dependent on higher policy levels and earmarked funding mechanisms (*ibid*).

Leipzig showcases elements of experimental governance through its integration of bioeconomy principles into cross-sectoral urban development frameworks. The Integrated Urban Development Concept (INSEK) 2030 embeds bioeconomy targets within a holistic vision for sustainable growth, linking circular economy initiatives such as zero-waste centres to spatial priorities including green corridors and mixed-use districts (Heinig et al., 2018). This approach reflects the New Leipzig Charter's emphasis on transformative, multi-stakeholder governance, which academic literature identifies as critical for aligning bioeconomy transitions with socio-ecological resilience objectives (Risi et al., 2020; Zeug et al., 2021).

Leipzig's Experimental Mechanisms and Governance Constraints
Leipzig's experimental governance is further evidenced by its adaptive policy mechanisms and innovative funding approaches (Kramer et al., 2024). The city's green recovery projects, funded through federal programs, test novel public-private partnerships for biowaste valorisation and urban agriculture initiatives (*ibid*).

These projects are spatially mediated through Structural Concepts that allocate land for biorefineries and community composting hubs, ensuring bioeconomy innovations align with demographic and climatic realities (Heinig et al., 2018), Academic studies note Leipzig's success in leveraging EU funding to pilot spatially targeted governance models, representing a key criterion for case study selection in sustainability transitions research (Zeug et al., 2021).

Despite these pioneering efforts in urban bioeconomy initiatives and commitment to developing "bio-principled city" concepts, Leipzig reveals significant power asymmetries at the multi-level governance scale (Boldt and Thrän, 2023). Policy-making is predominantly driven by supra-national and national actors, particularly the European Commission, constraining German local governments' financial and political capacity to implement bioeconomy transitions effectively (*ibid*). This dependency restricts their capacity for independent experimental governance and urban innovation (ibid). Furthermore, while broad stakeholder involvement is deemed essential, the lack of capacity and financial resources for comprehensive cooperation at the local level indicates that power imbalances can marginalize vital local participation (*ibid*).

Comparative Analysis of Experimental Governance Outcomes
Contrasting Governance Effectiveness
The contrasting experiences of Stuttgart and Leipzig highlight key determinants of effective experimental governance in bioeconomy-oriented spatial planning. Stuttgart's Urban Bioeconomy Lab demonstrated success through multi-level coordination, technical mediation, and spatial integration (Ministry of the Environment BW & Ministry of Rural Affairs BW, 2019). By embedding circular bioeconomy principles into land-use planning, Stuttgart enabled scalable pilot projects and resource circularity (Schuchardt et al., 2024). The Fraunhofer Institute's intermediary role fostered iterative learning and policy refinement (Federal Ministry of Education and Research, 2025). However, Stuttgart's centralised innovation network concentrated resources among dominant institutions, marginalising SMEs and grassroots actors (Stöber et al., 2023).

In contrast, Leipzig's INSEK 2030 struggled with vertical policy misalignment and limited local autonomy, impeding the translation of its bioeconomy vision into action (Boldt & Thrän, 2023; Webb et al., 2023). Fragmented coordination, rigid funding, and weak SME engagement further constrained Leipzig's circular bioeconomy initiatives (Webb et al., 2023).

Critical Success Factors for Experimental Governance
Effective experimental governance in bioeconomy transitions depends on several key conditions. Multi-level institutional alignment is fundamental: Stuttgart's success was driven by synergies between the Baden-Württemberg state bioeconomy strategy and municipal planning, which supported living labs (Webb et al., 2023). In contrast, Leipzig's fragmented policy mix revealed how misaligned agendas can undermine experimentation. Decentralised innovation networks are also crucial—while Stuttgart's centralised hubs accelerated technical solutions, they limited diversity and inclusion; Leipzig's lack of intermediaries hindered knowledge diffusion. Balancing technical efficiency with grassroots participation is essential. Spatial-material integration matters as well: Stuttgart's land-use plans anchored experiments in industrial ecosystems, enabling resource circularity (Schuchardt et al., 2024), whereas Leipzig's broad visions lacked spatial specificity, delaying implementation (Webb et al., 2023). Finally, financial and political autonomy empowers adaptive management, as seen in Stuttgart, while rigid federal funding constrained Leipzig (Ministry of the Environment BW & Ministry of Rural Affairs BW, 2019; Webb et al., 2023).

Strategic Implications and Future Directions
Both cases address strategic spatial planning dimensions that reveal important insights for bioeconomy development. Stuttgart's analysis differentiates network structures at regional and supra-regional levels, demonstrating how spatial scale influences innovation dynamics (Stöber et al., 2023). Leipzig's study strongly emphasises the urban-rural relationship, arguing that establishing the bioeconomy cannot be limited to urban areas due to biomass resource constraints (Boldt and Thrän, 2023). The city is envisioned as a nucleus driving regional structural change by revitalising urban-rural ties and fostering regional value-added networks (*ibid*). However, this approach requires improved connections to rural areas and greater involvement of SMEs, which are currently lacking (ibid).

The studies reveal key areas requiring further research and policy development. For Stuttgart, similar analyses in other urban regions are needed to validate findings and uncover regional differences (Stöber et al., 2023). For Leipzig, future work should assess how the policy mix can be improved and adapted to accelerate transitions, including mechanisms to ensure adequate funding at local levels (Boldt and Thrän, 2023). More broadly, empirical evidence is needed on the effectiveness of institutional innovations like bio-clusters on green productivity, and comparative studies across countries with different bioeconomy strategies would yield valuable insights (*ibid*).

Failure in experimental governance arises when experiments remain siloed or subordinated to incompatible higher-level agendas, as demonstrated by Leipzig's fragmented policy landscape. Future strategies should prioritise polycentric governance models that distribute agency across sectors and scales, ensuring bioeconomy transitions align with place-specific socio-ecological realities (O'Connor et al., 2023). While Stuttgart and Leipzig showcase potential avenues for bioeconomy advancement through innovation networks and integrated urban-rural systems, their experiences underscore the challenges of translating national strategies into coherent, effective local action. The current governance landscape, characterised by uncoordinated policies and limited local autonomy, reflects an experimental phase still in its 'infancy' with identifiable structural flaws. Addressing these issues through targeted policy interventions and continued research is crucial for realising the transformative potential of urban and regional bioeconomy development in Germany and across Europe more generally. See Table 1 for a comparative summary of experimental governance and bioeconomy spatial planning in Stuttgart and Leipzig, Germany.

Table 1: *Comparative Summary of Experimental Governance and Bioeconomy Spatial Planning in Stuttgart and Leipzig (de Almeida, 2025).*

Aspect	Stuttgart	Leipzig
Strategic Vision	Circular bioeconomy strategy (ZirBioS) with clear municipal and state alignment; vision operationalised through land-use planning and cascading biomass systems.	"Bio-principled city" vision embedded in INSEK 2030; remains mostly programmatic with limited concrete actions at local level.
Governance Structure	Strong multi-level coordination (municipal, state, research institutes); centralized innovation network with key gatekeepers (Fraunhofer, Hohenheim, Stuttgart University).	Fragmented policy mix; high dependence on supra-national/national directives and earmarked funds; weak local autonomy.
Experimental Approaches	Living Labs (Urban Bioeconomy Lab) as real-world testbeds for circular systems; pilots in biowaste, wastewater, construction materials.	Urban experiments in green recovery, biowaste valorisation, and urban-rural biomass networks; limited spatial and institutional integration.
Stakeholder Involvement	Broad mapping of stakeholders but practical influence concentrated among large institutions; SMEs and grassroots actors marginalised.	Policy rhetoric supports broad participation, but lack of resources, capacity, and SME engagement limits real involvement.
Spatial Planning Integration	Bioeconomy targets integrated into Preparatory Land-Use Plan; brownfield and industrial corridors repurposed for bio-based value chains.	Bioeconomy principles referenced in spatial plans, but urban-rural linkages and land allocation for biorefineries remain underdeveloped.
Key Successes	Scalable pilot projects; institutional learning; spatial mediation of bioeconomy; strong technical expertise and iterative policy refinement.	Piloting of new public-private partnerships; leveraging of EU funding for targeted innovation; recognition of urban-rural interdependencies.
Key Challenges/Failures	Centralized network limits resilience and innovation diversity; risk of "weak network failure" and knowledge gatekeeping.	Policy fragmentation, lack of vertical coordination, insufficient local autonomy, and weak translation from vision to action.
Lessons for Experimental Governance	Success linked to multi-level alignment, spatial-material integration, and financial/political autonomy; risk of exclusion if networks are too centralised.	Effective governance requires improved coordination, empowerment of local actors, and concrete mechanisms for stakeholder engagement and resource flows.

Discussion

The advancement of the bioeconomy, a key strategy for sustainability transitions, is shaped by the interplay of governance, spatial dynamics, and institutional contexts. Spatial planning plays a crucial, though often underdeveloped, role in navigating the complexities of the socio-ecological-technological systems central to the bioeconomy. Traditional planning frameworks marked by rigidity, fragmentation, and power imbalances can impede transformative change, as dominant interests may shape strategic visions and institutional inertia discourages experimental approaches.

Experimental governance, including strategies like Urban Experiments (UEs) and Living Labs (LLs), has emerged as a promising response to these challenges. These approaches advocate adaptive, reflexive, and exploratory governance that involves diverse stakeholders. LLs, in particular, act as user-centric, open innovation ecosystems embedded in real-world settings, fostering co-creation and collaborative innovation processes, often in urban or regional contexts. Such initiatives make experimentation more tangible and applicable to spatial issues.

However, the application of experimental governance faces significant obstacles. The Stuttgart case study demonstrates that bioeconomy innovation networks often revolve around prominent institutions acting as knowledge gatekeepers, with funding and projects concentrated among large, established actors potentially limiting wider stakeholder participation. The Leipzig case highlights difficulties in translating conceptual ideas into practice, revealing a fragmented and uncoordinated policy landscape and weak vertical policy coordination. This underscores the importance of urban-rural relationships but also reveals insufficient connections and SME involvement needed for effective regional transformation.

A fundamental challenge is the spatial nature of the bioeconomy, which involves production, processing, and consumption in specific locations, leading to geographical contradictions and uneven development, potentially creating resource peripheries. Spatial mismatches where governance boundaries do not align with environmental or social issues are critical, as is institutional fragmentation, which hinders the coherent implementation of experimental approaches. Addressing bioeconomy transitions effectively requires spatially integrated and regionally differentiated strategies that can navigate these complexities.

Conclusion

Steering societal transitions toward sustainability particularly through the bioeconomy is a complex challenge. While the bioeconomy promises to replace non-renewable resources and advance sustainability, its implementation is hampered by rigid governance, fragmented coordination, and institutional inertia. Power dynamics and resistance from incumbent actors further impede transformative change and experimentation. The bioeconomy's success is also shaped by spatial considerations and tensions between economic growth, ecological limits, and equity, often resulting in uneven development and spatial mismatches in governance.

Spatial planning, rooted in institutional contexts, is a crucial enabler for these transitions. When combined with a socio-ecological systems perspective, spatial planning helps map opportunities and threats, set strategic direction, and foster innovation. Experimental governance through mechanisms like testbeds and Living Labs (LLs) offers a way to address the inflexibility of traditional systems. LLs serve as real-world sites for co-creation and learning, encouraging institutional learning and collaboration, and marking a shift from top-down governance to more decentralised, participatory approaches.

However, integrating experimental governance within spatial planning is not without challenges. There is a risk of fragmentation or co-optation by powerful interests, which can perpetuate existing inequities. Overcoming these barriers requires a fundamental rethinking of systemic structures and power relations. Case studies highlight practical difficulties, such as innovation networks favouring established actors and the complexities of coordinating policy across urban and rural contexts.

Achieving a truly sustainable bioeconomy demands spatially nuanced regional integration, robust and harmonised governance mechanisms, and initiatives that address fundamental contradictions and promote equity. Multi-level governance coordinating efforts from international to local scales is essential.

Ongoing research is needed to develop strategies for collective action, spatially explicit governance instruments, and effective regional bioeconomy approaches. Ultimately, successful transitions depend not just on innovative interventions, but on their dynamic alignment with local social and ecological processes.

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