Anticipating bioeconomy transitions: An integrative systems approach for exploring uncertain futures

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Abstract

This paper addresses the contested nature of Europe's bioeconomy transition by developing an innovative methodological framework that integrates qualitative stakeholder insights with quantitative System Dynamics modeling. The bioeconomy, defined as the use of renewable biological resources to produce food, materials, and energy, has become central in European policy discourse as essential for achieving circular and low-carbon economies. However, this transition reveals fundamental tensions between competing visions, including industrial biotechnology focused on growth and global competitiveness, regional circularity emphasizing local development, and ecological sufficiency prioritizing reduced consumption and social justice.

Current future-oriented approaches to understanding these transitions show significant gaps - quantitative models typically emphasize technological change and economic growth while overlooking critical political dynamics, ecological sufficiency policies, and questions of social justice. Conversely, qualitative foresight approaches such as scenario workshops often lack explicit clarity on system interactions and internal consistency, limiting their ability to generate robust insights.

The integrative approach developed here employs a four-step iterative cycle: (1) Uncovering competing visions through literature review and analysis of eight position papers and blueprints recently published in relation to the upcoming update of the EU Bioeconomy Strategy; (2) Mapping system interactions via causal loop diagrams that make feedback loops visible; (3) Anticipating system behaviors through System Dynamics simulation modeling to explore nonlinearities and unintended consequences; and (4) Enabling transformation through multi-level stakeholder co-design processes that ensure outcomes are practical, legitimate, and actionable.

This methodology extends Blumberga et al.'s (2018) "biotechonomy" modular model by explicitly incorporating ecological sufficiency dynamics and industrial resistance feedback loops. The approach illuminates potential pathways toward an ecological bioeconomy while simultaneously highlighting systemic resistances that may emerge. By modeling how policies like consumption caps on resource-intensive bio-products can trigger counteracting responses from industrial stakeholders, it reveals the complex dynamics that may shift trajectories away from sustainability, enabling more robust transition strategies.

Through empirical application involving stakeholders from European NGOs, we demonstrate

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how this approach clarifies critical trade-offs, identifies leverage points, anticipates resistance, and develops actionable pathways toward ecological sufficiency and social justice. The research contributes both methodological innovation for sustainability transitions research and practical insights for policymakers navigating the complex socio-ecological challenges of bioeconomy transitions.

Keywords: Bioeconomy transition, system dynamics, stakeholder engagement, ecological sufficiency, futures thinking, causal loop diagrams, policy pathways, contested visions, transformative change