
How do Innovation Ecosystems facilitate Circular Economy through reuse as a material? System dynamic drivers in the European Textile

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Abstract

How Innovation Ecosystems Facilitate Circular Economy Implementation through Reuse as a Material in the European Textile Sector Summary

Circular Economy (CE) is understood as the regenerative system approached through a systems perspective (Kirchherr, Reike, and Hekkert 2017). This study focuses on the European textile and apparel sector, a dynamic example of CE transitions triggered by evolving EU regulations. These regulations emphasize recycling, sustainable design, and industrial symbiosis, particularly for polycotton, a blend of cotton and synthetic fibers. Traditional supply chain frameworks struggle to address the complexities of CE transitions, leading to the adoption of innovation ecosystem theories. This approach facilitates inter-supply chain connectivity, systemic interactions, and stakeholder engagement, including consumers.

Key research questions are: 1. What are the key drivers in the circular innovation ecosystem for textiles? And 2. To what extent can identifying innovation drivers for "reuse as a material" inform strategies for polycotton circularity?

The CE concept has gained momentum in Europe, supported by initiatives such as the French Anti-Waste Law (2022) and Extended Producer Responsibility (EPR) policies. These regulations encourage businesses to rethink textile reuse across three streams: post-industrial, pre-consumer, and post-consumer waste. Each stream presents unique challenges and opportunities for maximizing value through circular strategies.

While supply chain management frameworks have historically supported resource optimization, they face limitations in addressing CE complexities. Challenges include insufficient stakeholder integration, limited macro-environmental considerations, and a lack of dynamic feedback loops. Emerging concepts, such as green supply chains (Plaza-Úbeda et al. 2020) and sustainable supply chain management (Centobelli et al. 2022), partially address these gaps but fail to offer holistic solutions.

Innovation ecosystems (Tolstykh, Shmeleva, and Gamidullaeva 2020) provide a robust framework for CE transitions. By fostering systemic interdependence, dynamic interactions, and stakeholder diversity, this approach overcomes the limitations of linear supply chains. Key mechanisms include biochemical recycling, circular design, and industrial symbiosis, which

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collectively enhance material reuse and resource efficiency. For example, industrial symbiosis promotes inter-supply chain collaboration, transforming waste into valuable inputs for other industries.

Our present study entails a hybrid research protocol design including the use of qualitative and quantitative analysis methods, to provide an alternative analytical tool able to handle the complexity, inter-supply chain connection, macro-environmental impact and consumers influence that the available supply chain Planning, Logistics management and Inventory management tools do not offer. The presented protocol represents an original and novel design to be highlighted as one of the main outcomes of the study. The reason of using a hybrid research methodology that integrates a comprehensive literature review, expert opinions, and quantitative analysis offers is supported by the comprehensive understanding offered by the integration of a literature review, that provides a strong theoretical foundation, and the practical relevance gathered from the diverse insights obtained from the 10 experts across different roles, organizations and origins. The panel of experts is composed by scholars affiliated to the Kauno Waste Management Centre, Ministry of Economy and Innovation of the Republic of Lithuania, Circular Economy Forum in Austria, Technical University of Crete, Deutsche Bundesstiftung Umwelt, ECOPAL, Université de Lorraine, Universidad de Almería, University of Graz, and University of Pisa from seven European countries (Lithuania, Austria, Germany, Greece, Italy, Spain and France) that help us to improve our understanding of the causal relationships among drivers of the European Textile Ecosystem.

The research protocol design emerges as the first part of the protocol followed by the research methods implementation applied to the group of 10 experts in business and academic contexts, such as environmental transition, sustainable development, digital transformation, innovation ecosystems, supply chain management, and/or circular economy in Europe. This expert group's diversity ensures a variety of viewpoints, reduces bias, and incorporates region-specific insights into circularity drivers. Including practitioners alongside scholars and researchers ensures that the research findings are not just theoretical but are also relevant and applicable to real-world practices.

The quantitative analysis of the Causality matrix, network analysis, and Causal Systems Diagram, provides an objective way to validate the qualitative insights from experts, strengthening the credibility and reliability of the findings and facilitating a systematic understanding of interdependencies and causal relationships among circularity drivers. This helps prioritize the most influential factors for targeted interventions. The combination of qualitative and quantitative methods ensures a nuanced understanding that can better inform decision-making processes, policies, and strategies for circularity initiatives. The methods triangulation (literature review, expert opinions, and quantitative analysis) particularly suited for complex, multi-faceted topics like circularity, ensures the study is both deep and robust, minimizing the limitations inherent in using a single methodology. The methodology emphasizes stakeholder diversity and systemic approaches, enabling a comprehensive understanding of CE drivers in the European Textile Ecosystem.

The results are empirically validated through the textile and apparel case study, proposing a systemic and dynamic tool to analyze the CIE while identifying the major challenges and the forthcoming avenues of research and investment in the system. The author decided to limit the ecosystem boundaries of the textile and apparel sector analysis to Europe because the European Commission is developing a comprehensive set of new stringent regulations associated with the EU strategy for sustainable and circular textiles. A comprehensive analysis of the way textiles and apparels are sorted, recycled, designed, manufactured, and handled at the end of their life promoting the identification of the key-drivers used as innovative leverages to accelerate the circularity transition in Europe.

This study provides solid evidence about the advantages of studying circular innovations transitions in the textile and apparel sector in Europe through the lenses of system dynamics and ecosystems approach. This comprehensive perspective affords the complexity of dealing simultaneously with 1) systemic interdependence; 2) dynamic interaction; 3) global

macro-environment integration and 4) consumer orientation that a supply chain management theory cannot offer to the analysis of textile and apparel sector in Europe. Herein we display the causality matrix in Table 1 analyzing the previously identified 11 drivers that shape the circular transition.

The INN-SCO entry is symbolized as X, meaning Innovation (INN) and Education and Competencies (SCO) cause each other, in green color meaning the coincidence in the direction of the causal relationship represent more than 83% among the experts. Besides recommending a few minor corrections to the labelling, experts confirmed the overall structure and inclusiveness of the drivers. Herein, we define each one of the 11 variables as the main factors that positively impact or hinder the implementation of circular practices in the textile and apparel sector, displaying the highest causality effect and network connectivity corroborated by the experts.

The System Dynamics (SD) representation of causal drivers offers a deeper understanding of the interconnected forces that compete for the same resources displaying some trade-offs in the behavior. To display causal relationships, CLD makes use of causal loops, arrows that can be either positive (reinforcing behavior) or negative (balancing behavior). A reinforcing behavior, known in SD as reinforcing feedback, implies that if variable X is connected to variable Y, they move in the same direction (an increase in X will lead to an increase in Y, and a decrease in X will lead to a decrease in Y). A balancing relationship, also known as balancing feedback, suggests that one variable is influenced by another in opposite direction (e.g. an increase in X will lead to a decrease in Y, and a decrease in X will lead to an increase in Y).

Without surprise and validating the insights borrowed from the innovation and ecosystems literature, we recognize the advantages of approaching the textile and apparel sector with a systemic cause-effect perspective. The results of our study shed light on the relevance of macro-environmental integration (Cricelli, Greco, and Grimaldi 2021), systemic interdependence, dynamic interactions (Kaplinsky 2015; Konietzko, Bocken, and Hultink 2020) and the consumer orientation (Nuojuua, Pahl, and Thompson 2024; Polyportis, Magnier, and Mugge 2023; Ghisellini, Cialani, and Ulgiati 2016; Pakarinen et al. 2010) enabling CIE (Bjørnset et al. 2021) transitions in textile and apparel production, waste management, biochemical recycling and other side-related supply chains.

Keywords: innovation ecosystems, circular economy, industrial symbiosis, reuse as a material, textiles, Europe