A Conceptual Framework for SD-Based Recommendations Towards New Cross-Industry Circular Economy Material Streams in the Tire Industry

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1. Introduction

The transition toward a circular economy (CE) in the tire industry presents both urgent challenges and opportunities (Bassi et al., 2021). Tire production and waste management have long relied on linear value chains, with limited material recovery and considerable environmental impact (Kirchherr et al., 2017). While technical solutions for reuse, recycling, and energy recovery exist, the integration of these solutions across industries and material streams remains limited (Dwivedi et al., 2023). The complexity of tire materials, the diversity of stakeholders involved, and the dynamic nature of industrial systems all contribute to this gap. To address these issues, we propose a conceptual framework that applies system dynamics (SD) modeling to guide cross-industry collaboration and policy recommendations for new circular material flows in the tire industry.

2. Methodology

The proposed framework combines system dynamics modeling with cross-sectoral material flow analysis and participatory methods. System dynamics enables the exploration of feedback loops, time delays, and non-linear behaviors across the tire life cycle, from raw material sourcing to end-of-life management (Sterman, 2000). Our methodology follows an iterative process involving literature synthesis, stakeholder input, and structural modeling. The framework is designed to support decision-makers in assessing trade-offs, long-term impacts, and intervention points that facilitate the development of resilient circular supply networks.

3. Conceptual Framework

The proposed framework integrates material, product, and industry/company levels to support circular economy planning in the tire sector. At the material level, it facilitates the evaluation of alternative feedstocks and secondary uses for recycled tire materials, supported by standardized laboratory analyses (Farida et al., 2019; Okoye et al., 2021). These insights inform product-level activities, where material testing results are used in the development of waste-to-tire prototypes and viability assessments. The industry level incorporates SD tools, including causal loop diagrams and stock-and-flow models, to test hypotheses, policies, and business scenarios (Jovičić et al., 2022). This dynamic modeling approach captures feedback effects such as regulatory rebounds, technology lock-ins, and behavioral delays (Sterman, 2000), which are often missed by static models.

Methodologically, the framework demonstrates how early-stage data and prototyping can be iteratively embedded into system-level simulations, offering a scalable way to connect bottom-up innovation with top-down modeling. Conceptually, it contributes to circular economy system design by integrating material innovation, product development, and systemic modeling into a multi-level, multi-stream structure. In contrast to the often-isolated development of circular strategies, this framework emphasizes interconnection and real-world feedbacks to support more robust and actionable transitions.

4. Insights and Future Application

Preliminary analysis using the framework highlights several critical insights: material quality degradation strongly influences feasible reuse options, and economic incentives alone may not be sufficient to promote industrial symbiosis without regulatory alignment and shared infrastructure. Furthermore, delays in technological adaptation and information exchange across sectors can hinder the uptake of circular practices. These findings emphasize the need for coordinated strategies involving both industry actors and policymakers.

The framework will next be applied in case studies involving specific cross-industry streams (e.g., tire-to-construction, tire-to-polymer recovery), with the aim of generating context-specific, simulation-based recommendations. Stakeholder workshops will be conducted to refine model assumptions and validate behavioral drivers.

5. Conclusion

This work presents a SD-based conceptual framework for analyzing and supporting the transition to cross-industry circular economy material flows in the tire sector. By capturing system-level feedbacks and stakeholder complexity, the framework provides a basis for policy and design recommendations that extend beyond linear waste management strategies. Future work will focus on detailed model calibration, scenario simulations, and collaborative validation to support resilient and scalable circular transitions.

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