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RESEARCH ARTICLE

Systemic Interdependencies of Circular Plastics Ecosystems

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Abstract

This paper examines how circular economy ecosystems (CEEs) are enacted by investigating systemic interdependencies within emergent circular plastics ecosystems (CPEs). We present a qualitative case study on the plastics industry and show how systemic interdependencies, regulation, technology, markets, consumer behaviour, and collaboration form mutually reinforcing yet contradictory dynamics that shape plastic circularity outcomes. The findings reveal a set of core paradoxes at the heart of circular plastics transitions. Regulation operates as a layered and sometimes conflicting force, technological pathways are contested, market structures remain fragile and fragmented, and consumer participation is inconsistent. At the same time, collaboration proves fragile and difficult to sustain. Taken together, these systemic interdependencies generate what we term the "recycling for nothing paradox", in that despite significant investments in the recycling, reuse, and reduction of plastics, misalignments across the ecosystem dilute or neutralize progress and limit the transformative impact. Conceptually, this paper advances CEE research by framing CPEs as enacted, adaptive, and contested processes embedded in material-specific contexts. Practically, this paper underscores the need to address the systemic contradictions rather than isolated drivers of plastics circularity to enable the effective transition towards CPEs and their value chains.

Keywords Circular Economy · Case Study · Circular Plastic Ecosystem · Systemic · Transformation · Industry · Recycling for Nothing Paradox

1. Introduction

Plastic is a crucial synthetic, oil-based material that has fuelled economic growth and social well-being since the 1950s (Rasmussen, 2018; Geyer et al., 2017). While plastics are versatile, inexpensive, and deeply embedded in contemporary economies, their widespread use and disposal have also been identified as a source of significant environmental (Rasmussen, 2018; Geyer et al., 2017) and health-related harm (Deeney et al., 2025). Globally, plastics and plastic waste pose a critical challenge, as ever-increasing volumes of plastic-containing products end their lifecycles as waste that pollutes ecological systems (Rasmussen, 2018; Rhodes, 2018). To date, plastic pollution has been examined primarily within environmental and technical sciences, with a strong focus on waste management and technological solutions aimed at mitigating negative impacts (e.g., Horn et al., 2025; Cobben et al., 2022; Velter et al., 2022; Rhodes, 2018). While such approaches are necessary, they remain insufficient for understanding the broader, systemic nature of the plastics crisis. Addressing this challenge requires interventions that also engage with the social and economic dimensions of plastics manufacturing, use, and end-of-life practices (Lehtimäki et al., 2026).

The circular economy (CE) has emerged as a systemic model for addressing contemporary social and economic problems linked to resource use (Geissdoerfer et al., 2017). CE emphasises resource efficiency, waste minimisation, reuse, recycling, and closed-loop systems (Hossain et al., 2024; Kirchherr et al., 2023),

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with the aim of extending material lifecycles, preserving resource value, and reducing environmental degradation (Friant et al., 2020; Piispanen et al., 2020). Despite these ambitions, organisational interventions to accelerate the adoption of CE principles such as reducing, reusing, and recycling plastics remain difficult to implement in practice (OECD, 2022). This elusivity can be traced to several interrelated barriers. For example, regulatory barriers arise from fragmented and often inconsistent policies across national and supranational levels, creating uncertainty and delaying long-term investments. Market barriers reflect volatile prices for secondary materials, underdeveloped markets for recycled plastics, and limited consumer demand. Coordination barriers include low levels of trust, data asymmetries, and insufficient collaborative governance mechanisms, all of which constrain systemic alignment. Despite technological advances and growing policy attention, CE adoption in the plastics sector remains slow, fragmented, and largely experimental (OECD, 2022).

To better understand how systemic change can be achieved under such conditions, this paper examines circular plastics ecosystems (CPEs) as both a conceptual and an empirical framework to address the plastics crisis. CPEs have recently gained attention as an expanding area of research (Lehtimäki et al., 2026; Litaudon & Chen, 2023; da Silva et al., 2022; Pietrulla, 2022). In this study, CPEs are defined as evolving, structured, and non-hierarchical groups of independent plastics actors who collaborate interdependently to co-create complementary circular economic value while maintaining their own competitiveness (Aryee et al., 2025). Prior research has explored various aspects of CPEs, including industrial symbiosis and ecosystem design in reducing plastic waste (Ramírez-Rodríguez et al., 2025), the role of digital platforms and traceability tools in material circulation (van Langen et al., 2021), and the governance challenges associated with coordinating multi-actor systems across value chains (Harala et al., 2023; da Silva et al., 2022). Together, these studies point to the systemic potential of CPEs to transform plastics value chains through collaboration among heterogeneous actors, aligned incentives, and innovation-driven circularity.

Despite these advances, research on CPEs remains fragmented and nascent. Much of the existing literature is conceptual and thus, offers limited empirical insight into how CPEs evolve and operate in practice (Litaudon & Chen, 2023). In particular, there is a limited understanding of how collaboration, trust-building, and value co-creation mechanisms are established and sustained within CPEs, or how ecosystem strategies address systemic challenges such as regulatory misalignment, technological uncertainty, and inconsistent consumer behaviour (Aryee et al., 2025; Hossain et al., 2024; Kanda, 2023; Kanda et al., 2021). Addressing these gaps requires closer examinations of diverse ecosystem actors and how they negotiate shared goals, mobilise resources, and institutionalise new circular practices across organisational boundaries. Accordingly, this study asks: How is the circular economy ecosystem (CEE) enacted within a circular plastics ecosystem (CPE)? The current study provides an empirically grounded analysis of how plastics circularity is practiced and institutionalised within ecosystem settings in Finland. Our empirical data consists of seven qualitative interviews with plastics actors, enabling exploration of how actors within a nationally ambitious yet practically constrained system attempt to align regulation, technology, and collaboration in pursuit of circular transformation in the plastics sector. The Finnish context offers a particularly relevant empirical setting, as Finland is positioned as a frontrunner in CE policy and innovation (Finnish Government, 2021), while its plastics sector continues to face global challenges related to regulatory fragmentation, fragile market structures, and coordination deficits.

The findings indicate that while collaboration is central, it remains fragile, in that regulatory structures were found to operate as layered and often contradictory forces, market structures were fragmented, technological pathways were contested and unclear, and consumer participation was inconsistent. Two key implications follow. First, innovation, trust, and systemic alignment are critical for scaling circular plastics solutions. Second, strategies that harmonise regulation, sustain demand for recycled materials, and strengthen cross-sector collaboration are essential for overcoming systemic barriers. Taken together, these interdependencies give rise to what we term the "recycling for nothing paradox", which we define as the phenomena which occurs despite significant investments in recycling, reuse, and reduction, misalignments across the ecosystem neutralise or dilute progress towards circularity and limit the transformative impact of circular solutions. Therefore, this study contributes to theoretical understanding in both CEE and CPE literature as to how collaborative acumen and resultant decisions can shape systemic transitions (Aryee et al., 2025; Peçanha & Ferreira, 2024; Vidal et al., 2024; Thomas & Ritala, 2022).

The paper is structured as follows. The next section presents the theoretical background through a review and summary of CPE and CEE literature, followed by the methodology used in this study. The findings from our case study are then discussed, and the paper concludes with a summary of contributions, limitations, and directions for future research.

2. Theoretical Background

2.1. Circular Plastics Ecosystems

CPEs represent a specific derivation of the broader CEE concept, which seeks to address systemic tensions inherent in plastics production, consumption, and recovery (Figure 1). CPEs adopt system-level approaches to manage plastic flows across their entire lifecycle, with an emphasis on collaboration, innovation, and resource efficiency to reduce reliance on virgin fossil-based materials and to mitigate environmental degradation (Vidal et al., 2024; Geissdoerfer et al., 2017). The realization of this vision requires industry-wide collaboration reinforced by supportive regulatory frameworks, as these factors are essential for scaling the transformative potential of plastics circularity (Korhonen-Kurki et al., 2024). The design for recyclability reduces system complexity and facilitates efficient material recovery (Kumar et al., 2019), while technological innovations advance mechanical and chemical recycling, in particular. Both serve as important enablers for transforming post-consumer plastics into high-quality secondary raw materials (Skaldina et al., 2025). However, systemic challenges remain, as regional regulatory inconsistencies (OECD, 2022; Siltaloppi & Jähi, 2021; Lampinen et al., 2025) and the economic infeasibility of recycling lower-value plastic streams (Lehtimäki et al., 2025) continue to constrain CPE scalability.

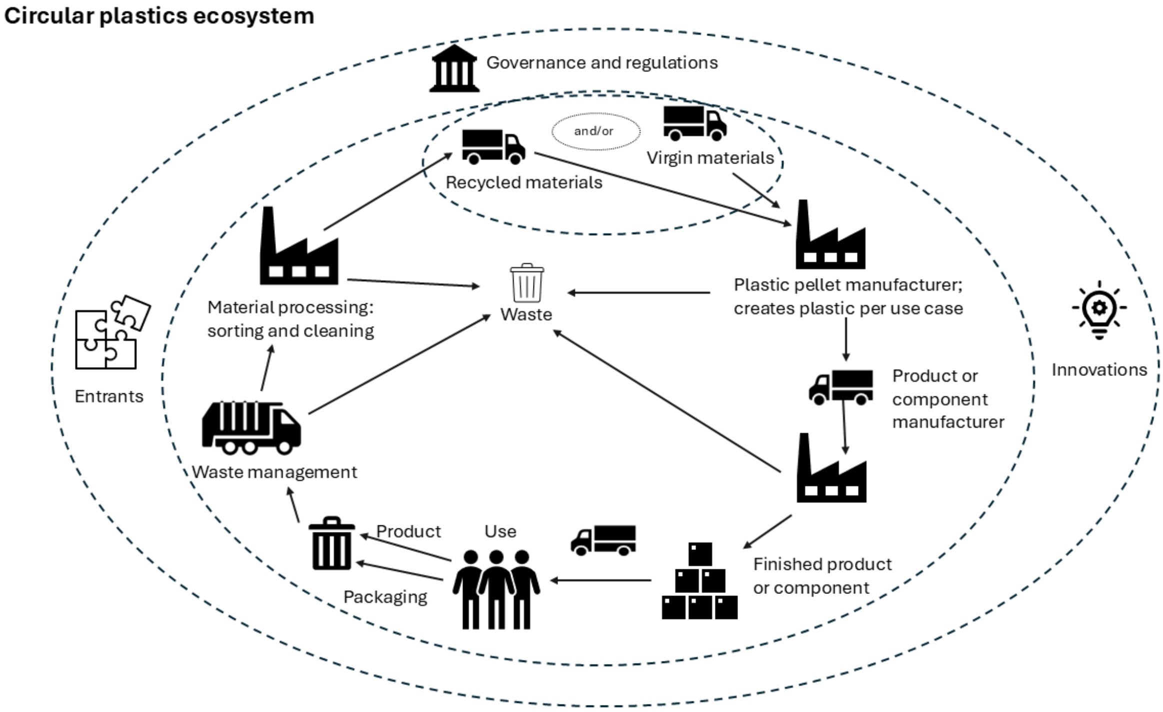

Figure 1. Circular plastics economy, a simplified image (Authors).

CEEs thrive on the interplay of diverse actors (Velenturf & Purnell, 2021), and similarly, actor collaboration is essential also for CPEs. Producers, consumers, recyclers, governments, and NGOs co-create synergies through interconnected roles in collection, redesign, processing, and repurposing of plastics. The advancement of CE principles (reduce, reuse, and recycle) within CPEs not only mitigates environmental impacts but also creates new markets for recycled materials and drives innovative business models. Importantly, consumer participation emerges as a decisive factor. Willingness to adopt recycled plastics increases when transparent labelling, product availability, and competitive pricing are assured (Horn et al., 2025; Tabas et al., 2025;

Ruokamo et al., 2022). This cooperative dynamic highlights the systemic nature of CPEs, where consumer acceptance, technological innovation, business experimentation, and regulatory actions must align.

CEE literature conceptualizes circularity as a systemic transformation which extends beyond firm-level actions and requires interdependent collaboration among diverse actors (Kaipainen et al., 2023). CEEs can be understood as cooperative, strategic, multi-partner alliances which work toward shared system-level goals. These goals include the creation of CE knowledge, sustainable business models, or new forms of economic value. From this perspective, CPEs embody a specialized form of CEE with plastics as their focal material flow. They illustrate how systemic alignment across business model innovations (e.g., product-as-a-service, modular design, sharing platforms) can extend product lifetimes, reduce virgin material extraction, and generate new forms of value-in-use that encourage sustainable consumer behaviours (Konietzko et al., 2023; Russell & Okorie, 2024; Toth-Peter et al., 2025).

More broadly, CEEs and CPEs represent systems-based approaches to sustainable resource management, through the integration of ecological, economic, and social dimensions within closed-loop material flows and regenerative processes (Korhonen et al., 2024; Pietrulla, 2022). Success depends on innovative business models which prioritize resource efficiency, service provision, and material recovery (Ritala, 2024; Bocken & Ritala, 2022; Snihur & Bocken, 2022), while digital technologies such as blockchain, IoT, and AI increasingly provide the transparency and accountability necessary for ecosystem trust and stability (Cagno et al., 2025). Interdependencies in CEEs further enable industrial symbiosis, where the by-products of one actor become inputs for another, reducing net resource use and environmental impact (Mielonen & Lehtimäki, 2024; Pietrulla, 2022; Chertow, 2007). These benefits require both reliable governance structures and digital infrastructures that facilitate data exchange and coordination (Velenturf & Purnell, 2021).

Despite their transformative potential, both CPEs and CEEs face systemic challenges. Hybrid economic, ecological, and social goals can generate tensions between actors with divergent priorities (Oskam et al., 2021). Policy fragmentation, infrastructure gaps, and ambiguous regulations hinder scalability and coherence. Such tensions highlight the need for governance mechanisms that mediate conflicts, align incentives, and stabilize long-term collaboration. Taken together, CPEs illustrate how CEEs can provide systemic pathways to address complex sustainability challenges. However, the realization depends on the orchestration of multi-actor collaboration, regulatory harmonization, and an integration of technological and business innovation (Aryee et al., 2025).

2.2. Synthesis

Plastics as an industrialized material exemplify both the promise and the paradox of the CE transition. While plastics remain indispensable to modern economies due to their versatility and cost-efficiency, large-scale plastic production and consumption continue to create profound environmental and societal challenges (OECD, 2022; Geyer et al., 2017). Research on the CPE has begun to illuminate the drivers, enablers, and barriers that shape this transition. However, despite valuable contributions, CPE research remains fragmented and theoretically underdeveloped, and thus, offers only partial insights into how circularity unfolds across regulatory, technological, market, behavioural, and ecosystem-level domains.

To clarify these limitations, we synthesize current research and make explicit the key gaps across six CPE themes in Table 1. First, regulation and governance are widely recognized as essential drivers of circular plastics transitions, yet there is a lack understanding of how multi-level governance systems interact, and how power asymmetries, lobbying, and institutional dynamics influence regulatory effectiveness (Ritala, 2024; Autio & Thomas, 2020). Second, circular business models such as reuse, leasing, and recycling are gaining prominence, but knowledge gaps persist regarding their economic scalability, long-term viability, and the contrasting roles of incumbents versus startups in shaping ecosystem evolution (Peçanha & Ferreira, 2024; Konietzko et al., 2023; Snihur & Bocken, 2022; Thomas & Ritala, 2022). Third, technological advancements in chemical and mechanical recycling, sorting technologies, and bio-based plastics enable circularity, yet research provides limited insight into systemic integration across value chains, diffusion barriers, and trade-offs such as the energy intensity of chemical recycling (Skaldina et al., 2025; Ramírez-Rodríguez et al., 2025; Hossain et al., 2024; Vidal et al., 2024).

Fourth, consumer behaviour is a critical driver, as adoption of recycled and bio-based plastics depends heavily on consumer awareness, preferences, and willingness to change. However, the literature has yet to address deep-seated cultural and behavioural barriers. Also, there is a lack of longitudinal perspectives on sustained engagement and limited evidence on how to incentivize behavioural change at scale (Tabas et al., 2025; Harala et al., 2023; da Silva et al., 2022; van Langen et al., 2021). Fifth, collaboration within CPEs across companies, NGOs, governments, and communities is essential for resource pooling, overcoming expertise gaps, and co-creating value. Yet, empirical work remains scarce on how ecosystems evolve over time, how they manage conflicts, power dynamics, or diverging interests, and how global–local interactions influence their functioning (Vidal et al., 2024; Peçanha & Ferreira, 2024; Thomas & Ritala, 2022; Re et al., 2023). Finally, although CE scholarship increasingly acknowledges systemic interdependencies, the field lacks integrative frameworks that capture the dynamic interplay, feedback loops, and mutual reinforcement among regulatory, market, technological, and behavioural drivers (Kirchherr et al., 2023; Gomes et al., 2022; Friant et al., 2020).

Table 1. Previous research on circular economy ecosystems.

CEE Themes	Findings	Identified Research Gaps	Selected References
Regulation & Governance	Regulations are critical drivers of circular plastics transition; policy frameworks incentivize recycling, reuse, and material substitution. Governance mechanisms shape collaboration in ecosystems.	Lack of clarity on how multi-level governance (EU, national, local) interacts; limited research on power asymmetries and lobbying in shaping regulatory effectiveness.	Autio & Thomas (2020); Ritala (2024)
Market Structures & Business Models	Circular business models (reuse, leasing, recycling) are emerging in plastics; ecosystems facilitate resource alignment and joint ventures.	Limited insights on economic scalability, profitability, and long-term market viability of circular plastics; underexplored dynamics of incumbents versus startups in ecosystems.	Konietzko et al. (2023); Snihur & Bocken (2022); Thomas & Ritala (2022); Peçanha & Ferreira (2024)
Technology & Innovation	Advances in chemical and mechanical recycling, bio-based plastics, and sorting technologies provide enablers for circularity. Innovation in niche ecosystems supports sustainable materials.	Gaps in understanding diffusion of new technologies, systemic integration across value chains, and trade-offs (e.g., energy intensity of chemical recycling).	Skaldina et al. (2025); Hossain et al. (2024); Vidal et al. (2024); (Ramírez-Rodríguez et al., 2025)
Consumer Behaviour	Consumers play an important role in driving demand for recycled or bio-based plastics; awareness and preferences influence adoption.	Research on cultural and behavioural barriers is limited; lack of longitudinal studies on sustained consumer engagement; lack of research on incentivizing behavioural change at scale.	Tabas et al. (2025); van Langen et al. (2021); da Silva et al. (2022); Harala et al. (2023)
Collaboration & Ecosystem Dynamics	Ecosystems function as platforms for collaboration, allowing actors to pool resources, address expertise gaps, and co-create value. Trust and transparency are essential for collaboration.	Few empirical studies on how ecosystems evolve over time; lack of research on managing conflicts, power dynamics, and diverging interests; underexplored global-local interactions.	Thomas & Ritala (2022); Re et al. (2023); Vidal et al. (2024); Peçanha & Ferreira (2024)
Systemic Interdependencies	CE literature emphasizes the interconnectedness of drivers (e.g., regulation shapes markets, which influences technology adoption).	Limited integrative frameworks for plastics; most studies focus on isolated drivers rather than dynamic interplay and feedback loops.	Kirchherr et al. (2023); Friant et al. (2020); Gomes et al. (2022)

Across these themes, we identify five cross-cutting gaps: (1) insufficient understanding of multi-level governance and power dynamics; (2) limited insights on the scalability and viability of circular business models; (3) weak theorization of technological integration and diffusion across value chains; (4) inadequate exploration of consumer behaviour, particularly cultural and longitudinal dynamics; and (5) a lack of systemic frameworks capturing interactions across drivers. These gaps underscore the need for a research lens that goes beyond isolated factors.

To address this fragmentation, this paper adopts a systemic interdependency perspective. This approach aligns with ecosystem thinking and elements of institutional and socio-technical transition theories, enabling us to examine the interdependencies, tensions, and paradoxes that characterize the transition toward plastics circularity. Rather than prescribing a single model, this lens provides a coherent structure for understanding the complex, multi-actor processes that shape the emergence and evolution of CPEs.

3. Methodology

3.1. Case Study

We utilized the multiple case study approach of contemporary phenomena (Eisenhardt, 2021; Eisenhardt & Graebner, 2007) as our research design. The qualitative data comprised thematic, deep-dive interviews with seven plastics industry executives from seven separate companies within the Finnish plastics sector. The chosen case companies represented a diverse range of roles within the plastic value chain, including recycling, manufacturing, and waste management. The seven companies included in this research were actively engaged in various stages of the plastics lifecycle (raw materials to finished product manufacturers) and based in Finland, a country with a strategic turn to the circular economy (Finnish Government, 2021) and under the associated frameworks of the European Union (e.g., European Commission 2015, 2018a, 2018b, 2018c, 2019a, 2019b, 2020a, 2022b, 2022c, 2024a, 2024b). Finland has nearly 600 businesses related to plastics with an estimated 10 000 employees in the 3.2B€ business value sector composed of nine industry sets (construction, medical, consumer, packaging, raw materials, recycling, subcontracting, technology, and transport (marine and automobiles). The plastics industry is expected to gain net value in the period leading up to 2030 (Finnish Plastics Industry Sector, 2025). This multiple company perspective in a dynamic environment enabled a rich contextual description of the plastics ecosystem, which was essential in theory development and practical applications (Ketokivi & Choi, 2014). In addition to the interviews, we referenced literature and publicly available materials related to the case companies and the plastics industry in Finland and the EU to provide additional contextual knowledge.

3.2. Data and Analysis

The primary data comprises seven in-depth, semi-structured narrative interviews with managerial level focal actors within the case companies. The participants had an interest in the same focal phenomenon (CE and plastics), and their inclusion allowed us to gain insights related to the research question (Eisenhardt, 2021). This ensured a high quality of data to study the focal phenomenon, CPEs. The semi-structured narrative interview method allowed participants to share their stories and experiences and detailed accounts of their perspectives and challenges yet maintaining narratives within the themes within the interview protocol. In consequence, we were provided rich, contextual insights into their roles, challenges, and interactions within the Finnish plastics ecosystem and their contributory role within the circular plastics economy. The structure of the interviews aided in the analysis stage for constant comparisons to find common patterns within the narratives and to abstract thematic constructs (Eisenhardt, 2021). The following themes were addressed during the interviews: company role in circular plastics, plastics use and material flows, packaging and product design, raw material production and circular inputs, actor analysis in the plastics value chain, enablers and barriers for circular business models, ecosystem dynamics and collaboration, management and internationalization, policy recommendations and future directions. In addition to the interviews, publicly available documentation related to the case companies and academic literature were included in the datasets.

The interviews were conducted by the first and second authors. The interviews were recorded (Microsoft Teams®), the transcripts were professionally transcribed. The interviews ranged in duration from 40 to 87 minutes (Table 2). The recorded interviews were complemented by researcher notes. To safeguard the privacy of participants and mitigate potential risks associated with the disclosure of sensitive or proprietary information, each interviewee was anonymized and re-identified as Case 1-7.

Table 2. Summary of case details and interview information.

Case ID	Role in the value chain	Key Focus & Strategy	Interview Date	Duration (min)	Status
1	Polymer Production	Advanced recycling, feedstock access, partnerships for collection, sorting, chemical recycling	Nov 2024	77	International; Large producer
2	Insulation Materials	Closed-loop recycling, collaboration for raw material recovery & innovation	Nov 2024	87	International; SME
3	Plastic Recycling	Comprehensive recycling systems, mechanical & chemical recycling integration	Nov 2024	77	International; Large producer
4	Medical Plastics	Hospital-specific circular solutions (in a highly regulated industry), partnerships for sustainable recycling	Nov 2024	75	International; SME
5	Biodegradable Materials	Bio-based material innovation, collaborative material development	Nov 2024	52	International; entrant, SME
6	Bio-based Materials	Chemically recycled materials integration, tailored ecosystems for proprietary materials	Nov 2024	53	International; SME producer
7	Innovative Packaging	Sustainable recycled materials, flexible partnerships for food & medical device (sensitive plastics) packaging	Mar 2025	40	International; SME

The analysis involved an iterative comparison between data and theory (Eisenhardt, 2021). This approach enriched the depth of analysis of the data and guided the identification of CEEs in the focal plastics ecosystem and facilitated the development of the research question (Vila-Henninger et al., 2022). During the analysis, we performed iterations of constant comparison within and across cases, thus examining the contexts and relationships within the data to the emergent theory (Eisenhardt, 2021, 1989). The following four steps were taken in the analysis: (1) All authors performed a close reading of the research material to maximize understanding of the empirical sites and to identify sections that were relevant to the research question. (2) In-vivo coding was performed by the first author. During the coding, an iterative inter-case and cross-case comparison of the data was made with a focus on sentences and paragraphs to detect the richness of meaning from the text. This led to the identification of common themes, patterns, and outliers through pattern recognition (Eisenhardt, 2021). The coding process allowed for the capture of the factual elements of company practices and the shaping behaviors such as values, motivations, and perceptions therein. Six themes related to regulations, market and business models, technology and innovations, consumer behaviors, collaboration and ecosystems, and systemic interdependencies were identified. The second and third author reviewed the coding, authors discussed the datasets, and after conceptual refinement, all authors came to agreement with the initial coding. (3) A literature review was completed to consolidate previous research on CEEs. Researchers' prior knowledge about the research field guided the literature review. (4) The coding of empirical material was finalized through identification of similarities between the in-vivo codes and a constant comparison between the consolidated codes and previous literature on CEE. These four steps of analysis ensured that each respondent's perspective was accurately accounted for, grounded the identification of common patterns in the iterative process of constant comparison of theory and data, and allowed for sharpening theoretically relevant constructs in CPE. Therefore, our theoretical interpretations are based on the focal empirical phenomenon (Eisenhardt, 2021; Mantere & Ketokivi, 2013) of CPE.

4. Findings

4.1. Regulation & Governance

Our analysis shows that in CPE regulation is not a neutral enabler of circular plastics, but a layered and often contradictory force that firms must actively navigate. Regulatory frameworks create both opportunities and barriers, as circularity targets are frequently misaligned across governance levels. In Case 1, a Polymer Producer illustrates how EU-level recycling and packaging directives encourage incumbents to integrate recycling into their product portfolios. However, the firm's progress is slowed by inconsistencies between EU targets, Finnish national regulation, and the availability of waste suitable for high-quality recycling. This is clearly reflected in the excerpt below.

"Some kind of regulation that would bring… well, long-term. Long-term goal setting. So, um, in a way… yes, to make investments you need that kind of a longer-term perspective, so that, well, you can then get the raw materials into use. So probably regulation and that kind of long-term vision, and the certainty that regulation does not change into something else every couple of years." (Case 1)

Similarly, the Plastics Recycler of Case 3 demonstrates the gap between ambitious EU quotas and the limited domestic capacity to process collected plastics. Because Finland must import and export certain plastics to meet recycling obligations, the credibility of a nationally self-sufficient CE model is undermined.

Sector-specific Medical Plastics (Case 4) and Innovative Packaging (Case 7) further highlight how regulation, particularly concerning hygiene and safety, can function as an outright barrier to circularity. Despite the technical possibility of recycling, hospital and food-related regulations often mandate incineration, eliminating potential recovery options. Collectively, the cases highlight a governance gap: the interaction between multi-level regulation (EU, national, and sector-specific) and the way lobbying, infrastructure constraints, and safety norms define the boundaries of what circularity is practically possible, as described in the following statements.

"Well, regulations (related to technology choices) are an extremely important part, as is the predictability factor...because when we want to invest ten million Euros, then we should be extremely sure that the case for this investment is valid. We can go on forever discussing validity for investments now." (Case 7)

"(In special plastics) we have really tight quality control, others have it a lot easier, because if we use recycled materials then we have to be able to prove that the material properties remain the same (as with virgin plastic use)." (Case 4)

4.2. Market Structures & Business Models

While new business models are emerging in the plastics sector, our findings show they remain constrained by scalability challenges, profitability concerns, and power asymmetries between incumbents and smaller players. The polymer producer from Case 1 leverages its market dominance, invests in chemical recycling as part of its strategy to transition toward circularity. However, this approach reinforces dependency on securing reliable, high-quality feedstock, leaving the company tied to linear value chains despite circularity investments.

"The demand for circular products enables us to do it and to make more investments in that direction. That it is available, and that it can be available, is also a factor in the price." (Case 1)

Insulation Materials (Case 2) operates a highly specialized closed-loop system, recovering proprietary products within the construction sector. This niche strategy creates stability but also vulnerability, since the strategy depends on cyclical construction demand and a limited customer base.

Biodegradable Materials (Case 5) highlights the middle ground: medium-sized firms seeking to expand circular portfolios through collaborative ecosystems. These firms face dual pressures: upstream suppliers and downstream customers demand consistent quality and price, despite fluctuations in recycled input availability.

Taken together, the cases illustrate that circular plastics markets remain fragmented, fragile, and unevenly distributed. Incumbents can mitigate risks via diversified portfolios, but smaller firms remain exposed.

"Making sustainable materials and increasing their amount is still one of our more important strategic priorities...it has always been a pertinent strategic goal." (Case 7)

"We try to be in the ecosystem, are we? Are we now a part of the ecosystem and how, and how widely.... Building our own ecosystem requires that someone gets involved with our materials, and then (we go from there). We use sidestream materials, because that is cost efficient; so, in that way, we probably are, in part, a part of the ecosystem." (Case 5)

4.3. Technology & Innovation

Technology emerges as both a differentiating factor and a contested space in the transition to circular plastics. Firms adopt distinct strategies depending on their resources, market position, and innovation logic. Polymer Producer (Case 1) invests in both chemical and mechanical recycling technologies with the aim of producing food-grade plastics from secondary materials. While such innovation provides a competitive advantage, it is also highly energy-intensive and yields uncertain returns. In contrast, Bio-based Materials (Case 6) pursues niche innovations through bio-based polymers, selectively collaborating with partners able to adopt these materials and thereby creating a proprietary ecosystem.

"We can now clean recovered plastics with circulated solvents, and ...that uses a small amount of energy compared with the use of chemical recycling. ...It's insane to burn raw materials away after they are already created; (we need to) take advantage of it (plastic) and plastic is just a top material to circulate, we just must get it to circulate better." (Case 1)

Insulation Materials (Case 2) show the limitations of mature technologies. Its reliance on mechanical recycling faces recurring challenges from contamination and input variability, showing that even well-established technologies can act as bottlenecks. Across cases, technology is a less definitive solution than an arena of competition and divergence, where mechanical, chemical, and bio-based pathways coexist, compete, and sometimes conflict.

"We discuss with our suppliers, have confidential discussions with our distributors, and also have gone and familiarized ourselves with the clinical end-user's surroundings." (Case 4)

4.4. Consumer Behaviour

Although consumers play a crucial role in enabling circular plastics, our findings indicate that their contribution is inconsistent and often unreliable. Plastic Recycling (Case 3) demonstrates the dependence of recycling companies on household-level sorting practices. Despite significant awareness campaigns, contamination levels remain high, reducing material quality and inflating processing costs. Similar dynamics are observed in institutional contexts: Medical Plastics (Case 4) and Innovative Packaging (Case 7), focused on hospital and food packaging plastics, reveals that medical staff and professionals act as institutional consumers and rarely prioritize recycling. Material safety requirements dominate, and sorting practices are inconsistently followed.

Biodegradable Materials (Case 5) reflect pressures from downstream customers rather than end-users. Here, clients demand affordable, high-quality recycled plastics but remain unwilling to absorb price premiums or tolerate aesthetic imperfections. These findings point out the instability and unpredictability of consumer-driven change. Rather than serving as a reliable driver, consumer and institutional behaviour emerge as a highly variable factor that both enables and constrains circular plastics markets.

"Consumers ask where should I put this tray? Do I have to rinse it first? What do I do with the lid as it is a different type of plastic? Packaging designers and developers should be involved in the entire lifecycle process thinking, because circularity is composed of so many different aspects and we can make (solutions

that make circularity easy for the consumer), such as agreeing that all polyethylene packaging is square, not blue, and polypropylene packaging is red and round – then it is easy for the post-consumer sorting to see what waste belongs where." (Case 5)

4.5. Collaboration & Ecosystem Dynamics

The cases collectively reveal that ecosystem collaboration is a crucial yet fragile driver of circular plastics, characterized by tensions, dependencies, and selective participation. The Polymer Producer (Case 1) describes how incumbents depend on a carefully curated network of partners to secure feedstock. This requires substantial governance mechanisms to align quality standards across the ecosystem. Insulation Materials (Case 2) showcase the fragility of collaboration in narrow, sector-specific systems where the withdrawal of a single partner can jeopardize the entire loop.

In contrast, Biodegradable Materials (Case 5) demonstrates co-innovation partnerships, where experimentation with new formulations and solutions occurs in collaboration with customers and suppliers. While this can generate innovation, it also demands high levels of trust, as failure risks reputational harm. Bio-based Materials (Case 6) exemplifies a different dynamic selective collaboration partnering only with firms able to adopt its proprietary bio-based innovations, thereby ensuring control but constraining openness. Taken together, the findings suggest that ecosystems provide essential platforms for resource pooling and knowledge exchange, but also function as sites of negotiation, contestation, and exclusion.

"In a circular value chain, no one can act on their own, and the partnerships we have are naturally those partners that we have. We are not really considering new avenues for collaboration, as we see that these existing networks and partnerships are just the ones we need to have." Adding, "when we consider our role in the ecosystem, we have progressed and continue to develop, and the recovery is as efficient as possible ... and we don't take care of the whole field, but we are experts at what we do and with our plastics." (Case 6)

4.6. Systemic Interdependencies

Our analysis demonstrate that systemic interdependencies play a central role in shaping circular plastics transitions, creating feedback loops that can simultaneously advance and hinder progress. Regulatory frameworks, market dynamics, technological investments, and collaborative practices are tightly interwoven, such that shortcomings in one dimension often cascade into others.

In systemic interdependence, regulation functions as both an enabler and a constraint, with effects rippling through technological and collaborative domains. For example, EU-level recycling quotas incentivize firms to invest in advanced recycling technologies (Case 1). Yet, without sufficient consumer participation in proper sorting (Case 3), such investments risk remaining underutilized. Sector-specific regulation further complicates this dynamic: in medical and food contexts (Cases 4 and 7), strict safety requirements limit recovery options, reducing the potential returns on innovation and weakening incentives for collaboration.

Market demand emerges as another critical interdependency. Cases 2 and 5 illustrate how the viability of recycled plastics depends on consumer and customer willingness to adopt such products. This, in turn, shapes the economic rationale for technological investment. When downstream customers prioritize price and appearance over sustainability, firms face difficulty justifying costly technological upgrades, even when technically feasible.

Finally, collaboration acts as mediating mechanisms that determine whether systemic interdependencies lead to virtuous or vicious cycles. As Cases 2, 5, and 6 illustrate, ecosystems capable of aligning interests and resolving conflicts can amplify both technological diffusion and market uptake. Conversely, fragmented or conflict-prone collaborations stall progress, creating bottlenecks that undermine collective outcomes. The excerpt below elaborates on the ecosystem actor perspective on the antecedents and outcomes of collaboration. This exemplifies the way in which all the participants pondered if they were a part of an ecosystem, how widely, and how it has formed over time, and realized that it was plastics that took the center stage.

"Circular economy is that they gather and we use their gathering, and we don't develop or invent this and invent these things in deep collaboration, there are differences and different levels, and it's a bonus that we

are collaborating at all; there is fundamental development and then there are partnerships... the circular material streams are efficient financially, and that is probably why, at least to some extent, we are involved." (Case 6)

4.7. Cross-cutting Patterns Across Circular Plastics Ecosystem Dimensions

Table 3 summarizes the key findings across six themes. These findings illustrate the dynamic interplay of enabling and constraining forces that characterize the enactment of CPEs. First, we demonstrate how regulation and governance act as both enablers and barriers, with EU-level directives stimulating investments but national and sectoral rules fragmenting implementation. Second, we highlight the fragility of market structures and business models, where incumbents mitigate risks through partnerships while smaller ventures remain vulnerable to fluctuating inputs and narrow demand. Third, we find that technology and innovation are contested, with different firms pursuing mechanical, chemical, or bio-based logics, none of which offers a singular solution to the CPE.

Fourth, we show how consumer behaviour remains inconsistent, as both households and institutional customers play decisive yet unreliable roles in driving demand for recycled materials. Fifth, we find that collaboration and ecosystem dynamics are central but fragile, with trust, alignment, and mutual commitment determining ecosystem viability. Finally, we highlight the importance of systemic interdependencies, where misalignments across governance, markets, technology, and consumers generate feedback loops that stall progress and waste investments.

Table 3. The enactment of circular ecosystem parameters in CPEs.

Theme	Key Findings	Illustrative Cases
Regulation & Governance	Regulation is multi-layered and often contradictory. While EU directives encourage circularity and stimulate technological investment, national rules, sector-specific safety standards, and infrastructural limitations constrain practical implementation. Misalignment across governance levels creates uncertainty for long-term planning and investment.	Case 1: EU directives drive chemical recycling investments. Case 3: Domestic infrastructure insufficient, forcing exports. Cases 4 & 7: Hygiene regulations block recycling.
Market Structures & Business Models	Circular business models remain fragile and unevenly distributed across the value chain. Incumbents leverage scale and diversified portfolios to buffer risks, whereas SMEs face vulnerabilities due to fluctuating feedstock quality, volatile demand, and dependence on narrow customer segments.	Case 1: Chemical recycling tied to feedstock supply. Case 2: Closed loop by nature, yet reliant on co-operative construction demand. Case 5: Medium-sized firm pressured by inconsistent quality/price of recycled inputs.
Technology & Innovation	Technology is not a universal solution, but a contested space defined by divergent pathways (mechanical, chemical, bio-based). Each technology faces distinct barriers, cost, energy intensity, contamination, or scalability. Technological choices shape and constrain collaboration, market opportunities, and resource flows.	Case 1: Dual investments in chemical & mechanical recycling. Case 2: Struggles with contamination in mechanical recycling. Case 6: Proprietary bio-based materials with selective partnerships.
Consumer Behaviour	Consumers both households and institutional actors play a critical but inconsistent role in enabling circular plastics. Sorting practices, price sensitivity, and cultural norms undermine stable demand for recycled or bio-based materials. Institutional settings amplify these challenges due to strict safety requirements and low prioritization of recycling.	Case 3: Dependent on household sorting, high contamination. Cases 4 & 7: Hospital staff is reluctant to prioritize recycling. Case 5: Downstream customers demand quality but resist premiums.

Table 3 (cont.). The enactment of circular ecosystem parameters in CPEs.

Theme	Key Findings	Illustrative Cases
Collaboration & Ecosystem Dynamics	Collaboration is essential but fragile. Ecosystem performance hinges on trust, shared standards, and mutual commitment. Selective participation, partner withdrawal, and asymmetries in control create vulnerabilities. Ecosystems can enable co-innovation or become bottlenecks that restrict progress.	Case 1: Standardized partner networks for feedstock quality. Case 2: Sector-specific collaboration vulnerable to partner withdrawal. Case 5: Trust-based co-innovation. Case 6: Selective partnerships reinforce proprietary control.
Systemic Interdependencies	Misalignments across governance, markets, technology, and behaviour generate systemic feedback loops that often neutralize progress. Investments in advanced recycling remain underutilized without aligned regulation, sufficient feedstock, and supportive market demand. Collaboration acts as a key mediating mechanism determining whether interdependencies lead to virtuous or vicious cycles.	Case 1: EU quotas drive tech investment but limited by consumer sorting (Case 3). Cases 2 & 5: Market demand shaped by consumer adoption. Case 6: Trust and collaboration mediate ecosystem dynamics.

Across the seven cases, we found that the circular plastics transitions are shaped by intertwined feedback loops which linked regulations, markets, technology, consumer behaviors, and collaboration. Strengths or weaknesses and misalignments in any one domain propagated through the wider system to either reinforce momentum or to dampen progress. One key pattern we identified is the regulatory–technological loop, in which EU-level targets encourage firms to invest in advanced recycling technologies, yet insufficient feedstock and inconsistent national implementation lead to underutilized capacity and an increase in investment hesitation (Cases 1, 3). The second identified pattern, the consumer–technology loop, shows how inadequate household or institutional sorting generates low-quality inputs, which in turn create bottlenecks in mechanical and chemical recycling processes; this reduces output quality and further weakens the consumer willingness to adopt recycled products (Cases 3, 5). The market–innovation loop is the third identified pattern and illustrates how demand for low-cost, consistent materials discourages firms from the introduction of circular innovations. This, in turn, slows market transitions and maintains incumbency advantages as incumbents are blocked (Cases 1, 2, 5). Finally, the fourth pattern of a collaboration–ecosystem loop, highlights how trust, shared standards, and coordination can drive efficient material loops and ecosystem expansion, whereas weak trust and fragmented participation lead to stalled CE implementation (Cases 2, 5, 6). Together, these interconnected loops demonstrate that progress in one part of the system depends on alignment across other parts of the system.

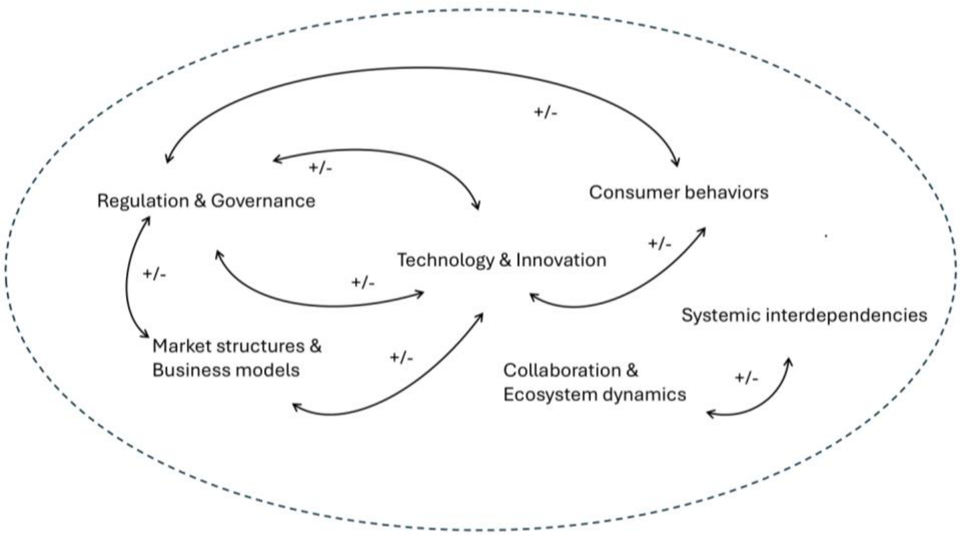

Figure 2. Systemic contradictions in circular plastics ecosystem (CPE).

Taken together, the "recycling for nothing paradox" reveals the importance of examining not only individual drivers of circularity, but also the ways in which interdependencies shape, distort, or neutralize the effective transition towards circular plastics value chains across the system. Despite substantial investments in recycling, reusing, and reducing plastics, systemic misalignments across regulations, markets, technologies, and consumer behaviors produce fragmented outcomes and limit transformative impact.

5. Discussion

This paper addressed the research question "How is the circular economy ecosystem (CEE) enacted in a circular plastic ecosystem (CPE)?" Drawing on seven in-depth cases from within the Finnish plastics industry, we find that CPEs are enacted through multi-layered interactions among regulatory frameworks, market structures, technological pathways, consumer practices, and ecosystem-level collaborations. Rather than presenting as a smooth systemic transition, enactment towards a CPE emerges as a contested and fragile process in which tensions between actors, misaligned incentives, and institutional contradictions that continually shape outcomes. Consequently, CPEs materialize as adaptive configurations of actors and strategies that both advance and constrain circular plastics ecosystem solutions.

Our findings contribute to the nascent literature on CPEs by offering a grounded and systemic view of how such ecosystems evolve in practice. The results of our research extend prior research on CPEs with two contributions. First, we extend current knowledge with empirically grounded theorization related to systemic contradictions that enable or constrain effective transition towards circular plastics value chains. Earlier studies have emphasized the transformative potential of CPEs through industrial symbiosis (Ramírez-Rodríguez et al., 2025), digital traceability and platform tools (van Langen et al., 2021), and governance arrangements in multi-actor systems (Harala et al., 2023; da Silva et al., 2022). While such work highlights the systemic potential of CPEs to transform plastics value chains, our research reveals the contradictory and layered realities that plastics actors identify when enacting circularity. By detailing how regulatory misalignments, fragile collaborations, contested technologies, and inconsistent consumer behaviors interact, we provide new insight into the mechanisms that both enable and constrain the systemic potential of CPEs. Second, this paper extends the largely conceptual nature of existing CPE research (e.g., Litaudon & Chen, 2023) by showing how trust, complementary roles, and value co-creation strategies emerge or falter in practice from the perspective of companies operating in CPEs. This responds to recent calls for more empirical research on the evolution, orchestration, and governance of circular ecosystems (Aryee et al., 2025; Hossain et al., 2024; Kanda, 2023), and advances theoretical understanding of CPEs as enacted, contested, and adaptive processes in material-specific boundary contexts (Eisenhardt, 2021) such as plastics. The findings of this study contribute to understanding the complex, multi-actor processes that shape the emergence and evolution of CPEs. In essence, this study provides new knowledge that CPEs do not emerge as linear or coordinated transitions but as contested, adaptive processes shaped by systemic contradictions and multi-actor dynamics.

6. Conclusions

CPEs are a topical yet nascent area of circular economy research (Lehtimäki et al., 2025; Litaudon & Chen, 2023; da Silva et al., 2022; Pietrulla, 2022). This research provides an empirically grounded analysis of CPE and sheds light on the systemic contradictions that enable or constrain effective transition towards circular plastics value chains. Through the conceptualization of these dynamics, our work contributes to emerging theory on CPEs and advances understanding of interdependencies and tensions between circular economy regulation, markets, technology, consumer behavior, and collaboration. Our study shows that despite significant investments in recycling, reuse, and reduction, misalignments across the plastics ecosystem dilute or neutralize progress, and thus, limit or slows the transformative impact of a circular plastics economy. Without an alignment between multiple system parameters, the system tends to reproduce a "recycling for nothing paradox".

As a managerial and policy contribution, the findings offer practical insights into sector-specific constraints on sourcing high-quality recycled materials, opportunities for innovation with sustainable materials, and the role of diversification in strengthening CPE solutions. We recommend that policymakers incentivize cross-sector collaborations and support niche experimentation, both of which appear essential to both the formation and resilience of CPEs.

Limitations to this research must be noted. The emergent nature of CPE research means that our conceptualization reflects an early-stage understanding that may evolve as the field develops. The focus on Finland restricts generalizability to other institutional contexts, and although our cases span diverse positions in the plastics value chain, they do not capture all possible ecosystem configurations. Further research in other institutional contexts is needed. Moreover, our emphasis on systemic and relational mechanisms does not extend to quantitative assessment of ecosystem-level circular performance. To address these limitations presents opportunities for future research to more fully theorize, model, and measure CPEs.

This research points toward several promising directions for future research. First, future studies could investigate governance mechanisms and coordination structures that enable actors to navigate the paradoxes identified therein, including the "recycling for nothing paradox". Second, a deeper examination of systemic misalignments such as conflicting regulatory layers or contradictory market incentives could reveal how circular transitions become stalled or distorted in other material-specific ecosystems. Third, more research is needed on the evolution of collaboration in CPEs, particularly how fragile forms of cooperation strengthen, break down, or reconfigure over time. Fourth, comparative research across national contexts would help clarify how institutional, cultural, and technological environments shape CPE dynamics differently. Finally, longitudinal insights, and multi-site case designs could enrich understanding of how CPEs scale and what forms of circular value creation they ultimately produce.

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Declarations

Competing Interests The authors declare no competing interests.

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